Kumar Abhinav BSc (Hons), MBBS, FRCS (Neurosurgery)

Clinical Fellow and Instructor in Cerebrovascular and Skull Base Neurosurgery, Department of Neurosurgery, Stanford University School of Medicine, Stanford, CA, USA

Neel Anand MD, Mch.Orth (Liverpool)

Chairman, Department of Spine and Orthopaedics; Director of Education, Research and Spine Fellowship, DOCS Surgical Hospital, Los Angeles; Professor of Orthopedic Surgery, Department of Orthopedic Surgery; Director, Spine Trauma, Minimally Invasive Spine Surgery, Spine Center, Cedars–Sinai Medical Center, Los Angeles, CA, USA

Benjamin J Challacombe BSc, MS, FRCS (Urol)

Consultant Urological Surgeon and Honorary Senior Lecturer, GSTT MDT Urological Cancer Lead, Clinical Robotic Surgery Lead and Fellowship Director, Guy’s Hospital and King’s College London, UK

Patricia Collins BSc (Hons), PhD, FHEA

Emeritus Professor of Anatomy, Anglo-European College of Chiropractic, Bournemouth, UK; Editor for Embryology and Development
David Richens FRCS
Cardiac Surgeon, Wooler, UK

Alistair C Ross MB, FRCS
Consultant Orthopaedic Surgeon, BMI Bath Clinic, Bath, UK

R Shane Tubbs MS, PA-C, PhD
Professor of Neurosurgery and Structural and Cellular Biology, Tulane University School of Medicine, New Orleans, LA, USA; Professor of Human Gross and Developmental Anatomy, Department of Anatomical Sciences, St George’s University, Grenada, West Indies; Professor, Centre of Anatomy and Human Identification, University of Dundee, Dundee, UK

Peter C Whitfield BM (Distinction), PhD, FRCS Eng, FRCS (Surgical Neurology), FHEA
Consultant Neurosurgeon, South West Neurosurgery Centre, University Hospitals Plymouth NHS Trust, Plymouth, UK; Honorary Associate Professor, Peninsula Medical School, Plymouth University, Plymouth, UK
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“To study the phenomena of disease without books is to sail an uncharted sea…”

SIR WILLIAM OSLER (1849–1919)

Gray’s Surgical Anatomy 1st edition, written by surgeons in collaboration with an anatomist of world renown, is unique in its concept and content; it is an historical landmark. The editors have assembled an international group of authoritative contributors who have employed several innovative concepts to present the material.

It serves as a textbook of regional anatomy, a dissection manual and as an atlas of operative procedures. This book will be important for medical students and surgeons of all levels of experience.

There are nine sections, each introduced by an overview of the region described in the chapters. The 86 chapters are well focused and follow a common template that describes core procedures, surface and surgical anatomy, surgical approaches, tips and anatomical hazards. The discussion is succinct and clear. Tables are used with great effect and properly located within the text. Line drawings are complete and beautifully executed. Pertinent radiographic images are provided. Intraoperative photographs are of the highest quality and properly illustrative. Living anatomy observed at operation is different from cadaver dissections. The authors point out use of normal anatomic landmarks that are important in procedures and the relationships of structures to one another. At the end of each chapter, Key References are provided as well as self-assessment questions and clinical cases that illustrate the use of anatomical knowledge for resolution. This novel and productive approach improves the relevance and practicality of the information.

Chapters describing anatomy of lumbar puncture, epidural analgesia, peripheral nerve blocks, echocardiographic anatomy of the heart and endoscopic anatomy of the gastrointestinal tract are outstanding additions not found elsewhere.

From a surgeon's perspective, this a most valuable resource. Every surgeon,
regardless of specialty or level of experience, should use this book. It will be
read and reread to the betterment of surgical patients. This book sets a new
standard and ensures smooth sailing in the ever-changing surgical seas.

Courtney M Townsend Jr., MD, FACS, FRCSEd (hon)  Robertson-Poth Distinguished Chair in
General Surgery Professor, Department of Surgery UTMB Galveston
In the preface to the first edition of his seminal anatomical text, Henry Gray wrote ‘This work is intended to furnish the Student and Practitioner with an accurate view of the Anatomy of the Human Body, and more especially the application of this science to Practical Surgery’. We share that objective. Human anatomy has not changed since Gray’s words were written in 1858, but our understanding of anatomy and its application to surgery has changed dramatically.

Anatomy is usually first encountered during medical school, historically in dissecting rooms and lecture halls, and increasingly through interactive computerized applications. Anatomy teaching does not currently rely on cadaveric dissection to the extent that it did in the past, but rather places greater reliance on three dimensional models or simulations, videos, cross sectional imaging and many other novel teaching adjuncts. Some medical schools no longer utilize cadaveric dissections. Regardless of how anatomy is taught, subsequently applying that critical foundational knowledge to surgical practice is essential to ensure the best possible patient outcomes.
The surgeon must not only appreciate the intricacies of ‘in situ normal anatomy’, but also the anatomical differences that are encountered during surgery, ‘operative anatomy’. These observed differences primarily occur as a consequence of changes in the specific locations of anatomical structures that occur during surgery, unique magnified remote intraoperative anatomical views and surgical exposures, as well as distortion of normal anatomy by the underlying pathology that is being treated.

An inadequate understanding of detailed surgical anatomy during even common straightforward procedures, for example when operating within the posterior triangle of the neck or on the surface of the hand, may result in iatrogenic damage to superficial structures resulting in potentially permanent morbidity. In this book we have combined both ‘normal’ and ‘operative’ anatomy in order to provide an expert perspective on very specific regions of interest and to meet the unique contemporary anatomical learning needs of the surgeon.

Surgery is evolving at an extremely rapid rate. The impact of technology, enabling minimal access procedures and robotic operations, has revolutionized patients’ journeys, with shorter hospital stays, smaller or absent scars and improved postoperative outcomes. Robotic surgery aids surgical access in ways that were not believed to be possible as little as 15 years ago: will some open surgical procedures, for example radical prostatectomy, still be performed in the years to come?

In this book we have brought together a group of experts to provide a unique contemporary anatomical guide for all surgical sub-specialties. The book has been subdivided into seven sections. For ease of reading, each chapter has a common template that includes: key anatomical relationships, hazards and top tips, self-assessment questions, and case histories. Anatomical and surgical videos are also provided online, along with additional material not included in the print version of the book.

Human factors, safer team working in ways to minimize error in our daily practice have also become so important that we have included a chapter to raise awareness, and to also encourage surgeons to look after themselves, in order to best serve their patients.

Firstly, we would like to thank all the contributing authors and our section editors, Kumar Abhinav, Neel Anand, Ben Challacombe, Patricia Collins, David Richens, Alistair Ross, R Shane Tubbs and Peter Whitfield who brought a wealth of scholarship and surgical and anatomical expertise to their roles as Section or Specialist Editors. We thank them for their
dedication and enthusiastic support in selecting and interacting with the authors in their Sections, and for helping us to meet deadlines, despite the ever-increasing demands on their time from clinical practice, hospital managers and other academic commitments.

We also thank the editorial team at Elsevier, under the leadership of Jeremy Bowes, for their guidance, professionalism, good humour and unfailing support over the last three years. In particular, we thank Joanne Scott, Wendy Lee and Joanna Souch for being available by telephone or e-mail to offer advice. We would also like to thank Richard Tibbitts and his medical illustration team at Elsevier who created many fantastic new figures for this book.

In this first edition we recognize that there will be areas that we have omitted that warrant further attention. We would be delighted to hear from our readers with suggestions for additional material that they would like to be included in future publication.

Finally, we acknowledge the influential and legendary work of Henry Gray and his fellow anatomist and illustrator, Henry Vandyke Carter, to whom anatomists and surgeons worldwide will forever owe a debt of gratitude.

Primum non nocere

Peter A Brennan

Susan M Standring

Sam M Wiseman
List of Contributors

Ahmed Abdulsalam MBBCh, MSc, FRCS-CTh
Senior Aortic Fellow
Liverpool Heart and Chest Hospital
Liverpool, UK

Kumar Abhinav BSc (Hons), MBBS, FRCS (Neurosurgery)
Clinical Fellow and Instructor in Cerebrovascular and Skull Base Neurosurgery
Department of Neurosurgery
Stanford University School of Medicine
Stanford, CA, USA

Kamran Ahmed MBBS, MRCS, PhD, FRCS (Urol)
Hon. Consultant Urological Surgeon & Andrologist
King's College Hospital, London
Senior Clinical Lecturer, King's College London
MRC Centre for Transplantation
Guy's Hospital Campus
London, UK

Mazin Al-kasspooles MD, FACS
Professor of Surgery
Director, Regional Cancer Therapies Program
Division of Surgical Oncology
Department of Surgery
University of Kansas Medical Center
Kansas City, KS, USA

Husam Alrumaih MD, MPH
Orthopaedic Consultant
Department of Orthopaedics
King Faisal Specialist Hospital and Research Center
Riyadh, Saudi Arabia

May Al-Sahaf MB, BCh
Speciality Registrar
Department of Thoracic Surgery
St Bartholomew's Hospital
London, UK

Adnan A Alseidi MD Ed.M, FACS
HPB Fellowship Director, HPB and Endocrine
Department of HPB Surgery
Virginia Mason Medical Center
Seattle, WA, USA

Keng Ang PhD, FRCS Ed (CTh)
Consultant Thoracic Surgeon
Department of Thoracic Surgery
Glenfield Hospital
Leicester, UK

Kristian Aquilina FRCS(SN), MD
Consultant Paediatric Neurosurgeon
Department of Neurosurgery
Great Ormond Street Hospital
Honorary Senior Lecturer
Institute of Child Health
University College London
London, UK

Laura M Arthur MBChB, MD, FRCS (Gen Surg), FEBS
Specialty Registrar in General Surgery
West of Scotland Deanery
Glasgow, UK

Eli M Baron MD
CoDirector Spine Trauma Program
Department of Neurosurgery
Cedars–Sinai Medical Center
Los Angeles, CA, USA

David Bennett BSc (Hons), MBChB, FRCSEd (Neurosurgery), MFSTEd
Specialty Registrar in Neurosurgery
Institute of Neurological Sciences
Queen Elizabeth University Hospital
Honorary Clinical Lecturer
University of Glasgow
Glasgow, UK

**Inderpaul Birdi FRCS (CTh), MCh**
Consultant Cardiac Surgeon
Department of Cardiothoracic Surgery
The Essex Cardiothoracic Centre
Basildon, Essex, UK

**Edward Black BSc MBBS FRCS(CTh)**
Consultant Thoracic Surgeon
Department of Thoracic Surgery
SEHA
Abu Dhabi, UAE

**John Blythe FRCS, FDS RCS (Eng), EACMFS**
Consultant Oral and Maxillofacial Surgeon
Barts Health NHS Trust
London, UK
Honorary Research Fellow
European Face Centre
Universitair Ziekenhuis Brussel
Brussels, Belgium

**Peter A Brennan MD, PhD, FRCS (Eng), FRCIS, Hon FRCS, FFST RCS (Ed), FDSRCS**
Consultant Surgeon, Honorary Professor of Surgery
Department of Maxillofacial/Head and Neck Surgery
Queen Alexandra Hospital
Portsmouth, UK

**Oliver Brunckhorst MBBS, BSc (Hons), MRCS**
NIHR Academic Clinical Fellow
King's College London
MRC Centre for Transplantation
Guy's Hospital
London, UK

Rick Catterwell MBBS MMiS FRACS (Urol)
Consultant Urologist & Clinical Senior Lecturer
Central Adelaide Health Network
University of Adelaide
Adelaide, Australia

Sami A Chadi MD, MSc, FRCSC, FACS
Staff Colorectal Surgeon, Division of Surgical Oncology, University Health Network and Princess Margaret Hospital
Assistant Professor, Department of Surgery, University of Toronto
Toronto, ON, Canada

Benjamin J Challacombe MS, FRCS (Urol)
Consultant Urological Surgeon and Honorary Senior Lecturer
Department of Urology
Guy’s and St Thomas’ Hospitals
London, UK

Jens Chapman MD
Spine Surgeon
Swedish Neuroscience Institute
Seattle, WA, USA

Aswin Chari MA, BMBCh, MRCS
GOSH Charity Surgeon-Scientist Fellow & Neurosurgical Registrar
Department of Neurosurgery
Great Ormond Street Hospital
London, UK

J Calvin Coffey BSc, MB, PhD, FRCSI
Professor of Surgery
Department of Surgery
4i Centre for Interventions in Infection, Inflammation and Immunity
Graduate Entry Medical School
University Hospital Limerick and University of Limerick
Limerick, Ireland
Declan AE Costello MA, MBBS, FRCS (ORL-HNS)
Consultant ENT Surgeon and Laryngologist
Wexham Park Hospital
Slough, UK

Jason M Cuellar MD, PhD
Assistant Professor
Department of Orthopedic Surgery
Cedars–Sinai Medical Center
Los Angeles, CA, USA

Anupam Das MS
Assistant Professor
Department of Head and Neck Surgical Oncology
Dr B Borooah Cancer Institute
Guwahati, Assam, India

Eytan A David MD, FRCSC
Consultant Surgeon, Otolaryngology, Otology and Neurotology
Department of Surgery
University of British Columbia
Vancouver, BC, Canada

Shanley B Deal MD
Chief General Surgery Resident
Department of General, Thoracic, and Vascular Surgery
Virginia Mason Medical Center
Seattle, WA, USA

Kristin DeGirolamo BSc Pharm, MD, MSc (Surgery)
General Surgery Resident
Department of Surgery
Faculty of Medicine
University of British Columbia
Vancouver, BC, Canada

Peter J DiPasco MD, FACS
Associate Professor of Surgery
Director, Student Surgery Clerkship
Division of Surgical Oncology  
Department of Surgery  
The University of Kansas Health System  
Kansas City, KS, USA

Elijah Dixon MD, BSc, MSc(Epi), FRCSC, FACS  
Professor of Surgery, Oncology, and Community Health Sciences  
Department of Surgery  
University of Calgary  
Calgary, AB, Canada

Peter Dockery BSc, PhD  
Established Professor of Anatomy  
Department of Anatomy, School of Medicine  
National University of Ireland  
Galway, Ireland

Claire L Donohoe MBBCh, MMedEd, PhD, FRCS  
Clinical Fellow  
Northern Oesophagogastric Unit  
Royal Victoria Infirmary  
Newcastle upon Tyne, UK

John P Duffy BSc, MBBS, FRCS, MS, FRCS(CTh)  
Consultant Thoracic Surgeon  
Department of Thoracic Surgery  
Nottingham University Hospitals NHS Trust  
Nottingham, UK

Dafydd S Edwards BSc (Hons), MBBS, FRCS (Tr&Orth), MD, DMCC  
Consultant Surgeon  
Department of Trauma and Orthopaedics (Upper Limb)  
Royal London Hospital, Barts Health NHS Trust  
London, UK

Oussama Elhage MD, FRCS (Urol)  
Consultant Urological Surgeon and Honorary Senior Lecturer  
Department of Urology  
Guy’s and St Thomas’ Hospitals and King’s College London
London, UK

Harold Ellis CBE, MCh, FRCS
Emeritus Professor of Surgery
University of London
London, UK

Mohamed MM Elsaegh MBBCh, MSc, MD, FRCS-CTh, FEBCTS
Senior Clinical Fellow
Department of Cardiothoracic Surgery
Royal Papworth Hospital NHS Foundation Trust
Cambridge, UK

Madan G Ethunandan MDS, FRCS (OMFS), FDSRCS, FFDRCS
Consultant Oral and Maxillofacial/Skull Base Surgeon and Honorary Senior Clinical Lecturer
Department of Oral and Maxillofacial Surgery
University Hospital Southampton
Southampton, UK

Karen Kim Evans MD
Associate Professor
Department of Plastic Surgery
Medstar Georgetown University
Washington, DC, USA

Mazin Fageir MBBS, MRCSEd, PG Cert Genomic medicine (Imperial College London)
Senior Clinical Fellow
Department of Trauma & Orthopaedic Surgery
Imperial College Healthcare NHS Trust
London, UK

Juan C Fernandez-Miranda MD, FACS
Professor of Neurosurgery and Medicine
Surgical director of Brain Tumor, Skull Base and Pituitary Centers
Stanford University Medical Center
Stanford, CA, USA
Mark L Field FRCS (C-Th), DPhil
Cardiac Surgeon
Thoracic Aortic Surgery
Liverpool Heart and Chest Hospital
Liverpool, UK

Christian Fisahn MD
Trauma and Orthopaedic Surgery Fellow
Department of General and Trauma Surgery
BG University Hospital Bergmannsheil
Ruhr-University
Bochum, Germany

Rachael O Forsythe MBChB, MRCS
Specialty Registrar in Vascular Surgery and Honorary Clinical Research Fellow
Edinburgh Vascular Service and Centre for Cardiovascular Science
Royal Infirmary of Edinburgh and University of Edinburgh
Edinburgh, UK

Kyle J Fortinsky MD, FRCPC, MBA
Clinical Fellow in Advanced Endoscopy
University of California Irvine
Irvine, CA, USA

Grey EB Giddins FRCS (Orth), European Diploma in Hand Surgery
Professor
Orthopaedic Department
Royal United Hospital
Bath, UK

Michael J Gleeson MD, FRCS, FRACS, FDS
Emeritus Professor
Departments of Otolaryngology and Neurotology
The National Hospital for Neurology & Neurosurgery; Guy's, Kings and St Thomas' Hospitals, King's College London
London, UK

Sushmith Ramakrishna Gowda Maj, RAMC, MBBCh, DMCC, MSc, FRCS
(Tr&Orth)
Specialty Trainee
Royal Centre for Defence Medicine
Queen Alexandra Hospital
Portsmouth, UK

S Michael Griffin OBE, MD, PRCSEd, FRCS(Eng), FRCP&S Glas (Hon), FRCSI (Hon), FCS HK, FFSTRCSEd
Professor of Surgery
President, Royal College of Surgeons of Edinburgh
Edinburgh, UK

Steven C Griffin MBBS, FRCSC/Th MS
Former Consultant Cardiothoracic Surgeon
Division of Surgery
American Hospital
Dubai, United Arab Emirates

Elizabeth A Gruber BSc (Hons), MBBS, MRCS, BDS, MFDRCSI, FRCS(OMFS)
Consultant
Department of Oral and Maxillofacial Surgery
Princess Alexandra Hospital
Harlow, UK

Amar Gupta MD
Hepatopancreaticobiliary Surgery Fellow
Department of Surgery
University of Calgary, Foothills Medical Centre
Calgary, AB, Canada

Benjamin Gupta BDS, MFDS, BMed, FRACDS(OMS)
Consultant Oral & Maxillofacial Surgeon
Newcastle, NSW, Australia

Jaime R Harvey MS, CAsP, FAsMA
Chief, Human Factors & Operational Safety Issues
Office of the US Air Force Chief Safety
Washington, DC, USA
Jason Harvey MBBS, FRCSEd, FRCS (Tr&Orth)
Consultant Spinal Surgeon
Wessex Spinal Unit
Southampton University Hospital
Southampton, UK
Fortius Clinic
London, UK

Robert J Hinchliffe MD, FRCS
Professor of Vascular Surgery
Bristol Centre for Surgical Research
University of Bristol
Bristol, UK

Tom Holland BA(Cantab), MBBS, MRCOG, MD(Res)
Consultant Gynaecologist
Guy's and St Thomas' NHS Foundation Trust
London, UK

Simon Holmes
Professor of Craniofacial Traumatology
Barts Health NHS Trust
Queen Mary University of London
London, UK

Claire Hopkins BMBCH, DM(Oxon), FRCS(ORLHNS)
Professor of Rhinology
King's College London;
Consultant ENT Surgeon, Guy's and St Thomas’ Hospitals
London, UK

Velupillai Ilankovan FRCS (Eng & Edin), FDSRCS (Eng & Edin)
Professor
Bournemouth University
Poole, UK:
Hon Professor in Head & Neck Surgery
Peking Union Medical School
Peking, China
Consultant Surgeon
Poole Hospital
Dorset, UK

**Joe Iwanaga PhD, DDS**
Associate Professor
Department of Neurosurgery
Tulane University School of Medicine
New Orleans, LA, USA

**Greg James BSc (Hons), MB, BS, PhD, FRCS (Eng), FRCS (Neurosurgery)**
Consultant Neurosurgeon
Department of Neurosurgery
Great Ormond Street Hospital
Honorary Senior Lecturer
University College London
London, UK

**Valerie AR Juniat BSc, MBChB, MSc, FRCOphth**
Clinical Fellow
Department of Adnexal Surgery
Moorfields Eye Hospital NHS Foundation Trust
London, UK

**Raj Jutley BMedSci, MD, FRCSEng, FCS, ECSA, FRCSC-Th**
Honorary Professor
Consultant Cardiac Surgeon
Pan Africa Heart Foundation
Nairobi, Kenya

**Zaheer S Kanji MD, MSc, FRCSC**
Clinical Instructor
Hepatobiliary and Pancreatic Surgical Oncology
University of British Columbia
Kamloops, BC, Canada

**Peter TW Kim MD, MSc, FRCSC, FACS**
Clinical Associate Professor
Hepatopancreatobiliary Surgery/Liver Transplantation
University of British Columbia
Vancouver, BC, Canada

Emma V King BMSc (Hons), MBChB, PhD, FRCS-ORL (HNS)
Consultant Head and Neck Surgeon
Department of Otolaryngology
Poole Hospital NHS Foundation Trust
Poole, UK
CR UK Associate Professor of Head and Neck Surgery
Cancer Sciences Division
University of Southampton
Southampton, UK

Matthew A Kirkman BSc, MBBS, MRCS, MEd
Specialist Trainee in Neurosurgery
Victor Horsley Department of Neurosurgery
National Hospital for Neurology and Neurosurgery
Queen Square, London
Specialist Registrar in Neurosurgery
Department of Neurosurgery
Great Ormond Street Hospital
London, UK

Dennis R Klassen MD, BSc (Hons), FRCSC, FACS
Assistant Professor
Dalhousie University
Queen Elizabeth II Health Sciences Centre
Department of Surgery
Division of General Surgery
Halifax, NS, Canada

Christopher Y Kong MD
Spine Surgeon
Department of Orthopedics
Cedars–Sinai Medical Center
Los Angeles, CA, USA

Manoj Kuduvalli MCh, FRCS (C-Th)
Consultant Cardiac and Aortic Surgeon
Liverpool Heart and Chest Hospital NHS Foundation Trust
Liverpool, UK

**Simon M Lambert BSc, MBBS, FRCS, FRCSEdOrth**
Consultant Orthopaedic Surgeon
Department of Trauma and Orthopaedics
University College London Hospital
London, UK

**Matthew J Laviolette MD, MSc, FRCSC**
General Surgery Resident
Department of Surgery
Division of General Surgery
University of Ottawa
Ottawa, ON, Canada

**Pilar Leal-Leyte MD**
Abdominal Transplant Surgery Fellow
Department of Abdominal Transplant Surgery
Baylor University Medical Center
Dallas, TX, USA

**James Learned MD**
Assistant Clinical Professor
Department of Orthopaedic Surgery
UCI Health
Orange County, CA, USA

**Ronald A Lehman Jr, MD**
Professor of Orthopaedic Surgery, Tenure; Chief, Reconstructive, Robotic and Minimally Invasive Spine; Director, Robotic Spine Surgery; Director, Athletes Spine Center; Co-Director, Comprehensive Adult and Pediatric Spine Fellowship; Director, Clinical Spine Research; Co-Director, Orthopedic Clinical Research
Department of Orthopedics
Daniel and Jane OCH Spine Hospital
New York, NY, USA

**Jennifer Li MD, MHSc, BSc**
General Surgery Resident
Michael J McKirdy MB ChB, FRCS, FRCS (General)
Consultant Oncoplastic Breast Surgeon
Royal Alexandra Hospital
Paisley, UK

Niall MH McLeod FRCS (OMFS), FDS, MRCS
Consultant
Department of Oral and Maxillofacial Surgery
Barts Health NHS Trust
London, UK

Todd PW McMullen MD, PhD, FRCSC, FACS
Associate Professor of Surgery and Oncology Director
Division of Surgical Oncology
University of Alberta
Edmonton, AB, Canada

Amin Madani MD, PhD
Endocrine and Acute Care Surgery
Division of General Surgery
University Health Network - Toronto General Hospital
Toronto, ON, Canada

Nicole Mak MD
General Surgery Resident
Department of Surgery
Faculty of Medicine
University of British Columbia
Vancouver, BC, Canada

Samir Mardini MD
Chair, Division of Plastic Surgery
Professor of Surgery
Mayo Clinic College of Medicine
Thomas Mathew MBBS, MD, DM, FRCP, FESC
Consultant Cardiologist
Trent Cardiac Centre Division
Nottingham University Hospitals
Nottingham, UK

Keith A Mayo MD
Director
Hansjörg Wyss Hip and Pelvis Center
Swedish Hospital
Seattle, WA, USA

Adrienne L Melck MD, MPH, FRCSC
Clinical Associate Professor
Department of Surgery
Faculty of Medicine
University of British Columbia
Vancouver, BC, Canada

Adal H Mirza BMBS, MRCS, DOHNS, MSc
ENT Registrar
Department of Otolaryngology and Head and Neck Surgery
University Hospital Southampton
Southampton, UK

Elliot J Mitmaker MD, MSc, FRCSC, FACS
Associate Professor
Department of Surgery
McGill University Health Center
Montreal, QC, Canada

Julie A Mundy MBBS, MBA, FRACS (General & Cardiothoracic Surgery)
Associate Professor, Director
Department of Cardiothoracic Surgery
University of Queensland and Princess Alexandra Hospital
Brisbane, Queensland, Australia
Benjamin Namdarian PhD, FRACS (Urol)
Robotic Urology Fellow
Guy's and St Thomas' Hospitals NHS Foundation Trust
London, UK

Rajesh Nair MD, FRCS (Urol), FEBU, MSc (Urol)
Consultant Urological Surgeon
Guy's and St. Thomas’ NHS Foundation Trust
The Urology Centre
Guy's Hospital
London, UK

Richard W Nason MD, BSc, MSc, FRCSC
Professor
Department of Surgery
University of Manitoba
Head and Neck Surgical Oncologist
CancerCare Manitoba
Winnipeg, MB, Canada

Yujiro Obikane MD
Attending Neurosurgeon
Department of Neurosurgery
Kasai Shoikai Hospital
Tokyo, Japan

Sandip S Panesar MB BCh, BAO, MSc
Post-doctoral Research Fellow in the Fiber Tractography Laboratory
Department of Neurosurgery
Stanford University
Stanford, CA, USA

Brian A Parsons BSc, MBChB, MD, FRCS (Urol)
Consultant Urological Surgeon
Department of Urology
Royal Devon and Exeter Hospital
Exeter, Devon, UK

K Alok Pathak MS, Dip Nat. Bd, MNAMS, FRCS(Glasg.), FRCSEd, FRCSC
Professor
Department of Surgery
Director, Surgical Fellowships
University of Manitoba
Head & Neck Surgical Oncologist & Program Director, Head & Neck Surgical Oncology Fellowship
CancerCare Manitoba
Winnipeg, MB, Canada

Erlick A Pereira MA, BM, BCh, DM, FRCS (SN), SFHEA
Consultant Neurosurgeon and Senior Lecturer in Neurosurgery
Academic Neurosurgery Unit
St George's and University of London
London, UK

Nicole Powell-Dunford MD, MPH, FAAFP
Associate Professor
US Army School of Aviation Medicine
Department of Military and Emergency Medicine
Uniform University of the Health Sciences
Bethesda, MD, USA

Eitan Prisman MD, MA, FRCSC
Associate Professor Divisions of Otolaryngology Head & Neck Surgery
University of British Columbia
Vancouver, BC, Canada

Fayez A Quereshy MD, MBA, FRCSC, FACS
Staff Surgical Oncologist, University Health Network
Associate Professor, Department of Surgery, University of Toronto
Toronto, ON, Canada

David Richens FRCS
Cardiac Surgeon
Wooler, UK

Geoffrey E Rose BSc, MBBS, MS, DSc, MRCP, FRCS, FRCOphth
Professor and Consultant Ophthalmic Surgeon
Department of Adnexal Surgery
Moorfields Eye Hospital NHS Foundation Trust
London, UK

Alistair C Ross MB, FRCS
Consultant Orthopaedic Surgeon
BMI Bath Clinic
Bath, UK

Jordan DW Ross BSc, MBBS
Registrar
Department of Cardiothoracic Surgery
Princess Alexandra Hospital
Brisbane, Queensland, Australia

Arun Sahai PhD, FRCS (Urol)
Consultant Urological Surgeon and Honorary Senior Lecturer
Department of Urology
Guy's Hospital, Guy's and St Thomas’ NHS Trust, King's Health Partners
London, UK

Hanish Sall MD
Specialist Registrar Cardiology
Nottingham University Hospital
Nottingham, UK

Jason Samarasena MD
Associate Clinical Professor of Medicine
Division of Gastroenterology and Hepatology – Interventional Endoscopy
H. H. Chao Comprehensive Digestive Disease Center
University of California Irvine
Orange, CA, USA

Ahmad Sayasneh MBChB, MD(Res), MRCOG
Consultant Gynaecological Oncology Surgeon
Guy's and St Thomas’ NHS Foundation Trust
Honorary Senior Clinical Lecturer
Faculty of Life Sciences and Medicine
King's College London
London, UK
Thomas A Schildhauer MD
Professor, Medical Director and Chairman
Department of General and Trauma Surgery
BG University Hospital Bergmannsheil
Ruhr-University
Bochum, Germany

Alexis Schizas MBBS, BSc, MSc, MD, FRCS
Consultant Colorectal Surgeon
Gastrointestinal Medicine and Surgery
Guy's and St Thomas’ NHS Foundation Trust
London, UK

Duncan SG Scrimgeour MBChB, BSc (Hons), MSc, PhD, PgCERT-MRS, MRCS, MFST RCS (Ed)
Specialty Registrar in Colorectal/General Surgery and Intercollegiate Research Fellow
Department of Colorectal Surgery and Centre for Healthcare Education and Research Innovation
Aberdeen Royal Infirmary and University of Aberdeen
Aberdeen, UK

Tian Ee Seah BDS (Sing), MDS, OMS (Sing), FRACDS (Aus), FAMS (Sing)
Visiting Consultant
Cleft and Craniofacial Dentistry Unit
Kadang Kerbau Women's and Children's Hospital
Singapore

Majed Shabbir BSc, MBBS, MD, FRCS
Clinical Lead Andrology and Genito-Urethral Reconstruction
Department of Urology
Guy's and St Thomas’ Hospital
London, UK

Rahul S Shah BSc, MBChB, MRCS
Neurosurgical Registrar
Department of Neurosurgery
John Radcliffe Hospital
Oxford, UK
Julia Sharma MD, FRCSC  
Pediatric Neurosurgeon  
Valley Children's Hospital  
Madera, CA, USA

Neil Sharma MBChB, PhD, FRCS (ORL-HNS)  
Consultant Head and Neck Surgeon  
University Hospital Birmingham NHS Trust  
Clinician Scientist  
University of Birmingham  
Birmingham, UK

David J Shewring MB BCh, FRCS(Orth), Dip Hand Surg (Eur)  
Consultant Hand Surgeon  
University Hospital of Wales  
Cardiff, UK

Yotam Shkedy MD  
Attending Surgeon  
Department of Otolaryngology – Head and Neck Surgery  
Rambam Health Care Campus  
Haifa, Israel

Andrew J Sidebottom BDS, FSDRCS, MBChB, FRCS (OMFS)  
Consultant Oral and Maxillofacial Surgeon  
Maxillofacial Unit  
Queens Medical Centre and Nottingham University Hospitals  
Nottingham, UK

Arvind Singh MCh CVTS, FRCS CTh  
Consultant Cardiac Surgeon  
The Essex Cardiothoracic Centre  
Basildon, Essex, UK

Clare Skerritt FRCS (Paeds), MBBS, MRCS, MSc  
Specialist Registrar in Paediatric Urology  
Department of Paediatric Urology  
Evelina Children's Hospital  
London, UK
Susan M Standring MBE, PhD, DSc, FKC, Hon FAS, Hon FRCS
Emeritus Professor of Anatomy
Department of Anatomy
King's College London
London, UK

Marissa Suchyta BA
Doctoral Student
Division of Plastic Surgery
Mayo Clinic
Rochester, MN, USA

Adam Szafranek FRCS, MD
Consultant Cardiac Surgeon
Nottingham University Hospitals
Nottingham, UK

Arash K Taghizadeh MB, BS, MSc, FRCS (Urol)
Consultant Paediatric Urologist
Department of Paediatric Urology
Evelina London Children's Hospital
London, UK

Lee A Tan MD
Assistant Professor
Department of Neurological Surgery
UCSF Medical Center
San Francisco, CA, USA

William AS Taylor MBChB, FRCS (SN)
Consultant Neurosurgeon
Department of Neurosurgery
Institute of Neurological Sciences and Queen Elizabeth University Hospital
Glasgow, UK

Ramesh Thurairaja BM, MD, FRCS (Urol), FEBU
Consultant Urological Surgeon
Department of Urology
Guy’s and St Thomas’ Hospital
London, UK

R Shane Tubbs PhD, MS, PA-C
Professor
Department of Neurosurgery
Tulane University School of Medicine
New Orleans, LA, USA

Florence Unno MD, MAst
Orthopaedic Surgeon
Hansjörg Wyss Hip and Pelvis Center
Swedish Medical Center
Seattle, WA, USA

Juan S Uribe MD, FAANS
Professor and Vice-Chairman Department of Neurosurgery
Chief Division of Spinal Disorders
Volker K.H. Sonntag Chair of Spine Research
Barrow Neurological Institute
Phoenix, AZ, USA

John T Vetto MD, FACS
Professor of Surgery
Division of Surgical Oncology
Oregon Health & Science University
Portland, ON, USA

Andrew C Vivas MD
Resident Physician
Department of Neurosurgery
University of South Florida
Tampa, FL, USA

David A Waller FRCS(CTh)
Consultant Thoracic Surgeon
St Bartholomew's Hospital
London, UK

Dara Walsh
Wei-Hsin Wang MD
Attending Neurosurgeon, Neurological Institute
Department of Neurosurgery
Taipei Veterans General Hospital
Taiwan

Adam C Watts MBBS, BSc, FRCS (Orth)
Consultant Elbow Surgeon
Wrightington Hospital
Visiting Professor
University of Manchester
Manchester, UK

Adam V Weizman MD, MSc, FRCPC
Assistant Professor of Medicine
Division of Gastroenterology
Department of Medicine
Mount Sinai Hospital, University of Toronto
Toronto, ON, Canada

Erich M Wessel DO
Surgical Resident
Department of Surgery
University of Kansas Hospital
Kansas City, KS, USA

Peter C Whitfield BM (Distinction), PhD, FRCS Eng, FRCS (Surgical Neurology), FHEA
Consultant Neurosurgeon
South West Neurosurgery Centre
University Hospitals Plymouth NHS Trust
Plymouth UK
Honorary Associate Professor
Plymouth University Peninsula Medical School
Plymouth, UK
Shawnee A Williams Lt Col, USAF, BSC, PhD, CAsP
Commander
Special Warfare Human Performance Section
United States Air Force
San Antonio, TX, USA

Nathan E Wiseman MD, BSc(MED), FRCSC
Associate Professor
Department of Surgery
Faculty of Medicine
University of Manitoba
Consultant Pediatric Surgeon
Sections of Pediatric and Cardiothoracic Surgery
The Winnipeg Children's Hospital
Winnipeg, MB, Canada

Sam M Wiseman MD, BSc, FRCSC, FACS
Professor, Department of Surgery
Faculty of Medicine, University of British Columbia
Consultant Head & Neck Surgeon, Surgical Oncologist, General Surgeon
Department of Surgery, Division of General Surgery
St. Paul's Hospital & Providence Health Care
Research Director, Department of Surgery, St. Paul's Hospital & Providence Health Care
Consultant Surgical Oncologist, British Columbia Cancer Agency
Vancouver, BC, Canada

Herbert J Witzke MD
Clinical Fellow
Department of Cardiothoracic Surgery
Barts Heart Centre, St Bartholomew's Hospital
London, UK

Alastair Younger MB ChB, MSc ChM, FRCSC
Orthopaedic Foot and Ankle Surgeon
Professor
Head Division of Distal Extremities
Department of Orthopaedics
University of British Columbia;
Director of Foot and Ankle Research
St. Paul’s Hospital;
President British Columbia Orthopaedic Association
Partner, Footbridge Centre for Integrated Foot and Ankle Care
Vancouver, BC, Canada

Adrian Zammit MD, MSc (UCL), MSc (Edin), MRCS
Specialist Registrar in Neurosurgery
South West Neurosurgery Centre
University Hospitals Plymouth NHS Trust
Plymouth, UK

Daniel Zamora-Valdes MD, MSc
LDLT Fellow
Department of Abdominal Transplant Surgery
Baylor University Medical Center
Dallas, TX, USA

Christopher J Zarembinski MD
Staff Anesthesiologist
The Pain Center
Department of Anesthesiology
Cedars–Sinai Medical Center
Los Angeles, CA, USA

Siham Zerhouni MD CM, MSc, FRCSC
Clinical Instructor
General Surgical Oncologist
University of British Columbia
Kamloops, BC, Canada
Dedications

To Rachel, Ellie, Katie and Rosalind.

PETER

To Helen and Caroline.

SUSAN

To Natalie, Jacob, Isabel, Nicole and my parents.

SAM

To teachers, colleagues and students - past, present and future.

PETER, SUSAN, SAM
SECTION 1
Introduction

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Introduction

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A short history of surgery

Harold Ellis

The history of surgery is marked by a series of revolutionary advances usually made by a single pioneer and his or her disciples. Such advances have occurred with ever-increasing frequency over the last century.

The first surgeons were those men and women, now lost in time, who became experts at binding up the wounds, splinting the fractures and lancing the abscesses of their fellows, as well as dealing with a surprising number of other ills. We can visualize their activities in the reports of explorers and medical missionaries of the nineteenth and early twentieth centuries from such diverse and isolated places as the Atlas Mountains of North Africa, the jungles of Central Africa and the forests of Borneo. Trephination of the skull, management of arrow and other wounds, drainage of abscesses and numerous other procedures were witnessed being performed by surgeons who had never previously encountered outside visitors. Most remarkable, in 1884, Robert Felkin MD recorded and drew a ‘classical’ caesarean section performed in what is now Uganda, the patient first being intoxicated with banana wine. When Felkin left, 11 days later, both mother and child were well.

The early surgeons were pragmatic. Wounds involving brain, thoracic or abdominal viscera or the major arteries were known to be lethal and, by and large, were left untreated. Fractured limbs were straightened and splinted, and kept immobilized till clinical union was achieved. The appearance of pus in a wound, called ‘laudable pus’, was regarded as a good prognostic sign, in contrast to spreading gangrene, which usually presaged death. Remarkably, a drawing of circumcisions being performed has been recovered from Memphis, in ancient Egypt, dated as between 3000 and 2400 BCE. The operation was practised widely in the ancient world, as a ritual rather than for any surgical reason.

‘Cutting for the stone’, perineal lithotomy for vesical calculi, was performed by ancient Hindu, Greek, Roman and Arab surgeons. Many of their patients were children, but why this was a common disease in children still remains a mystery.
The pathology of war wounds underwent a radical change with the introduction of gunpowder and firearms in Europe in the fourteenth century. Gunpowder was first used at the battle of Crécy in 1346, when Philip VI of France was defeated by Edward III. The gross tissue destruction produced by musket and cannon shot provided the anaerobic conditions for tetanus and gas gangrene, which now became all too common. It was assumed that the cause was the gunpowder. The remedy? Destroy this poison in the wound with cautery or with boiling oil; the latter was the more popular since it was recommended in the standard textbook of the Italian surgeon Giovanni da Vigo (1450–1525), which went through 40 editions in many languages. Of course, the ‘treatment’ actually made matters worse.

One of the really great figures in surgery was Ambroise Paré (1510–1590), a French military surgeon who trained at the Hôtel-Dieu in Paris. At his first experience of war, in the campaign at Turin in 1537, Paré ran out of boiling oil with which to treat a barn full of seriously wounded men and used simple dressings for the remainder of his patients, in what must be regarded as the first randomized controlled trial in history! He relates how, next morning, he found his ‘treated’ group were in agony, while his ‘controls’ were resting comfortably. He wrote, ‘then I resolved never again to so cruelly burn the poor wounded by gunshot’. Paré went on to show that bleeding from the major blood vessels should be treated not by red-hot cautery (then the standard practice) but by simple tying of the divided vessels.

Further generations of surgeons, in Europe and later in the USA, pushed forward our knowledge of anatomy and surgical pathology, and attempted increasingly complex surgery, such as ligation of the major arteries, lithotomy for vesical calculi, and ever more extensive surgery for cancers of the breast and the other superficial and accessible structures. They were dreadfully impeded in their labours by the twin problems of wound infection and the agonies of the knife. These barriers were to be significantly resolved over a surprisingly short number of years between 1846 and 1867.

From the earliest times, surgeons had attempted to assuage the pain of injury and surgery. Large doses of opium or alcohol, or a combination of the two (laudanum), were often employed but with little success. The major advance was the use of the inhalation of ether, introduced by a Boston dentist, William Morton (1819–1868), first for dental extractions, and then, on 16 October 1845, for the removal of a small benign lump in the neck, performed by the senior surgeon at the Massachusetts General Hospital, John Warren (1778–1856). Three weeks later, Warren performed an above-
knee amputation for tuberculosis of the knee on a 21-year-old servant girl, safely and painlessly under ether anaesthesia given by Morton. The news that major surgery could be performed without pain spread as fast as news could travel – around the USA by coach and around the world by sail. Within days of the news reaching each major centre, surgeons purchased ether and constructed a copy of Morton’s simple apparatus. For example, James Robinson, a London dentist, gave ether for a dental extraction on 19 December 1845. Two days later, Robert Liston (1794–1847) carried out a completely successful above-knee amputation on a butler with chronic osteomyelitis of the tibia at University College Hospital, London.

James Young Simpson (1811–1870), Professor of Obstetrics in Edinburgh, used ether successfully in his obstetrics practice in January 1847. However, ether had the disadvantages of a slow induction and the tendency to produce vomiting. After experimenting with a range of volatile organic fluids, Simpson hit upon chloroform, with its advantages of a pleasant smell and easy induction, and by November 1847 he was able to publish his satisfactory results. Chloroform was successfully administered by John Snow to no less a patient than Queen Victoria during the birth of her eighth child in 1851, the Queen declaring herself delighted with the result. One great barrier to surgical advance, pain, had been overcome. The new specialty of anaesthesia was born and immediately adopted by the profession.

In marked contrast, the acceptance of antisepsis was a much slower process. Most surgeons seemed to accept suppuration and pus formation as the ‘normal’ process of wound healing. The proof that microorganisms are the cause of wound infection began to be provided by the work of the chemist Louis Pasteur (1822–1895), working at the Sorbonne in Paris. His brilliant, yet simple, experiments demonstrated that the putrefaction of milk, broth and so on was produced not by exposure to air, as previously thought, but by microorganisms present in the air, which he demonstrated under the microscope.

The value of cross-fertilization of ideas in academia is exemplified by the fact that it was the Professor of Chemistry at the University of Glasgow, Thomas Anderson, who drew the attention of the young Professor of Surgery at the university Joseph Lister (1827–1912), to Pasteur's work, published in French journals of chemistry. Lister was intensely interested in the problems of wound healing and infection, and immediately realized that it was exposure not to the air but to the microorganisms in the air that resulted in wound sepsis. But how to kill the organisms? Applying Pasteur's technique
of boiling was obviously impossible. Lister decided to use crude carbolic acid, having heard that this agent had proved effective in cleaning the stinking drains of the city of Carlisle, the smell of which resembled his surgical wards in the Glasgow Royal Infirmary!

Lister’s crucial experiment took place on 12 August 1867, not in the operating theatre but in a side ward. The patient was an 11-year-old boy who had been run over by a wagon and who had sustained a compound fracture of the tibia. The wound was treated with crude carbolic acid and dressed with gauze soaked in this agent; the fracture was immobilized in a splint. After 4 days, the dressing was changed: there was none of the usual stench of hospital infection nor its other familiar features. Six weeks after the accident, the young patient walked out of the hospital. Over the next 2 years, Lister treated 11 patients with major compound limb fractures. There was one case of hospital gangrene in a tibial fracture, requiring amputation, and one death. This was a man with a major compound femoral shaft fracture. All was progressing well until the patient had a major secondary haemorrhage after 7 weeks: the femoral artery was tied but the patient died. Reading this report, it seems likely that if blood transfusion had been available at that time, recovery might well have taken place. The other nine patients all recovered, free from infections. This was a remarkable result, compared with the universal infection rate and 46% mortality for compound fractures in the hospital before the carbolic acid regime was adopted. Lister delayed publishing his results until he produced a series of papers in *The Lancet* in 1867. He was now also able to treat tuberculosis of joints and to operate on patients with non-united fractures of the patella and olecranon, undertaking procedures that previously would have been considered malpractice, since suppuration following what amounted to conversion of a closed into an open fracture would have been almost inevitable.

Surprisingly, it took time for Lister’s work to be widely adopted. Most surgeons believed that carbolic acid was another of the many hundreds of medicaments that surgeons had employed over the ages, without realizing that the Listerian method involved a totally novel attitude to wound management. In the meantime, over the next two decades following Lister’s initial work, other surgeons, particularly in Germany, were advancing surgical technique by the *prevention* of bacterial contamination of wounds – aseptic surgery – in which instruments, dressings, drapes and so on were sterilized in autoclaves, and sterile masks, caps and gowns were employed. The use of rubber gloves was popularized by William Halsted (1852–1922) of Baltimore
in 1889. By the end of the nineteenth century, surgical wards and operating theatres came to resemble the facilities we see today.

Successively, the abdominal cavity, the chest, the heart, and the cranium and its contents all became accessible to the surgeon. Important landmarks include those established by Theodor Billroth (1829–1894), who carried out a successful partial gastrectomy for a pyloric cancer in 1881; Ernest Miles (1869–1947), who performed the first successful abdominoperineal resection of a rectal carcinoma in 1907 at the Royal Cancer Hospital (later the Marsden Hospital) in London; Harvey Cushing (1869–1939) in Boston, who laid down the principles of modern neurosurgery; and Theodor Kocher (1841–1917), who established thyroid surgery in Berne, Switzerland, in work that earned him the first of the few Nobel prizes that have been awarded to surgeons.

From the 1930s onwards, surgery in all its branches has advanced by almost geometrical progression. It would require a book rather than a chapter to record the contribution of antibiotics, heralded by the publication of the isolation of penicillin by Lord Howard Florey (1898–1968) and his team in Oxford; the work on joint replacement surgery, which owes much to Sir John Charnley (1911–1982) at Manchester; and the growth of endoscopic and minimal access surgery, which owes a great debt to the introduction of fibre optics by Harold Hopkins (1918–1984), Professor of Applied Optics at Reading. The development by Sir Roy Calne (1930–) of effective drugs to prevent transplanted organ rejection – first 6-mercaptopurine in 1960, then azathioprine in 1961 and cyclosporine in 1976 – led to the foundation of modern organ transplantation surgery.

Who can foretell what exciting changes the immediate future of surgery may see?
Further Further Reading

Improving surgical performance through human factors recognition and enhanced team working

Peter A Brennan, Nicole Powell-Dunford, Shawnee A Williams, Jaime R Harvey

Human error is a significant cause of personal and organizational mistakes, and the need to recognize and address human factors (HF), performance optimization and team dynamics is essential to improve patient safety. Surgical errors are usually multifactorial rather than the fault of one individual: organizational issues, team dynamics and HF are often at the root of many incidents. The World Health Organization (WHO) surgical checklist and aviation-style communication training were designed to optimize surgical performance by mitigating human fallibility and communication challenges. The brief and debrief processes are other performance improvement practices that have been rated favourably when incorporated into healthcare. Stress and fatigue, emotional status, hunger, situational awareness and ergonomics can all lead to error but are often underappreciated.

This chapter aims to raise awareness of both individual and organizational HF, as well as provide techniques to combat human errors that are commonly seen in the operating theatre. An understanding of HF in modern surgery is just as important as knowing the surgical anatomy to improve safety for patients.
**Background**

Over 70% of air crashes occur as a result of human error rather than technical failure: communication problems potentially account for up to 80% of these. The appreciation of many factors leading to human error, including poor communication, stress, repetition, tiredness, and an acceptance that a certain degree of failure is inevitable, has resulted in significant improvements in air safety. These lessons, especially with regard to ensuring optimized performance, team dynamics and HF, have been applied to the operating theatre environment. The 1999 USA Institute of Medicine report *To Err Is Human* and subsequent publications have highlighted death from preventable medical errors: errors in surgery were second only to errors in medication as the most common cause of error-related death. Recent estimates place avoidable US patient deaths at over 400,000 per year, placing preventable harm in the top three causes of death. In the UK, it is estimated that there are approximately 4000 deaths per year due to medical error, with a disproportionate amount of harm caused by errors during surgery. Despite the introduction of the WHO Surgical Safety checklist, the number of ‘Never Events’, such as wrong-site surgery, is increasing. While iatrogenic mistakes are relatively rare, near-misses are far more common; analysis of the root causes that follow any incident can help to avoid otherwise preventable errors.
Where do potential human-related problems originate?

Recognition of several identifiable HF common to both aviation and medicine is crucial in helping to minimize error (Box 2.1). These include stress, fatigue and tiredness, lack of effective team working, poor communication and imperfect leadership. Failures contributing to error could include increased perceived or actual pressure to meet waiting list targets; having more patients on an operating list; seeing more patients in a busy outpatient clinic; and working long hours without a break.

Box 2.1

Simplified human factors analysis and classification system (HFACS) relevant to practising surgeons

The different levels are analogous to the holes in the Swiss cheese model (see Fig. 2.2), which can line up, causing an error.

Organizational influences within the hospital

- Climate, process and resource management within the hospital
- Communication, training and recognition of human factors responsible for possible error
- Hospital targets and pressures to deliver results (either perceived or real)

Unsafe supervision

- Loss of situational awareness, especially if not recognized by the theatre team
- Inadequate supervision of junior staff
- Failure of the team to know what to do when things go wrong
- Failure of briefings/complacency with World Health Organization
checklist

Preconditions to unsafe acts

- Environmental factors: background noise, distractions, lighting, ambient temperature, humidity
- Fatigue, hunger and nutritional status
- Emotional influences (anger, personal issues)
- Tiredness, boredom, communication issues
- Panic

Unsafe acts (less likely)

- Unfamiliarity with changes from what is seen as a ‘normal event’
- Multitasking
- Operating outside of one's area of expertise
Organizational role in surgical performance

Senior management commitment is core to safety across organizations. An open and transparent culture should be central to any hospital agenda. Unaccountable and authoritarian leadership, along with a ‘blame culture’, led to an excess of 35 deaths on the Bristol paediatric heart surgery service, triggering a host of changes to limit preventable surgical incidents.\(^5\) Pilots, ground engineers and other safety personnel freely question any safety issues related to their charge of an aeroplane, and the airline company itself has a duty to address any concerns, even if this means grounding a flight shortly before takeoff. Top management and surgical team leaders must create a safe environment for error reporting. A high-performing surgical team must, in turn, ensure the use of evidence-based best practices, such as the complete WHO surgical checklist, avoidance of human error traps, and recognition of situations in which error or harm is more likely to occur (Box 2.2).

Box 2.2

When to take special care

It is important to recognize situations in which error/harm is more likely:

- Site- and side-specific procedures
- Staffing limitations/high turnover rates
- Changes in physical environment
- Changes in staff/scheduling
- Significant changes in the life situation of team members – divorce, death in family
- Special patient factors, e.g. a Jehovah's Witness who is unable to accept transfusion; obesity

While a surgeon's life is not at stake during an operation, the psychological effects of a surgical incident can be devastating to teams and individuals.\(^6\) The remainder of this chapter focuses on human error at a personal and team level.
What human factors should surgeons be thinking about?

Personal HFs that could lead to error include tiredness and fatigue, nutritional status, emotional states including anger and stress, multitasking (dealing with more than one task at a time) and loss of situational awareness (Box 2.1).

Tiredness and fatigue

Tiredness and fatigue are well recognized in aviation and other high-risk industries as contributors to error, and consequently there are strict guidelines in place. Crews are allowed to work only for a certain number of hours before being replaced (Fig. 2.1). Recognizing that periods of intense concentration cannot be maintained for more than 20–30 minutes at a time, many airlines ensure that one pilot is as fresh as possible for landing, taking over the final approach from the other pilot who has flown the initial descent. The influence of these factors in surgical performance is less well known: tiredness will undoubtedly affect decision-making, the performance of complex mental tasks, and situational awareness, even if individuals think that they are immune and can operate for many hours at the same level of expertise without a break. The ability for insufficient or poor-quality sleep to degrade performance is dramatically underestimated by healthcare providers.
Using Reason's Swiss cheese model of human error\textsuperscript{7} as a template (Fig. 2.2), it can be appreciated that tiredness, an emotional factor such as anger, and a stressful procedure can all align to raise the risk of a serious medical error significantly. Box 2.2 highlights some of the high-risk situations that can increase the likelihood of error. Good team dynamics and communication are fostered when just a few seconds are taken to question a decision made either by oneself or a by colleague: a phrase such as ‘Let me check I've got this right’ can be extremely useful. Other phrases such as ‘I'm not happy’ and ‘I'm going to intervene/take control’ can also be used in high-risk situations where a potential error is perceived as being likely to happen.
**Nutritional status and hydration**

Hydration, nutrition and recovery significantly underpin HF and performance in a demanding operating-room setting. Levels of dehydration have been shown to influence cognitive function and performance. Meals with protein, complex carbohydrates in moderation and healthy fats (e.g. those derived from fish, olive oil or avocado), which are high in vegetable and fibre content, are considered to be the best. Simple sugars, processed food and trans-fatty acids do not support the long-term focus and endurance required in theatre. One best practice involves stopping operating (or allowing the procedure to continue without you if there is suitable expertise) every 2–3 hours for a 10–15-minute recovery break during complex surgery. A brief time spent away from the theatre can promote a fresh outlook, improve morale and comfort, and allow a nutritional break. Recovery is also optimized by regular and sound sleep, which is linked positively to nutrition and hydration.

**Stress and emotional factors at work**

We bring our whole self to work, and that includes any emotional or psychological elements that might be affecting us. While these can often be suppressed during busy times, powerful emotions such as anger or upset can
sometimes resurface, particularly during periods of increased mental workload or during high-risk situations, leading to a sentinel event that might contribute to human error. A sentinel event is an unexpected occurrence involving death or serious physical or psychological injury, or the risk thereof. Serious injury specifically includes loss of limb or function. A simple mnemonic, HALT (Box 2.3), is a useful reminder of these factors: a short break, if it is clinically safe to take one, when one or more of these factors becomes apparent is beneficial for the individual and ultimately for the patient. Stress management can be valuable in surgical training and patient care, and HF training during medical education aims to increase awareness of personal stress.

Box 2.3

‘HALT’ factors: when to consider stopping or informing a team member

<table>
<thead>
<tr>
<th>H</th>
<th>Hungry</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Anxious or angry</td>
</tr>
<tr>
<td>L</td>
<td>Late or lonely</td>
</tr>
<tr>
<td>T</td>
<td>Tired</td>
</tr>
</tbody>
</table>

Impact of checklists and team dynamics on surgical performance

The WHO surgical checklist has been associated with significant decreases in postoperative mortality and morbidity. While checklists may not be able to address every aspect of surgical practice, team dynamics and briefings can help optimize performance. There are many instances in surgery where the mental and/or physical workload dramatically increases (e.g. in complex microvascular reconstruction) and this can have an adverse effect on performance. In such cases, team dynamics are crucial. The airline industry enforces a ‘sterile cockpit’ policy in which noise is kept to a minimum below 10,000 ft and conversation relates only to procedural issues during high-risk procedures such as landing and takeoff. The sterile cockpit concept shows
promise for reducing error in anaesthesia and surgery. It is important to discuss the concept with the theatre team at the preoperative briefing session, so that everyone is aware of the need to eliminate non-essential communications at certain times. Poor team dynamics have led to ‘failure to intubate’ tragedies, in which surgeons were not able to establish a surgical airway despite excessively long attempts at oral tracheal intubation. In such cases, ancillary staff who were aware of a prolonged hypoxic state were reluctant to assert the need for intervention, no individual took a leadership decision-making role during the difficult airway intervention, and the team had not been designated roles during a difficult airway situation.

The amount of mental capacity (or bandwidth) for certain tasks reflects previous experience. A new trainee may use far more mental capacity trying to perform certain tasks compared to an established surgeon and, as a result of intense concentration on the task in hand, might not communicate or interact with other team members.

Developing the team is also useful in promoting a sense of shared responsibility for patient safety. Team performance is often substantially improved when front-line staff visibly track important performance metrics such as blood loss, correct swab counts, and needle and instrument checks.

The introduction of the WHO checklist and team brief has improved theatre safety, but ‘Never Events’ still occur. There is still much that can be done around team interaction and better understanding of other team members. The initial team brief and a subsequent debrief after surgery can lead to better patient care, enhanced team working and a feeling of being valued. In aviation, pilots will always discuss ‘What If?’ situations in the preflight briefing to develop an understanding of who will perform what role if something goes wrong (Fig. 2.3). Some clinicians begin patient care by asking the team ‘How could we kill this patient today?’ Box 2.4 summarizes items that could be included in a good briefing and debriefing. The nominated team leader can sum up what has been discussed and, when necessary, repeat this to the team to confirm that there is shared understanding. It would also be helpful for team members to monitor each other for signs of loss of situational awareness and the other factors mentioned above, looking especially for signs of tiredness and fatigue.
Box 2.4

**Items to consider during a team briefing**

The great advantage of a well-prepared team is that every member knows their role and looks out for their colleagues. It can also help team members to feel valued.

**Briefing**

- Introductions, open culture, ‘anyone can speak up if concerned’
- Leadership and team working
- Identify the major steps and who will be doing what
- Ask ‘What am I expected to do if and when something goes wrong?’
• Situational awareness – how to intervene when something does not seem right
• Decision-making

Debriefing

• Consider debriefing for learning:
  What went well?
  One thing that I (we) could do more of?
  One thing that I (we) could do less of?
  What should I (we) do differently next time?
• Say ‘thank you’ to the team

An open, no-blame culture and an attitude that ‘everyone is equal’ lead to better team working and enhanced patient safety. In aviation, the most junior airline pilots can question the decision of the most senior captain without fear of retribution or discrimination. At least in theory, several classical aviation disasters have been averted as a result of the flattening of the hierarchical gradient issues that this behaviour seeks to address. While a hierarchal gradient between trainees and consultants is inevitable, it should be sufficiently flat to allow and even encourage challenge when something might not be quite right, without fear of repercussions.¹⁰ This could always be included in a team brief so that trainees, nurses or students who may be present all feel valued and are in no doubt that they can question the person in charge if they have concerns. We should be striving for a ‘smooth and enjoyable flight’ in our operating rooms, even if the view from the office is not quite as glamorous (Fig. 2.4).
Situational awareness

An important HF to recognize is how we relate to any given situation and how this might change over time. Surgeons can develop tunnel vision during long, complex procedures, particularly when indicators they recognize confirm their actions, while others in the team may realize there is a potential problem. The loss of time perception is one of these factors and can have catastrophic consequences, as the following case from the UK illustrates. A fit, healthy woman died following failed intubation for a routine ear, nose and throat procedure because an otherwise competent team lost all situational awareness as critical minutes passed during failed attempts to intubate her. The patient's husband, an airline pilot, recognized that the same tunnel vision involved in her death had occurred in a fatal plane crash, where a prolonged attempt to troubleshoot a landing light and a crew member's failure to communicate assertively resulted in the plane running out of fuel.

Lack of situational awareness is responsible for many diving accidents, even in experienced divers. Its recognition is an important aspect of developing surgical skill, and a lack of situational awareness has been directly linked to surgical errors. Improving the ability of surgeons to manage their own situational awareness through training and workload
management during surgery, as well as the invaluable role that a well-briefed team can have in recognizing when something is not quite right, are all essential requirements to reduce medical error\textsuperscript{11} (Fig. 2.5).

\textbf{FIG. 2.5} The three key elements that make up situational awareness (SA).
HF training outside the operating theatre

Developments in technology and medical practice have led surgeons to perform an ever-increasing range of minimally invasive procedures. Physicians are undertaking more invasive procedures, such as interventional radiology, percutaneous coronary interventions and gastrointestinal endoscopic resections. The patient safety lessons learned from surgery and theatres with regard to team briefs, application of the WHO surgical checklists, and other HF training therefore need to be extended to all aspects of medical practice and to multiple hospital situations. It is clear that HF training incorporates really important safety principles, such as improved team communication, an open reporting culture, a no-blame culture, regular team safety briefings and safety leadership. Aviation-based ‘crew resource management’ communications training has led to improved reduction in wrong-site surgery. Hospitals should recognize that, through organizational development, they are able to influence attitudes, values and culture with regard to patient safety and that HF training is a simple, cost-effective and egalitarian way of engaging all members of staff.
Avoiding human error traps

• Read out the WHO checklist with the participation of all team members. N.B. Postoperative outcomes are worse when only part of the checklist is used.
• Ensure that staff undertake regular communication training.
• Use the briefing/debriefing to improve team working.
• Prohibit avoidable interruptions and distractions during key parts of an operation.
• Mandate the use of positive two-way communication.
• Ensure 6–8 hours of rest, daily physical activity and adequate nutrition before undertaking surgery.
• Look out for each other as part of a team.
• Take regular breaks and ensure you eat and drink regularly.
• Try to recognize in yourself when something does not seem right.
• Do not assume physically uncomfortable postures unless absolutely necessary. Adjust the equipment and table for the comfort of yourself and your team.

Tips for Improving Patient Safety

These include procedures for optimized human performance in the
operating theatre, creating an atmosphere where errors can be recognized early.
Encourage behaviours that ensure optimum alertness for managing the unexpected – adequate sleep, appropriate nutrition and management of personal stress.
Be prepared for the unexpected and know your own role when something goes wrong.
Ensure a flat hierarchal gradient in your team. Introduce all operating team members to each other.
Prior to starting a procedure, when acting as surgical team leader, state: ‘Please speak up if you see an error about to be made or are worried about anything at all.’
Do not tolerate toxic, belittling or bullying conversation within your theatre because it has a negative impact on the reporting of hazards.
In order to increase alertness for potential incidents, recognize that all of us can make errors – employ debriefs and record patient safety metrics.
Use evidence-based practices like the World Health Organization checklist and communication training.
Conclusion

HF and team dynamics, as well as a commitment to continual performance improvement, are increasingly appreciated as essential aspects of patient safety. However, serious medical errors still occur that could be reduced or prevented by recognizing and adopting various measures in our individual practices. An appreciation of the HF discussed in this chapter as being potential slices of the Swiss cheese model, which, if overlooked, could line up to cause medical error, is a great step for improving an individual's safety in the operating room, or wherever patients are seen and treated. HF, team dynamics and continual process improvement training should be considered essential for all medical staff in the future, just as they have been for airline employees for many years.
Further Reading


Single Best Answers

1. When is human error more likely to occur?
   A. At the start of the day
   B. If the WHO checklist is followed
   C. When the team has been briefed
   D. When you are angry with other team members
   E. After a lunch break

   **Answer: D.** Remember ‘HALT’ and try to stop what you are doing if you are *hungry, angry, late/lonely, or tired.*

2. Which of the following situations raises the likelihood of a medical error?
   A. Getting married
   B. Eating too much at lunchtime
   C. Returning to work after a weekend break
   D. Starting a job at a new hospital
   E. Trying to finish a busy operating list as you have an important meeting to attend

   **Answer: E.** While starting a new job can be stressful, processes should be in place to ensure that teams work together. Rushing or trying to complete a task in order to do something else raises the risk of error.

3. What is the maximum time for which you can maintain intense concentration?
   A. 5–10 minutes
   B. 10–15 minutes
   C. 20–30 minutes
D. 40–60 minutes
E. 60–90 minutes

**Answer:** C. Concentration will also be affected by the complexity of the task being performed, experience, background noise and other factors.

4. Which of the following should NOT be done during team briefing?
   A. Making introductions
   B. Assigning roles to team members in the event of an emergency
   C. Telling the team that, as you are the lead surgeon, your instructions should always be followed
   D. Asking team members to intervene if they feel uncomfortable during the procedure
   E. Giving praise when something has gone well

**Answer:** C. It is important to lower hierarchy. This can be done at the start of an operating list with a sentence such as ‘While I am the lead surgeon, if you have any concerns about what we are doing or are unsure, please don't hesitate to speak up or stop me, no matter how trivial your concern may be.’
SECTION 2
Head and Neck

OUTLINE

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Chapter 5 Face and scalp
Chapter 6 Orbit and orbital trauma
Chapter 7 Orbit and orbital adnexae
Chapter 8 Nose and paranasal sinuses
Chapter 9 Infratemporal fossa and pterygopalatine fossa
Chapter 10 Temporomandibular joint
Chapter 11 Mouth
Chapter 12 Salivary glands
Chapter 13 External and middle ear
Chapter 14 Temporal bone
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This chapter contains an overview of the topographical anatomy of the head and neck. These anatomical regions are probably amongst the most complex in the body because so many structures are contained within a relatively small area. The head contains the brain (see Section 3) and specialized sensory organs such as the eyes, ears, nose and oral cavity (for taste appreciation). The head and neck collectively house the upper parts of the alimentary and respiratory tracts. The neck is delimited superiorly by the mandible and floor of the mouth (anteriorly) and the skull base (posteriorly), and inferiorly by the scapulae (posteriorly) and the thoracic inlet (centrally). The anterior neck contains the thyroid and parathyroid glands. Approximately 300 of the 800 lymph glands found in the body are contained within the head and neck. It is therefore not surprising that many diseases, including malignancy such as lymphoma, result in lymph node enlargement and present with a neck mass.
Skin and fascia

Face and scalp

The scalp consists of five main layers: skin, subcutaneous tissues, epicranial aponeurosis, loose areolar connective tissue and pericranium. Posteriorly, it is continuous with the superficial fascia on the back of the neck. The scalp has a rich vascular, lymphatic and neural supply, and bleeds readily following trauma or surgical incision. Laterally, the scalp blends into the temporal region, where it has a looser texture.

On the face, three fascial layers (a subcutaneous fibroadipose tissue, a superficial musculo-aponeurotic system (SMAS) and the parotid–masseteric fascia) lie superficial to the plane of the facial nerve and its branches. The SMAS layer is important for raising parotid skin flaps and for aesthetic procedures. On the lateral side of the head, above the zygomatic arch, the temporoparietal fascia lies in the same plane as the SMAS but does not blend with it. It is superficial to the temporal fascia and blends superiorly with the epicranial aponeurosis. The parotid gland itself is surrounded by a fibrous capsule derived from the deep cervical fascia. The face has a good blood supply and there are also numerous vascular anastomoses that cross the midline; for example, the labial arteries supplying the lips bleed and pulse from both sides when transected.

Neck

The superficial cervical fascia contains a variable amount of adipose tissue, superficial lymph nodes and platysma. The aponeurotic fibres of platysma gradually fan out in this layer, either fading away within the posterior triangle, or becoming skin ligaments, or continuing into the fascia that covers pectoralis major and deltoid. Platysma is important surgically because most neck incisions entail raising subplatysmal flaps in order to gain access to the underlying structures, and to help preserve the blood supply to the skin, particularly in the previously irradiated neck.

Descriptions of the organization of the deep cervical fascia are largely based upon the classic work of Grodinsky and Holyoke. The deep cervical fascia is conventionally subdivided into three sheets (superficial or investing, middle and deep layers) and the carotid sheath, a condensation of the deep fascia that envelops the common and internal carotid arteries, internal
jugular vein, vagus nerve and ansa cervicalis.

The superficial layer of the deep cervical fascia (SLDCF) encircles the neck, ensheathing trapezius and sternocleidomastoid. A simplified ‘rule of twos’ is often used to describe the SLDCF: it encloses two glands (submandibular and parotid), two muscles (sternocleidomastoid and trapezius) and two ‘spaces’ (suprasternal space and the ‘subvaginal’ space of the posterior triangle). Above the hyoid bone, and on both sides of the neck, the SLDCF splits to enclose the submandibular salivary gland and fuses with the periosteum along the superior nuchal line of the occipital bone, over the mastoid process, and along the entire base of the mandible. Inferiorly, it fuses with the periosteum covering the acromion, clavicle and manubrium of the sternum. Just above the manubrium, the SLDCF splits to enclose the suprasternal space, which contains a small amount of areolar tissue, the lower parts of the anterior jugular veins and the jugular venous arch, the sternal heads of the sternocleidomastoid muscles and lymph nodes.

The middle layer of the deep cervical fascia is subdivided into a muscular layer (surrounding the infrahyoid strap muscles) and a visceral layer (including the pretracheal and buccopharyngeal fasciae). The visceral layer extends from the base of the skull posteriorly, and from the hyoid bone and thyroid cartilage anteriorly and laterally. It invests the thyroid gland, larynx, trachea, pharynx and oesophagus, and continues into the superior mediastinum along the great vessels, ultimately fusing with the fibrous pericardium. Laterally, it merges with both the SLDCF and the carotid sheath.

The deep layer of the deep cervical fascia is subdivided into alar fascia anteriorly and prevertebral fascia posteriorly. The alar fascia is separated posteriorly from the prevertebral fascia by loose connective tissue that fills the so-called danger space (Ch. 16) and is separated anteriorly from the pharynx/oesophagus, and the visceral layer of the middle deep cervical fascia, by loose connective tissue that fills the retropharyngeal space. The prevertebral fascia forms a fascial floor for the posterior triangle of the neck. The phrenic nerve (motor supply to the diaphragm) and the trunks of the brachial plexus in the root of the neck all lie deep to the prevertebral fascia, and so it is important to be careful not to breach this fascia when operating in this area. As the subclavian artery and the brachial plexus emerge from behind scalenus anterior they carry the prevertebral fascia downwards and laterally behind the clavicle as the axillary sheath.

The fascial layers of the head and neck define a number of potential tissue
spaces’ or compartments above and below the hyoid bone (Tables 3.1 and 3.2). These spaces are important because they allow the potential spread of infection, enabling rapid progression from the skull base to the mediastinum or to other spaces, with significant clinical sequelae. Use of the three layers of the deep cervical fascia 'to delineate multiple compartments of the suprahyoid and infrahyoid neck is the current paradigm and allows segmentation of pathology into well-defined fascially enclosed spaces'. For example, airway compromise can occur quickly when the submandibular and sublingual spaces are involved bilaterally with infection (Ludwig's angina), or severe trismus may occur with involvement of the masseteric or pterygoid spaces. In health, the tissues within these spaces are normally either closely applied to each other or filled with relatively loose connective tissue.

TABLE 3.1

Cranial ‘spaces’ and their contents

<table>
<thead>
<tr>
<th>Spaces with subdivisions</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parotid space</td>
<td>Parotid gland, retromandibular vein, facial nerve, external carotid artery, lymph nodes</td>
</tr>
<tr>
<td>Masticator space, buccomasseteric region, Suprazygomatic, Infratemporal, Nasopharyngeal, Retrozygomatic</td>
<td>Mandible (or just the alveolar ridge), masseter, medial and lateral pterygoids, mandibular division of trigeminal nerve, extension of buccal fat</td>
</tr>
<tr>
<td>Superficial and deep temporal spaces</td>
<td>Superficial: superficial temporal vessels and branches of the auriculotemporal and facial nerves, temporoparietal fat pad</td>
</tr>
<tr>
<td>Buccal space, Submandibular space, Submaxillary, Sublingual, Submental</td>
<td>Buccal fat pad, parotid duct, Hypoglossal nerve, lingual nerve, submandibular and sublingual glands, submandibular duct, lymph nodes</td>
</tr>
</tbody>
</table>

(Modified from A.K. Guidera, P.J. Dawes, A. Fong, M.D. Stringer, Head and neck fascia and compartments: no space for spaces, Head Neck 36 (2014) 1058–1068.)
TABLE 3.2

Cervical ‘spaces’ and their contents

<table>
<thead>
<tr>
<th>Spaces with subdivisions</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parapharyngeal space, paranasopharyngeal, lateral pharyngeal, peripharyngeal, pharyngomaxillary, pterygopharyngomaxillary, pterygopharyngeal, pterygomandibular, pharyngomasticatory and lateral pharyngeal cleft Prestyloid/anterior/anterolateral Poststyloid/retrostyloid/posterior/posteromedial Carotid space, carotid sheath, vascular space</td>
<td>Fat, tonsillar vessels, ascending palatine artery, ICA, IJV, cranial nerves IX, X, XI and XII, sympathetic plexus, lymph nodes ICA, IJV, cranial nerve X, sympathetic plexus, lymph nodes</td>
</tr>
<tr>
<td>Retropharyngeal space</td>
<td>Fat, lymph nodes (suprahyoid only)</td>
</tr>
<tr>
<td>Danger space</td>
<td>No contents</td>
</tr>
<tr>
<td>Perivertebral space, paravertebral space, prevertebral space</td>
<td>Prevertebral muscles</td>
</tr>
<tr>
<td>Prevertebral space, paravertebral, perivertebral, paraspinal</td>
<td>Paraspinal muscles, phrenic nerve, cervical nerve roots</td>
</tr>
<tr>
<td>Visceral space, pretracheal space, anterior visceral space, previsceral space</td>
<td>Pharynx, larynx, trachea, oesophagus, thyroid gland (+/− parathyroid glands)</td>
</tr>
<tr>
<td>Anterior cervical space</td>
<td>Lymph nodes</td>
</tr>
<tr>
<td>Posterior cervical space</td>
<td>Lymph nodes, cranial nerve XI, cervical plexus</td>
</tr>
</tbody>
</table>

Abbreviations: ICA, internal carotid artery; IJV, internal jugular vein; IX, glossopharyngeal nerve; X, vagus nerve; XI, (spinal) accessory nerve; XII, hypoglossal nerve.

(Modified from A.K. Guidera, P.J. Dawes, A. Fong, M.D. Stringer, Head and neck fascia and compartments: no space for spaces, Head Neck 36 (2014) 1058–1068.)
Bones and joints

Skull and mandible
The skull consists of the calvaria and basicranium (collectively known as the cranium), which surround the brain. The facial skeleton is primarily composed of thin-walled bones, some of which contain air-filled cavities (the paranasal sinuses), and the mandible. The cranial cavity contains the brain and the intracranial portions of the cranial nerves; the blood vessels that supply and drain the brain and the haemopoietic marrow of the overlying bones; the meninges (dura, arachnoid and pia mater); and the cerebrospinal fluid in the subarachnoid space. Most of the venous blood from the brain and cranial bones drains into the internal jugular vein via sinuses that lie between the endosteal and meningeal layers of the dura mater. Internally, the cranial base is divided into anterior, middle and posterior cranial fossae, which contain the frontal and temporal lobes of the cerebral hemispheres and the cerebellum, respectively. Foramina in the bones of the skull base and facial skeleton transmit neurovascular bundles that may be compromised by pathology or trauma that involves these sites.

The bony orbits contain the eyeballs, ocular muscles and lacrimal glands together with their associated neurovascular supplies, and are separated by the complex ethmoid bones medially. The temporal bones contain the inner, middle and external ears. The maxillae contain the maxillary air sinuses and also bear the upper teeth. The mandible bears the lower teeth and articulates with the temporal bones at the temporomandibular joints, a site where the glenoid fossa is very thin. The skull articulates with the first cervical vertebra (atlas), and movements of the skull on the cervical vertebrae occur at the atlanto-occipital joints.

The skull provides attachments for many muscles, including all the craniofacial muscles, the ocular muscles, the muscles that act on the temporomandibular joint, the superior constrictor of the pharynx, the muscles of the soft palate, all but one of the extrinsic muscles of the tongue (palatoglossus), the muscles of the suboccipital region, and the cranial attachments of trapezius and sternocleidomastoid.

Cervical vertebrae
There are seven cervical vertebrae. They are the smallest of the movable vertebrae and are characterized by a disproportionately large vertebral canal.
All but the seventh are also characterized by a foramen in each transverse process, the foramen transversarium. The first (atlas), second (axis) and seventh (vertebra prominens) cervical vertebrae are atypical. The first spinous process that may be palpated is the seventh vertebra.

**Hyoid bone and laryngeal cartilages**

The hyoid bone lies in the midline at the front of the neck at the level of the third cervical vertebra. It is suspended from the styloid processes by the stylohyoid ligaments and gives attachment to the suprathyroid and infrahyoid groups of muscles. This bone is usually fractured during strangulation. The skeletal framework of the larynx is formed by a series of cartilages (the single cricoid, thyroid and epiglottic cartilages, and the paired arytenoid, cuneiform, corniculate and tritiate cartilages), interconnected by ligaments and fibrous membranes, and moved by several muscles.
Muscles

The striated muscles of the head and neck produce the movements of the facial soft tissues that animate many aspects of communication; the movements at the temporomandibular joint that occur during mastication and speech; the conjugate movements of the eyeballs; and the coordinated movements that occur during activities such as swallowing or speaking, and turning the head in response to visual and/or auditory stimuli. The superior tarsal muscle, sphincter and dilator pupillae and the ciliary muscle are all smooth muscles.

The superficial muscles of the neck are platysma, sternocleidomastoid and trapezius. Sternocleidomastoid is a key landmark because it divides the neck into anterior and lateral regions (anterior and posterior triangles, respectively). Muscles in the anterior region are organized according to their relationship with the hyoid bone as supra- and infrahyoid groups. Suprahyoid muscles connect the hyoid bone to the mandible and the base of the skull, and include mylohyoid, geniohyoid, stylohyoid and digastric. Infrahyoid ‘strap’ muscles connect the hyoid to the sternum, clavicle and scapula, and are arranged in two planes such that sternohyoid and omohyoid lie superficial to sternothyroid and thyrohyoid (Ch. 18).

Broadly speaking, the muscles that form part of the cervical musculoskeletal column lie anterior, lateral or posterior to the cervical vertebrae. The anterior and lateral groups include longi colli and capitis, recti capitis anterior and lateralis, scaleni anterior, medius, posterior and minimi (when present). The posterior group consists of the cervical components of the intrinsic muscles of the back, overlaid by some of the extrinsic ‘immigrant’ muscles of the back that run between the upper limb and the axial skeleton (trapezius and levator scapulae). The intrinsic muscles are arranged in superficial and deep layers. The superficial layer contains splenius capitis and cervicis. The deeper layers include the transversospinal group (semispinales cervicis and capitis, multifidus and rotatores cervicis), interspinales and intertransversarii, and the suboccipital group (recti capitis posterior major and minor, and obliquus capitis superior and inferior).
Vascular supply and lymphatic drainage

**Arterial supply**

Branches of the carotid and subclavian arteries supply the head and neck (Fig. 3.1).
Carotid system

The cervical portion of the common carotid artery is similar on both sides. Each lies within the carotid sheath of deep cervical fascia, together with the internal jugular vein and vagus nerve. In the lower part of the neck, the arteries are separated by a narrow gap that contains the trachea, and higher up they are separated by the thyroid gland, larynx and pharynx. At the level of the upper border of the thyroid cartilage (C4), the common carotid artery
bifurcates into the external and internal carotid arteries. Surgically, it should be noted that the internal carotid may be superficial to the external carotid at the bifurcation; it has no branches in the neck and so is easily distinguishable from the external carotid artery, should the latter require ligation, e.g. to control haemorrhage from a penetrating injury to the neck. The external carotid artery passes upwards on either side of the neck. It usually gives off the ascending pharyngeal, superior thyroid, lingual, facial, occipital and posterior auricular arteries before entering the parotid gland where it divides into its terminal branches, the superficial temporal and maxillary arteries. The ascending pharyngeal artery is often not seen surgically and the lingual and facial arteries are sometimes joined to form a linguo-facial trunk. Branches of the external carotid artery supply the face, scalp, tongue, upper and lower teeth and gingivae, palatine tonsil, paranasal sinuses and nasopharyngeal tube, external and middle ears, pharynx, larynx and superior pole of the thyroid gland. They also anastomose with branches of the internal carotid arteries on the scalp, forehead and face, in the orbit, nasopharynx and nasal cavity, and with branches of the subclavian artery in the pharynx, larynx and thyroid gland.

The internal carotid artery supplies most of the ipsilateral cerebral hemisphere, eye and accessory organs, forehead, and part of the external nose, nasal cavity and paranasal sinuses. It passes up the neck anterior to the transverse processes of the upper three cervical vertebrae and enters the cranial cavity via the carotid canal in the petrous part of the temporal bone.

**Subclavian artery**

Several branches of the subclavian arteries supply structures in the head and neck. The vertebral arteries pass through the foramina transversaria of the first six cervical vertebrae, enter the cranial cavity through the foramen magnum and unite at the lower border of the pons to form the basilar artery. Collectively, the vertebral arteries supply the upper spinal cord, brainstem, cerebellum and occipital lobe of the cerebrum. Branches from the thyrocervical trunk supply the inferior poles of the thyroid gland and the parathyroid glands, the larynx and the pharynx, and branches from the costocervical trunks supply deep cervical muscles. These may cause troublesome bleeding for the unwary in the posterior triangle, and are always located superficial to the prevertebral fascia. These vessels are sometimes useful for microvascular anastomosis during free flap surgery.
Venous drainage

The veins of the neck lie superficial or deep to the deep investing fascia and, unlike the arteries, exhibit considerable anatomical variation. Superficial veins drain into either the external, anterior or posterior external jugular veins. Deep veins drain into either the internal jugular vein or the subclavian vein (Fig. 3.2). The internal jugular vein drains blood from the skull, brain, superficial face and much of the neck, descends in the neck within the carotid sheath, and usually unites with the subclavian vein behind the sternal end of the clavicle to form the brachiocephalic vein. The left internal jugular vein usually receives the thoracic duct, which enters the vein in a variable position, sometimes as high as 3 cm above the clavicle. The right subclavian vein receives the right lymphatic duct, typically as the vein joins the internal jugular vein.
Lymphatic drainage

Anatomically, lymph nodes in the head and neck are arranged in two vertical chains and two horizontal rings located on either side of the neck. The outer ring consists of the occipital, pre-auricular (parotid), submandibular and submental nodes (Fig. 3.3). The inner ring is formed by conglomerations of mucosa-associated lymphoid tissue (MALT) located primarily within the nasopharynx and oropharynx. The vertical chain consists of superior and inferior groups of nodes related to the carotid sheath. All lymph vessels of...
the head and neck drain into the deep cervical nodes, either directly from the tissues or indirectly through the nodes in outlying groups. Lymph is returned to the systemic venous circulation via either the right lymphatic duct or the thoracic duct, both situated in the deep tissue at the root of the neck.

The thoracic duct drains lymph and chyle from the entire body except from the right side of the head and neck, right upper limb and right hemithorax.
Commonly, the thoracic duct is joined by the cervical lymph trunks near its termination in either the left internal jugular vein, or at the venous angle between the left internal jugular and subclavian veins. Less often, the thoracic duct may empty into the subclavian vein, or into combinations of veins via multiple branches. Rarely, it may terminate on the right side. During operations in the lower neck, iatrogenic injury to the thoracic duct may lead to a troublesome chyle leak or fistula. Anatomical variation is not uncommon in both the thoracic duct and the right lymphatic duct, particularly at or near their lymphovenous junctions, i.e. in the areas explored during dissection of level IV and V lymph nodes.8

The right lymphatic duct drains lymph from the right cervical and thoracic regions and the right upper limb. Commonly, it is formed by the union of the right jugular, bronchomediastinal and subclavian lymphatic trunks, and empties into the junction of the right subclavian and internal jugular veins. In rare cases where the main duct is absent, the right jugular, bronchomediastinal and subclavian lymphatic trunks terminate individually. The cervical lymphatic trunks may independently enter the venous system on both the left and right sides.

Surgically, lymph node location within the neck is described in terms of neck levels as follows: level I, submental and submandibular triangles; level IIA, upper neck passing inferiorly as far as the carotid bifurcation, anterior to the spinal accessory nerve; level IIB, upper neck posterior to the vagus nerve extending to the skull base; level III, mid neck, passing from the carotid bifurcation to omohyoid; level IV, lower neck, passing from the omohyoid to the clavicle; level V, posterior triangle divided into Va (above the accessory nerve) and Vb (below the spinal accessory nerve as it crosses the posterior triangle). Standardized terminology relevant to lateral neck dissection9 and central neck dissection10 has been published (Ch. 15).
**Innervation**

**Cranial nerves**

Twelve pairs of cranial nerves pass through named foramina in the skull: they are individually named and numbered (using Roman numerals) in a craniocaudal sequence (Table 3.3). Some are functionally mixed, while others are either purely motor or purely sensory, and some also carry pre- or postganglionic parasympathetic fibres that are secretomotor to the salivary and lacrimal glands, or are motor to the smooth muscle within the eyeball and orbit. Branches of the oculomotor, trochlear, trigeminal, abducens, facial, glosopharyngeal, vagus, spinal accessory and hypoglossal nerves supply the muscle groups within the eyeball, face, neck, pharynx, larynx and tongue. The abducens nerve has the longest intracranial course and therefore is one of the most likely branches to be damaged by a head injury. Branches of the trigeminal, glossopharyngeal and vagus nerves transmit general sensory information from the skin of the face and the part of the scalp not supplied by the cervical plexus, the epithelium lining the oral and nasal cavities, the paranasal sinuses, middle ear, pharynx and larynx, and the dorsal, lateral and ventral surfaces of the tongue, the cornea, the intracranial meninges, and the periosteum and bones of the skull.

**TABLE 3.3**

**Cranial nerves: distribution and function (including parasympathetic components)**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Distribution/function</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Olfactory</td>
<td>Olfaction</td>
</tr>
<tr>
<td>II</td>
<td>Optic</td>
<td>Vision</td>
</tr>
<tr>
<td>III</td>
<td>Oculomotor</td>
<td>Motor to medial rectus, superior rectus, inferior rectus, inferior oblique, levator palpebrae superioris Preganglionic parasympathetic drive to ciliary ganglion</td>
</tr>
<tr>
<td>IV</td>
<td>Trochlear</td>
<td>Motor to superior oblique</td>
</tr>
<tr>
<td>V</td>
<td>Trigeminal</td>
<td>Three divisions: ophthalmic, maxillary and mandibular</td>
</tr>
<tr>
<td></td>
<td>Ophthalmic (V&lt;sub&gt;i&lt;/sub&gt;)</td>
<td>General sensation from forehead, scalp, eyelids, external nose, globe of eye, conjunctiva, ethmoid sinuses</td>
</tr>
<tr>
<td></td>
<td>Maxillary (V&lt;sub&gt;ii&lt;/sub&gt;)</td>
<td>General sensation from mid face, lower eyelid, nasal cavity, maxillary sinuses, palate, upper lip, maxillary teeth Postganglionic parasympathetic drive from neurones in pterygopalatine ganglion</td>
</tr>
<tr>
<td></td>
<td>Mandibular (V&lt;sub&gt;iii&lt;/sub&gt;)</td>
<td>General sensation from scalp, lower face including lower lip, tongue, floor of mouth, mandibular teeth, tympanic membrane, tragus and crus of helix of external ear</td>
</tr>
<tr>
<td>Cranial Nerve</td>
<td>Function</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>VI Abducens</td>
<td>Motor to lateral rectus</td>
<td></td>
</tr>
<tr>
<td>VII Facial</td>
<td>General sensation from part of tympanic membrane, small inconstant areas of external acoustic meatus and skin behind pinna (fibres supplying pinna may travel with auricular branch of vagus)&lt;br&gt;Proprioception from facial muscles&lt;br&gt;Taste from anterior two-thirds of tongue (excluding vallate papillae)&lt;br&gt;Motor to muscles of face, stapedius, posterior belly of digastric, stylohyoid&lt;br&gt;Preganglionic parasympathetic secretomotor and vasodilator drive to pterygopalatine and submandibular ganglia</td>
<td></td>
</tr>
<tr>
<td>VIII Vestibulocochlear</td>
<td>Sensations of equilibrium and motion (vestibular division)&lt;br&gt;Hearing (cochlear division)</td>
<td></td>
</tr>
<tr>
<td>IX Glossopharyngeal</td>
<td>General sensation from posterior third of tongue, oropharynx, tympanic membrane and external acoustic meatus&lt;br&gt;Sensation from carotid body (chemoreceptors) and carotid sinus (baroreceptors)&lt;br&gt;Taste from posterior third of tongue (and from vallate papillae)&lt;br&gt;Parasympathetic secretomotor and vasodilator drive to otic ganglion&lt;br&gt;Motor to stylopharyngeus</td>
<td></td>
</tr>
<tr>
<td>X Vagus</td>
<td>General sensation from pharynx, larynx, trachea, oesophagus, part of auricle and external auditory meatus&lt;br&gt;Visceral sensation from thoracic and abdominal viscera&lt;br&gt;Sensation from aortic bodies (chemoreceptors) and aortic arch (baroreceptors)&lt;br&gt;Taste from scattered taste buds on base of tongue, valleculae and epiglottis&lt;br&gt;Parasympathetic preganglionic drive to glands and smooth muscle in pharynx, larynx, thoracic and abdominal viscera (ganglia are typically in walls of viscera)&lt;br&gt;Motor to pharyngeal, external laryngeal and oesophageal striated muscles</td>
<td></td>
</tr>
<tr>
<td>XI Accessory</td>
<td>Traditionally, two roots of the accessory nerve were described: a cranial root and a spinal root. The cranial rootlets were said to join the vagus nerve as it exited the skull. In recent years, the existence of a cranial root of the accessory nerve has been challenged on the grounds that the rootlets are often variable and sometimes absent. The nerves supplying the muscles of the soft palate (except tensor veli palatini) and the intrinsic muscles of the larynx arise from neuronal cell bodies in the nucleus ambiguus, and travel via branches of the vagus&lt;br&gt;‘Cranial root’ Motor to muscles of soft palate (except tensor veli palatini) and intrinsic muscles of larynx (distributed via vagus from pharyngeal plexus)&lt;br&gt;Spinal root Motor to sternocleidomastoid and trapezius</td>
<td></td>
</tr>
<tr>
<td>XII Hypoglossal</td>
<td>Motor to all intrinsic and extrinsic muscles of tongue except palatoglossus</td>
<td></td>
</tr>
</tbody>
</table>

Branches of the trigeminal nerve innervate the temporomandibular joint. The olfactory, optic, trigeminal, facial and vestibulocochlear nerves contain axons that transmit the special sensations of olfaction, vision, hearing, balance and taste. The olfactory nerve is the only sensory cranial nerve that projects directly into the cerebral cortex rather than indirectly via the thalamus. The optic nerve terminates in the thalamus. The other ten pairs of cranial nerves are attached to the brainstem or, in the case of the spinal accessory nerve (SAN), to the upper cervical spinal cord, and their component fibres arise from or terminate in named cranial nerve nuclei. With a single exception, all of the cranial nerves are confined to the head and neck. The exception is the vagus, which travels through the neck and thorax,
and enters the abdominal cavity by passing through the diaphragm along with the oesophagus.

**Reflexes**

Several reflexes involving structures in the head and neck are mediated by sensory and motor branches of specific cranial nerves, and are coordinated via appropriate nuclei in the brainstem (**Table 3.4**). They include swallowing, gagging, retching and vomiting, sneezing and coughing, lacrimation, jaw jerk, visual reflexes (pupillary light reflex and accommodation), the corneal ‘blink’ reflex and the stapedial reflex. Reflexes that involve energetic exhalation, e.g. sneezing and coughing, also involve the recruitment of cervical and thoracic spinal neurones in order to mediate the coordinated contraction of intercostal and abdominal wall muscles that this activity requires.

**TABLE 3.4**

<table>
<thead>
<tr>
<th>Reflex</th>
<th>Afferent limb</th>
<th>Efferent limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corneal</td>
<td>V₁ (conjunctival innervation)</td>
<td>VII (orbicularis oculi)</td>
</tr>
<tr>
<td>Blink (somatosensory and trigeminal)</td>
<td>Median nerve or supraorbital nerve used for testing</td>
<td>VII (orbicularis oculi)</td>
</tr>
<tr>
<td>Gag</td>
<td>IX</td>
<td>X</td>
</tr>
<tr>
<td>Swallowing</td>
<td>IX</td>
<td>IX, X</td>
</tr>
<tr>
<td>Pupillary light</td>
<td>II</td>
<td>III (sphincter pupillae); T1 (dilator pupillae)</td>
</tr>
<tr>
<td>Accommodation</td>
<td>II</td>
<td>III (sphincter pupillae, ciliaris, medial rectus)</td>
</tr>
<tr>
<td>Glabellar</td>
<td>V₁</td>
<td>VII (orbicularis oculi)</td>
</tr>
<tr>
<td>Masseteric (jaw jerk)</td>
<td>V₃ᵢ</td>
<td>V₃ᵢ</td>
</tr>
<tr>
<td>Corneomandibular (von Sölder phenomenon)</td>
<td>V₁</td>
<td></td>
</tr>
<tr>
<td>Sneeze</td>
<td>V₅, V₁</td>
<td>V, VII, IX, X, phrenic nerve (C3,4,5); segmental thoracic nerves innervating intercostal and abdominal muscles</td>
</tr>
<tr>
<td>Vestibulo-ocular</td>
<td>VIII (vestibular component)</td>
<td>III, VI</td>
</tr>
</tbody>
</table>

**Spinal nerves**

There are eight pairs of cervical spinal nerves. Cutaneous branches of the dorsal rami of the second, third, fourth and fifth cervical nerves innervate the scalp and the skin over the back of the neck, and motor branches of all of the
cervical dorsal rami supply cervical postvertebral muscles. All of the cervical ventral rami supply anterior and lateral groups of prevertebral muscles. The upper four cervical ventral rami form the cervical plexus, whose branches collectively innervate the infrahyoid strap muscles and the diaphragm, the skin covering the lateral and anterior parts of the neck, and the angle of the mandible. The lower four cervical ventral rami, together with most of the first thoracic ventral ramus, form the brachial plexus. As a general rule, branches of the cervical plexus that are superficial to the prevertebral fascia are sensory, e.g. the supraclavicular nerves (C3,4) and greater auricular nerve (C2,3), while many branches deep to the fascia are motor, the most important being the phrenic (C3,4,5).

**Parasympathetic nerves**

In the head and neck the parasympathetic system innervates the salivary and lacrimal glands, the mucous glands of the oral and nasal cavities and paranasal sinuses, and the sphincter pupillae and ciliary muscles in the eyeball ([Fig. 3.4](#)). Many thousands of preganglionic parasympathetic axons travel in the vagus from cell bodies of the dorsal motor nucleus of the vagus in the medulla. Although they travel through the neck in the right and left vagi, they are destined for pulmonary, cardiac, oesophageal, gastric and intestinal targets. They synapse in minute ganglia in the walls of the viscera and do not innervate structures in the head and neck.
There are four pairs of parasympathetic ganglia in the head and neck, and they are named ciliary, submandibular, pterygopalatine and otic (see Table 3.3 and Fig. 3.4).

**Ciliary ganglion**

Preganglionic axons originate in the Edinger–Westphal preganglionic nucleus of the midbrain. They travel via a branch of the oculomotor nerve (nerve to the inferior oblique) to the ciliary ganglion, where they synapse. Postganglionic fibres travel in the short ciliary nerves, which pierce the
scleral coat of the eyeball, and run forwards in the perichoroidal space to enter the ciliary muscle and sphincter pupillae. Their activation mediates accommodation of the eye to near objects, and pupillary constriction.

**Submandibular ganglion**

Preganglionic axons originate in the superior salivatory nucleus. They emerge from the brainstem in the nervus intermedius and leave the main facial nerve trunk in the middle ear to join the chorda tympani, which subsequently joins the lingual nerve. In this way, they reach the submandibular ganglion, where they synapse. Postganglionic fibres innervate the submandibular, sublingual and lingual salivary glands. Some axons presumably re-enter the lingual nerve to access the lingual glands, while others pass directly along blood vessels to enter the submandibular and sublingual glands. The submandibular ganglion, as it leaves the lingual nerve itself before entering the submandibular gland, has a very rich blood supply; it is therefore usually prudent to ligate the ganglion when removing the submandibular gland, as it tends to bleed.

Some preganglionic fibres may synapse around cells in the hilum of the submandibular gland. Stimulation of the chorda tympani dilates the arterioles in both glands, as well as having a direct secretomotor effect.

**Pterygopalatine ganglion**

The preganglionic axons travel in the greater petrosal branch of the facial nerve and the nerve of the pterygoid canal, and relay in the pterygopalatine ganglion. Postganglionic secretomotor axons innervate secretory acini and blood vessels in the palatine, pharyngeal and nasal mucosa via the palatine and nasal nerves, but whether they also innervate the lacrimal gland via the zygomatic and zygomaticotemporal branches of the maxillary nerve, as was once thought, is less certain. It is likely that postganglionic orbital branches, carrying a mixture of postganglionic parasympathetic and somatic sensory axons, pass through the inferior orbital fissure and innervate the lacrimal gland and ophthalmic artery directly. Some axons pass into the cranial cavity via the ethmoidal vessels to innervate the choroid. The pterygopalatine ganglion is believed to be the main source of parasympathetic input to the choroid.

**Otic ganglion**
The preganglionic axons originate in the inferior salivatory nucleus and travel in the glossopharyngeal nerve and its tympanic branch. They traverse the tympanic plexus and lesser petrosal nerve, and pass through the foramen ovale to reach the otic ganglion, where they synapse. Postganglionic fibres pass by communicating branches to the auriculotemporal nerve, which conveys them to the parotid gland. Stimulation of the lesser petrosal nerve produces vasodilatory and secretomotor effects.

**Sympathetic nerves**

In the neck, the sympathetic chain (trunk) lies behind and medial to the carotid sheath, and anterior to the transverse processes of the cervical vertebrae and the prevertebral muscles. There are usually three cervical ganglia on each side – superior, middle and inferior (cervicothoracic) – and they may be connected by a solid trunk or by two or three fibrous strands. The ganglia receive preganglionic fibres from neurones whose cell bodies lie in the intermediolateral column of the upper thoracic spinal cord. There is no preganglionic output from the cervical spinal cord. Postganglionic fibres reach their target tissues in the head and neck via the cervical spinal nerves and perivascular nerve plexuses that are distributed along the carotid and vertebral arteries. Surgical damage to the sympathetic chain will result in unilateral ptosis, a constricted pupil (miosis) and anhidrosis, collectively referred to as Horner's syndrome.
Development of the head and neck: summary

The most rostral neural crest cell population makes a major contribution to the skull, forming the whole viscerocranium and the rostral part of the neurocranium. The boundary between the neural crest and the cranial mesoderm lies between the frontal and parietal bones (coronal suture) of the calvaria. The skull base is formed by neural crest rostral to the tip of the notochord, and is sclerotome-derived (i.e. from paraxial mesenchyme) in the notochordal region. The tip of the notochord lies immediately caudal to the hypophysial fossa. Broadly speaking, the bones of the skull base are formed by endochondral ossification (chondrocranium), whereas those of the calvaria and face ossify directly from mesenchymal condensations, i.e. by intramembranous ossification. The occipital, temporal and sphenoid bones and the mandible are of compound structure with respect to their tissue origins and/or type of ossification.

The most cranial portion of the foregut, the embryonic pharynx, is the scaffolding around which the face, palate and anterior neck structures are built. The development of this region from neural crest, paraxial mesenchyme, surface ectoderm and foregut endoderm involves the spatiotemporal coordination of cell movement, tissue growth and tissue interactions. As successive populations of neural crest cells migrate around the pharynx at progressively more caudal levels, five pairs of pharyngeal arches (also known as branchial arches or gill arches) are formed, numbered 1, 2, 3, 4 and 6 for phylogenetic reasons. This process is complete by stages 14–15 (32–36 days post fertilization). Pharyngeal clefts (grooves) separate the arches externally and they are matched internally by internal depressions (pharyngeal pouches). Each pharyngeal arch consists of an epithelial covering – ectoderm externally and endoderm internally – filled with mesenchyme that is mainly of neural crest origin, with a contribution from primitive streak-derived mesenchyme (paraxial mesenchyme). The neural crest cells of each arch form a skeletal element with its associated connective tissue, and give rise to the walls of an aortic arch blood vessel lined with endothelium derived from angiogenic mesoderm. Paraxial mesenchyme also forms the muscle(s) associated with each pharyngeal arch (Fig. 3.5). Motor and sensory innervation is derived from arch-specific cranial nerves.
FIG. 3.5 The muscular derivatives of the prechordal mesenchyme, unsegmented paraxial mesenchyme and rostral somites. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 36.7.)
References


Core Procedures

- Surgical exposure of fracture articulations
- Reduction of displaced facial fractures
- Osteosynthesis of fracture sites

The facial skeleton provides a framework for housing the special senses of vision, taste and olfaction; the muscle attachment of the sphincters of the orbit and mouth; and the articulating apparatus that allows movement of the mandible against the maxilla to facilitate mastication.

Facial appearance and symmetry depend in part on the scaffolding effect of the facial skeleton that supports the overlying complex arrangement of soft tissue attachments (ligamentous, adipose and muscular).

In direct parallel with the bony orbit, the facial skeleton is made up of a complex arrangement of bones divided into a number of functional regions (Fig. 4.1). Biomechanically, each of these regions responds in stereotypical ways to an escalation of energy transfer,\(^1,2\) which present different reconstructive aims and surgical objectives. With severe energy transfer there is extension of fracture configuration between these surgical zones; reconstruction of such injuries is therefore extremely complex.\(^3\)
FIG. 4.1  The interrelationships of the adjacent anatomical subunits. The Le Fort I zone (red box), Le Fort II (yellow box), Le Fort III (light blue box), upper third zone (purple box), naso-orbito-ethmoid zone (blue box) and nasal zone (light blue box with red margin) are demonstrated. The overlapping nature of the osseous structures is obvious; although considered separately, these are clearly related surgically.
Surgical surface anatomy

The craniofacial skeleton provides support for the muscles of facial expression, and ligamentous attachment and support for named collections of fat that modify facial appearance. The facial bones are relatively superficial in most individuals and bony landmarks may be palpated readily (Fig. 4.2). Key landmarks enable the skin marking for anatomical incisions appropriate for the surgical exposure of fracture sites. The landmarks for the mandible include the symphysis, lower border, angle and temporomandibular joint (TMJ); collectively, they facilitate skin marking of approaches to the entire lower border of the mandible and the neck of the condyle. The lateral canthus of the eye and palpation of Whitnall's tubercle facilitate identification of the frontozygomatic suture, a key surgical fixation site in both lateral and central fractures of the middle third of the face. The supraorbital and infraorbital margins must be sought during physical examination to diagnose fractures of the orbit. The zygomatic projection and zygomatic arch are superficial and readily palpated.
Three foramina (supraorbital, infraorbital and mental) transmit sensory nerves. These foramina may be identified on each side by a line drawn from the supraorbital notch and the junction of the medial and middle thirds of the supraorbital rim (which is palpable) through to the region between the lower premolar teeth. At rest, the maxillary incisors are covered by the upper lip, which lifts 2–4 mm on smiling.
Surgical anatomy and classification of fractures of the mandible

The mandible articulates with the temporal bone at the TMJ (Ch. 10). Surgically, the mandible is subdivided into anatomical regions (Fig. 4.3) that fail in stereotypical ways when subjected to an increasing volume of energy transfer: the consequences of these failures are fixed according to standardized protocols. Muscle attachments are consistent and the action of the muscles directly influences the magnitude and direction of bony displacement.

![Diagram of mandible segments](image)

**FIG. 4.3** Anatomically, the mandible may be divided into eight segments: condyle (purple), coronoid (brown), ramus (yellow), angle (orange), body (red), parasymphysis (green), symphysis (blue) and dentoalveolar (not coloured). The inherent tension, torsion and compression forces are unique for each segment. Fractures anterior to the angle involving the dentoalveolar segment are classed as compound fractures.

Disturbance of the anatomical integrity of the mandible produces an established constellation of physical signs. The inferior alveolar nerve emerges from the infratemporal fossa, enters the mandible at the mandibular foramen and passes ventrally to exit at the mental foramen. Any fracture between these two foramina is likely to cause a neurological deficit manifest by altered sensation of the lower lip and chin up to the midline.

In dentate patients, fractures passing through the periodontal ligament are *de facto* compound to the oral cavity and therefore at risk of infection.
Displacement of fractures through the alveolar bone causes pathological mobility of the affected teeth, and loss of the three-dimensional anatomy compromises the dental occlusion. Subperiosteal bleeding is common with extension into the lingual soft tissues; a sublingual haematoma is pathognomonic of a fracture of the mandible. The stability of a fracture depends on a number of factors: an intact periosteum; the degree of comminution of the fracture articulations; the number of fractures; and the direction of the fracture lines.

**Favourable and unfavourable fracture patterns**

Following cortico-cancellous disruption, the mandible will demonstrate abnormal mobility across the fracture site. The degree of instability and subsequent displacement depends on the direction of the fracture, which is influenced by the vector of muscle action.

The historical discussion of favourable versus unfavourable fractures was highly relevant when established treatment was intermaxillary fixation (wiring the jaws together using interdental fixtures) but is less relevant in contemporary surgical practice where the imperative is toward anatomical fixation using titanium bone plates. The terms horizontal and vertical are defined from the viewpoint of the observer (Figs 4.4 and 4.5). Horizontally favourable fractures extend from the upper border of the mandible downward and forward; unfavourable fractures run from the upper border downward and backward, and the displacement is influenced by the elevators of the mandible, masseter and temporalis. Vertically favourable fractures run from the buccal plate anteriorly and backward through the lingual plate; unfavourable fractures run from the lingual plate posteriorly to the buccal plate. Medial pterygoid exerts a significant displacing force. Displacement is more common when there are both vertically and horizontally unfavourable fracture lines.
FIG. 4.4 The fracture characteristics of the mandible in the horizontal (sagittal) plane. The orange fracture line has no body resistance or undercut on the superior margin to withstand the tendency of masseter to lift the proximal fragment. The blue line depicts a favourable fracture pattern. The actions of masseter are illustrated by the green arrow which will impact upon the stability of the fracture pattern.
FIG. 4.5 The orientation of the fracture in the vertical (axial) plane will determine whether the proximal fragment of the fracture will be displaced medially by medial pterygoid. The blue line represents a favourable fracture with the most proximal bone lingually on the distal fragment preventing displacement. A fracture along the orange line will predispose to displacement. The actions of the pterygoid muscles are illustrated by the green arrows which will impact upon the stability of the fracture pattern.

Combination mandibular fracture

The mandible is a ring-type structure, which means that there is a high probability of synchronous fractures, and therefore a second fracture must be actively sought. Typically, there will be a primary ‘direct’ fracture and a secondary ‘indirect’ fracture. The common combination fractures occur at the parasympysis and contralateral condylar neck or angle.

High-energy mandibular fractures

Escalation of energy transfer across the mandible changes the fracture pattern from that of a simple linear nature with predictable combinations to unpredictable segmentation of fracture articulations and multiple different fracture sites. Of particular surgical significance is segmentation of the lower border of the mandible, a biomechanically strong structure, which dictates the fundamental approach to reconstruction. Sagittal splitting of the buccal
and lingual cortices results in a very unstable construct and surgical reconstruction requires a more robust superstructure (Figs 4.6 and 4.7).

**FIG. 4.6** A high-energy mandibular fracture. Note the long length of the fracture paths (orange arrows), which are atypical and extend along the biomechanically robust areas. There is segmentation of the lower border.

**FIG. 4.7** Inferior view of the mandible shown in Fig. 4.6 demonstrating a fractured and segmented lower border (orange arrows), a displaced fractured condyle (green arrows) and splitting of the buccal and lingual cortices (blue arrows). This fracture pattern is highly complex and difficult to reconstruct.
Osteosynthesis of the mandible

The muscle attachments of the mandible cause zones of tension and compression across a fracture site that influence the efficiency of osteosynthesis. This phenomenon was first described by Michelet and Champy, and are well known to surgeons as Champy lines (Fig. 4.8). It is essential to understand that the mandible anterior to the mental foramina is subject to both lateral and rotational forces and so it is necessary to equalize these forces with two plates. Fractures of the parasymphysis require a miniplate above the mental foramen and one below, procedures that are technically challenging. There is often a loop of the mental nerve anteriorly that may be damaged inadvertently by passing a screw to the canal. Fractures of the body and angle of the mandible can be managed predictably with a single mandibular plate.

Failure of fixation is predictable; there are several patient- and management-related aetiological factors. Complex fractures involving tissue loss and pathological lesions may be managed by more rigid fixation involving bicortical fixation and screws that lock into both the bone and the plate itself.
Intraoral access to fractures of the body, angle and symphysis can be achieved with a linear buccal mucoperiosteal incision down to the fracture. The incision should be 3–5 mm below the mucogingival junction to aid suture closure. With fractures involving the parasymphysis, the mental nerve must be protected. The nerve exits the mental foramen approximately 5 mm apical to the root apices of the first and second premolars; occasionally there are two foramina. An incision anterior or distal to the premolar region will allow blunt dissection and identification of the mental foramen and protection of the nerve prior to completing the incision superior to these structures. Care must be taken not to avulse the nerve through excessive retraction. Periosteal and perineurial release will allow further mobility.

**Fragility fracture of the mandible**

Loss of dental tissue will result in loss of the bone associated with the teeth, and ultimately to a mandible consisting of the bare skeletal basal bone construct; fractures of this bone produce some of the most unpredictable patterns to manage surgically. There is a variation in the amount of resorption observed in the edentulous mandible. Height directly influences prognosis: the thinnest mandibles demonstrate the poorest prognosis with failure of bone union. The atrophic mandible is subject to the same vectors of muscle pull as in the dentate mandible, but because of the relatively reduced surface area at the fracture site, these patterns tend to be extremely unstable. Bruce recognized the poor outcomes likely after fixation and demonstrated in his retrospective and prospective studies that prognosis was worse in the more atrophic mandibles.\(^{10,11}\) This concept was refined by Luhr, who designated three groups that predicted prognosis and influenced fixation techniques (Fig. 4.9\(\text{Fig. 4.9}\)).\(^{12}\)
Fractures of the mandibular condyle

The temporomandibular (glenomandibular) joint is diarthrodial: that is, it is subdivided into upper and lower joint spaces by a fibrocartilaginous articular disc (Ch. 10). The mandible enjoys a unique freedom of movement because this arrangement allows each joint to rotate and translate in concert with the contralateral articulation.

The TMJ should be considered as part of an anatomical unit that consists of the articular surface of the mandibular condyle and the ramus of the mandible, known as the ramus–condyle unit (RCU). This concept is central to the management of condylar fractures because reconstruction of the joint must restore not only the articulation, but also the posterior vertical height of the mandible. Historically, these injuries were managed by re-establishing the dental occlusion by wiring the maxillary and mandibular teeth together and thereby ‘controlling the malunion’ of the RCU.

Classification of fractures of the RCU

Fractures of the RCU have been classified in a number of ways but none has achieved universal acceptance and international implementation. Important
factors related to management strategies that were initially summarized by Lindahl take into account the location of the fracture, the degree of displacement of the fracture, and whether or not the head of the condyle is in the glenoid fossa. The integrity of the condyle–ramus height and of the TMJ relates to the preservation of the lateral pole of the condylar head. Long-term, fractures of the medial pole alone, with or without displacement, may minimally compromise this arrangement. However, where fractures run within or lateral to the lateral pole there is a threat to ipsilateral TMJ function and the vertical height of the condyle–ramus. Open reduction and fixation of the latter is advised to limit TMJ disability and malocclusion (Figs 4.10 and 4.11).

**FIG. 4.10** Classification of condylar fractures. A line is placed tangentially along the posterior border of the ramus and condyle (blue line) and a second line is placed perpendicular to this line, passing through the sigmoid notch (yellow line). When more than 50% of the fracture line is above the perpendicular line (green line), a high condylar fracture or neck fracture is diagnosed. Low condylar or condylar base fractures are fractures in which more than 50% of the fracture is below the line (orange line). Diacapitular or intracapsular fractures are fractures above the condylar neck.
FIG. 4.11 Intracapsular or condylar head fractures. Fractures running through the lateral pole (yellow and orange lines) predispose to functional disability of the temporomandibular joint and loss of condylar height. Multifragmented or severely dislocated or displaced fragments may predispose to avascular necrosis. The blue line divides the condyle into lateral and medial poles.

The displacement of the fracture can be described in terms of shortening of the neck of the condyle and angulation. Attempts have been made to quantify these parameters to influence the decision to operate; with increased surgical experience it has been recognized that more predictable results are achieved even with small displacements.

Open reduction and internal fixation of the mandibular condyle

Contemporaneous management across the field of craniofacial traumatology is moving toward open reduction and anatomical fixation of the majority of facial fractures, which avoids the need for protracted periods of wiring of teeth together to produce a controlled non-anatomical articulation. This surgical evolution with respect to fixation of the mandibular condyle has followed increasing evidence of improved surgical outcomes in patients treated by open reduction, together with growing confidence in the open surgical approaches required to access this region.13
Surgical approaches to the RCU

Surgical access to the RCU can be achieved in a number of ways, depending on the level of the fracture and the degree of segmentation, as well as the position of the fractured condyle with respect to the mandible. Laterally, the parotid gland and its neurovascular contents, including the facial nerve, retromandibular vein and branches of the external carotid artery, are the immediate anatomical relations of the mandible. Medially, the maxillary artery and pterygoid venous plexus are surgically close and easily damaged. The parotid gland is surrounded by deep cervical fascia, which must be respected; if it is incised, it must be repaired meticulously prior to skin closure.

The mandibular condyle can be divided into three surgical zones that will influence the surgical approach.

Low fractures below the sigmoid notch may be approached by a periangular type of incision, which is well tolerated aesthetically and provides good surgical access. The angle of the mandible is close to the skin surface and masseter is readily identified and incised, following skin incision and blunt dissection, and with the surgeon looking for branches of the facial nerve that may occasionally be encountered. The submuscular plane is then expanded, and because there is no layer of periosteum the fracture elements are identified.

High fractures on or above the sigmoid notch include the head of the condyle plus the neck of the mandible and are approached by a retromandibular incision. After superficial fascia undermining, platysma is identified as it adheres to the parotid fascia and is divided; the parotid gland is now readily identified. Blunt dissection of the gland in the line of the branches of the facial nerve is straightforward, and the surgical window is developed to expose masseter as before.

Head fractures, known as diacapitular fractures, are technically challenging to reduce and fix because the medial fragment of the head is frequently attached to the lateral pterygoid muscle, which retains the vascularity of the segment but results in retraction of the fragment into the infratemporal fossa. This makes surgical retrieval of the fragment technically challenging, with bleeding and herniation of the muscle fibres of both lateral and medial pterygoid into the surgical window, as well as potential damage to the maxillary artery, retromandibular veins and the veins of the pterygoid plexus. Branches of the facial nerve must be negotiated surgically.
There are two standard approaches to gain access to the head of the condyle: namely, pre- and retro-auricular. After a pre-auricular incision,\textsuperscript{18} the dissection proceeds along the external auditory canal inferiorly and down to the superficial temporal fascia superiorly. The soft tissue is incised at the root of the zygomatic arch, and the superficial temporal fascia incised with the
deep temporal fascia to the level of temporalis. The soft tissue is then advanced anteriorly as one, using the arch as a guide. The head of the condyle and fractured neck of the mandible can be readily identified by blunt dissection. The head of the condyle is typically pulled anteriorly by the head of the lateral pterygoid and displaced into the infratemporal fossa. The contents of the fossa must be respected during surgery, and therefore it is imperative to develop the subperiosteal plane around the head fragment and deliver it carefully so reduction can be performed. The mandible can be distracted anteriorly and inferiorly, ideally under conditions of reversible muscle relaxation, to help expose and deliver the fragment. The head of the condyle can be approached via a posterior retro-auricular incision\(^{19}\) that requires division of the external auditory canal. Once this has been achieved, the posterior aspect of the mandible and head of the condyle can be exposed. Careful repair of the canal must be observed because there is a risk of post-surgical stenosis.

Fractures of the neck of the condyle are typically fixed with miniplates. High levels of tension and torque require a double plating philosophy.\(^{20}\) Fractures of the head of the condyle are treated with lag-screw fixation.\(^{21}\) It is important to appreciate that not every condylar fracture can be reconstructed, particularly if grossly comminuted.
Surgical anatomy and classification of fractures of the zygomatic bone

Each zygomatic bone forms the projection of the cheek, as well as contributing to the floor and lateral wall of the orbit, and the walls of the temporal and infratemporal fossae. It provides the osseous scaffold of the face in this region, together with soft tissue attachments, both ligamentous and muscular. The zygomatic bone articulates with the frontal bone superiorly, the temporal bone posteriorly, the maxilla laterally and anteriorly, and the greater wing of the sphenoid medially. Each one of these articulations can be involved in fracture configurations and appreciation of these relationships will influence management. The zygomatic bone forms part of the orbital skeleton and therefore extensions of the fracture into the orbital floor not only are to be expected, but also explain the clinical symptoms. The infraorbital nerve passes through the floor of the orbit and exits on to the face via the infraorbital foramen; damage to the foramina or nerve itself will result in altered sensation, which is one of the key physical findings observed in fractures of this region.

Fracture pattern is influenced by volume of energy transfer and area of strike, as well as vector. A number of patterns are recognized. They vary from segmental injuries to detachment of the zygomatic bone at its articulations with adjacent cranial bones. The classical description of a tripod fracture involving separation at all of the adjacent sutures is a misnomer and the fracture should more properly be termed a `pentapod fracture’. Segmental fractures are caused by large forces where narrow areas of strike are seen at the infraorbital margin and laterally at the zygomatic arch.

Surgical approaches to the zygomatic bone

The zygomatic bone may be repositioned surgically in a number of ways. The Gillies temporal approach was initially described in 1927 and is an exercise in understanding the anatomy of the temporal region. The skin incision is placed 3 cm above the route of the external ear in the hairline and is followed by blunt dissection to the deep temporal fascia; a branch of the superficial temporal artery or vein often requires coagulation. The temporal fascia, which is attached to the superior temporal line superiorly and the zygomatic arch inferiorly, is incised and a zygomatic elevator passed on temporalis deep to the fascia and under the body of the zygomatic bone and
the zygomatic arch. This will then allow the body or the arch to be elevated into position.

The Keen intraoral approach allows access to the medial surface of the body of the zygomatic bone and the zygomatic arch via an incision in the buccal sulcus.\textsuperscript{24} It is important to remain subperiosteal to avoid encroachment on the buccal fat pad, which, if violated, will cause fat to spill into the wound and obscure the surgical view.

The Dingman approach is now rarely used but may occasionally be useful.\textsuperscript{25} The frontozygomatic suture commonly requires reduction and fixation, and it is possible to insert an elevator through the skin incision at this point to lift the zygomatic bone forward.

Full surgical exposure\textsuperscript{26} is required for extensive fractures of the zygomatic complex and lateral middle third of the face. Following coronal flap exposure (see below), an extension in the pre-auricular plane is used in exposure of the head of the mandibular condyle. The entire central and lateral skin flap can then be raised off the zygomatic arch and the whole area degloved. The bony elements can be repositioned accordingly and fixed.

It is possible to gain a point of application to reduce the zygomatic complex by passage of a percutaneous hook. Access is at the point of intersection between the lateral canthus of the eye and the alar rim of the nose. Alternatively, a Langenbeck retractor can be passed via a buccal vestibular incision to avoid the skin stab incision.

A percutaneous screw can be passed into the body of the zygoma and used to reposition the bone remotely by direct traction, a method that was initially described as the Carroll Girard method.\textsuperscript{27}

**Fixation points**

The purpose of fixation is not only to hold the bone in position, but also to ensure precise anatomical reduction. Each fracture articulation may be exposed, repositioned and fixed. The key fracture articulation is the frontozygomatic suture, and therefore should be considered as the first point of fixation if required in the majority of cases. This osseous articulation is robust, which means that it is rarely segmented and provides good screw anchorage.

The lateral maxillary buttress can be approached via a transoral incision and subperiosteal dissection. The infraorbital articulation is typically approached via a transconjunctival incision (Ch. 7). It is important to
appreciate that there may be extension of the fracture pattern into the orbit itself; this is known as an impure blowout fracture. This will require reconstruction following repair of the orbital frame, thus turning an impure blowout into a pure one, which is managed in a similar way. The zygomatic arch articulation is approached via a coronal and temporal incision (Fig. 4.13).
FIG. 4.13  A, A right zygomatic complex fracture showing comminution and displacement posteroinferolaterally and significant disruption of the orbital floor (yellow arrow). Displacement at the frontozygomatic suture will draw the medial canthal tendon and suspensory system of the globe inferiorly (orange arrow). B, A right zygomatic complex fracture (lateral view) showing comminution (blue and yellow arrows) and displacement posteroinferolaterally and significant disruption of the orbital floor. Displacement at the frontozygomatic suture will draw the medial canthal tendon and suspensory system of the globe inferiorly (green arrow). C, A frontal view post-open reduction and internal fixation via a coronal, transconjunctival lid swing and intraoral approach. Blue arrows, reduction of sphenozygomatic suture (key landmark for reference of reduction of comminuted zygoma); C, orbital floor titanium prefabricated plate; green arrows, inferior orbital rim osteosynthesis plating; yellow arrows, zygomaxillary buttress osteosynthesis plating; orange arrow, frontozygomatic suture osteosynthesis plating. D, A lateral view post-open reduction and internal fixation via a coronal, transconjunctival lid swing and intraoral approach. Blue arrows show double 1.3 mm osteosynthesis plate for comminuted zygomatic arch reconstruction. Abbreviation: P, zygomatic prominence.
Surgical anatomy and classification of fractures of the maxilla

The maxilla forms the whole of the upper jaw and contributes to the floor and lateral wall of the nose, the floor of the orbit, and the boundaries of the infratemporal and pterygopalatine fossae. Each maxilla has a body and four processes that articulate with the zygomatic, frontal and palatine bones; the alveolar process contains the maxillary teeth.

Fracture patterns

Depending on the fracture pattern, patients will present with a number of physical signs. Since fractures of the maxilla have a characteristically long fracture path, they are usually associated with high-energy injuries that typically produce significant facial swelling, manifesting in periorbital oedema and haematoma. The orbits may be affected and both vision and eye movement could be compromised. Similarly, the infraorbital nerve and the zygomaticofacial branches of the maxillary nerve may be compromised. Three-dimensional disruption of the maxilla will result in alteration of dental occlusion, and commonly the maxilla may be both mobile and malpositioned.

Le Fort fractures

Biomechanically, the maxilla fractures in a wide variety of patterns, initially classified by Le Fort into three levels of injury (Fig. 4.14). By convention, fractures are described according to the highest Le Fort level. A Le Fort I fracture runs above the apices of the maxillary teeth from the piriform aperture of the lateral nasal margin to the pterygoid plates. Patients with a pure Le Fort I fracture demonstrate an unstable maxillary dentition and occlusion; if the fracture involves the infraorbital canal, there will be sensory compromise. A Le Fort II fracture is described as a pyramidal fracture that runs from the pterygoid plates with an anterior and superior vector crossing the orbital margin across the ethmoid bone. Patients with a pure Le Fort II fracture demonstrate a mildly deranged dental occlusion, often have epistaxis, and may have orbital involvement. Since the nasal bridge is part of the maxillary segment, there may also be deviation of the nasal bridge. These fractures may be associated with anterior skull-base extension and may cause
a cerebrospinal fluid (CSF) leak, although typically this is associated with Le Fort III patterns. A Le Fort III fracture is known as a craniofacial dysjunction. The fracture pattern is a long path that progresses from the fracture of the zygomatic arch, lateral wall and medial walls of the orbit and the ethmoid. The distance between the fracture and the dental occlusion means that occlusal disharmony is usually mild. Orbital signs are often marked, and together with Le Fort II fractures, these fracture patterns are often associated with intracranial extension of the fracture through the cribriform plate.

**FIG. 4.14** The classic description of fractures of the maxilla by Le Fort. This is a three-dimensional CT reformat detailing the three levels of Le Fort fractures: Le Fort I (low level, blue line), Le Fort II (mid level, orange line) and Le Fort III (high level, green line).

**Mixed-pattern fractures – beyond Le Fort**

Le Fort designed his classification system on the basis of a limited mechanism of energy transfer, and without access even to plain film radiology. The anatomical information available from modern CT scanning technology enables a much more detailed analysis and understanding of the disruption. This has been driven by clinical need because advances in pre-hospital emergency care and anaesthesia mean that an increasing number of patients with severe craniofacial fractures survive beyond the accident scene. Thus the Le Fort classification has endured but it represents an oversimplification. For example, it does not include segmental injuries,
particularly a split palate; nor does it allow for segmentation of the major maxillary fracture element, such as the overlap between a Le Fort III fracture with an additional element, or medial extension into the naso-orbito-ethmoid (Fig. 4.15). Although higher-energy injuries are associated with higher-level Le Fort injuries, complex maxillary fractures are often difficult to quantify and understand. In order to satisfy classification into a Le Fort-type pattern, then, there must be a bilateral fracture with disruption at both pterygoid plates. The pattern can be heterogeneous and mixed: for example, a Le Fort I on the left and a Le Fort III on the right. There can also be involvement at multiple levels, and in high-energy mechanisms it is by no means unusual for Le Fort I, II and III to coexist on one or both sides.

**FIG. 4.15** Beyond the Le Fort classification. Key: Le Fort II fractures, green arrows; Le Fort I fracture, purple arrows; frontonasal dysjunction, blue arrows; a left Le Fort III component. Traditionally, this fracture would be described by the highest-level fracture, but this grossly oversimplifies the fracture pattern and illustrates the interrelationship of adjacent anatomical and surgical–pathological subunits. Orange arrows, mandibular angle and parasymphysis fractures; yellow arrows, osteosynthesis plates from previous mandibular fractures. Blue and purple arrows indicate a split maxillary fracture, which is not formally defined by the Le Fort classification.

### Surgical fixation

Surgical reduction and fixation of the maxilla has undergone a stepwise evolution over the last 70 years. Historical techniques involved reducing the
dental portion of the maxilla into place using the dental occlusion as a guide, and then stabilizing the major fragment either with a frame or wires. This did not normally produce a perfect aesthetic outcome but led to a controlled malunion with residual compound facial deformity involving the nasal, orbital and zygomatic areas.

Advances in imaging\textsuperscript{30} and surgical osteosynthesis\textsuperscript{31} have facilitated precise reduction, resulting in better three-dimensional reconstruction and reduced recovery times.

The principles of fixation of the middle third of the facial skeleton are based on the biomechanical principles of the constituent bones, which in turn are influenced by the varying thickness of the bones (\textbf{Fig. 4.16A}). The thickened areas are referred to as buttresses: the correct three-dimensional position of the maxilla is achieved by perfect reduction and fixation along the anatomical buttresses. The anterior projection of the zygomatic prominences depends on the projection of the zygomatic arch, and the width of the face is controlled by correct reconstruction of the frontal bar and orbital margins. Contemporaneous surgical open reduction and internal fixation involves repositioning the fracture elements using the dental occlusion as a guide, with a wide soft tissue exposure through a variety of incisions, depending on the level of fracture. Surgical exposure must address the fracture articulations and include management of the orbit, which is frequently implicated (\textbf{Fig. 4.16B}).
FIG. 4.16  A Le Fort II fracture pattern, frontonasal dysfunction and left zygomatic complex fracture. A, A three-dimensional CT scan. Blue arrows, frontonasal dysjunction; green arrows, pyramidal fracture pattern running across maxillae; purple arrows, dysjunction of vertical buttresses; orange arrows, left zygomatic fracture. B, A postoperative scan. Fixation of complex fractures of the middle and lower thirds of the facial skeleton follows a well-ordered strategy with the aim of reproducing the correct anatomical position of the maxilla in relation to the mandible, and correct anterior and lateral projection of the zygomatic prominences. This can be performed via a ‘top-down’ or ‘bottom-up’ approach. The frontal bone establishes the correct position of the upper portion of the frontozygomatic suture. The vertical pillars of thickened bone are known as boxes and are reconstructed first. The projection of the zygomatic prominences depends on the presence of an intact zygomatic arch, which is reduced and fixed anatomically. The width of the face is controlled by reconstruction at the orbital margins. Sagittal fractures of the maxilla are treated on their merits and non-stereotypical plates used to reconstruct the anterior maxillary wall or the body of the zygomatic bone. C, A three-dimensional reconstruction showing the fractures of the nasal bone (blue arrows) and the septal fracture (green arrows). Note the angulation of the nasal complex (orange line) away from the midline, and the additional maxillary and frontal bone fractures.
Surgical anatomy and classification of fractures of the nasal bones

Poor diagnosis and management of nasal bone fractures will predispose to nasal deformities and functional airway limitations reflecting intranasal disruption and dysfunction. The paired nasal bones articulate with the frontal bone and the paired ethmoids and maxillae to form the naso-orbital-ethmoid (NOE) complex. The cephalic border of each nasal bone articulates with the nasal process of the frontal bone, which is the epicentre of this confluence. Laterally, the nasal bones articulate with the frontal processes of the paired maxillae. The nasal bones are thicker and stronger in their proximal two-thirds; the transition zone can be represented on the face by a line bisecting the medial canthi. A fracture line commonly passes across the transition zone, producing mobilization and bony displacement at this point.

The ethmoidal groove on the internal surface of the nasal bones accommodates the perpendicular plate of the ethmoid, which forms a buttress with the proximal part of the nasal bones and, in conjunction with the vomer and palatine process of the maxilla, stabilizes the cartilaginous septum. Strong fibrous connections between the nasal bone and upper lateral cartilage predispose to entire side-wall disruption on nasal bone displacement (Ch. 8).

The upper lateral cartilage and dorsal septum are hafted to form one unit. As a consequence, a lateral blow to the nasal bones and upper lateral cartilage will have a concertina effect, distorting the septum. Early reduction of the nasal bone and upper lateral cartilage reverses this distortion. However, delays in management will predispose to a chronic deformation. In children this septal injury leads to the phenomenon of duplication, when the overlying ends of the fractured septum continue to grow, rather like tectonic plates, predisposing to a tension nose. Forces from an anterior to posterior direction will lead to caudal septal displacement out of the maxillary and vomer crests at the inferior margin of the septum.

The internal nasal valve is the site of highest airway resistance. The area is bordered medially by the septum, superolaterally by the caudal margin of the upper lateral cartilage, inferolaterally by the fibrofatty attachments to the piriform rim, and inferiorly by the floor of the piriform aperture. Minor deviations in the septum will negatively influence the dynamics of nasal airflow. This is assessed by Cottle’s test, rhinomanometry and endoscopic assessment. Septal correction with spreader grafting may be indicated for
restoring the nasal valve area.

Accurate targeting of the nasal sensory supply is imperative when achieving pain-free reduction under local anaesthesia. The external nose is innervated by branches of the ophthalmic and maxillary divisions of the trigeminal nerve. The cephalic half of the nose is supplied by the supratrochlear and infratrochlear nerves and by the external nasal branch of the anterior ethmoidal nerve. Anaesthesia can be achieved at the medial aspect of the brow (caution is required to prevent intra-arterial injection and retrograde vasospasm of the retinal artery), 5 mm medial to the medial canthus and the midpoint between the junction of the nasal bone caudally and the upper lateral cartilage, respectively. The caudal half of the external nose is supplied by the anterior ethmoidal and infraorbital nerves. The latter can be anaesthetized by passage of the hypodermic needle 7 mm inferior to the infraorbital rim at the level of the medial limbus or infiltration into the canine fossa. Sensory innervation of the mucosa covering the nasal septum is provided by the anterior and posterior ethmoidal nerves (branches of the nasociliary nerve) and by branches of the maxillary nerve, mainly via the nasopalatine nerve. Mucosal anaesthesia should be achieved with 4% lidocaine HCl with 1 : 100,000 adrenaline (epinephrine) topical application inside the nasal cavity.

Epistaxis is a common complication and can cause significant haemorrhage. Trauma to the external nose may damage any of the five arteries coursing towards Little's area (Kiesselbach's plexus), in the anterior inferior region of the nasal septum. The arteries include the anterior and posterior ethmoidal arteries derived from branches of the internal carotid artery, and the sphenopalatine, greater palatine and septal branch of the superior labial artery, derived from branches of the external carotid artery.

Fracture patterns

The fracture pattern of nasal injuries depends on the vector of the injury, the volume of energy and the surface area of strike. Lateral vector fractures may involve a direct fracture at the point of strike but the fracture pattern will escalate to involve the nasal septum and an indirect fracture of the contralateral nasal bone (Figs 4.16C and 4.17). Anterior vector fractures are classified by an anatomically applied nasal fracture classification system described by Stranc and Robertson, based on the magnitude and extension of the fracture pattern.
FIG. 4.17  A lateral nasal fracture pattern. The large orange arrow demonstrates the vector of the force. The simplest pattern is an isolated fracture of the ipsilateral nasal bone (blue arrow); however, in this case, fracture progression has included the nasal septum (yellow arrow) and the contralateral nasal bone (green arrow). Note the additional craniofacial fractures (turquoise arrows).

The extent of injury can be classified into six planes (Fig. 4.18): three frontal and three lateral planes. Frontal plane 1 represents energy transfer to the lower third of the external nose, leading to upper and lower lateral cartilage displacement posteriorly. The posterior limit of the nasal fracture is represented by a line bisecting the lowest point of the nasal bone and the anterior nasal spine. Frontal plane 2 represents higher-energy transfer with greater displacement of the lateral cartilages, nasal septum and anterior nasal spine; nasal bone splaying and septal deviation are common. Frontal plane 3 combines frontal plane 2 with NOE fracture. Lateral plane 1 represents a low-energy state, causing ipsilateral nasal bone displacement only, whereas lateral plane 2 represents a higher-energy state, causing ipsilateral and contralateral displacement of the nasal bone and septum. Lateral plane 3 represents lateral plane 2 in combination fractures of the frontal process of the maxilla and NOE.
Anterior nasal fractures are classified according to Stranc and Robertson. This classification reflects escalating energy transfer and has direct implications for both surgical approach and prognosis. The orange line indicates the frontal plane 1; the yellow line indicates the frontal plane 2; the blue line indicates the frontal plane 3. The greater the energy transfer, the higher the risk of naso-orbito-ethmoid (NOE) involvement.

Clinical examination and radiological assessment are required to determine the frontal and lateral planes of disruption. This is problematic in the early post-injury period because of epistaxis and oedema. Both anterior and posterior nasal packing may be required to control haemorrhage. Oedema may take 7–14 days to subside before accurate diagnosis will be possible.
Surgical anatomy and classification of fractures of the naso-orbito-ethmoid complex

Grossly comminuted NOE fractures are amongst the most technically challenging of facial fracture patterns to manage. The three-dimensional projection of the nasal bridge grossly oversimplifies the underlying anatomy. Extension of the energy transfer through the nasal bridge to include the ethmoid results in an exponential degree of segmentation and escalation in complexity (Fig. 4.19). Fractures of this region must be considered in conjunction with the anatomy of the medial canthus, and management is directed by degree of segmentation and structures involved.

![Image of nasal bridge projection](image)

**FIG. 4.19** The three-dimensional projection of the nasal bridge grossly oversimplifies the underlying anatomy. Extension of the energy transfer through the nasal bridge to include the ethmoid results in an exponential degree of segmentation and escalation in complexity. Lower blue arrows indicate nasomaxillary fracture. Upper blue arrows indicate high nasal bridge fracture extending through frontal bone/ethmoidal bones into anterior cranial fossa. This injury may present clinically with cerebrospinal fluid rhinorrhea.

The medial canthal tendon (ligament) is a complex three-dimensional structure that is in several well-defined layers. It has a long, robust attachment to the frontal process of the maxilla, and extends anteriorly and laterally to the anterior lacrimal crest. A shorter, posterior component
extends to the posterior lacrimal crest. Laterally it is attached to the tarsus and more superficially has a surgically inconsequential attachment to superficial muscles.

The classic Markowitz classification details the degree of segmentation of the central fragment.\(^3^4\)

Type 1 is a fracture separation of a monoblock segment that includes the nasal bridge, a substantial portion of the ethmoid bone, and the medial orbital margin running inferiorly into the piriform aperture of the nose. These fractures can be manipulated into place by exposure of the orbital margins and transoral incisions, and fixed with osteosynthesis plates. Type 2 is a segmentation of the central fragment, with separation of the attachments of the medial canthal tendon. There is mild telecanthus (widening of the distance between the two medial canthal tendons). There is, by definition, enough bone attached to the tendon so that, by securing the minor fragment to the main segment, the position of the medial canthus is maintained. The degree of segmentation of the central fragment is not defined, which means that surgically this is a very heterogeneous group, with varying degrees of reconstructive complexity and therefore of prognosis. Type 3 is segmentation of the central fragment, with separation of the medial canthal tendons. There is usually more pronounced telecanthus; the free tendons need to be identified, and transfixed with wires into position. These are extremely difficult fractures to manage and the position of the medial canthal tendon must be relatively posterior to the globe.

Ayliffe recognised the importance of the central fragment, but also the relative imperfection of the degree of segmentation of the central fragment, which does not feature in the Markowitz classification.\(^3^5\) In the authors’ view, the addition of two further subclassifications to the original classification has merit. A number of patients sustain energy transfer without displacement, while others present with grossly segmented central fragments that require more extensive bone grafting surgery (Table 4.1). Surgical reconstruction involves exposure of the fracture articulations together with reduction and fixation using miniplates. Depending on the complexity of the injury, the fracture elements can be reduced and fixed via a combination of transoral, transconjunctival and scalp flaps. The medial canthal repair must reposition the tendon posterior to the posterior lacrimal crest using a specially designed titanium wire. This is technically challenging, and best achieved via a cantilevered plate anchoring the wire.
### TABLE 4.1

Surgical predictors and prognosis related to naso-orbito-ethmoid complex fracture classifications

<table>
<thead>
<tr>
<th>Physical feature</th>
<th>Markowitz</th>
<th>Ayliffe</th>
<th>Surgical significance</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undisplaced fracture</td>
<td>–</td>
<td>1</td>
<td>Conservative management</td>
<td>Excellent</td>
</tr>
<tr>
<td>Displaced central fragment</td>
<td>1</td>
<td>2</td>
<td>Reduction and fixation</td>
<td>Excellent</td>
</tr>
<tr>
<td>Segmentation of central fragment – canthal tendon attached to bone</td>
<td>2</td>
<td>3</td>
<td>Reduction and fixation – plates; coronal flap often required</td>
<td>Good</td>
</tr>
<tr>
<td>Segmentation of central fragment – canthal tendon not attached to bone</td>
<td>3</td>
<td>4</td>
<td>Reduction and fixation – plates and canthal tendon wire</td>
<td>Fair to good</td>
</tr>
<tr>
<td>Gross segmentation of central fragment requiring bone graft</td>
<td>–</td>
<td>5</td>
<td>Full surgical exposure and cranial bone reconstruction, plates and wires</td>
<td>Fair</td>
</tr>
</tbody>
</table>
Surgical anatomy and classification of fractures of the upper third of the face

Fractures of the upper third of the face represent a group of injuries in which the facial injury extends into the cranial compartment. The precise three-dimensional shape of the craniofacial region is of strategic importance when reconstructing combined fractures of the middle and upper thirds of the face. The anatomy is complicated by the presence of the frontal sinus system, which contains respiratory epithelium. Management has evolved over the last 10–15 years, and while it is important to consider the individual components of the upper third segment, their interrelationship must also be appreciated.

Frontal sinus fractures

The frontal sinuses represent one of the four craniofacial sinuses distributed around the orbits and cranial base (Ch. 8). The anterior wall of the sinus forms part of the anatomy of the brow and the posterior wall forms the anterior limit of the intracranial compartment. The sinus is lined with pseudo-stratified columnar ciliated mucosa; if the outflow track drainage through the frontonasal duct is compromised, ongoing production of mucus will produce a destructive expansile mucocele. In the Stanley and Gonty classification, frontal sinus fractures are divided into four main groups. Type 1 are anterior table fractures (either isolated to the anterior table or accompanied by fractures of the supraorbital rim or the nasoethmoidal complex). Type 2 are anterior and posterior table fractures (both transverse and vertical). Type 3 are posterior table fractures and type 4 are through-and-through fractures of the frontal sinus. Greater emphasis is now placed on nasofrontal outflow tract injury in managing frontal sinus fractures; much less aggressive surgery may be required if patency of the duct can be restored.
FIG. 4.20 An axial CT of a frontal sinus fracture. Note the extensive overlying soft tissue swelling. The Stanley and Gonty classification includes reference to fractures of the anterior (green arrows) and posterior (orange arrows) walls, together with the state of the overlying soft tissues. Because of the additional soft tissue injury, this particular fracture is a type 4 fracture. In addition to the management of the sinus, it is important to reconstruct the frontal bar (blue arrow) correctly to enable anatomical reconstruction of adjacent fractures of the central midface (naso-orbito-ethmoid, NOE) and lateral midface (zygomatic/maxilla).

The aim of treatment of the frontal sinus complex is to restore the shape of the region and, in addition, to ensure that the patient has a ‘safe sinus’. While difficult to define precisely, a safe sinus is one where mucus drains freely and there is no pathological communication between the nasal cavity and the intracranial compartment. Awareness of the risk of meningitis has led to the development of aggressive surgical algorithms, including frontal craniotomy with removal of the posterior wall of the frontal sinus, obliteration of the sinus mucosa, and reconstruction of the skull base to seal the nasal cavity from the intracranial compartment (cranialization). This surgery is not without risk of intra- and extracranial complications; each case must be discussed within the multidisciplinary team and a risk–benefit analysis for operative versus conservative surgery must be undertaken.

**Orbital roof fractures**

The orbital roof represents the interface between the anterior cranial fossa and the orbit. Fractures of this region involve depression of the roof fragments into the orbit. Significant descent of the orbital roof manifests as an orbital dystopia with depression of the orbital axis; inferior and anterior movement of the globe produces a lowering (hypoglobus) and an anterior movement (exophthalmos) that distinguish an orbital roof fracture from an orbital floor fracture. The anterior movement may be pulsatile.
because the brain may be in intimate contact with the orbital tissues. Reconstruction is best achieved with surgical control of the skull base via an intracranial approach. Removal and subsequent replacement of the superior orbital rim facilitate an accurate reconstruction.

**Frontal bar reconstruction**

Satisfactory reconstruction of the upper third of the face involves restoration of the contour of the region, providing support for the forehead, and ensuring correct placement of the cranial side of the frontozygomatic suture and the anterior and central positioning of the root of the nose. Anatomical repositioning of the NOE and upper third fractures, both zygomatic and maxillary, depends entirely on reconstruction of the frontal bar (Fig. 4.21).

![Anatomical repositioning of the naso-orbito-ethmoid (NOE) and upper third fractures, both zygomatic and maxillary, depends entirely on reconstruction of the frontal bar (double-headed blue arrow). Yellow arrow demonstrates the displacement at the infra orbital fracture articulation. Green arrows highlight the fracture articulations of the zygomatic bone. Orange arrows are the strategic buttresses which have collapsed and will need reducing and stabilising.](image)

The standard approach to frontal sinus fractures is coronal. Prior to surgery, the scalp should be shaved and, following preparation, a broken line (zigzag or wave) skin mark is made 2 cm posterior to the hairline. Precise position will be dictated by fracture pattern and any recent neurosurgical intervention (such as an intracranial pressure monitoring device). The mark
may be extended into the pre-auricular region if NOE or midfacial fracture management is required. The authors recommend 60–100 ml tumescence (40 ml 5% levobupivacaine, 1 ml 1 : 1000 adrenaline (epinephrine), 1500 iu hyalase, 40 mg triamcinolone acetonide in 1 litre of 0.9% saline) for hydrodissection of the subgaleal plane. A skin incision is made to the full limits of the scalp wound; dissection inferior to the subgaleal layer is initially performed only in the central region. This allows the lateral extent of the coronal incision to be approached in a ‘two-pronged’ attack with scissor dissection from below and blade or unipolar diathermy from the skin down. At the superior temporal line care must be taken to avoid damage to the underlying temporal fascia. The pre-auricular dissection is carried out to the same depth until the root of the zygomatic arch is located. Dissection in a subgaleal plane is halted 2 cm above the superior orbital rim and 1 cm above the zygomatic root. An oblique incision is made from the two points through the superficial layer of the deep temporal fascia, exposing the underlying fat: this manoeuvre ensures protection of the frontal branch of the facial nerve. Dissection can proceed subperiosteally and deep to the superficial leaf of fascia down to the lateral orbital rim and zygomatic arch. A 3 mm osteotome is used to release the supraorbital neurovascular bundle from its canal and allow further flexibility in turning down the scalp flap. A pericranial flap, a donor flap to line the cranialized frontal sinus, is subsequently raised on either an anterior or a lateral pedicle.

Propagating anterior skull-base fractures

With advances in resuscitation and imaging, patients are now surviving injuries that previously would have proved fatal. After an injury causing segmentation of the frontal bar and frontal sinus involvement, residual energy is propagated through the anterior cranial fossa across the orbital process of the frontal bone, the cribriform plate and crista galli of the ethmoid, and the lesser wings, jugum sphenoidale and prechiasmatic sulcus of the sphenoid. This group of bones collectively constitutes a heterogeneous biomechanical structure. There is increasing evidence that two distinct groups of anterior skull-based fractures depend on the vector of energy transfer. Anterior-based fracture mechanisms tend to result in more survivable injuries. Fractures produced following extension into the skull base can be propagated into the anterior skull base and beyond. The difference in energy transfer across the skull base may, in part, be explained
by the local anatomy, where the more delicate central part of the anterior cranial fossa acts as a ‘crumple zone’ in order to absorb force, while the lateral part of the anterior cranial fossa behaves like a ‘buttress’, resulting in increased energy transfer.45

Surgically, the anterior skull base can be subdivided into different regions that influence surgical management in terms of both approach and prognosis (Fig. 4.22). Surgical management of anterior skull-base fractures is directed toward repositioning grossly displaced fragments (the orbital roof), and reconstructing the partition between the nasal cavity and sinuses and the intracranial compartment. In higher-energy mechanisms, the skull base parallels the experience of the lower face and midface, and there is segmentation of the individual skeletal elements (Fig. 4.23). Deficiency fractures require significant surgical intervention (including bone graft, alloplastic materials, and pedicled pericranial soft tissue local flaps supported by fibrin glue) to ensure a robust partition.

**FIG. 4.22** The anterior skull base can be subdivided into subunits that have surgical relevance. These are the posterior sinus wall region, orbital roof (yellow), anterior ethmoid and cribriform plate (orange), posterior ethmoidal roof (green), roof and lateral wall of sphenoid sinus and adjacent temporal bone (purple).
Energy propagation and fracture propagation can extend still further into the middle and posterior cranial fossae (Fig. 4.24) and may therefore violate the facial nerve canal, resulting in CSF otorrhoea, which will require anatomical partition as with anterior fractures. Energy propagation may also extend to the calvaria (cranial vault), producing linear fractures, secondary fractures and segmentation (Fig. 4.25). As yet, these extended fracture complexes involving the calvaria, cranial base and facial skeleton are unclassified.
FIG. 4.24  Energy propagation and fracture propagation can extend still further into the middle and posterior cranial fossae. Green arrows, lower fracture crossing cribriform plate and anterior cranial fossa. Orange arrows, lower fracture extending into middle cranial fossa.

References


Face and scalp

Velupillai Ilankovan, Tian Ee Seah

**Core procedures**

- Management of scalp lacerations
- Development of the scalp coronal or bicoronal flap to give access to the upper facial skeleton and for craniofacial surgery
- Donor site for reconstruction to cover defects by mobilization of a variety of scalp flaps
- Use of part of the scalp primer as a vascularized flap to cover defects in craniofacial surgery, particularly to line the frontal sinus
Scalp

Clinical anatomy

The scalp consists of the skin, connective tissue and muscle covering the vault of the skull. It extends from the top of the forehead to the superior nuchal line posteriorly, and projects down to the zygomatic arch and external auditory canal (external acoustic meatus) laterally. For descriptive purposes, the forehead is considered as part of the scalp. Conventionally, the scalp is described as being composed of five layers: thick, hairy skin; richly vascular dense connective tissue; the aponeurosis of occipitofrontalis (galea aponeurotica, epicranial aponeurosis); loose areolar connective tissue forming a potential subaponeurotic space; and pericranium (periosteum on the outer surface of the skull). The three outer layers, the scalp proper, are closely adherent and can be separated from the underlying loose areolar tissue.

The skin of the scalp possesses numerous sebaceous glands and is a common site for sebaceous cysts, some having a familial tendency. In older patients keratin secretion can result in ‘keratin horn’, which has a precancerous tendency. ¹

The scalp is supplied by the external and internal carotid arteries. The fact that their branches anastomose freely has clinical significance. The superficial temporal and posterior auricular arteries supply the lateral scalp; the occipital artery supplies the posterior scalp; the supratrochlear and supraorbital arteries supply the anterior scalp. Scalp lacerations continue to bleed profusely because the elastic fibres of the underlying galea aponeurotica prevent initial vessel retraction. Careful cauterization of these feeding vessels during two-layered repair is essential in order to prevent haematoma formation. The pericranial layer, if involved, cannot usually be closed because it retracts. The anterior branch of the superficial temporal artery in the scalp is the ideal donor site for a temporal artery biopsy (the gold standard to confirm a diagnosis of giant cell arteritis).

The lymphatic drainage of the scalp involves facial, submandibular, parotid, auricular, occipital and superficial cervical nodes. Cutaneous malignancies of the scalp usually metastasize to the parotid lymph nodes and subsequently to the cervical nodes, particularly to level II nodes (Ch. 15). Posterior scalp lesions drain to the occipital lymph nodes.

Occipitofrontalis is innervated by the facial nerve: occipitalis by the
posterior auricular branch arising at the stylomastoid foramen and frontalis by the temporal branch. Damage to the latter will result in a ptotic forehead: informed consent must be obtained if any surgical skin excision is to be carried out along the forehead and in raising flaps for temporomandibular and face-lift procedures and for parotidectomy. Much of the scalp is innervated by cutaneous branches of the trigeminal nerve. The skin of the forehead and scalp, nearly as far back as the lambdoid suture, is supplied by the supratrochlear and supraorbital nerves (ophthalmic division of the trigeminal nerve). In trigeminal neuralgia, if medical treatment fails to control lancinating pain in the supraorbital nerve dermatome, neurectomy of this nerve may be offered, although it will produce permanent anaesthesia of the affected scalp. The skin covering the temple is supplied by the zygomaticotemporal nerve (maxillary division of the trigeminal nerve) and the auriculotemporal nerve (mandibular division of the trigeminal nerve). The posterior scalp is innervated by the dorsal rami of C2 and C3 (great auricular nerve and third occipital nerve, respectively). The scalp behind the auricle is supplied by the lesser occipital nerve (C2). An expected complication following neck dissection is numbness of the posterosuperior scalp as a result of sacrifice of branches of the cervical plexus, including the lesser occipital nerve (Ch. 15).

**Surgical approaches and considerations**

Flaps based on the first three scalp layers, including bicoronal and hemicoronal flaps, provide access for trauma and various craniofacial surgical procedures. Access to the temporomandibular joint and zygomatic arch is via a modified pre-auricular approach (the modified hockey stick incision) described by Al-Kayat and Bramley. This incision with temporal extension is used in a face-lift procedure and in parotidectomy. The Gillies approach, used to elevate zygoma fractures, is based on a temporal incision at a 45° angle 2.5 cm superior and anterior to the helix (avoiding the superficial temporal artery). Dissection is continued down to the deep portion of the deep temporal fascia, which is incised. A zygomatic elevator is introduced deep to the fascia, medial to the depressed arch segment, to elevate the bone and reduce the fracture. If the surgeon keeps to this plane, the frontal branch of the facial nerve is protected and the fascial attachment to the zygomatic arch is undisturbed.

Scalp defects are covered by different types of flap, based on advancement,
rotation or transposition (Fig. 5.1). When cutaneous malignancy of the scalp does not involve the pericranium, defects are covered by these different scalp flaps, depending on site. When a scalp flap is not adequate to cover large defects, the exposed pericranium can be covered by either a split-thickness or a full-thickness skin graft.
The scalp can also be used as a large donor site to cover various facial, oropharyngeal and head and neck defects, such as: bilobed scalp flap; galeal pericranial flap (Fig. 5.2); galeal frontalis flap (Fig. 5.3); and forehead island and composite flaps (Fig. 5.4). The majority of the flaps have an axial pattern based on the superficial temporal, supratrochlear or supraorbital arteries and veins. If the external carotid artery is ligated in the neck, as part of the management for head and neck cancer, choosing an axial patterned flap such as a forehead flap would not be reliable. However, raising a bicoronal flap for cranial access is possible because of the rich vascular anastomoses between the internal and external carotid arteries, despite ligating the external carotid artery. In general, the veins have a similar distribution to the arteries; each artery is usually accompanied by a pair of venae comitantes. Scalp veins communicate with intracranial venous sinuses via emissary veins, which pass through various foramina in the skull.
FIG. 5.2  A, A hemicoronal incision the right side of the scalp. B, A galeal pericranial flap based on the 'CALP' layers of the scalp, including the connective tissue layer, aponeurosis, loose connective tissue layer and periosteum. It excludes the skin.
FIG. 5.3 A galeal frontalis flap. The galea with frontalis is raised.
FIG. 5.4  A, B, A forehead island flap used to repair a large cheek defect. C, D, A composite flap, based on a raised superior orbital artery used to reconstruct the defect of the medial wall. E, Another composite flap based on the superficial
temporal artery, with temporalis and outer calvaria used to reconstruct the anterior maxilla.

A large scalp defect – for example, one created as a result of avulsion in trauma or malignancy – is covered by composite cutaneous tissues brought in from a distant site as a microvascular transfer. The common flaps are either an anterolateral thigh flap (ALT flap) or a radial forearm fasciocutaneous flap (RFFF). Recipient vessels are usually anastomosed to the superficial temporal artery and vein using 10/0 Ethilon sutures. Where there is inadequate length or a vessel matching problem, a vein graft is placed as an interpositional recipient vessel and the distal end is sutured to vessels in the neck.

The scalp is used as an access site in endoscopic aesthetic surgery. Three vertical incisions down to the parietal bone are placed 2.5 cm posterior to the hair line and two transverse temporal incisions down to the deep part of the deep temporal fascia are placed over temporalis. The dissection will form a tunnel ‘optical cavity’, where instruments and endoscope can be inserted to carry out brow lift.

Calvarial bone ossifies in mesenchyme, which results in lesser resorption and has the potential for early vascularization when used as a reconstructive tissue. Components harvested from the cranial vault for facial reconstruction include the following:

- Full-thickness calvaria is used particularly in children.
- The outer calvaria is an excellent donor site and is commonly used in the reconstruction of orbital wall and frontal sinus defects, and in nasal reconstruction and midface repair (Fig. 5.5).
- Trephined bone is harvested using a craniotomy, particularly when osteoplastic flaps are raised to access the skull base and the brain.
- Skull shavings are versatile filling materials and can be used as a lining if incorporated with the
attached pericranium.

• Pedicle flaps, based on superficial temporal, supraorbital or supratrochlear arteries, are used in reconstructing large defects of the orbit or nose, or in congenital deformities: for example, in Treacher Collins syndrome, to reconstruct the zygomatic arches (Fig. 5.6).
FIG. 5.5  A, A calvarial bone graft taken from the outer calvaria. B, Lateral orbital osteotomy with calvarial bone graft to correct orbital dimension in a Goldenhar syndrome.
When there is involvement of the pericranium, the calvaria will be exposed and additional measures are required to repair the exposed defect. This is done either by drilling multiple holes with a round burr in the outer calvaria so that bleeding can occur from the diploë, or by removing the whole outer calvaria. In older patients, vitality of the outer calvaria is dependent on diploic perfusion; further measures should be taken to achieve scalp healing if perfusion is inadequate. The recent introduction of innovative materials and substitutes such as Integra (Integra®, Integra Life Sciences Corp, Plainsboro, NJ, USA) and ReCell (RECELL® SYSTEM, Valencia, CA, USA) technology has revolutionized scalp reconstruction.6
**Face**

The face lies anterior to the ears and extends from the hair margin to the chin and lower border of the mandible. The auricles, scalp and neck are anatomically, clinically and pathophysiologically linked structures. For descriptive purposes the face is conventionally divided transversely into upper, middle and lower compartments, and vertically into five sections, two lateral, two orbital and one nasal (Fig. 5.7). The face can also be divided into specific areas or ‘aesthetic units’ within which the skin shares similar characteristics, including colour, texture, thickness, amount of subcutaneous fat and presence or absence of hair. Aesthetic units are separated from each other by well-defined ridges and creases termed aesthetic borders. The latter contain obvious landmarks such as hairlines, eyebrows, nasolabial folds, philtrum, vermilion borders and labiomental folds. The principal aesthetic units of the face include the forehead, eyelids, nose, cheeks, lips, chin and auricles. Aesthetic subunits are separated by less discrete borders than those separating aesthetic units (Fig. 5.8). For completeness, the scalp and neck may be included in order to encompass the head and neck as one region.
FIG. 5.8  Aesthetic subunits.
The direction in which facial skin tension is greatest varies regionally. Skin tension lines, which follow the furrows formed when the skin is relaxed and can be made prominent by pinching, are known as ‘relaxed skin tension lines’ (RSTLs). In the living face, these lines frequently coincide with wrinkle lines (Fig. 5.9) and can therefore act as a guide in planning elective surgical incisions in order to achieve a good aesthetic outcome (Fig. 5.10). RSTLs are perpendicular to the lines of maximum extensibility (LME), which reflect the orientation and stretching of elastic fibres. Kraissl's wrinkle lines are formed at right angles to the underlying muscle fibres and are made prominent in response to different facial expressions; they often do not follow RSTLs. Where possible, excision and flap repair should be made parallel to the RSTLs in order to place the maximum closure tension perpendicular to the LME and parallel to the RSTLs. There are exceptions to this principle, particularly in the lower lid. It should be noted that Langer's lines were described as ‘cleavage lines’ in cadavers and were never intended to delineate the ideal lines for surgical incisions.
FIG. 5.10  Relaxed skin tension lines.
Facial profile and landmarks are different according to ethnic groups and therefore facial assessment should be based on ethnically appropriate anthropometric measurements,\(^8\) while bearing in mind that published measurements are incomplete and based on direct and indirect anthropometric techniques. Patients with facial deformities display marked variations (Fig. 5.11).
Surgical surface anatomy

The upper face consists of the forehead and the hairless area of the temple. The middle face includes the globe, periorbital structures, cheeks, nose and upper jaw. The lower face includes the perioral structures, chin and lower jaw.

The forehead extends from the hair margin to the eyebrow and spans the region between the scalp and upper eyelids. Metopic synostosis produces midline bossing with a ridge. Variable transverse creases on the skin may become prominent when expressing surprise or fright emotions. Contraction of underlying facial muscles produces wrinkles. The temple is demarcated superiorly by the temporal crest indicating the upper limit of temporalis, which becomes obvious when the teeth are clenched.

The external nose is a pyramidal structure located in the midline of the midface and attached to the facial skeleton; the overall shape is very variable. The upper angle or root is continuous with the forehead and the free tip forms the apex, which projects anteriorly. The lateral surfaces unite in the median plane to form the dorsum, which is narrowest at the medial canthus. The lobule is an area containing the tip of the nose. Its base contains two ellipsoidal apertures, the external nares or nostrils, which open on to its inferior surface, separated by the nasal septum and columella, which usually projects below the alar margin. The alar sulcus is a groove in the skin bounding the nasal alae above and joining the nasolabial groove (sulcus),
which separates the cheek from the upper lip. Below, the alar sulcus curves towards the tip of the nose but does not reach it.

The oral aperture is formed by the upper and lower lips, joined at the oral commissure. The sharp junction between the red mucosal zone and the skin is the vermilion border (Ch. 11). The midline region of the upper lip presents a shallow vertical groove, the philtrum, limited above by its attachment to the columella, and ending below in a slight tubercle limited by lateral ridges: it is formed by the decussation of the oblique fibres of orbicularis oris. The labiomental groove separates the lower lip from the chin. In older patients the marionette lines separate the oral commissure and the lateral lower lip from the mandible and chin. The chin is the protrusion in the midline of the mandible.

Clinical anatomy

Fascia

Subcutaneous fibroadipose tissue is present throughout the face, although the degree of adiposity varies in different parts and with age. Anteriorly, it crosses the nasolabial fold on to the lip, and superiorly, it crosses the zygomatic arch: in both locations the layer is more fascial than fatty. The fat content of the subcutaneous tissue in the cheek accounts for the cheek mass. Part of the subcutaneous adipose tissue is the zygomatic (or malar) fat pad, a more or less discrete aggregation of fatty tissue inferolateral to the orbital margin.

The superficial or investing layer of deep cervical fascia from the neck extends on to the face; it splits into two layers between the mastoid process and the angle of mandible to enclose the parotid gland, becoming the parotid fascia. The superficial layer of the parotid fascia is attached to the tip of the mastoid process, the lower border of the cartilaginous part of the external auditory canal and the lower border of the zygomatic arch. The deep layer extends along the base of the skull from the tip of the mastoid process towards the opening of the carotid canal, where it merges with the fascia around the internal carotid artery. Part of the deep layer extends between the styloid process and the angle of the mandible as the stylomandibular ligament. Posterosuperiorly, the fascia is attached to the external occipital protuberance and the superior nuchal lines anterior to the lower border of the mandible from the angle to the chin.

The superficial muscular aponeurotic system (SMAS), described by Mitz
and Peyronie, is thickest over the parotid gland and temporal region and in the scalp, and thinnest over the masseter muscles and the zygomatic region. It often varies in thickness among patients, depending on their build and the amount of facial ageing, and can often be divided into fixed and mobile portions. The fixed portion lies over and firmly adheres to the parotid gland. The mobile portion lies medial to the parotid directly over the mimetic muscles, facial nerves and parotid duct; elevation of the SMAS and mobilization therefore result in movement of the mid and lower face (Fig. 5.12). Around the forehead and temple, this layer is termed temporal parietal fascia; the frontal branch of the facial nerve travels between this layer and the superficial part of the deep temporal fascia. A standard face-lift procedure with SMAS elevation and anchoring, which is different to skin elevation, will give a good unoperated cosmetic outcome. SMAS elevation achieves a pull in a superior vector. Plication techniques described by different authors involve either folding a flap just under the zygomatic arch or anchoring a flap on to the deep part of the temporal fascia above the zygomatic arch (Fig. 5.13). The face-lift SMAS plication (FLISP) flap may be used for reconstruction of defects of the temporofrontal and zygomatic regions following tumour excision.

**FIG. 5.12** Mobilization of the superficial muscular aponeurotic system (SMAS) layer in a superior vector.
Retaining ligaments

The many retaining ligaments of the face are divided into osteocutaneous and fasciocutaneous ligaments. The zygomatic and mandibular ligaments are examples of osteocutaneous ligaments; they originate from the periosteum of the zygoma and the parasympysis of the mandible, respectively, and are inserted directly into the dermis. The masseteric and parotid cutaneous ligaments are examples of fascial coalescences between the superficial and deep facial fasciae; they fix both superficial and deep fasciae to underlying structures such as the parotid gland and masseter, and extend into the dermis. Ageing-related attenuation of these fasciocutaneous ligaments

**FIG. 5.13** Elevation of the superficial muscular aponeurotic system (SMAS) layer and plication to the deep part of the temporal fascia.
results in the descent of the malar and buccal fat pads, augmenting the nasolabial folds and exacerbating the jowls. In a face-lift procedure the zygomatic ligament should be released and, with elevation of the SMAS layer, the masseteric and parotid ligaments should be tightened in order to obtain improvement of the nasolabial fold and resuspension of the buccal and malar fat pads.

The orbitomalar (or zygomatic) ligament is the major support structure of the midface. It is an osteocutaneous retaining ligament that originates at the inferior orbital rim just below the arcus marginalis and penetrates orbicularis oculi anteriorly before inserting into the dermis. It contributes to the formation of the lid–cheek junction and to the formation of the tear trough (together with the origins of levator labii superioris and levator labii superioris alaeque nasii). The orbitomalar ligament also plays a role in malar descent and the formation of malar festoons commonly seen in midface ageing. The buccal fat pad is situated below the malar fat pad. It has a main body surrounded by buccinator, masseter and the zygomatic arch, and temporal, buccal, pterygoid and pterygoid palatine extensions. The buccal fat pad also descends in ageing, increasing the marionette fold and the jowls. It serves as a donor site in many reconstructive techniques and can be used as a pedicle flap in loss of orbital volume and in closure of oro-antral fistulae. The temporal extension can be taken into the globe via the inferior orbital fissure.

**Fat**

Four specific collections of fat in the face are clinically significant. Retro-orbicularis oculi fat (ROOF) extends from the mid supraorbital rim to beyond the lateral orbital margin and is part of the galeal fat pad, which contributes to the fullness of the upper lid: it becomes hypertrophic with ageing. Sub-orbicularis oculi fat (SOOF) is similar to ROOF, lying deep to orbicularis oculi and superficial to the facial mimetic muscles. The malar fat pad is a triangular structure in the subcutaneous plane superficial to the SMAS. Ageing causes it to descend, unmasking the orbital fat pads. The latter play an important role in both upper and lower blepharoplasty. There are two main fat pads in the upper eyelid and three fat pads in the lower eyelid (Ch. 7). The two upper fat pads are the central and medial fat pads, located in the pre-aponeurotic space just anterior to the aponeurosis of levator palpebrae superioris. They are separated by the presence of the trochlea and the tendon of superior oblique and its fascial connections to the trochlea. The medial fat pad is more fibrous and paler than the central fat pad. The lower lid contains
medial, central and temporal pads. The medial pad is similar to its counterpart in the upper lid and contains fibrous, pale fat. During blepharoplasty, the inferior oblique muscle is commonly visible, separating the medial and central fat pads. Aggressive fat transposition techniques that suture the fat below the orbital rim can create a lasso effect, impairing the function of inferior oblique and producing diplopia. The central and lateral fat pads are separated by an interpad septum and the arcuate expansion of Lockwood’s ligament, which should be preserved during lower lid dissection to maintain lateral support. The medial fat pad in the upper lid is a separate structure (Fig. 5.14).

**FIG. 5.14** Fat pads of the face.

**Vascular supply**
The face is supplied by branches of the facial, superficial temporal, maxillary and ophthalmic arteries. The superficial temporal and facial arteries are
common recipients for microvascular anastomoses in reconstructions of the face and scalp. A scalp defect is reconstructed using the microvascular fasciocutaneous flap: the superficial temporal artery and vein are the most common recipient vessels. The facial artery is the common recipient for facial, maxillary and mandibular reconstructions. The dorsal nasal branch of the ophthalmic artery, which is a branch of internal carotid artery, can be used as a recipient vessel in selective defect reconstruction if the facial artery has already been sacrificed to reconstruct defects along the nasolabial and columellar areas. The facial vein is the usual recipient site for microvascular free flap anastomosis.

**Lymphatic drainage**

The lymph nodes in the face are mainly located around the parotid gland. Parotid nodes may number up to 20 and are divided into extraglandular and intraglandular groups. The former is further divided into pre-auricular and infra-auricular groups that collectively drain the lateral and frontal aspects of the scalp, anterior auricle, external auditory canal, skin of the lateral face and buccal mucosa. Most groups drain into both the internal and external jugular chains. Cancers of the anterior scalp, temporal bone and buccal mucosa may require parotidectomy with facial nerve preservation in order to resect these nodes. The occipital nodes are divided into superficial and deep groups. The superficial group consists of two and five nodes located between sternocleidomastoid and trapezius at the apex of the posterior triangle. The deep group consists of between one and three nodes and is located deep to splenius capitis and along the course of the occipital artery. The superficial group drains the occipital scalp and the posterior cervical skin into the deep group and upper spinal accessory node. The deep group receives lymphatic drainage from the deep musculature of the neck and occipital region. There are between one and four posterior auricular nodes, located over the dense fibrous insertion of sternocleidomastoid on to the mastoid process. These nodes drain the posterior parietal scalp, the skin overlying the mastoid process and the postauricular area into the infra-auricular parotid nodes and the deep cervical nodes associated with the internal jugular vein and spinal accessory nerve; they must be removed in any neck dissection for cancers of the posterior scalp.

**Innervation**

The facial nerve (Video 5.1) innervates all of the muscles of the face except
temporals and masseter (innervated by the trigeminal nerve) (Video 5.2) and levator palpebrae superioris (innervated by the oculomotor nerve). Sensory innervation is mainly via the ophthalmic, maxillary and mandibular branches of the trigeminal nerve; the skin over the angle of the mandible is supplied by the greater auricular nerve (anterior primary rami C2, 3).

The facial nerve may be damaged or affected by intra- or subcranial injury. The former will cause an upper motor neurone (UMN) palsy and the latter will cause a lower motor neurone (LMN) type palsy. In UMN facial palsy the voluntary movements of the lower half of the face only will be affected; emotional and involuntary movements are less affected. In LMN facial palsy, muscles in both upper and lower parts of the face will be affected.

The most common form of facial palsy is Bell's palsy (Fig. 5.15). There is a loss of muscle tone on the affected side with overflow of tears (epiphora), drooping of the corner of the mouth and an inability to keep the oral vestibule free from food while chewing; these collectively impair drinking and mastication.

Fracture of the skull base along the temporal bone involving the internal auditory canal (internal acoustic meatus) or the otic capsule may cause similar injuries. Needle electromyography can give useful information regarding the status of denervation or reinnervation.

**Frey's syndrome**

Frey's syndrome (auriculotemporal syndrome) may be a complication after
parotidectomy or endoscopic thoracic sympathectomy. Symptoms range from erythema related to the smell or taste of food to gustatory sweating and are thought to reflect aberrant innervation of sweat glands in the overlying flap of skin by regrowing cholinergic postganglionic parasympathetic axons that previously innervated the parotid via the auriculotemporal nerve. Diagnosis is clinical and by the iodine starch test (Fig. 5.16). Gustatory sweating can be treated with a regular injection of botulinum toxin or topical anticholinergic drugs such as scopolamine. In order to prevent the occurrence of Frey’s syndrome, it is always advisable to place a dermal fat graft at the time of parotidectomy.

**FIG. 5.16** Iodine starch test. Iodine is applied to the parotid region and the starch powdered over it: during gustatory sweating, the starch will turn blue in the presence of iodine.

**Muscles**

Craniofacial muscles are associated with the orbital margins and eyelids, external nose and nostrils, lips, cheeks and mouth, pinna, scalp and cervical skin, and collectively are often called, not very accurately, ‘muscles of facial expression’. Their organization differs from that of muscles in most other regions of the body because there is no deep membranous fascia beneath the skin of the face, and many small slips of muscle that are attached to the facial skeleton insert directly into the skin. Two other muscles seen on the face are temporalis and masseter, both muscles of mastication that act on the
temporomandibular joint (Ch. 10).

The ‘muscles of facial expression’ are divided into orbital, nasal, auricular and oral groups (Video 5.3).

The circumorbital and palpebral group of muscles is composed of orbicularis oculi, corrugator supercilii and levator palpebrae superioris. Orbicularis oculi is a broad, flat, elliptical muscle that surrounds the circumference of the orbit and spreads into the adjacent regions of the eyelids, anterior temporal region, infraorbital cheek and superciliary region. It has orbital, palpebral and lacrimal parts, and a small ciliary bundle (Ch. 7). The orbital part is the largest and extends on to the face some distance beyond the orbital rim in concentric loops. It arises from the nasal part of the frontal bone, frontal process of the maxilla and the medial palpebral ligaments. The palpebral part is the central part and is confined to the eyelids. It arises mainly from the medial palpebral ligament and runs across the eyelids to insert into the lateral palpebral raphe. The lacrimal part forms a muscular sling, which arises from the lacrimal bone and passes behind the lacrimal sac, where some fibres insert into the lacrimal fascia. Other fibres insert into the tarsal plate of the eyelids near the lacrimal canaliculi and into the lateral palpebral raphe. The orbital part is involved in forced closure of the eye. The palpebral part is involved in involuntary eye closure, particularly blinking. When the lacrimal fascia is pulled on, the lacrimal part may dilate the lacrimal sac and so aid drainage of tears into the sac.

When the entire orbicularis oculi muscle contracts, the skin is thrown into folds that radiate from the lateral angle of the eyelids. Such folds, when permanent, cause wrinkles in middle age (the so-called ‘crow's feet’); these can be minimized by serial injection of botulinum toxin in order to improve the cosmesis of the periorbital area. Depressor supercillii is a part of orbicularis oculi and is inserted into the skin and subcutaneous tissue of the eyebrow. Corrugator supercili is a small pyramidal muscle located at the medial end of each eyebrow, lying deep to the frontal part of occipitofrontalis and orbicularis oculi, with which it is partially blended. Corrugator and depressor supercili are medial depressors of the forehead: regular injection of botulinum toxin into these muscles can reduce vertical and transverse wrinkles, and can elevate the medial brow.

The muscles of the external nose include procerus, nasalis and dilator naris anterior, depressor septi nasi and levator labii superioris alaeque nasi. Procerus arises from the nasal bone and the upper part of the lateral nasal cartilage, and is inserted into the glabellar skin between the eyebrows. It is a
medial depressor of the forehead, active in frowning and helping to reduce the glare of bright sunlight, both actions that cause marked transverse wrinkles. Regular intramuscular injection of botulinum toxin will prevent muscle contraction and will provide good aesthetics. Nasalis has transverse and alar parts. The transverse part (compressor naris) arises from the maxilla and expands into an aponeurosis that merges with its counterpart across the bridge of the nose and with the aponeuroses of procerus and fibres from levator labii superioris alaeque nasi, and may also blend with the skin of the nasolabial and alar folds: it compresses the nasal aperture at the junction of the vestibule and the nasal cavity. The alar part is attached to the maxilla above the lateral incisor and canine, and to alar skin and the cartilaginous part of the nasal septum: it helps to widen the nostrils.

The muscles of the auricular group are the anterior, superior and posterior auricular muscles, of which the most constant is the superior auricular muscle.

**Surgical considerations**

The facial muscles are derived from the second pharyngeal arch and any developmental disorder that affects these muscles may cause facial asymmetry. Möbius syndrome, dystonia and muscle dystrophy all present with muscle dysfunction. Cleft lip and palate is the most common congenital deformity involving orbicularis oris and the malposition of other perioral muscles. In unoperated bilateral cleft patients, the premaxilla is mobile from birth and only apically fixed to the vomer; in the absence of an intact orbicularis oris, the growth of the premaxilla is uncontrolled, such that it may either project or rotate up under the nose.\(^\text{10}\) Interestingly, midface growth is not affected, even though there is no symmetrical muscle activity (Fig. 5.17\(^\text{11}\)).

Repair of cleft lip depends on careful muscle dissection and subperiosteal mobilization of the whole group of muscles, particularly the transverse fibres of nasalis, levator labii superioris, levator labii superioris alaequae nasi, zygomaticus major and minor, and the oblique fibres of orbicularis oculi. The deep horizontal layer of orbicularis oculi and depressor septi nasi are separated by careful dissection from the glandular layer of the adjacent mucosa. On the cleft side, the horizontal fibres are carefully dissected from the mucosa without damaging the median frenulum and septum of the upper lip. The skin repair is based on the principle of rotation advancement flaps.\(^\text{11}\)
Various reconstructive techniques are described in the literature to repair defects resulting from malignancy of the upper or lower lip. When the whole lip is excised, standard repair will result in microstomia and lip incompetence. The three-layered repair described by Sayan et al\textsuperscript{12} is an example of rearranging local muscle groups without disturbing their motor innervation. It involves mobilization of the perioral musculature: ensuring intact innervation and performing a simultaneous commissurotomy result in a functional mouth with no microstomia and preserved sensation.

Temporalis fascia and temporalis muscle, together with masseter and the anterior belly of digastric, are used in static facial reanimation surgery. Temporalis slings may be anchored to the nasolabial fold. Masseter may be elevated from the angle of the jaw and sutured to the upper lip and modiolus to help maintain lip function and, to some degree, lip symmetry. Transferring the anterior belly of digastric subdermally to the affected lower lip will aid lower lip function. Temporalis muscle has other uses in oropharyngeal reconstruction: for example, in reconstruction of the soft palate or maxillary defects and as lining tissue for lateral oropharyngeal defects (Fig. 5.18).
A. A localized temporalis flap in which a strip is incised and elevated to reconstruct maxillary defects. B. Temporalis flap. C. Temporalis flap split down the middle for palatal reconstruction. (Courtesy of Professor Nabil Samman.)

D. Transferred split temporalis muscle flap used to line two surfaces. E. A modified muscle flap based on temporalis fascia may be used to line large defects such as oropharyngeal defects.
Tissue plane infections

The spread of infections in soft tissues is influenced by the natural barriers offered by bone, muscle and fascia. Around the jaws, potential tissue ‘spaces’ are primarily defined by muscles: principally, mylohyoid, buccinator, masseter, medial pterygoid, superior constrictor and orbicularis oris (Fig. 5.19). These spaces become apparent only when inflammatory products destroy the loose connective tissue they normally contain. The important potential spaces on the face are the buccal space, lying between skin and buccinator; the infraorbital space, lying between the bony attachments of levator labii superioris and levator anguli oris; the submasseteric space, between the bony mandible and masseter; the parotid space between the parotid gland and overlying fascia; and the pterygomandibular space between the medial surface of the ramus of the mandible and medial pterygoid. The submental and submandibular spaces are located below the inferior border of the mandible, beneath mylohyoid in the suprahyoid region of the neck (Ch. 15).
Facial trauma

Trauma affects soft and hard tissues of the face. Soft tissue laceration should be repaired in layers to produce good long-term surgical outcome. Systematic clinical examination is essential in order to identify damage to motor and/or sensory nerves. In facial lacerations, trauma to the temporal, buccal and marginal mandibular branches should be suspected if there is a ptotic forehead, asymmetric upper lip and loss of symmetrical function of the lower lip, respectively. Knowledge of the terminal distribution of these nerves is required: exploration using loupe magnification or an operating microscope is essential. On the forehead, the temporal branch of the facial nerve travels above the zygomatic arch approximately 2 cm in front of the pretragal sulcus,
lying between the deep part of the superficial temporoparietal fascia and the superficial part of the deep temporal fascia. The buccal branch of the facial nerve is always superficial to the upper lip musculature as it travels over masseter, whereas the mandibular branch is deep to the depressor musculature of the lower lip and therefore unlikely to sustain damage in normal lip lacerations.

### Tips and Anatomical Hazards

On the face, where possible, excision and flap repair should be made parallel to the RSTLs in order to place the maximum closure tension perpendicular to the LME and parallel to the RSTLs. The buccal fat pad serves as a donor site in many reconstructive techniques and can be used as a pedicle flap in loss of orbital volume and in closure of oro-antral fistulae. Aggressive fat transposition techniques that suture the fat below the orbital rim can create a lasso effect, impairing the function of inferior oblique and producing diplopia. The superficial temporal and facial arteries are common recipients for microvascular anastomoses in reconstructions of the face and scalp. Frey’s syndrome (auriculotemporal syndrome) may be a complication after parotidectomy or endoscopic thoracic sympathectomy. In order to prevent the occurrence of Frey’s syndrome, it is always advisable to place a dermal fat graft at the time of parotidectomy. Potential tissue ‘spaces’ around the face become apparent only when inflammatory products destroy the loose connective tissue they normally contain. The important potential spaces on the face are the buccal, infraorbital, submasseteric, parotid and pterygomandibular spaces. Soft tissue laceration on the face should be repaired in layers to produce good long-term surgical outcome. Trauma to the temporal, buccal and marginal mandibular branches of the facial nerve should be suspected if the patient presents with a ptotic forehead, asymmetrical upper lip and loss of symmetrical function of the lower lip, respectively. The buccal branch of the facial nerve is always superficial to the upper
lip musculature as it travels over masseter, whereas the mandibular branch is deep to the depressor musculature of the lower lip and therefore unlikely to sustain damage in normal lip lacerations.
The outer calvaria is an excellent donor site and is commonly used in the reconstruction of orbital wall and frontal sinus defects, and in nasal reconstruction and midface repair.
References


Single Best Answers

1. The five layers of the scalp are represented by the acronym 'SCALP'. Which one of the following describes the tissues represented by these letters?

A. Skin, dense Connective tissue, Aponeurosis, Loose connective tissue, Papillary tissue
B. Skin, dense Connective tissue, Aponeurosis, Loose connective tissue, Periosteum
C. Skin, dense Connective tissue, Aponeurosis, Loose fascia, Periosteum
D. Skin, dense Connective tissue, Acellular matrix, Loose fascia, Periosteum
E. Skin, Cuticle, Aponeurosis, Loose connective tissue, Periosteum

Answer: B. Skin, dense Connective tissue, Aponeurosis, Loose connective tissue, Periosteum.

2. Which one of the following is a common complication that may result after raising a flap for temporomandibular, parotid or face-lift surgery?

A. Transient or permanent blindness
B. Epistaxis
C. Transient or permanent diplopia
D. Transient or permanent mental paraesthesia
E. Transient or permanent palsy of the temporal branch of the facial nerve

Answer: E. Damage to the temporal branch of the facial nerve can produce transient or permanent palsy, resulting in an ipsilateral ptotic forehead.

3. From which one of the following are the ‘muscles of facial expression’ derived?

A. First pharyngeal arch
B. Second pharyngeal arch  
C. Third pharyngeal arch  
D. Fourth pharyngeal arch  
E. Fifth pharyngeal arch  
**Answer: B.** The mimetic facial muscles, buccinator, stylohyoid and the posterior belly of digastric are all derived from the second pharyngeal arch.

4. Which one of the following muscles can be used as a versatile myogenous flap in repairing maxillary and oropharyngeal defects?  
   A. Masseter  
   B. Lateral pterygoid  
   C. Temporalis  
   D. Medial pterygoid  
   E. Buccinator  
   **Answer: C.** Temporalis.

5. Which one of the following describes the classification of the facial suspension ligaments?  
   A. Musculocutaneous and fasciocutaneous  
   B. Osteocutaneous and fasciocutaneous  
   C. Osteocutaneous and musculocutaneous  
   D. Only osteocutaneous  
   E. Only musculocutaneous  
   **Answer: B.** Retaining ligaments of the face are divided into osteocutaneous and fasciocutaneous ligaments. The zygomatic and mandibular ligaments are examples of osteocutaneous ligaments, and the masseteric and parotid cutaneous ligaments are examples of fasciocutaneous ligaments.
Clinical Cases

1. A 69-year-old male patient presented with a cancerous lesion on the skin over the zygomatic buttress region (Fig. 5.20A). This region had to be anaesthetized prior to surgical excision.
A. Describe the sensory supply over this region.

The skin over the zygomatic buttress region is primarily innervated by the zygomaticofacial and zygomaticotemporal nerves, which are branches of the maxillary division of the trigeminal nerve. Towards the ear, the skin is supplied by the auriculotemporal nerve, which is a branch of the mandibular
division of the trigeminal nerve.
The lesion has been excised with a healthy margin to prevent recurrence.

B. With reference to Fig. 5.20B, describe the layers that have been removed and the layer that has been left by the surgeon.
The skin and subcutaneous layer over the zygomatic area have been excised, leaving an intact SMAS layer.

C. What is the SMAS layer and what muscles might it contain in this region?
SMAS is an acronym for superficial muscular aponeurotic system: it contains the mimetic muscles of facial expression. In this region, the SMAS is thin and contains the lateral edges of orbicularis oculi.

D. A flap was mobilized over the zygomatic and temporal regions to close the defect (Fig. 5.20C). Describe the motor nerve that lies in this region.
The frontal, zygomatic, buccal, marginal mandibular and cervical branches of the facial nerve innervate the muscles of facial expression. In this case, care was taken by the surgeon not to injure the frontal and zygomatic branches of the facial nerve. Upon exit from the parotid gland, the frontal branch of the facial nerve travels deep to the temporal parietal fascia and on the surface of the superficial layer of the deep temporal fascia, and supplies frontalis. The zygomatic branch exits the parotid gland and supplies orbicularis oculi.

2. A 50-year-old male patient presented with a fracture of the medial wall of the left orbit, which had resulted in canthal detachment from the medial wall due to trauma. Conjunctival chemosis and slight periorbital ecchymosis could be seen in his left eye (Fig. 5.21A).
A. Describe the anatomy of the medial canthal ligament and its insertions.

The deep and superficial extensions of the preseptal and pretarsal parts of orbicularis oculi form the medial canthal ligament, which has an anterior limb and posterior limb. The anterior limb inserts into the anterior lacrimal crest, nasal bone and maxillary bone; the posterior limb inserts into the
posterior lacrimal crest (Fig. 5.21B).

B. What does this three-dimensional reconstruction of the CT scan (Fig. 5.21C) show?
   The scan shows a fracture of the medial wall of the left orbit.

C. Describe the anatomy of the lower eyelid.
   The lower eyelid is divided into anterior, middle and posterior lamellae. The anterior lamella contains skin and the preseptal and pretarsal parts of orbicularis oculi, and the posterior lamella contains the tarsal plate, orbital septum, inferior tarsal muscle, capsulo-palpebral fascia and the palpebral conjunctiva. Some descriptions include the orbital septum, subseptal (or orbital) fat and fibroadipose tissue posterior to the septum in a middle lamella. In this case, the orbital fracture has been reduced via the subciliary approach. An incision is made 2 mm below the lower eyelash on the skin and extended to the lateral crow's feet. Either a pre-muscle dissection is made, developing a skin flap, or a retro-muscle dissection is made with a stepwise skin–muscle flap to access the arcus marginalis (the thickening of the periosteum at the orbital rim). Incision and dissection allow access to the fractured medial segment. Canthal detachment is repaired by internal fixation of the medial orbital fracture with craniofacial plates and screws.
The paired orbits housing the globes are highly evolved and specialized structures that maintain the structural integrity of the globe and the highly complex coordinated movements that facilitate binocular vision. The neuromuscular mechanisms are complex and require considerable neurological investment, in that, of the twelve cranial nerves, three nerves are required for eye movement and one for visual information, with one contributing to the control of lacrimation.

The eyes are also the focal point for an observer to fix on during conversation. Asymmetry is obvious and often disfiguring.

- Surgical access to the orbit
- Orbital dissection
- Deep orbital dissection
Surgical surface anatomy

The influence of the orbit on the surface anatomy of the globe is profound. Clinical assessment looks at the width of the palpebral aperture, which is typically 10 mm from upper to lower eyelid. This is subdivided into two measurements. The margin reflex distance (MRD) one is the light reflection of the camera to the upper eyelid (MRD 1 at 4 mm), and the margin reflex distance two (MRD 2 at 6 mm) is the distance between the light reflection of the camera to the lower eyelid.

The lower eyelid typically crosses the cornea at 5 and 7 o'clock and should be symmetrical with the contralateral orbit. In some individuals there is increased scleral show, and the sclera is visible below the iris.

The thickness of the upper eyelid can be increased in retropositioning of the globe, in which case the major contribution is that of the palpebral part (the white double-ended arrows in Fig. 6.1).
FIG. 6.1  The complex surface anatomy of the globe and periorbita. Note the position of the iris as it crosses the upper and lower eyelids (black arrows) and the position of the light reflection related to the upper and lower eyelids (blue and yellow arrows). The shape of the upper lid and distance from the margin to the eyebrow are influenced by the globe position, and subdivided into palpebral (white arrow) and orbital parts (green arrow). The shape of the lateral and medial canthus (red lines) is dictated by the underlying tendons, the medial ligament opening out of the angle and exposing the caruncle (C). Skin creases caused by muscle skin attachments (orange arrows) vary according to age and race.

The appearance of the orbit is also dependent on the position of the soft tissue attachments in the form of the medial and lateral canthal tendons, the position of the eyebrow, and the condition of the overlying skin.
Clinical anatomy

The orbit is classically described as a pyramidal structure that is made up of four bony walls (floor, medial and lateral walls, roof) and a fifth wall, closed by the upper and lower eyelids on their fibrous soft tissue skeleton, the tarsal plates, which are rigidly attached both medially and laterally. This essentially closed system is analogous to that of the lower limb, which is at risk of a compartment syndrome caused by any volume-occupying medium, usually blood in the form of a retrobulbar haematoma, but also air as a tension pneumo-orbit, or even cerebrospinal fluid (Fig. 6.2).¹,²

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**FIG. 6.2** An axial CT scan demonstrating a left orbital retrobulbar haematoma (blue arrows) following fracture of the left medial orbital wall (red arrows).
Surgical pathology

Historically, the mechanism of failure of the orbit in response to trauma has been described in terms of either transfer of energy to the infraorbital margin with secondary dissipation along the floor (buckling theory), or a direct blow to the globe with onward propagation through the floor. Each orbit is made up of seven constituent bones that have differing thicknesses and strengths, and whose individual physical characteristics influence the lines of failure and subsequent fracture configurations (Fig. 6.3). These have distinct surgical pathologies and can be separated functionally into a number of different functional units.

The floor (blue on Fig. 6.3) is composed of the orbital process of the maxilla anteriorly, and the orbital process of the palatine bone posteriorly. The medial wall (purple) is composed of very thin bones, the ethmoid and lacrimal bones. Because the bone in this region is thin, it is prone to fracture with differing degrees of comminution, depending on the volume of energy transfer running across it; the pathway of energy propagation has long been
disputed but it is, in fact, largely academic and clinically irrelevant.

The frontal bone (red) forms the roof of the orbit. It separates the anterior cranial fossa from the orbit and so any fracture propagation is part of a craniofacial sequence with all of the attendant sequelae.

The lateral wall (yellow), composed of the zygomatic bone and the greater wing of the sphenoid, is thick and fracture separation at this part represents a fracture of the zygomatic bone.

The orbital apex (green) is composed of the lesser and greater wings of the sphenoid, which are separated by the superior and inferior orbital fissures. The robust bone is implicated in only the most severe mechanisms.

**Enophthalmos**

Fractures of the orbital floor, the medial wall and the roof present clinically according to the size, position and surface area of the wall deficits. The fundamental physical sign is that of enophthalmos, which is defined as a relative difference in the anterior position of the globe compared to the contralateral side. This manifests in a smaller palpebral aperture, resulting in a smaller eye and a relative increase in the amount of upper lid visible. The globe may sit lower, which is called hypoglobus.

There are a number of theories as to the aetiopathogenesis of this condition.

**Orbital volume**

The soft tissue volume constrained by the orbital septum acts as a closed box. If this box is opened, with tearing of the orbital septum and herniation of orbital contents, then there is a relative increase in the volume of the orbit, which will alter the relative position of the globe (Fig. 6.4).\(^4\)\(^–\)\(^6\)
FIG. 6.4 Volume analysis scans. A, A non-injured left orbit. B, An injured right orbit: note the substantial increase in orbital volume of nearly 4 cm$^2$, which caused 4 mm of enophthalmos.

**Geometry of the orbital walls**

The advent of modern CT scanning technology, with the ability to render planes of view in three dimensions, has led to an increased understanding of orbital fracture configuration patterns, as well as refining surgical reconstruction (Fig. 6.5). Recent advances and refinements in surgical technique allow for full exposure and visualization of extensive orbital defects and have made accurate reconstruction possible. Greater surgical understanding has led to the identification of key internal orbital shapes and regions, which has subsequently refined reconstruction. Key examples are recognition of the sinusoidal shape of the floor on sagittal section, the posteromedial bulge of Hammer,$^7,8$ and the importance of reconstructing the orbital floor.
Fat contraction/rupture of septum

In some cases following major energy transfer, technically perfect reconstructions that restore the sigmoid curvature and the posteromedial bulge, and correct the relative orbital volume increase, can still manifest as enophthalmos. In these cases, it is assumed that there has been loss of fat through direct trauma to the adnexae, resulting in a reduction in soft tissue volume. This is logical, albeit difficult to prove. In thyroid eye disease, exophthalmos is reduced by surgically producing blowout-type fractures to the medial wall, floor and, in some cases, lateral wall. Following bone decompression, the full benefit of posterior movement is achieved by incising the orbital septum and periosteum, and allowing increased herniation. It is thus likely that a combination of soft tissue effects contributes to the loss in position.

Trapdoor-type fracture

This pattern of fracture is typically seen in the paediatric age group, who sustain linear fractures of the floor, which springs apart, allowing herniation of the orbital adnexae, and then closes, trapping the soft tissues (Fig. 6.6). This is analogous to a strangulated hernia and may indeed induce long-term adverse changes if a muscle is involved. It is believed that this type of fracture is due to mild to moderate energy transfer exploiting the elastic nature of the paediatric orbital bone. There is typically no subconjunctival
haemorrhage, so these injuries are termed ‘white eye blowout fractures’. Some authorities regard this as an emergency requiring immediate management on presentation. It is important to understand that this injury pattern may occur in the medial wall and in adults.

FIG. 6.6 A coronal CT of a trapdoor-type fracture (red arrow). Note the herniated orbital contents (yellow arrows). This type of injury often results in trapping of orbital soft tissue contents and diplopia on up-gaze. There may be minimal swelling and subconjunctival haemorrhage, in which case these are known as ‘white eye blowout fractures’.

Diplopia

Ocular movements are complex and are produced by six muscles and three cranial nerves. The muscles themselves are composed of fast-twitch fibres and are very thin, which makes them very vulnerable to damage. In order to coordinate movements, the eye muscles must be in pristine condition and free to move; fractures compromising this freedom result in diplopia.

Diplopia may be classified as monocular or binocular diplopia, monocular implying an intraocular pathology, and binocular reflecting dysmotility of the globes. Dysmotility can be caused by entrapment of the muscles within a trapdoor fracture, but may also be myogenic, reflecting direct damage to the musculature, or neurogenic, from damage either to an individual muscle or
to a cranial nerve at the apex of the orbit.

It is important to diagnose the exact aetiology preoperatively because this will influence treatment planning, the recovery of the patient, and ultimately prognosis.

Depending on which part of the orbit is damaged, the pattern and extent of double vision, together with the degree of handicap, are variable. The multidisciplinary team therefore includes an orthoptist, who will diagnose any premorbid diplopia, quantify the damage to the different eye muscles, prognosticate and plan treatment for the control of temporary diplopia with prisms, and orchestrate strabismus surgery accordingly.

It is important to differentiate the various patterns of diplopia in fractures of the orbital floor. These are subdivided into types I to III (Table 6.1). Types II and III involve patterns of diplopia that include the down-gaze. Diplopia on down-gaze is functionally handicapping because the patient will experience more functional disturbance; it implies damage to the inferior rectus itself, which, although it may recover, is unlikely to be improved by repair of the orbital floor. It is also important to understand that patients may experience diplopia post surgery for large defects, which may persist for 6 months.11

**TABLE 6.1**

**Patterns of post-traumatic double vision (diplopia)**

<table>
<thead>
<tr>
<th>Part of orbit affected</th>
<th>Muscles involved</th>
<th>Pattern of diplopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>Inferior rectus</td>
<td>I – diplopia on up-gaze</td>
</tr>
<tr>
<td></td>
<td></td>
<td>II – diplopia on down-gaze</td>
</tr>
<tr>
<td></td>
<td></td>
<td>III – diplopia on both up- and down-gaze</td>
</tr>
<tr>
<td>Medial wall</td>
<td>Medial rectus</td>
<td>Diplopia on abduction (looking laterally)</td>
</tr>
<tr>
<td>Roof</td>
<td>Superior rectus</td>
<td>Diplopia on up-gaze and down-gaze</td>
</tr>
<tr>
<td></td>
<td>Lateral rectus</td>
<td>Torsional (Duane's syndrome)</td>
</tr>
</tbody>
</table>
Surgical approaches and considerations

Access to the orbital contents for exploration and reconstruction of floor and medial wall defects depends on identification of the subperiosteal plane, which is achieved via access through the lower eyelid.

For access and reconstruction, the lower eyelid is divided into an anterior lamella containing skin and the preseptal and pretarsal parts of orbicularis oculi, and a posterior lamella containing the tarsal plate, orbital septum, inferior tarsal muscle and capsulopalpebral fascia, and the palpebral conjunctiva. Surgical access may be achieved via either a transcutaneous (anterior) or a transconjunctival (posterior) approach. The transconjunctival approach is fast becoming the surgical access of choice and provides unparalleled access with minimal aesthetic disturbance. The lower eyelid is everted over a Desmarres retractor, and the conjunctiva incised using a cutting diathermy and dissected in the interface between the conjunctiva and orbicularis oculi. This approach can be extended via a preseptal dissection, which, while technically challenging, is both elegant and respectful of the anatomy (Fig. 6.7). Maintenance of the integrity of the orbital septum controls the orbital fat, which very much improves the surgical window (Fig. 6.8). Incision of periosteum then allows identification of the subperiosteal plane (Fig. 6.9). The width of the surgical exposure can be increased by sectioning of the lateral canthus; this is known as the McCord lid swing (Fig. 6.10).
FIG. 6.7  Eversion of the lower eyelid over a Desmarres retractor. Following a mucosal incision, the conjunctiva is stretched posteriorly and a bloodless plane identified; this is known as the middle lamella.

FIG. 6.8  Maintenance of an intact orbital septum allowing bloodless dissection of the floor and, in this case, the medial wall.
FIG. 6.9 Identification and lateral exploitation of the subperiosteal plane following incision of the periosteum. The lateral wall of the orbit is robust and facilitates development.

FIG. 6.10 The McCord lid swing technique. The width of the surgical exposure can be increased laterally by exposure of the lateral canthal tendon (yellow arrow) and incision (blue line). The whole lateral segment can then be ‘swung’ inferiorly (red arrow).
Orbital vascularity

The orbit has a rich blood supply (Video 6.1), provided by multiple perforating vessels derived from both the internal and the external carotid arterial systems. These require surgical control in the repair of extensive floor and medial wall defects.

The infraorbital artery and vein accompany the infraorbital nerve running along the floor of the orbit. Downie and Evans described an anatomical variant perforating the orbital floor.\(^{13}\) Occasionally, the infraorbital vessels can be torn; the hole is usually small and responds to gentle bipolar diathermy with a lightly open tip on the side wall.

The zygomaticofacial artery is an inconsistent vessel, which may be encountered on first entering the orbit during a lateral dissection. It requires coagulation by bipolar diathermy prior to surgical division. If the vessel is inadvertently torn, the bleeding can be troublesome; while diathermy can be applied to the orbital septum, the ostium in the lateral orbital wall requires obturation with bone wax.

The anterior and posterior ethmoidal vessels perforate the medial wall of the orbit in a line running along the suture between the ethmoid and frontal bones. They are thus very superior, and would be encountered only in the most superior of dissections (Video 6.1). Their anterior and posterior positions are not constant (Fig. 6.11).\(^{14,15}\)
Orbital dissection: orbital floor and medial wall

Onward access in the subperiosteal plane is required to delineate the fracture margins and deliver herniated soft tissue contents back into the orbit (Fig. 6.12). Strict adherence to this plane is mandatory to avoid key anatomical structures, specifically the lacrimal apparatus and inferior oblique (Fig. 6.13). Dissection of larger floor and medial wall fractures is technically challenging because of the narrowing of the optical window at the back of the orbit; the need to control adnexal soft tissue due to rupture of the septum; and the proximity to critical muscular and neurovascular structures. In addition, placement of alloplastic or autogenous reconstructive material must ensure that it fits the defect and avoids trapping any orbital contents.
FIG. 6.12 Exposure of a moderate-sized orbital floor fracture. The fracture margin is demonstrated by the blue arrows, and the herniated orbital contents (C) have been mobilized from the maxillary antrum.

FIG. 6.13 Floor and medial wall subperiosteal dissection allowing full exposure of an extensive floor and medial wall (yellow arrows). The medial wall fracture is visualized along the blue arrow. Note that strict adherence to the subperiosteal plane avoids damage to the inferior oblique and the lacrimal sac, which are anterior to the blue arrow and have not been damaged.
Concept of the deep orbit

The term ‘deep orbit’ was defined by Evans and Webb, who recognized the surgical difficulties in dissection towards the back of the orbit and the need to achieve a sound footplate on which to seat reconstructive material. While there are anatomical landmarks and safe distances quoted (Fig. 6.14), these are not consistent and are difficult to interpret intraoperatively. Extensive dissection is technically challenging due to the small optical window available and the proximity to vital structures. There are established measurements derived from studies on intact dried skulls, but these are not totally robust at best, and are difficult to apply in acute injury, where the landmarks themselves may be disrupted. While advances in computer technology have developed navigation systems and additional adjuncts that allow real-time verification of anatomical position, there are some key anatomical features that are of greater significance.

**FIG. 6.14** Anatomical distances in millimetres. Note that these are not robust or consistent, especially the anterior ethmoidal foramen (AE) and the posterior ethmoidal foramen (PE); they are still useful, however. Other abbreviations: ALC, anterior lacrimal crest; FZ, frontozygomatic suture; IOF, infraorbital fissure; ION, infraorbital nerve; OC, optic canal; SOF, superior orbital fissure; SON, supraorbital nerve; WT, Whitnall’s tubercle.
The deep orbit commences at the anterior limit of the inferior orbital fissure, which represents the point at which the orbit begins to narrow. The dissection can then proceed, utilizing the key anatomical structures described below (Fig. 6.15).

![Structured dissection to the orbital process of the palatine bone (the posterior limit of subperiosteal dissection using the intraorbital landmarks identified by Evans). The red arrows indicate the path of dissection. The key structures facilitating this approach are the infraorbital nerve (yellow line) and the interior orbital fissure, the greater wing of sphenoid and the palatine bone itself.](image)

The infraorbital nerve is a robust structure that is positioned in a canal under the orbital floor anteriorly and is subperiosteal posteriorly. In acute injuries, this plane between the orbital periosteum and the nerve is readily developed and may be followed posteriorly to the inferior orbital fissure, marking the posterior wall of the maxillary sinus, where the nerve turns medially to cross the pterygopalatine fossa to enter the skull at the foramen rotundum.

The posterior wall of the maxillary antrum may be used in conjunction with the infraorbital nerve. A periosteal dissector is inserted below the plane of the nerve and angled 45° inferiorly. The posterior wall is identified; the elevator is then moved cranially to feel the posterior floor from the inferior aspect. This is a useful landmark if the inferior orbital fissure is included in the fracture complex.

The infraorbital fissure runs posteromedially from the lateral orbit,
connecting with the infratemporal fossa anteriorly and the pterygopalatine fossa posteriorly. The fissure is bounded laterally by the orbital plate of the greater wing of the sphenoid, medially by the maxilla, and anteriorly and posteriorly by the palatine bone. No critical neurovascular structure passes through the fissure, and any soft tissue can be removed with a bipolar diathermy.

The orbital plate of the greater wing of the sphenoid is a robust bone that is rarely segmented. It constitutes a constant landmark that provides the surgeon with a rigid structure to re-establish the subperiosteal plane, if required. The bone is seen as a three-pointed star, the sphenoid trigone, on the axial CT slice. If this area is fractured, there is often associated optic neuropathy and loss of vision.

The orbital plate of the palatine bone is a constant landmark and is located at the medial aspect of the inferior orbital fissure. The bone is a robust structure, unlike that of the orbital floor, and can be located either by using the infraorbital nerve and dissecting medially, or by using the posterior wall of the maxillary antrum and tracing this landmark superiorly.

**Confluence of the orbit**

The confluence of the orbit is a term described by Evans and Webb to illustrate the convergence of the key anatomical landmarks described above. If these key areas are dissected, the full extent of a floor fracture will be observed, together with surgical landmarks, ensuring the correct seating of any autogenous or alloplastic reconstruction. Reconstruction of this region is required to re-establish Hammer's key area (the confluence of the inferior orbital fissure, the infraorbital nerve, the orbital plate of the palatine bone and the greater wing of the sphenoid). Reconstruction of the inferomedial aspect of the orbit is vital in achieving volume restoration. Dissection from the rim proximally to the inferior orbital fissure is required. With extensive orbital floor disruption the infraorbital nerve can be used to trace back to the fissure; the orbital plate of the palatine bone and the greater wing of the sphenoid can then be located. The orbital plate often withstands damage in orbital floor fractures and provides a secure posterior landmark to place the reconstructive plate. These four areas provide surgeons with safe and reliable landmarks to avoid collateral damage in heavily comminuted orbital fractures.
Reconstruction

Following exposure of the fracture articulations and reduction of the herniated contents, the orbital defects must be reconstructed. While there are numerous reconstructive options, both autogenous and alloplastic in contemporary surgical practice, the material used must be dimensionally stable, well tolerated and tailored to the shape and size of the defect.\(^{20}\) In simple defects, most sheet materials are adequate. For more complex defects, however, a three-dimensional construct is required to replicate the subtle curves and prominences that define globe position; in these instances, alloplastic titanium produces superior results.\(^ {21}\) The intraorbital three-dimensional shape is highly conserved\(^ {22}\) and this has been used to develop preformed orbital plates that reliably mimic the floor and medial wall.\(^ {23}\) A typical case demonstrating the key reconstructive principles is illustrated in Figs 6.16–6.19. A custom-made titanium plate can be fabricated in cases involving more complex-shaped defects.\(^ {24}\)

**FIG. 6.16** A three-dimensional reconstruction showing a titanium plate.
FIG. 6.17  An axial CT scan showing reconstruction of the posteromedial bulge (yellow arrows).

FIG. 6.18  A coronal CT scan showing seating of the titanium reconstruction superomedially. Note the gap between the depressed orbital floor and the graft (red arrows) and the close positioning of the upper limit of the medial wall (yellow arrow).
FIG. 6.19 A sagittal CT showing the sigmoid curvature of the orbital floor (yellow arrows). It is crucial to seat the posterior aspect of the plate on the orbital process of the palatine bone (blue arrow).
Conclusion

Predictable reconstruction of the orbit can be achieved only by strict adherence to the principle of subperiosteal exposure of the orbital defect. Extensive dissection using robust anatomical landmarks ensures safe exposure and reconstruction of defects posterior to the inferior orbital fissure and middle to upper medial wall.

Tips and Anatomical Hazards

Inadequate surgical access: the approach must be tailored to the size and position of the defect. Medial wall defects are technically difficult to expose and reconstruct.

Inadequate dissection: it is essential to achieve a subperiosteal dissection in order to preserve the integrity of the orbital septum.

Inferior orbital fissure: the contents of this anatomical region need to be divided to achieve surgical exposure of the posterior aspect of the orbit in order to place the reconstruction adequately.

Incorrect choice of reconstructive material: both alloplastic and autogenous grafts may be used. Titanium reconstructions replicate the internal contours more satisfactorily but can trap adnexal soft tissues, causing ocular motility problems.

Failure to achieve haemostasis: the orbital contents are prone to compartment-type syndromes from postoperative bleeding. Meticulous haemostasis is thus required.

Treatment planning: the side and position of the defect should be assessed using CT scans in axial, coronal and sagittal views.

Choice of incision: use of a preseptal transconjunctival approach enables lateral extension via a cantholysis, and medial extension via a transcaruncular incision. These are cosmetically robust and provide enough access for non-cranio-orbital fracture patterns.

Dissection: in cases with a ruptured orbital septum, a subperiosteal plane is best achieved on the lateral orbital margin, dissecting on to the robust lateral wall.

Strategies for orbital haemorrhage: postoperative orbital haemorrhage
can be sight-threatening. An anatomical strategy can facilitate control of bleeding (Table 6.2).

**TABLE 6.2**

*Strategies for management of orbital haemorrhage*

<table>
<thead>
<tr>
<th>Site</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perforating orbital vessel: typically the zygomaticofacial branch, which can be identified by blunt dissection</td>
<td>Elective control of the vessel by bipolar diathermy; plugging of the hole in the lateral orbital wall with bone wax</td>
</tr>
<tr>
<td>Branch from infraorbital artery</td>
<td>Packing of the orbit with soaking wet gauze for 1 minute; on removal, careful use of a bipolar diathermy on the infraorbital bundle with a short burn</td>
</tr>
<tr>
<td>Bleeding from antral lining</td>
<td>This can occur from the floor or medial wall. Application for 2 minutes of a ribbon gauze strip soaked in 1 in 1000 adrenaline (epinephrine) will slow the flow. If bleeding is intractable, the bone overlying the fracture is removed and the lining exposed to bipolar diathermy</td>
</tr>
<tr>
<td>Bleeding from fat</td>
<td>In large defects when fat herniates through a ruptured orbital septum, packing for 5 minutes with a saline and tranexamic acid-soaked gauze is helpful</td>
</tr>
<tr>
<td>Bleeding from high medial wall</td>
<td>This normally responds to adrenaline-soaked ribbon gauze and careful bipolar diathermy</td>
</tr>
<tr>
<td>Postoperative bleeding</td>
<td>The lateral cantholysis repair suture can be tied 1 day postoperatively and ‘left long’ immediately postoperatively; this allows for self-decompression</td>
</tr>
</tbody>
</table>
References


21. Ellis E, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus


Single Best Answers

1. Which of the following anatomical components may be involved in an orbital fracture patient suffering diplopia on downward gaze?
   A. Orbital floor or oculomotor nerve (superior branch)
   B. Medial wall or trochlear nerve
   C. Lateral wall or abducens nerve
   D. Orbital roof or oculomotor nerve (superior branch)
   E. Orbital floor or oculomotor nerve (inferior branch)

   **Answer: D.** Diplopia on downward gaze is associated with a ‘blow-in’ fracture from the orbital roof. The frontal bone fragment impinges on superior rectus and superior orbital compartment fat, preventing downward gaze. An orbital floor fracture predisposes to inferior rectus entrapment or injury to the inferior branch of the oculomotor nerve: hence diplopia on upward gaze.

2. Which one of the following is the most common extraocular muscle to be affected by dysmotility after an orbital fracture?
   A. Inferior oblique
   B. Superior rectus
   C. Medial rectus
   D. Inferior rectus
   E. Superior oblique

   **Answer: D.** Inferior rectus is the most commonly affected muscle to suffer motility issues. This occurs via direct or, more commonly, indirect mechanisms. The globe is held in position by a suspensory network between extraocular muscles and suspensory ligaments. The fasciae and septa radiating between bone and globe are interspersed with periocular fat. Globe
motility is inhibited in fractures when the connective tissue arrangement becomes incorporated into the fracture. This is often seen as a ‘teardrop’ deformity on a plain film X-ray or coronal CT image. In more significant fractures, inferior rectus may be involved: this is clinically manifest as inability of the globe to rotate superiorly, leading to diplopia on upward gaze.

3. A patient with an orbital floor fracture complains of anaesthesia of the anterior and lateral cheek. Which of the following nerves have been injured?

A. External nasal branch of the nasociliary nerve and infraorbital nerve
B. Infratrochlear and supratrochlear nerves
C. Infraorbital and supraorbital nerves
D. Zygomaticotemporal and zygomaticofacial nerves
E. Infraorbital and zygomaticofacial nerves

**Answer:** E. Several cutaneous nerves derived from branches of the trigeminal nerve issue from the orbit. The supratrochlear, infratrochlear, supraorbital, lacrimal and external nasal nerves are all branches of the ophthalmic division of the trigeminal nerve. The infratrochlear and external nasal nerves are derived from the nasociliary nerve. The zygomaticotemporal, zygomaticofacial and infraorbital nerves are branches of the maxillary division of the trigeminal nerve. The infraorbital nerve passes successively through the foramen rotundum, pterygopalatine fossa and inferior orbital fissure to enter a short bony canal, from which it emerges through the infraorbital foramen; its cutaneous branches supply the skin of the medial cheek, lateral nose and upper lip. The zygomaticotemporal and zygomaticofacial nerves exit the orbit superolaterally and inferolaterally, passing through foramina to supply the scalp of the anterior half of the temporal fossa above the zygomatic arch.
and the skin over the zygomatic arch and the upper cheek, respectively.
Clinical case

1. A 21-year-old boy has been hit in the eye with a cricket ball. He attends shortly after the injury, complaining of loss of vision and severe pain. He has clinical features of a retrobulbar haemorrhage and needs a lateral canthotomy and cantholysis.

A. Describe the anatomy of the eyelids and lateral canthal tendon.
The upper and lower eyelids are composed of several analogous structures, located in the anterior, middle and posterior lamellae. The anterior lamella contains skin and the preseptal and pretarsal parts of orbicularis oculi. The posterior lamella contains the lid retractors, superior or inferior tarsal, tarsus and palpebral conjunctiva. Some descriptions include the orbital septum, subseptal (or orbital) fat and fibroadipose tissue posterior to the septum in a middle lamella. The lateral canthal region contains the lateral canthal tendon, Lockwood's ligament, the check ligament of lateral rectus and the lateral horn of the levator aponeurosis. The lateral canthal tendon attaches to Whitnall's tubercle, a bony ridge on the medial aspect of the lateral orbital rim, approximately 10 mm below the frontozygomatic suture. The function of the lateral canthal tendon is to draw the eyelid laterally, superiorly and posteriorly.

B. Describe the procedure for lateral canthotomy and cantholysis.
Verbal and written consent; standard preparation with a solution safe to the eye (e.g. Trisept, Savlon); local anaesthesia – 1 mL 2% lidocaine or xilocaine with adrenaline (epinephrine); horizontal scissor cut through the skin and upper and lower lateral canthal tendon intersection down to bone; control of local haemorrhage with bipolar diathermy; vertical scissor cut to release the lateral canthal tendon of the inferior eyelid; confirmation of improved laxity of the lower eyelid.

C. What is the common source of a retrobulbar haemorrhage, its clinical significance and management?
The prevalence of blindness associated with retrobulbar haemorrhage is approximately 0.3. Irreversible blindness occurs when there is a tamponade in the retinal circulation for more than 90 minutes. If the retrobulbar pressure exerted by a haematoma is greater than the patient's diastolic pressure, the retinal vein will obstruct. A generated pressure greater than the patient's systolic blood pressure will compress the retinal artery. The vessel
commonly injured is the anterior ethmoidal artery, as the result of a fracture involving the medial orbital wall.

The classic signs and symptoms of a retrobulbar haemorrhage are ptosis; deteriorating vision in the affected eye; ophthalmoplegia; dilated pupils; ocular pain; proptosis; and loss of the pupillary light reflex. A manometer will also confirm raised intraocular pressures.

Classically, management has been divided into medical and surgical strategies. However, there should be no delay in implementing the surgical measures. The medical measures should be considered as adjuncts and include the early administration of intravenous mannitol (1–2 g/kg 20%), intravenous acetazolamide (500 mg) and intravenous methylprednisolone (1 g). The acute surgical manoeuvre is lateral canthotomy and cantholysis, which allows the anterior displacement of the globe and release of the ‘compartment syndrome’. This can be performed under local anaesthesia placed directly into the canthal region. Clot evacuation and staged canthoplasty should be performed under general anaesthesia.
### Core Procedures

- Anterior approach to upper eyelid ptosis repair
- External dacryocystorhinostomy
- Anterior orbitotomies in four quadrants
- Transcutaneous and transconjunctival orbital decompressions
Clinical anatomy

The orbit is a quadrilateral pyramid, with its base facing forward, laterally and slightly inferiorly. It contains the globe, extraocular muscles, nerves, vessels and some associated structures such as the nasolacrimal apparatus (Ch. 6). The volume of the adult Caucasian orbit is about 30 ml.

Eyelids

From superficial to deep, the eyelid consists of skin, subcutaneous tissues (prominent in the Asian preorbicularis fat pad), striated muscle fibres of orbicularis oculi, areolar connective tissue of the orbital septum, and the tarsal plates; above the tarsal plates, the superior tarsal smooth muscle (Müller's muscle) lies on the upper forniceal conjunctiva (Fig. 7.1).
FIG. 7.1 An oblique sagittal section through the midpoint of the orbit, showing the relationship between the globe, vertical recti and two oblique extraocular muscles. Both oblique muscles pass beneath the respective rectus muscles. The intermuscular sheath is continuous with Tenon’s capsule around the globe, with the retractor fascia for the upper and lower tarsus, and with fine fibrous septa that run throughout the orbital fat. Anteriorly, levator palpebrae superioris becomes a thin fibrous aponeurosis, fibres of which insert on to the anterior face of the upper tarsal plate and into the dermis at the upper eyelid skin crease to raise the upper tarsal plate and prevent downward slippage of the skin and orbicularis oculi during lid opening.

The upper eyelid also receives insertion from levator palpebrae superioris, which acts as a lid retractor, the muscle being inserted through an
aponeurosis that descends into the upper lid posterior to the orbital septum. Some aponeurotic fibres cross the orbital septum and merge with fibres of the pretarsal head of orbicularis oculi and with the anterior surface of the tarsal plate. The lateral horn of levator indents the medial surface of the lacrimal gland, thereby defining a smaller palpebral lobe (not actually in the eyelid, despite being termed ‘palpebral’) that carries the lacrimal ductules into the upper conjunctival fornix, and a larger orbital lobe situated in the lacrimal fossa superolaterally. Levator palpebrae superioris runs parallel to superior rectus, and they share a common fascial sheath that forms part of the larger intermuscular orbital septa of Tenon’s capsule. The common sheath between these two muscles inserts anteriorly around the upper conjunctival fornix, thereby preventing prolapse of the upper fornix on up-gaze; this complication may arise if the sheath is damaged during ptosis repair.¹

The anatomy of the lower eyelid is similar in structure to the upper lid, but with the absence of a levator muscle. The lower lid retractors – part of Tenon’s capsule – consist of a sheet of fibrous tissue that extends from the sheath of inferior rectus, splits to enclose inferior oblique where it blends with the inferior suspensory (Lockwood’s) ligament of the globe, and runs forward to the lower border of the tarsal plate, accompanied by smooth muscle of the inferior tarsal muscle (see Fig. 7.1).¹

The horizontal extremities of the tarsal plates are attached to the orbital margins by the canthal ligaments. The medial canthal ligament comprises the preseptal and pretarsal heads of orbicularis oculi, and each of these has a superficial and deep component. The superficial heads fuse medially to form that part of the medial canthal ligament attached to a point about 2–5 mm anterior to the anterior lacrimal crest (Fig. 7.2), and the deep heads attach to the posterior lacrimal crest. Complete loss of tendinous fixation leads to an unopposed action of orbicularis and canthal dystopia, with rounding of the affected canthus, hiding of the caruncle, a narrow horizontal palpebral aperture (<28 mm in adults) or an increased intercanthal distance.
FIG. 7.2  The anterior limb of the left medial canthal tendon, a condensation of the pretarsal fibres of orbicularis oculi, as seen during lacrimal drainage surgery. The insertion of the tendon (white arrow) is generally a few millimetres anterior to the anterior lacrimal crest (broken line). The latter is a ridge on the maxillary bone from which the inferonasal orbital septum arises along the orbital entrance.

Orbital roof

The roof is composed of the orbital plate of the frontal bone and the lesser wing of the sphenoid. The superior margin has a supraorbital notch or foramen, transmitting similarly named vessels and nerves, and, in 50% of the population, a frontal notch lying more medially. The trochlea is a complex connective tissue sling anchoring the tendinous part of superior oblique to the orbital wall at the troclear fovea, a small depression lying close to the superomedial margin.

Lateral orbital wall and orbital floor

The lateral wall is composed of the greater wing of the sphenoid, the orbital surface of the zygomatic bone, and the zygomatic process of the frontal bone. The superior orbital fissure lies between the greater and lesser wings of the sphenoid. It transmits the oculomotor, trochlear and abducens nerves, the ophthalmic division of the trigeminal nerve, and the superior ophthalmic vein. The fissure is at least 28 mm from the frontozygomatic suture at the rim and, due to this depth and the curvature of the lateral wall, is rarely at risk during orbital surgery.
The floor is composed of the large orbital plate of the maxilla, the zygomatic orbital plate anterolaterally and the orbital process of the palatine bone.

The infraorbital foramen, lying about halfway along the inferior rim, is more or less vertically aligned with the supraorbital notch and is continuous with the infraorbital canal. The anterior (and occasionally middle superior) alveolar nerves join the infraorbital nerve within the canal; if they are damaged – e.g. during blowout fractures of the orbital floor or during orbital decompression – there may be numbness of the upper lip and ipsilateral three front teeth. The entrance to the nasolacrimal canal lies anteromedial on the floor, just behind the lower part of the anterior lacrimal crest; close to the canal, a pit marks the origin of inferior oblique, which is the only extraocular muscle with an origin in the anterior part of the orbit.

**Medial orbital wall**

The medial wall is composed of the frontal process of the maxilla, the lacrimal bone, the lamina papyracea of the ethmoid and the body of the sphenoid.

Anteromedially, the lacrimal sac fossa is demarcated by the anterior and posterior lacrimal crests. The anterior and posterior ethmoidal vessels and nerves are located at similarly named foramina situated at the level of the frontoethmoidal suture. Although their position is variable, a ‘rule of 24–12–6’ has been suggested as a guide when operating along the medial wall, based on the approximate distance (in millimetres) from the anterior lacrimal crest to the anterior ethmoidal foramen, from the anterior to the posterior ethmoidal foramen, and from the posterior ethmoidal foramen to the optic canal, respectively. This means that the optic canal is found approximately 42 mm posterior to the anterior lacrimal crest.

**Nasolacrimal system**

Nasolacrimal drainage begins with the superior and inferior lacrimal puncta, which are portals to the vertical ampullae and then horizontal segments of the respective canaliculi. The individual canaliculi fuse to form the common canaliculus 0–5 mm from the entrance to the lacrimal sac at the ‘common internal opening’; the common canaliculus passes anteroinferiorly through the thick lateral fascia of the lacrimal sac to enter the lumen of the sac about
4 mm below its apical fundus. The lacrimal sac lies in the lacrimal fossa, formed by the lacrimal bone and the frontal process of the maxilla. The lacrimal fascia, mingling with the various heads of the medial canthal tendon, is attached behind to the posterior lacrimal crest of the lacrimal bone and in front to the anterior lacrimal crest of the maxilla. It lies between the sac and the medial palpebral ligament anteriorly and the lacrimal part of orbicularis oculi posteriorly. The angular vein crosses the anterior surface of the medial palpebral ligament about 8 mm medial to the inner canthal commissure.

**Blood supply to the globe and optic nerve**

Two distinct arterial systems are involved in supplying the eye. The central artery of the retina and its branches are distributed to the inner two-thirds of the retina. The outer one-third of the retina, which includes the photoreceptors, is avascular and nourished by tissue fluid derived from the choroidal vessels. The fovea centralis is completely avascular. The optic nerve head is supplied by both the central retinal artery and a circumpapillary anastomosis from the short posterior ciliary arteries.

The anterior segment of the eye, which includes the iris, ciliary body and insertions of the recti muscles, has a generous blood supply due to extensive anastomoses between branches of the anterior ciliary arteries and the anterior uveal network derived from the two long posterior ciliary arteries. For this reason, extensive anterior segment ischaemia is rare, unless the surgeon carries out simultaneous surgery on three or more rectus muscles.

The central retinal artery, a branch of the ophthalmic artery, enters the orbital segment of the optic nerve about halfway along its length and typically from the undersurface. This arrangement confers a dual blood supply on the anterior portion of the nerve, both from the central retinal artery and from perforating vessels arising in the dural sheath. In contrast, the posterior portion of the optic nerve is at greater risk of ischaemic neuropathy following surgery because it has a single dural arterial supply.

Venous drainage from the orbit tends to be a vascular network that is largely directed posteriorly towards the superior and inferior orbital fissures; the four vortex veins from the globe drain into this network. Enlargement of the superior ophthalmic vein and orbital swelling can occur with raised pressure in the ipsilateral cavernous sinus (as with a dural shunt), or where the superior fissure is embarrassed by masses in sphenoidal wings, as with a
sphenoidal wing meningioma.
Surgical approaches

Approach to the upper part of the orbit

The superior two-thirds of the orbit can be accessed through an incision in the upper eyelid skin crease, biased medially to access superonasal masses or laterally to reach superotemporal or lacrimal gland masses.

Incision through the skin crease and underlying orbicularis should be followed by 3–5 mm upward dissection in the plane between the muscle and the orbital septum, thereby avoiding damage to the levator aponeurosis (with resulting ptosis if the damage is not realized or repaired). Once alongside the extraconal preaponeurotic fat pad (and therefore clear of the aponeurosis), the septum can be opened and the lesion sought within orbital fat. The septum is buttonholed centrally and then divided medially and/or laterally, according to the quadrant in which orbital exploration is needed (Fig. 7.3A).
FIG. 7.3  **A**, A grey mass revealed during right anterior orbitotomy via an upper eyelid skin crease incision. Once through skin and orbicularis oculi, exploration (preseptal at this stage) should be directed slightly upwards to reduce the risk of damage to the levator aponeurosis. **B**, The external face of the orbital lobe of the right lacrimal gland (black arrows), accessed by dividing the superotemporal orbital septum at the arcus marginalis and moving the gland inferonasally. The orbital rim is outlined by a broken line. **C**, The preseptal plane of the upper eyelid, as revealed during ptosis surgery. The upper border of the tarsal plate is denoted by the broken line; the horizontal line of the 'white fold' (a connective tissue condensation where
fibres of the levator aponeurosis traverse those of the orbital septum) is indicated by white arrows; the preaponeurotic orbital fat pad (black arrow) lies under the thin, white collagen layer of the orbital septum.

The intraconal space is reached by division of Tenon’s capsule along the appropriate border of the levator/superior rectus complex, and then displacement of these muscles (within their surrounding fascial complex) laterally or medially. For posterior masses within the superotemporal quadrant, the surgeon needs to bypass the lacrimal gland and divide the quite tough fibrous tissues, whereas superomedially it is advisable to bypass the tendon of superior oblique before passing through the relatively tenuous Tenon’s fascia of this quadrant.

Approach to the lacrimal gland

After a lateral third upper-lid skin-crease incision, the preseptal plane is followed to the superolateral orbital rim, the arcus marginalis divided for 2 cm above the lateral canthal tubercle, and the orbital lobe of the gland mobilized inferomedially to expose its external face (Fig. 7.3B). Biopsies from this aspect of the gland are preferred to transconjunctival biopsies of the so-called palpebral lobe because lacrimal gland diseases tend to spare the latter and palpebral lobe biopsy carries an inexcusable risk of dry eye. The absolute exception to this mode of mobilizing the lacrimal gland is when pleomorphic adenoma is suspected; in such cases, the gland should be mobilized by dissection of the extraperiosteal plane.

Anterior approach ptosis surgery

Levator palpebrae superioris is approached through a skin crease incision, and the suborbicularis plane followed upwards for a few millimetres until the extraconal fat pad is evident through the septum. The septum is then divided and, when the preaponeurotic fat is lifted upwards, the whole anterior levator complex may be examined directly for any defects (Fig. 7.3C). Excess skin and/or orbicularis may be excised and the skin crease is reformed by picking up underlying deep tissues linked to the levator action.

Approach to the lateral orbit

The lateral half of the orbit can be accessed through a horizontal canthotomy without disturbing lateral fixation of the upper or lower canthal tendons,
thus providing wide access with minimal bleeding (Fig. 7.4A). This approach is particularly useful for exploration of lateral orbital masses, for biopsy of diffuse masses (it being possible to biopsy muscle, fat and lacrimal gland through this route) and also for removal of large masses from the relatively shallow orbits of children (Fig. 7.4B). Further access can be increased by dividing the fornical conjunctiva for a short distance (the ‘low’ lower-lid swinging flap) or by raising the lateral fixation of one or both limbs of the lateral canthal tendon from the underlying bony tubercle. It is imperative to avoid damage to the lateral rectus sheath or bulbar conjunctiva during lateral canthotomy because this can lead to adhesion syndromes with troublesome postoperative diplopia (Fig. 7.4C).
FIG. 7.4  A, The horizontal canthotomy incision, which usefully maintains lateral fixation of both tarsal insertions, provides ready access for biopsy of intraconal and extraconal tissues (right orbit). B, An optic nerve tumour being excised through a lateral canthotomy incision. The tumour has been dissected from the back of the left globe prior to division of the tumour at the orbital apex. C, A patient referred with restrictive strabismus due to adhesions between the globe and orbital rim. This can occur where the lateral canthotomy incision has disrupted the bulbar conjunctiva or Tenon’s sheath around lateral rectus. D, Wide exposure of an orbital mass through a ‘low’ left lower eyelid swinging flap, with the conjunctival incision based low in the fornix. This flap is particularly valuable for masses in the lower two-thirds of either the extraconal or the intraconal space.

Approach to the lateral orbit and orbital floor

For the ‘low’ lower-lid swinging flap, the lower lid is disconnected with a slightly downward-directed lateral canthotomy and cantholysis, and a medially directed conjunctival incision placed along the lowest point in the inferior fornix. This incision through the conjunctiva and lower lid retractors enters extraconal fat within the inferotemporal quadrant, and thereby gives access to the lower two-thirds of the orbit, with panoramic views of masses
within this quadrant or in the posterior third of either inferior or lateral rectus. The intraconal space is reached by division of fibrous septa between the inferior and lateral recti, these being the most widely spaced muscles and thereby giving widest access to this orbital compartment (Fig. 7.4D). Optic nerve biopsy or resection is readily achieved through this route.

Lateral wall fenestration is easily performed for reducing proptosis, and this can be achieved through lateral extension of either a horizontal canthotomy incision or a lateral third upper-lid skin-crease incision; the latter approach is to be preferred, as it avoids canthal disruption (Fig. 7.5A). After tissues above and below the incision are undermined to expose the periosteum overlying the lateral orbital rim, the superficial leaf of the deep temporal fascia is divided along the posterior edge of the lateral orbital rim. The periosteum is raised forwards over the orbital rim, past the arcus marginalis, and raised widely across the lateral wall of the orbit, dividing vascular bridges as necessary. The lateral orbital wall is fenestrated back into the marrow space of the greater wing of the sphenoid, preferably with preservation of an anterior bar of the lateral rim. The orbital tissues are displaced into the newly created space by opening the periosteum behind the arcus marginalis (which is evident as a periosteal inflexion) and with backward incision towards the orbital apex (Fig. 7.5B). The fat septa in the inferotemporal quadrant are disrupted widely to encourage a marked prolapse of intraconal and extraconal fat, and the external leaf of periosteum is rejoined to the deep temporal fascia.
FIG. 7.5  

A, A laterally extended upper-lid skin-crease incision, as used for lateral wall orbital decompression. Only the outer 1–1.5 cm of the incision runs across lines of relaxed skin tension, and therefore requires deep sutures during closure. 

B, Tissues prolapsed into the right lateral orbital wall fenestration behind the undisturbed bar of the lateral rim. Prolapsed extraconal and intraconal fat lies below the prolapsed orbital lobe of the lacrimal gland (white arrow). 

C, The right orbital rim (black arrows), reached through a ‘high’ lower-eyelid swinging flap. This route avoids orbital fat spillage by keeping the orbital septum intact. The conjunctival incision is placed high in the fornix, 1 mm below the inferior tarsus, and the preseptal plane followed down to the orbital rim. 

D, An orbital mass (oval broken line) revealed through a right lower-eyelid skin-muscle blepharoplasty flap. This approach has the advantage that excess skin and muscle within the eyelid can be addressed during surgical repair. The orbital rim is outlined with black arrows.

**Approaches to the orbital floor**

Experienced orbital surgeons prefer to avoid having fat in their operative field but the ‘low’ lower-lid swinging flap deliberately enters extraconal fat and should therefore be avoided during orbital floor work. Two aesthetically acceptable approaches to the orbital floor are available. The first is lower-
limb lateral cantholysis followed by internal division of tissues just below the lower tarsus, a point at which the conjunctiva, lower lid retractors and septum fuse (the ‘high’ lower-lid swinging flap; Fig. 7.5C). The second approach is through a subciliary blepharoplasty incision whereby the lower-lid skin and orbicularis are divided just below the lash line and the preseptal (post-orbicularis) plane followed inferiorly to the sub-orbicularis oculi fat pad (SOOF), just outside the inferior orbital rim (Fig. 7.5D).

The inferior orbital fissure often comes into view inferolaterally while work is being carried out along the orbital floor; the infraorbital nerve runs anteromedially from this fissure in a canal or groove in the orbital floor. A significant artery passes between the orbit and medial edge of the infraorbital canal about halfway along its length. This artery generally needs cauterizing prior to division when raising periosteum from the orbital floor; cautery quite frequently leads to a temporary paraesthesia of infraorbital nerve territory.

**Retrocaruncular approach to the medial wall**

The retrocaruncular approach to the orbit, passing behind the largely undisturbed lacrimal sac, provides rapid and excellent access to the ethmoidal sinuses, the medial half of the orbital floor, and extraconal structures within the medial part of the orbit. It allows access to the true orbital apex, i.e. back to the anulus of Zinn, and is therefore particularly valuable when inferomedial orbital decompression is required for medically resistant compressive thyroid optic neuropathy.

Gentle conjunctival diathermy is applied to the back edge of the caruncle and continued for 1 cm into the inferior fornix, caution being taken to avoid damage near the inferior canaliculus. The conjunctiva is opened along the incision, and closed scissors are directed posteromedially, along the undersurface of the posterior lacrimal fascia, to reach the posterior lacrimal crest; it is important to emphasize that this part of the dissection is intraperiosteal, within the extraconal fat pad. The ridge of the posterior lacrimal crest is very evident and provides a key landmark to allow a move into the extraperiosteal space, should this be required (Fig. 7.6A).
FIG. 7.6  A, The retrocaruncular approach to the right medial orbital wall and floor. The tough posterior lacrimal sac fascia naturally directs the surgeon towards the posterior lacrimal crest (broken line), behind which is the lamina papyracea of the anterior ethmoidal air cells (white arrow). B, Ethmoidectomy for relief of dysthyroid optic neuropathy. Through the retrocaruncular incision, all air cells can readily be removed back to the anulus of Zinn (broken line), and can be combined with orbital floor excision through the same incision. C, A large left orbital dermoid cyst being excised intact through a retrocaruncular orbitotomy. D, Where a large implant is required to bridge an orbital floor and medial wall fracture, it is best to combine the retrocaruncular incision with a lower fornix incision. The origin of inferior oblique (white arrow) may be divided after placing a 5/0 soluble suture, for later reattachment to fascia near the entrance of the nasolacrimal duct (left side).

A 9–11 mm malleable retractor is placed between the eyelids to protect the lacrimal sac and bipolar diathermy is used to tease the fat away from the anterior part of the lamina papyracea (and orbital floor if necessary). At this stage, the plane of dissection is intraperiosteal; if ethmoidectomy is required or fractures are being repaired, the extraperiosteal plane should be entered immediately behind the posterior lacrimal crest. The upper limit for peeling periosteum from the underlying bone is clearly defined by the anterior and posterior neurovascular bundles, and the lower limit can readily be taken as far laterally as the infraorbital nerve, or even beyond that point if necessary.
The orbital apex may be reached through this route, allowing decompression right back to the anulus of Zinn (Fig. 7.6B), and large medial tumours may be removed through this approach (Fig. 7.6C).

For very wide access to the medial wall and orbital floor, it is possible to divide the origin of inferior oblique (Fig. 7.6D), with later reattachment to fascia near the entrance to the nasolacrimal canal.

**Approaches to nasolacrimal system surgery: external dacryocystorhinostomy**

There are two main approaches to external dacryocystorhinostomy: either through the most common paranasal incision or through a medially extended subciliary incision, the latter allowing simultaneous eyelid reconstruction in patients with acquired or congenital deformity.

In the paranasal approach, a 1 cm skin incision is placed about 8 mm in front of the medial canthal tendon (MCT) and the subcutaneous plane followed backwards to the anterior limb of the MCT. After disinsertion of the anterior limb, the surgeon should extend the periosteal incision inferolaterally along the anterior lacrimal crest and superiorly to the fundus of the lacrimal sac, thereby allowing the lacrimal sac and nasolacrimal duct to be moved laterally from the bony fossa. The thin bone between the sac and nasal cavity is breached near the lacrimomaxillary suture, and a large osteotomy fashioned: this extends superiorly to the skull base, 8–10 mm on to the nasal bones, inferiorly to the nasolacrimal canal, and posteriorly to include the posterior lacrimal crest and some anterior ethmoidal air cells. The medial face of the lacrimal sac is opened widely from its fundus into the nasolacrimal duct and silicone intubation is passed as required. The nasal mucosa is incised to create a larger anterior and a smaller posterior nasal mucosal flap, and these flaps are sutured widely to the corresponding flaps of lacrimal sac mucosa to provide a wide soft tissue anastomosis with primary intention healing.

**Tips and Anatomical Hazards**

**General**
Although the maximal view for an apex lesion (the ‘conoid of view’) is about $50^\circ$ by $30^\circ$, the view is smaller in practice due to orbital fat spilling into the operative field and the presence of many relatively fixed orbital structures. The conoid of view may be increased by moving the incision nearer to the site of the lesion (as this shortens the depth of the cone) or by displacing an orbital wall outwards, the latter being the main rationale for bone-swinging lateral orbitotomy.

Masses along the orbital roof are best reached by downward displacement of the preaponeurotic fat pad, whereas masses involving superior rectus or levator palpebrae superioris are reached by passage in the plane below the fat pad.

In superior-approach surgery, upward dissection along the plane between orbicularis oculi and the septum prior to entering the orbit avoids later ptosis due to direct damage to tissues of the anterior levator complex.

Due to the horizontal portion of the palatine bone, the maxillary roof does not reach the orbital apex, falling short by about 5 mm. Therefore, while removal of the floor helps with orbital decompression, it does not achieve maximal decompression of the apex and is generally insufficient for compressive optic neuropathy.

Retaining the anterior half of the maxilloethmoidal bone strut prevents fat prolapse from blocking maxillary aeration, the latter causing secondary imploding antrum syndrome.

If accessing the medial wall from across the orbital floor, it is important to stay behind the lacrimal sac and the origin of inferior oblique. After division with a ‘low’ lower-lid swinging flap, the lower-lid retractors should be left to heal spontaneously; suturing of the retractors encourages lower-lid retraction and entropion (especially medial).

It is important to remember the 24–12–6 rule for the approximate distances (in millimetres) from the anterior lacrimal crest of the anterior ethmoidal artery, posterior ethmoidal artery and optic canal, respectively.

There may be permanent postoperative visual loss from ischaemic optic neuropathy, especially ischaemia of the posterior half of the intraorbital optic nerve (with its exclusively dural blood supply). The risk is greatest with masses wedged in the orbital apex, particularly
those situated below the optic nerve, because the ophthalmic artery enters the orbit below the optic nerve at the apex.

**Superior Orbit**

Incisions should be placed to avoid damage to the supratrochlear and supraorbital nerves, levator palpebrae superioris and the trochlea; all of these structures are related to the superior orbital margin. The trochlear nerve is the only motor nerve found within the extraconal space of the orbit. It passes lateral to medial across the levator/superior rectus complex, and can be damaged inadvertently when accessing the superonasal quadrant. The secretomotor fibres of the lacrimal nerve enter the posterior pole of the lacrimal gland together with the lacrimal artery. Damage to the posterior pole of the gland may lead to a permanent loss of reflex tearing (but not basal lacrimal secretion) and patients should be warned of this potential complication of surgery in this area. The loss of secretomotor action is of value in the permanent surgical cure of ‘crocodile tears’ after facial nerve palsy.

Upper eyelid ptosis is usually transient, but a complete and permanent ptosis can occur when operating near the superior orbital fissure or when resecting large masses within the apical intraconal space. Periorbital sensory loss may follow ischaemia to ophthalmic branches of the trigeminal nerve or resection of nerves along the orbital roof. In the absence of neural resection, hypoesthesia almost always recovers over a few weeks to months, with occasional symptoms of aberrant reinnervation.

Sensory loss may occur below the level of the skin incision following upper-eyelid skin-crease incision. The upper eyelid is supplied by radial twigs from the ophthalmic branches of the trigeminal nerve; some patients will note that their lashes feel numb after surgery. Transiently reduced pretarsal orbicularis function of the upper eyelid may lead to diminished speed and force of blink following an upper-lid skin-crease incision.

**Lateral Orbit**
Damage to the sheath of lateral rectus should be avoided because of the risk of an adhesion syndrome.

**Inferomedial Orbit**

Damage to the junction of the lacrimal sac and nasolacrimal duct may later cause watering of the eye.

As the medial and inferior recti are the dominant extraocular muscles, particularly in thyroid eye disease, removal of the medial orbital wall and floor carries a higher risk of diplopia when these muscles prolapse into the spaces created. This tendency might be reduced by preservation of the inferomedial bone strut (maxilloethmoidal interface), but preserving the anterior strut also prevents the secondary imploding antrum syndrome that can occur after inferomedial decompression of the orbit.

**Orbital Floor**

Periorbital sensory change along the distribution of the infraorbital nerve may follow manipulation or altered blood flow into the infraorbital canal and/or at the inferior orbital fissure.

Damage to the long ciliary nerve and ciliary ganglion during orbital surgery, most commonly with the ‘low’ lower-lid swinging-flap approach to lesions in the intraconal space, can lead to persistent mydriasis and vermiform pupillary contraction. More importantly, the mydriasis can be associated with a hypoesthetic cornea; the patient should be aware of the risks of neurotrophic cornea.
References

Further Reading

Single Best Answers

1. Which one of the following nerves is NOT transmitted through the superior orbital fissure?
   A. Lacrimal nerve
   B. Frontal nerve
   C. Maxillary nerve
   D. Trochlear nerve
   E. Nasociliary nerve

**Answer:** C. The superior orbital fissure lies between the greater and lesser wings of the sphenoid and transmits the oculomotor, trochlear and abducens nerves, the ophthalmic division of the trigeminal nerve (which gives rise to the lacrimal, frontal and nasociliary nerves), and the superior ophthalmic vein. The maxillary nerve runs through the inferior orbital fissure, which lies between the greater wing of the sphenoid and the maxilla. Other structures transmitted through the inferior orbital fissure include the zygomatic nerve, branches of the pterygopalatine ganglion, and the inferior ophthalmic vein.

2. Which one of the following statements about levator palpebrae superioris is NOT correct?
   A. Its nerve supply is the superior branch of the oculomotor nerve
   B. The aponeurosis of levator palpebrae superioris indents the lacrimal gland into a thin orbital portion and a thick palpebral portion
   C. It originates from the inferior surface of the lesser wing of the sphenoid above and anterior to the optic canal
   D. It shares a common fascial sheath with superior rectus
   E. It can be damaged during anterior approach ptosis surgery or
an upper skin-crease approach for orbital surgery

**Answer: B.** Levator palpebrae superioris is a striated muscle of the upper eyelid that inserts into the lid posterior to the orbital septum via its tendinous aponeurosis. The medial and lateral expansions of the aponeurosis form the horns. The lateral horn indents the lacrimal gland, causing it to wrap around the aponeurosis, and dividing the gland into a thin palpebral portion and a thick orbital portion. It is preferable to take biopsies from the orbital portion, as lacrimal gland diseases tend to spare the palpebral lobe, and palpebral lobe biopsies carry a higher risk of postoperative dry eye.

3. Which one of the following statements about the ophthalmic artery is correct?

A. It gives rise to the infraorbital artery  
B. It gives rise to the central retinal artery, which has branches supplying the outer third of the retina  
C. The anterior portion of the optic nerve is at greater risk of perioperative ischaemic optic neuropathy during orbital surgery than the posterior portion  
D. Simultaneous anterior segment surgery on three or more recti muscles supplied by the ciliary arteries can lead to anterior segment ischaemia  
E. It is a branch of the external carotid artery

**Answer: D.** The ophthalmic artery is a branch of the internal carotid artery. It enters the orbital cavity via the optic canal, giving rise to the central retinal artery, which has branches supplying the inner two-thirds of the retina. The posterior part of the optic nerve has only a single dural arterial supply, whereas the anterior portion of the optic nerve has a dual blood supply (from the central retinal artery and from perforating vessels...
arising in the dural sheath): the posterior optic nerve is therefore at greater risk of ischaemic optic neuropathy. Although the anterior segment of the eye has a generous blood supply due to anastomoses of the branches of the ciliary arteries, simultaneous surgery on three or more recti muscles confers a risk of extensive anterior segment ischaemia and should be avoided if possible. The infraorbital artery arises from the maxillary artery and enters the orbital cavity via the inferior orbital fissure.

4. Which one of the following statements is correct?
   A. The optic canal lies in the lesser wing of the sphenoid
   B. Medial to the supraorbital notch is a small depression for superior rectus
   C. The medial orbital wall is formed by the lacrimal bone and the nasal bone
   D. Superior incisions may damage the trochlea and inferior oblique
   E. The third cranial nerve is the only motor nerve found within the extraconal space of the orbit

**Answer:** A. A small depression medial to the supraorbital notch and lying just behind the orbital margin houses the trochlea (the fibrous pulley for the tendon of superior oblique). Superior oblique is supplied by the trochlear nerve, which is the only motor nerve found within the extraconal space of the orbit. The medial orbital wall is formed by the frontal process of the maxilla, the lacrimal bone, the lamina papyracea of the ethmoid and the body of the sphenoid. Superior incisions should be placed so as to avoid damage to the supratrochlear and supraorbital nerves, levator palpebrae superioris and trochlea, all of which are structures related to the upper margin of the orbit.

5. Which one of the following statements about eyelid anatomy is correct?
A. The upper eyelid retractors consist of levator palpebrae superioris and Horner's ligament
B. Disruption of the parasympathetic innervation to Müller's muscle results in Horner's syndrome
C. There are typically three upper eyelid fat pockets
D. The sensory nerves to the eyelids are derived from the facial nerve
E. The anterior limb of the medial canthal tendon inserts on to the frontal process of the maxillary bone

Answer: E. The upper eyelid retractors consist of levator palpebrae superioris and Müller's muscles. The levator is supplied by the oculomotor nerve. Müller's muscles are supplied by the sympathetic nervous system; sympathetic disruption therefore results in Horner's syndrome, where patients classically present with a partial ptosis, miosis and ipsilateral anhydrosis. There are typically two upper-eyelid fat pockets (one medial, one central) and three lower-eyelid fat pockets (medial, central, lateral). These fat pockets can be used as surgical landmarks to identify the plane behind the septum and anterior to the lid retractors. The ophthalmic and maxillary divisions of the trigeminal nerve provide the main sensory input to the eyelids, while the temporal and zygomatic branches of the facial nerve provide the main motor input. The anterior limb of the medial canthal tendon provides the major support for the medial canthal angle.
Clinical Case

1. A 48-year-old male is referred with a 1-year history of painless visual loss in his left eye. He does not have any other ocular, neurological or systemic symptoms, nor does he have any significant past medical history. On examination of his left eye, visual acuity is 6/12 (20/40) on Snellen chart, with absent colour perception. He has a left moderate relative afferent pupillary defect. The left optic disc shows early diffuse atrophy without any disc swelling. Examination of his right eye is normal. There is no proptosis and eye movements are normal. The patient undergoes MRI scanning (Figs 7.7 and 7.8).

FIG. 7.7 An axial T1-weighted MRI scan of the patient's brain and orbits.
A. Describe the findings on the MRI scans.
Fig. 7.7 is an axial image that shows a well-circumscribed, homogenous, circular, intraconal lesion at the apex of the orbit abutting the optic nerve. The lesion is isointense to muscle and grey matter.
Fig. 7.8 is a sagittal image that shows the lesion located below the optic nerve. The ophthalmic artery passes over the optic nerve (from inferiorly, passing laterally, and then over the nerve heading medially; red circle), just in front of the lesion.

B. Describe the anatomical structures within the superior orbital fissure, inferior orbital fissure and optic canal at the orbital apex.
The superior orbital fissure contains (from lateral to medial) the lacrimal nerve, frontal nerve, trochlear nerve and superior ophthalmic vein. Within the tendinous ring, which bridges the medial end of the superior orbital fissure, are the superior and inferior divisions of the oculomotor nerve, the nasociliary nerve and the abducens nerve.
The inferior orbital fissure contains the inferior ophthalmic vein, infraorbital nerve, zygomatic nerve, branches of the pterygopalatine ganglion, and the infraorbital vein and artery.
The optic canal transmits the ophthalmic artery and optic nerve, where the ophthalmic artery runs inferolaterally to the optic nerve.

C. What ocular risks are associated with this lesion and its removal?
This patient has an inferior intraconal ‘peanut’ tumour under the optic nerve in the posterior orbit. Lesions in this area could lead to vision loss (from compression of the optic nerve or posterior ischaemic optic neuropathy), a permanently dilated pupil and hypoaesthetic cornea (from ciliary ganglion paresis), and motility problems (from interruption of the
intraconal innervation at the orbital apex via the oculomotor, trochlear or abducens nerve).

D. What is the conoid of view and why is this knowledge important when planning surgery?

The conoid of view is the maximal view for an orbital apex lesion, measuring about 50° by 30°. The conoid of view is smaller in practice due to orbital fat spilling into the operative field and the presence of many relatively fixed orbital structures.

E. What surgical approach would you consider for removal of the lesion?

Lateral orbitotomy. This approach would displace the orbital wall outwards, allowing a wider and less oblique view of the area, and thus increasing the conoid of view and subsequent access to the orbital apex.

F. What pitfalls must be considered during surgical resection of the lesion?

The ophthalmic artery enters the orbit below the optic nerve at the apex. Due to its position, the ophthalmic artery is at risk of direct surgical injury when the ‘peanut’ tumour at the apex is approached, or indirect surgical injury with vasospasm, which could result in ischaemic optic neuropathy and permanent postoperative visual loss.

Additionally, heat generated during bipolar diathermy to control intraoperative haemorrhage could lead to increased localized inflammation, subsequently augmenting the risk of vasospasm at the orbital apex and visual loss. Surgeons should take steps to reduce haemorrhage through appropriate preoperative counselling (such as advising patients to stop medications that can increase bleeding risk) and taking perioperative precautions (such as judicious handling of tissues).
Nose and paranasal sinuses

Claire Hopkins

This chapter is divided into two sections, dealing with the nose and paranasal sinuses, respectively.
Nose

Core Procedures

- Endoscopic ligation of the sphenopalatine artery
- Septorhinoplasty

Surface landmarks

The proportions of the nose and face should be carefully evaluated (Fig. 8.1). The angle of rotation and tip projection, height of the dorsum and any existing asymmetry are often key points to be addressed during surgery. A caudal septal deviation may be clearly visible on the basal view of the nose. The thickness of the soft tissue envelope is variable and is assessed; any irregularity resulting from surgery is likely to be visible and palpable in the setting of a thin overlying soft tissue envelope.
Clinical anatomy

Although the terms ‘concha’ and ‘turbinlate’ are often used interchangeably, anatomists rarely use the latter term, while clinicians rarely use the former; in this chapter, turbinate is used to describe the bony structures, together with their overlying soft tissue and mucosa that are encountered during surgery. The middle turbinate acts as a useful landmark during surgery to help with orientation, and therefore is preserved where possible (see Fig. 8.15).
The external nose consists of paired nasal bones, and lateral (upper lateral) and major alar cartilages (lower lateral) (Fig. 8.2). The paired nasal bones vary in thickness and width, which is of significance in planning osteotomies. The superior margin of the lateral cartilage inserts on to the undersurface of the nasal bones. The nasal bones, septum and lateral cartilages form the dorsum. The lateral and major alar cartilages are attached by fibrous tissue, often forming a scroll. The infra-tip break describes the profile of the nose where the inferior tip lobule turns into the columella, and the rhinion is a descriptive term for the point at the lower end of the median suture joining the nasal bones.
The major alar cartilages and caudal cartilaginous septum determine the structure of the tip of the nose; asymmetry is common. The nasal septum is formed posteriorly by the vomer, posterosuperiorly by the perpendicular plate of the ethmoid, and anteriorly by the quadrilateral cartilaginous septum. Attachment to the anterior nasal spine, a projection of the maxillary crest, the maxilla and the vomer is important in providing stability to the nose. Deviations and deformities in these structures are common and may lead to nasal obstruction.

The perpendicular plate of the ethmoid bone (part of the bony nasal septum) articulates with the undersurface of the nasal bones and provides support to the dorsum of the nose. A midline bony spine deep to the fused...
nasal bone projects inwards to articulate with the perpendicular plate of the ethmoid and fuses with the fibrous tissue connecting the lateral nasal cartilages and cartilaginous septum. This is known as the keystone area and provides essential support to the nasal dorsum.

Significant nasal growth occurs from the age of 8–12 years, with a slightly longer duration in males, and is usually completed by the age of 15–16. The cartilaginous nasal septum is an important growth centre in the developing midface. Surgery in the paediatric population should therefore be delayed if possible, and should be conservative when it is performed.

**Surgical approaches and considerations**

**Endoscopic ligation of the sphenopalatine artery**

In the setting of intractable or recurrent epistaxis, arrest of haemorrhage by surgical ligation or interventional radiology is required when conservative management has failed. The majority of bleeds requiring surgery arise posteriorly, from the territory of the sphenopalatine artery; the exceptions are those complicating facial trauma, when the anterior ethmoidal artery is often involved.

The sphenopalatine artery may be approached endoscopically as it leaves the sphenopalatine foramen. The foramen transmits the vessel from the pterygopalatine fossa and is found posterior to the posterior wall of the maxillary sinus, at the posterior part of the middle turbinate. For inexperienced surgeons, a large middle meatal antrostomy, allowing clear identification of the posterior wall of the maxillary sinus, may help correct placement of the mucosal incision. More experienced surgeons may palpate the transition from the softer posterior fontanelle of the maxillary sinus to the hard palatine bone. A wide mucosal incision is made on the lateral nasal wall, posteroinferiorly to the antrostomy, on to the palatine bone. The flap is elevated in a subperiosteal plane, looking for the crista ethmoidalis, which is a reliable landmark for the artery as it emerges through the foramen. The artery may emerge as a single vessel but often has several branches. Each branch must be ligated (usually with bipolar diathermy or with vascular clips) (Fig. 8.3).
FIG. 8.3  Endoscopic left sphenopalatine ligation. A wide maxillary antrostomy has been performed to expose the posterior wall of the maxillary sinus (MAX). A mucosal flap has been elevated in a subperiosteal plane. The sphenopalatine artery has been identified (light blue arrow) emerging from the sphenopalatine foramen behind the crista ethmoidalis (dark blue arrow).

Seotorhinoplasty

When congenital or post-traumatic deformity of the nose results in functional obstruction of the nasal airway, this may be corrected by reshaping the septum (septoplasty) or external nose (rhinoplasty). Surgery may also be requested for aesthetic reasons.

Sceptorshinoplasty may be performed endonasally. An incision is made through the skin of the nasal vestibule and between the major alar and lateral cartilages in the scroll area, in order to access the nasal dorsum, and along the caudal edge of the nasal septum. The soft tissue envelope is elevated off the structures of the dorsum in a plane deep to the superficial musculo-aponeurotic system (SMAS) (Fig. 8.4).
FIG. 8.4 Closed approach septorhinoplasty. The surgical plan is mapped on to the surface; a dorsal hump has been removed and the components (nasal bones, lateral cartilage and septum) are being removed in a mass, via an endonasal incision. Osteotomies will be performed, along with partial resection of the cephalic margin of the major alar cartilages, to increase tip rotation and to reduce volume in the tip.

Better access may be achieved using an open approach, making an incision through the skin of the columella and taking care not to damage the medial crura of the major alar cartilages. This affords excellent exposure of the nasal bones, septum, and lateral and major alar cartilages. The bones may be mobilized and reshaped with osteotomies, and the lateral cartilages may be repositioned to correct deviations of the dorsum. The dorsum may be reduced, removing parts of the nasal bones, lateral cartilages and septum, or augmented by graft material.

The tip may be adjusted by suturing, cutting or augmenting the shape and size of the major alar cartilages (Fig. 8.5).
FIG. 8.5  Open approach septorhinoplasty. An incision has been made in the skin of the columella and the nose has been ‘degloved’ in a plane below the superficial musculo-aponeurotic system. This reveals the paired lateral and major alar cartilages. The attachment of the lateral cartilages to the septum has been divided to allow placement of a ‘spreader graft’ (arrow) that will lateralize the lateral cartilage and thereby increase internal cross-sectional area, improving the nasal airway and reducing obvious asymmetry externally.

Deviations of the septum are corrected by judicious resection of cartilage and bone, maintaining or repairing attachments to the lateral cartilages, medial crura of the major alar cartilages and anterior nasal spine. Excessive resection of cartilage may lead to a ‘saddle nose’, depression or ptosis of the tip (Fig. 8.6).
FIG. 8.6 Open septoplasty. An incision has been made in the skin of the columella and the nose has been 'degloved' in a plane below the superficial musculo-aponeurotic system. The attachment of the medial crura of the major alar cartilages has been released, and the mucosa of the septal cartilage has been fully elevated bilaterally in a subperichondrial plane. This has allowed excellent access to the anterior cartilaginous septum.
Paranasal sinuses

Core Procedures

• Drainage of the paranasal sinuses

Endoscopic sinus surgery is undertaken electively when medical treatment for chronic disease has failed, or in an emergency setting where a complication of acute sinusitis has developed. The development of rigid endoscopes allowing excellent endonasal visualization of anatomical structures has led to open approaches to the sinuses becoming a rare exception, and the majority of cases are performed endoscopically. The challenge for surgeons, therefore, is to translate the two-dimensional images from a CT scan into a three-dimensional model of the sinuses, enabling movement through the sinuses in a stepwise but safe fashion, avoiding damage to surrounding critical structures.

Development

The development of the paranasal sinuses is complex. The ethmoid bone develops from the nasal capsule, a component of the endochondral skull base, as is the sphenoid bone. The maxillae and frontal bones derive from intramembranous ossification. Nasal mucous membrane within the ethmoid bone lines the ethmoidal air cells. During the neonatal period, these become continuous with air spaces developing within the relatively small maxillae. Pneumatization of the ethmoidal air cells occurs at birth. Pneumatization of the maxillary sinuses is noted in 45% of neonates within the first month and universally by 7–12 months. Both sinuses are well developed by the age of 4 years. In contrast, the frontal and sphenoidal sinuses are undeveloped at birth. The sphenoid bone starts to pneumatize at the end of the first year but then enlarges slowly, reaching full size only by the early teenage years. The frontal sinus is the last to develop; it starts as a small outpouching from the infundibulum and slowly pneumatizes the frontal bone from the age of 2 years. Accelerated expansion occurs from the age of 5, and is almost always pneumatized by 14–15 years. Aplasia of the frontal sinuses is relatively
common; unilateral aplasia is sometimes found in adults and bilateral aplasia occasionally occurs. It is important to confirm the presence of normal frontal sinuses on CT imaging preoperatively before attempting to enter them endoscopically (Fig. 8.7).

**FIG. 8.7**  
A, A coronal CT section, demonstrating the agger nasi anterior ethmoidal cell (blue arrow) narrowing the drainage pathway of the left frontal sinus. Removing this cell ('uncapping the egg') will enlarge the drainage pathway. The uncinate process (yellow arrow) can be seen inserting on to the lamella of the middle turbinate. Uncinectomy will expose the natural ostium of the maxillary sinus, which may then be enlarged. B, An absent frontal sinus (asterisk). C, A coronal CT demonstrating variations in the frontal sinus with multiple cells within the frontal recess.

**Clinical anatomy**

The paired sinuses are the maxillary, frontal, ethmoidal (anterior and posterior groups) and sphenoidal sinuses.\(^1,2\) The maxillary, frontal and sphenoidal sinus each typically consists of a single air cell of varying size. In contrast, the ethmoidal sinuses are a complex of multiple air cells or spaces, divided by fine bony partitions. Ethmoidal air cells may also extend into the maxillary, frontal and sphenoid bones, into or displacing the adjacent sinus. They all open into the lateral wall of the nasal cavity, allowing equilibration of air and drainage of mucus; again, the positioning of these sinus ostia is variable (Figs 8.8 and 8.9).
FIG. 8.8 A coronal section through the nasal cavity, viewed from the posterior aspect. The plane of the section on the right side is more anterior. The normal orifice of the maxillary sinus is shown on the right side and an accessory orifice on the left side.
FIG. 8.9  A, B, Sagittal CT scans showing the frontal, ethmoidal and sphenoidal sinuses. The arrows in A indicate the hiatus semilunaris. (A, Courtesy of Professor D Bell.)
The location and interrelationship of each sinus group (Video 8.1) must be carefully studied on the preoperative CT scan. Image guidance may help in translating images taken in the coronal, axial and sagittal planes into a three-dimensional model (Fig. 8.10). Preoperative CT is essential not only to demonstrate the sinus anatomy and to evaluate extent of disease, but also to mitigate against the risk of complications due to anatomical variations. The mnemonic ‘CLOSE’ is a useful reminder of key anatomical landmarks to be identified on preoperative imaging.

**Cribriform niche**

The ethmoidal air cells are dehiscent superiorly, and the roof of the nasal cavity is formed by the fovea ethmoidalis of the frontal bone. Medially, the cribriform plate and a vertical lateral lamella form the olfactory cleft, which houses the olfactory nerves (Fig. 8.11). The depth of the lateral lamella is variable, but the deeper the fossa, the higher the potential risk of damaging
the lateral lamella during endoscopic surgery, resulting in cerebrospinal fluid rhinorrhoea. The risk is also higher when asymmetry exists between sides.

**FIG. 8.11**  
A, A coronal section of the skull. Medial rectus (purple arrow); inferior turbinate (yellow arrow); anterior ethmoidal air cells (green arrow). Abbreviations: C, concha bullosa (pneumatized middle turbinate); M, maxillary sinus; O, olfactory cleft; S, nasal septum. B, An axial CT section through the paranasal sinuses. The basal lamella of the middle turbinate is indicated by the blue arrow, and the optic foramen is indicated by the purple arrow. Abbreviations: E, left posterior ethmoidal air cell (with anterior ethmoid bulla positioned anterior to this); S, right sphenoid. C, A parasagittal CT section demonstrating the frontal sinus (F), anterior ethmoidal cell (AE), posterior ethmoidal cell (PE), sphenoidal cell (S), pituitary fossa (sella turcica; P) and middle turbinate (MT). The blue arrow indicates the basal lamella of the middle turbinate. Other abbreviations: C, cribriform niche; IT, inferior turbinate.

**Lamina papyracea**

The ethmoidal labyrinth is separated from the orbital cavity by the paper-
thin lamina papyracea. This may be dehiscent as a result of previous surgery or trauma, or congenital deformity, allowing orbital contents to prolapse into the paranasal sinuses. If this is not identified preoperatively, the orbit is at risk of penetrating iatrogenic injury.

(Onodi) sphenoethmoidal cell

If a posterior ethmoidal cell pneumatizes posterosuperiorly to the sphenoidal sinus, the optic nerve and carotid artery are closely related to the ethmoidal cell, and the smaller sphenoidal cell is displaced medially and inferiorly. In such cases, attempting to enter the sphenoidal sinus through the ethmoidal cells places the optic nerve at risk (Fig. 8.12).

**FIG. 8.12** A, A coronal CT demonstrating a normal right-sided sphenoidal sinus and a small left-sided sphenoidal sinus (S). The left sphenoethmoidal cell is also shown (asterisk). Pneumatization of the left anterior clinoid process (green arrow) means that the optic nerve (yellow arrow) lies exposed within the sphenoethmoidal cell. The foramen rotundum (blue arrow) and pterygoid (Vidian) canal (red arrow) can also be seen. B, An endoscopic view of a right Onodi cell; the optic nerve is visible in the posterolateral wall of the cell (asterisk). C, A coronal CT demonstrating well-pneumatized sphenoidal sinuses. The foramen rotundum (asterisk) and internal carotid artery (arrow) are also shown. D, A sagittal CT demonstrating the sphenoidal sinus (S), pituitary fossa (arrow) and posterior sphenoethmoidal cell (asterisk).
Sphenoidal sinus
The bone overlying the optic nerve and carotid artery in the lateral wall of the sphenoidal sinus may be dehiscent, increasing the risk of iatrogenic injury.

Ethmoidal arteries
The anterior and posterior ethmoidal arteries are branches of the ophthalmic artery (internal carotid supply) and traverse the roof of the ethmoidal sinuses before entering the intracranial cavity medially. The posterior ethmoidal artery is usually embedded within the bone of the anterior skull base, but the anterior ethmoidal artery may pass through the anterior ethmoidal air cells, particularly when there is extensive pneumatization of the supraorbital recess. This places the artery at risk of injury. Should a ligated artery retract into the orbit, this may result in an orbital haematoma and potential loss of vision.

Surgical approaches and considerations
The ostiomeatal complex (Fig. 8.13) is the focus of basic endoscopic surgical technique, which mainly aims to enlarge the sinus ostia to improve drainage of secretions and access to topical therapy\(^3,4\) (Fig. 8.14).
FIG. 8.13 A coronal CT scan through the ostiomeatal complex. Red arrows indicate the direction of mucociliary flow; the blue area shows the middle meatus; and the asterisks mark the infundibulum.

FIG. 8.14 An endoscopic view of the right ostiomeatal complex. The uncinate and ethmoid bulla are intact; the natural ostium of the maxillary sinus is not visible but the hiatus semilunaris may be identified (red arrow). The approximate limit of the uncinectomy is shown in red. There is a small polyp in the frontal recess (yellow arrow).

The uncinate process conceals the natural ostium of the maxillary sinus;
uncinectomy is usually the first step performed, care being taken to avoid orbital penetration. Retrograde dissection may reduce this risk, particularly when the uncinate is lateralized. If necessary, the natural ostium of the sinus may be enlarged, incorporating any accessory ostia in the posterior fontanelle into the antrostomy. Next, the ethmoid bulla is opened and all partitions separating different cells are carefully removed. The anterior artery may be exposed. The transition from anterior to posterior ethmoidal cells is marked by perforating through the basal lamellae.

If the frontal sinuses are obstructed, particular attention is given to the agger nasi cell of the anterior ethmoidal group. Removal of the roof of the agger cell (‘uncapping the egg’) may be sufficient to expose the frontonasal recess, but if additional cells encroach on the drainage pathway of the frontal sinus, these must also be carefully dissected (Fig. 8.15).

![Completed right basic endoscopic sinus surgery](image)

**FIG. 8.15** Completed right basic endoscopic sinus surgery. An uncinectomy has been performed (black line demonstrates line of excision), exposing the natural ostium of the maxillary sinus (star), which has been enlarged. The anterior ethmoidal cells have been opened but the basal lamella (BL) is intact. The agger nasi cell has been uncapped, allowing unobstructed access to the frontal sinus (yellow arrow). The right anterior ethmoidal artery is exposed but preserved (blue arrow). Other abbreviations: MT, middle turbinate.

The sphenoidal sinus is most safely entered via its natural ostium. Moving posteriorly through the nasal cavity, along the septum to the sphenethmoidal recess, it is often possible to see or palpate the natural ostium, which is closely associated to the attachment of the superior
turbinate. It may be enlarged, taking care posteriorly to avoid damage to the septal branch of the sphenopalatine artery.

**Tips and Anatomical Hazards**

Care must be taken when working along the skull base with an angled scope, as it is easy to become disorientated and cause an injury. Inexperienced surgeons should work with a 0° endoscope where possible, but a 30° scope is very useful when looking for the natural ostium of the maxillary sinus and when working in the frontal recess. The anterior skull base slopes downwards posteriorly, so that it is better to work from back to front along the skull base, moving away from danger.

Landmarks of the floor of the orbit, the choana and the face of the sphenoid are usually preserved, even with extensive disease, and can allow identification of the skull base in the sphenoid, thereby facilitating back-to-front dissection.

Preservation of the middle turbinate is a useful landmark for any surgeon who may have to follow you.

Disease or previous surgery may destroy or distort landmarks such as the middle turbinate, ethmoid bulla and basal lamella. If the anterior ethmoidal artery is damaged, it may retract into the orbit, leading to an orbital haematoma and loss of vision.

Septations in the sphenoidal sinus often insert into the carotid artery and should not be avulsed.

Image guidance must be used only to augment sound knowledge of the anatomy; it should not be followed blindly.
References


Further Reading


Standring S. *Gray’s Anatomy*. forty-first ed. Elsevier: London; 2016 [Ch. 33].
Single Best Answers

1. Which one of the following sinuses is present at birth?
   A. Frontal
   B. Ethmoidal
   C. Sphenoidal
   D. Uncinate

   **Answer: B.** Only the ethmoidal and maxillary sinuses are present at birth. The sphenoidal sinus starts to pneumatize at the end of the first year, and the frontal sinus slowly appears after 2 years of age. The uncinate is a process rather than a sinus.

2. Which one of the following statements about the anterior ethmoidal artery is correct?
   A. It crosses the roof of the ethmoids from lateral to medial
   B. It crosses the roof of the ethmoids from medial to lateral
   C. It is situated posterior to the posterior ethmoidal artery
   D. It supplies the posterior portion of the septum

   **Answer: A.** The anterior ethmoidal artery runs from posterolateral to anteromedial, traversing the roof of the ethmoids before entering the intracranial cavity medially. That is why inadvertent damage to this artery may result in retraction of the damaged stump into the orbit, where it may continue to bleed, resulting in an orbital haematoma. If this is noted intraoperatively or immediately postoperatively, then lateral canthotomy/inferior cantholysis, followed by a more definitive endoscopic/external orbital decompression as an emergency, may be necessary to avoid pressure on the optic nerve and permanent visual loss. The posterior ethmoidal artery supplying the posterior septum is situated posterior to the anterior ethmoidal:
hence its name.

3. Where is the natural ostium of the maxillary sinus usually located?
   A. Anterior to the uncinate process
   B. Below the inferior turbinate
   C. Anterior to any accessory ostia
   D. Within the bulla ethmoidalis

   **Answer: C.** The uncinate process often conceals the natural ostium of the maxillary sinus, which lies behind. The inferior turbinate is below the natural maxillary ostium. Accessory ostia may be present in the posterior fontanelle (the mucosal covering of the medial wall of the maxillary sinus) behind the natural ostium, and should be connected to the natural ostia during sinus surgery to avoid any recirculation of mucus.

4. Which one of the following is the name of the anatomical landmark between the anterior and posterior ethmoids?
   A. Bulla ethmoidalis
   B. Agger nasi
   C. Superior turbinate
   D. Ground/basal lamellae of the middle turbinate

   **Answer: D.** If the ground/basal lamellae are perforated low and medially to access the posterior ethmoids through the anterior ethmoids during functional endoscopic sinus surgery, there is a lower chance of iatrogenic injury to the skull base or orbit. The agger nasi and bulla ethmoidalis are classified as anterior ethmoidal cells.

5. Which one of the following is a reliable landmark for the emergence of the sphenopalatine artery through its foramen?
A. Crista ethmoidalis  
B. Crista galli  
C. Sphenopalatine ligament  
D. Vidian nerve  

**Answer:** A. The sphenopalatine artery usually emerges from just behind a prominence of bone on the posterolateral wall of the nasal cavity called the crista ethmoidalis. Sometimes it is necessary to remove this prominence cautiously to gain full access to the artery. The crista galli is located intracranially. The sphenopalatine ligament does not exist, and although the Vidian nerve is in the vicinity of the sphenopalatine artery, it cannot be used as a reliable landmark for locating the artery.  

6. Which one of the following structures is formed from the overlap of the lateral and major alar cartilages?  
A. Keystone area  
B. Scroll area  
C. Infra-tip break  
D. Rhinion  

**Answer:** B. The area of overlapping fibrous tissue between the lateral and major alar cartilages is called the ‘scroll area’; this is one of the nasal tip support mechanisms. The ‘keystone area’ is where the quadrangular cartilage attaches superiorly to the perpendicular plate of the ethmoid and is important for structural support of the septum. The infra-tip break describes the profile of the nose where the inferior tip lobule turns into the columella, and the rhinion is a descriptive term for the point at the lower end of the median suture joining the nasal bones.
Clinical Cases

1. A 39-year-old patient presents with long-standing symptoms of maxillary sinusitis, resistant to medical therapy, with facial pain and nasal discharge.

A. Describe the shape and relations of the maxillary sinus.
   The maxillary sinus is roughly pyramidal. Its base is medial and forms much of the lateral wall of the nose; its floor is related to the alveolar process of the maxilla and the dental roots; its roof is the floor of the orbit and contains the infraorbital canal; the lateral wall is related to the zygoma.

B. Describe the drainage of the maxillary sinus and how this may be improved surgically.
   The natural ostium is found superiorly on the medial wall of the sinus, and leads into the ethmoidal infundibulum and then, via the hiatus semilunaris, into the middle meatus. The superior edge of the uncinate process is the floor of the hiatus semilunaris; uncinectomy therefore enlarges the drainage pathway and exposes the natural ostium.

C. On the preoperative CT scan (Fig. 8.16A), what important anatomical features can be seen?
The nasal septum appears straight, and the middle and inferior turbinates are visible. There is pneumatization of the supraorbital recess on each side, and the anterior ethmoidal arteries are exposed in the anterior ethmoidal cells (the blue arrow on Fig. 8.16B shows the path of the anterior ethmoidal artery leaving the orbit and crossing the ethmoidal cell). The lamina papyracea is intact on both sides, and the close proximity of medial rectus to the lamina can be appreciated. There is no asymmetry of the skull base and the olfactory fossa is shallow. The external nose, consisting of paired nasal bones, lateral and major alar cartilages.

2. An elderly patient presents to the accident and emergency department with torrential epistaxis.
A. Describe the blood supply to the nose.

The nose receives its blood supply from branches of both the internal carotid (ophthalmic artery) and external carotid arteries (maxillary and facial arteries). The ophthalmic artery gives off anterior and posterior ethmoidal branches, which supply the ethmoidal and frontal sinuses and superior aspects of the septum.

The sphenopalatine artery, the terminal branch of the maxillary artery, supplies the turbinates, meatuses and posterior septum. Branches of the greater palatine and superior, anterior and posterior alveolar arteries supply the floor of the nose and the maxillary sinus, and the superior labial branch of the facial artery supplies the anterior nasal cavity and septum.

B. If bleeding fails to settle, how might the feeding vessels be approached surgically?

Intractable haemorrhage usually arises from the sphenopalatine artery. This can be accessed endoscopically, and identified as it leaves the sphenopalatine foramen. It may have multiple branches. If the vessel cannot be controlled in the nose and bleeding is life-threatening, the sphenopalatine artery is ultimately a branch of the external carotid, which may be ligated in the neck, above the facial artery or common lingual–facial trunk.

C. Why is damage to the anterior ethmoidal artery of particular concern?

The anterior ethmoidal artery arises from the internal carotid circulation, and therefore cannot be controlled in the neck or treated with embolization. If the ligated anterior ethmoidal artery retracts into the eye, it may continue to bleed, leading to a haematoma contained behind the orbital septum, which will lead to increasing pressure on the optic nerve and risk of blindness.

3. A 27-year-old man reports right-sided nasal obstruction following a rugby injury some months previously.

A. Describe what structures make up the external nose and septum.

The septum is made of the cartilaginous quadrangular cartilage anteriorly and the perpendicular plate of the ethmoid bone and the vomer posteriorly (Fig. 8.17).
B. Describe what can be seen on the photograph and the anatomical basis of correction.

There is asymmetry of the basal view of the nose. The columella is displaced, and the caudal end of the septum can be seen in the right nostril. The caudal septum normally sits in a tongue-and-groove fashion between the medial crura, and is secured by its attachment to the anterior nasal spine.

The anterior septum has become displaced; a septoplasty may be performed to correct this. The septum must be mobilized by elevating the overlying mucosa. It must be straightened and reattached to the spine, and secured in a pocket between the medial crura of the major alar cartilage.

C. How might vasoconstrictive agents injected into the septum and inferior turbinates during surgery cause blindness?

There is a rich submucosal venous plexus in the septum and turbinates. The veins of the anterior septum drain via anterior ethmoidal veins to the ophthalmic veins; there are numerous arteriovenous anastomoses, and vasoconstrictors may therefore access the intracranial and ophthalmic arterial circulation.
Infratemporal fossa and pterygopalatine fossa

Madan G Ethunandan

**Core Procedures**

**Pathology in the Infratemporal and Pterygopalatine Fossae**

- Biopsy
- Partial/selective excision
- Total clearance/compartment resection
- Route for more proximal surgery

**Open Approaches**

- Lateral
- Anterior
- Inferior
- Superior
- Combinations

**Endoscopic Approaches**

- Endonasal
- Transmaxillary
- Transpterygoid
- Combinations

The space behind the maxilla (retro-maxilla) and beneath the skull is
principally occupied by the infratemporal fossa (ITF) and pterygopalatine fossa (PPF). These are well-defined spaces that contain masticatory muscles and neurovascular structures, including two parasympathetic ganglia.\textsuperscript{1–3} Their relative inaccessibility, contents and proximity to vital structures have made clinicians historically wary of dealing with pathologies in this area. However, improvements in imaging and advances in surgical techniques have rendered the ITF and PPF more accessible. The area is of interest to clinicians in several specialties, who access it through a variety of routes and who all need an in-depth knowledge of the relevant three-dimensional anatomy in order to undertake procedures safely and to avoid complications.
Infratemporal fossa

Clinical anatomy

Bones and joints

The ITF lies deep to the ramus of the mandible, behind the maxilla and below the middle cranial fossa. There is a lack of consensus in the surgical literature about the boundaries and content of the ITF\textsuperscript{1–3}; the details in this chapter refer to the ‘conventional’ ITF. It has a roof and anterior, lateral and medial walls, and is open to the neck, with no defined floor. It communicates with the temporal fossa superiorly deep to the zygomatic arch, the orbit anteriorly through the inferior orbital fissure, and the pterygopalatine fossa through the pterygomaxillary fissure.\textsuperscript{1–3} Although it is termed the ‘infratemporal fossa’, more than 80% of the roof is formed by the infratemporal surface of the greater wing of sphenoid. The remainder of the roof is formed by the infratemporal surface of the temporal bone, extending up to the articular eminence of the temporomandibular joint and the spine of the sphenoid. The roof contains the foramen ovale, foramen spinosum and sphenoid emissary foramen (of Vesalius). The average depth from the zygomatic root to the foramina ovale and spinosum is 26.2 mm (range 22–29 mm) and 31.7 mm (range 25–36 mm), respectively. The ITF communicates with the middle cranial fossa through these foramina (Fig. 9.1).
The anterior wall is formed by the posterior wall of the maxilla, extending inferiorly down to the maxillary tuberosity and superiorly up to the inferior orbital fissure. It communicates with the orbit through the inferior orbital fissure. The medial wall is formed anteriorly by the lateral pterygoid plate (of the pterygoid process of the sphenoid bone) and posteromedially by tensor veli palatini and levator veli palatini, and the pharyngobasilar fascia. 

The inferior portion of the pterygoid plates unites with the maxilla in the region of the maxillary tuberosity and pyramidal process of the palatine bone. The space above this junction, between the pterygoid plates and maxilla, forms the pterygomaxillary fissure, through which the ITF communicates with the PPF (see Fig. 9.1; Video 9.1). The size of the fissure and the extent of the junction vary and are of relevance for pterygomaxillary dysjunction during maxillary surgery and pterygopalatine (sphenopalatine) ganglion nerve blocks via a lateral route.

The inferior orbital fissure and the pterygomaxillary fissure meet each other at right angles and the PPF communicates with the orbital apex through the medial part of the inferior orbital fissure. The posterior margin of the lateral pterygoid plate is in line with the foramen ovale: the curvilinear line can be followed posterolaterally across the foramen spinosum up to the styloid process. A plane exists between the styloid process and the pterygoid hamulus (at the inferior tip of the medial pterygoid plate), which forms the
basis of the stylohamular dissection described by Friedman.\textsuperscript{1,4} This plane can be readily identified by palpating the tip of the styloid process and gentle finger dissection in an anterior and medial direction to the tip of the pterygoid plate, and is a surgical aid to the medial boundary of the ITF. The internal carotid artery (ICA) lies deep to this plane and is protected when using this plane as a guide during ITF clearance via a lateral approach (Fig. 9.2).

![Orientation lines, base of the skull. Key: a, lateral pterygoid plate; b, foramen ovale; c, foramen spinosum; d, spine of sphenoid; e, carotid canal; f, styloid process; g, foramen lacerum; h, medial pterygoid plate; i, base of pterygoid hamulus; 1, lateral line; 2, pharyngotympanic (Eustachian) tube; 3, position of internal carotid artery; 4, stylohamular dissection plane.](image)

The lateral wall is formed by the medial surface of the ramus of the mandible and the coronoid process. It communicates with the temporal fossa superiorly, deep to the zygomatic arch (Fig. 9.3A).
Pharyngotympanic tube

The pharyngotympanic tube is divided for descriptive purposes into three portions: cartilaginous, junctional and bony. The cartilaginous segment passes posterolaterally from the torus tubarius in the nasopharynx, deep to the posterior edge of the medial pterygoid plate, crosses the anterior pharyngobasilar fascia in the muscular lacunae between the superior pharyngeal constrictor and the skull base, and passes through the posteromedial PPS before attaching to the bony part of the tube at the
junction of the squamous and petrous parts of the temporal bone. Posteromedially, the tube is related to the foramen lacerum and levator veli palatini, which is attached to it. It is a very useful landmark for the adjacent extracranial (parapharyngeal) portion of the ICA and the posteromedial limit of dissection along the roof of the ITF (see Figs 9.2, 9.3D).³,⁵

**Muscles**

The lateral pterygoid muscle runs horizontally along the roof and provides a key to understanding the relationships of structures within the ITF.¹⁻³ The upper head arises from the infratemporal surface and crest of the greater wing of the sphenoid and the lower head from the lateral surface of the lateral pterygoid plate. Both heads pass posterolaterally and are inserted into the pterygoid fovea in the condyle of the mandible and the articular disc and fibrous capsule of the temporomandibular joint (Fig. 9.3B, Videos 9.1 and 9.2).

The medial pterygoid muscle arises as two heads: the smaller superficial head arises from the maxillary tuberosity and pyramidal process of the palatine bone, and runs ‘superficial’ to the lower head of the lateral pterygoid muscle. The larger deep head arises from the medial surface of the lateral pterygoid plate and the pterygoid fossa, and runs ‘deep’ to the lateral pterygoid muscle (Fig. 9.3C). The muscle fibres run inferiorly and posteriorly (mimicking masseter) and are inserted on to the roughened area at the inferior and posterior aspect of the medial surface of the angle of the mandible; the muscle attachment may extend as far as the mandibular foramen. Medial pterygoid and masseter form the ‘pterygomasseteric’ sling. The sphenomandibular ligament extends between the spine of the sphenoid and the lingula of the mandibular foramen; together with the pterygomasseteric sling, it controls the arch of rotation of the mandible. The pterygomasseteric sling, the sphenomandibular ligament and the stylomandibular ligament (extending from the tip of the styloid process to the angle of the mandible) have to be detached from the mandible if additional access is required to the ITF via a mandibular swing procedure (Fig. 9.4 and Video 9.3).
Tensor veli palatini is a triangular muscle which arises from the membranous portion of the pharyngotympanic tube (auditory or Eustachian tube), the scaphoid fossa and the spine of the sphenoid. It lies lateral to the medial pterygoid plate, levator veli palatini and the pharyngotympanic tube, and deep to the upper end of medial pterygoid (see Fig. 9.3D). It becomes tendinous as it descends, hooks around the pterygoid hamulus at an acute angle and is inserted into the palatine aponeurosis.¹⁻³

Levator veli palatini is a cylindrical muscle on the lateral aspect of the posterior nasal choanae. It arises from the inferior surface of the petrous temporal bone, anterior to the carotid canal and the inferior aspect of the cartilaginous portion of the pharyngotympanic tube and the adjacent carotid sheath. It lies posteromedial to tensor veli palatini and runs beneath the pharyngotympanic tube in an oblique, inferomedial and anterior direction, passing above the concave upper margin of the superior constrictor, to blend into the palatine aponeurosis with its contralateral fellow.¹⁻³

**Vascular supply and drainage**

The maxillary artery, the larger terminal branch of the external carotid artery,
enters the ITF between the neck of the mandibular condyle and the sphenomandibular ligament.\textsuperscript{1-3} It runs a variable course in relationship to the lateral pterygoid muscle (it may be superficial or deep) and enters the PPF through the pterygomaxillary fissure, terminating as the sphenoplatine and descending (greater) palatine vessels (see Fig. 9.3B). The proximal part of the maxillary artery can be very close or adherent to the medial temporomandibular joint capsule and can be injured during surgery. When ITF clearance surgery is contemplated, early identification and control of the maxillary artery as it passes close to the mandibular condyle can significantly reduce troublesome bleeding and improve visibility (see Figs 9.3B, 9.4; Video 9.1).\textsuperscript{6}

The maxillary artery is traditionally divided into three segments: namely, mandibular, pterygoid and pterygopalatine.\textsuperscript{1–3} The mandibular segment runs along the inferior aspect of the lower head of the lateral pterygoid muscle and gives rise to deep auricular, anterior tympanic, middle meningeal, accessory meningeal and inferior alveolar arteries. The inferior alveolar artery descends from the maxillary artery and, along with the inferior alveolar nerve, forms a neurovascular bundle which enters the mandibular foramen (see Fig. 9.3B, C).

The middle meningeal artery ascends between the lateral pterygoid muscle laterally and tensor veli palatini medially, to enter the cranial cavity through the foramen spinosum (see Fig. 9.3B). It arises at an average distance of 12.2 mm (range 1–17 mm) from the origin of the maxillary artery.

In a lateral/infratemporal fossa approach to the skull base, the middle meningeal artery is identified prior to the main trunk of the mandibular nerve.

The accessory meningeal artery can arise either from the maxillary artery or as a branch of the middle meningeal artery. This variability often reflects the relationship of the maxillary artery to the lateral pterygoid muscle: the accessory meningeal artery arises from the maxillary artery if the maxillary artery lies deep to the lateral pterygoid, and from the middle meningeal artery if the maxillary artery lies superficial to the lateral pterygoid. The accessory meningeal artery enters the skull through either the foramen ovale or the sphenoid emissary foramen (which lies 2–3 mm medial to the foramen ovale and also transmits an emissary vein communicating between the pterygoid plexus and the cavernous sinus).\textsuperscript{3}

The pterygoid segment of the maxillary artery runs deep to the ramus of the mandible and the attachment of temporalis, and either deep or
superficial to lateral pterygoid. It gives off anterior and posterior deep temporal, pterygoid, masseteric and buccal branches. These vessels often display extensive cross-anastomoses and variations in branching patterns.

The pterygopalatine segment of the maxillary artery runs between the two heads of the lateral pterygoid muscle and enters the PPF through the pterygomaxillary fissure (Fig. 9.5). It gives off infraorbital, posterior superior alveolar, recurrent meningeal, Vidian, descending palatine and sphenopalatine branches. The posterior superior alveolar artery descends along the posterior surface of the maxilla before piercing its posterolateral wall and may bleed following maxillary tuberosity fractures.
The sphenopalatine artery, the largest of the terminal branches of the maxillary artery, enters the nasal cavity through the sphenopalatine foramen and is a major source of blood supply to the nose. Ligation of the artery may be needed to control refractory epistaxis: it can be accessed endoscopically at the sphenopalatine foramen at the posterior end of the middle turbinate (concha). The terminal branches of the sphenopalatine artery form the basis of the axial pattern nasoseptal (Hadad-Bassagasteguy flap) and middle turbinate flaps, commonly used in endoscopic skull base surgery.

As the descending palatine artery descends within the greater palatine canal it gives off lesser palatine branches which supply the soft palate. It exits the greater palatine foramen as the greater palatine artery, which supplies the hard palate. The descending palatine artery can be transected in
its canal at the posterior end of the bone cuts along the lateral wall of the nose during a Le Fort osteotomy. The greater palatine arteries form the basis of axial pattern, posteriorly based palatal mucosal flaps; the entire palatal mucosa can often be pedicled on a single greater palatine artery.

The pterygoid venous plexus is a network of venous channels intimately related to the lateral pterygoid muscle. It occupies the space between the roof of the ITF and the lateral pterygoid, and surrounds the muscle. Contraction of the lateral pterygoids acts as a venous pump that aids venous drainage. The pterygoid venous plexus communicates with the cavernous sinus through emissary veins traversing the foramina ovale and lacerum and the foramen of Vesalius; with the orbit through the ophthalmic veins and venous channels along the inferior orbital fissure; and with the facial veins through the deep facial veins. Bleeding from the plexus can be troublesome and not easily controlled with diathermy. Packing with a haemostatic gauze can be useful. When ITF clearance is planned, ‘compartment resection’ should be considered, including the whole of lateral pterygoid, by sectioning it at its attachment to the mandibular condyle and the pterygoid plates and dissecting along the roof of the ITF, so as to encompass the whole muscle (Video 9.4)."
motor supply to lateral pterygoid, masseter and temporalis and sensory supply to the buccal mucosa through the long buccal nerve. The deep temporal nerves enter the deep surface of temporalis, emerging from the upper border of lateral pterygoid. The nerve to masseter passes laterally along lateral pterygoid and through the sigmoid notch to enter the deep surface of masseter. The buccal nerve, which is the only sensory branch of the anterior division, runs anterolaterally, between the two heads of lateral pterygoid, and inferiorly to emerge deep to the anterior border of the ramus and masseter. It runs forward on the surface of buccinator to supply sensation to the buccal mucosa. Its location along the anterior border of the ramus is utilized for obtaining local anaesthesia along its distribution and it can be injured during incisions that traverse this area.

The posterior division is mainly sensory and gives rise to the lingual, inferior alveolar and auriculotemporal nerves. The nerve to mylohyoid is its only motor branch; it arises from the inferior alveolar nerve, just before it enters the mandibular foramen, and supplies mylohyoid and the anterior belly of digastric. The auriculotemporal nerve arises from two roots which encircle the middle meningeal artery; it runs laterally, posterior to the mandibular, and superiorly, closely related to the superficial temporal vessels.

The average length of the posterior division before it divides into the lingual and inferior alveolar branches is 13.5 mm (range 6–32 mm). The lingual nerve descends between lateral pterygoid and tensor veli palatini, emerging below the inferior border of lateral pterygoid. The chorda tympani, a branch of the facial nerve, emerges from the petrotympanic fissure, deep to the auriculotemporal and inferior alveolar nerves; it joins the lingual nerve about 8.4 mm (range 0–20 mm) from the point at which the lingual leaves the posterior division. The lingual nerve passes downward and anteriorly between the mandibular ramus and medial pterygoid, and is located anterior to the inferior alveolar nerve in the pterygomandibular space (inferior ITF). It is closely related to the alveolar process of the mandible in the third molar region, before entering the floor of the mouth and going on to supply the mucosa of the tongue and floor of mouth (Fig. 9.6; see Figs 9.3, 9.4).
The inferior alveolar nerve, the largest branch of the posterior division, emerges from the lower border of the lateral pterygoid; it runs inferiorly and laterally between the sphenomandibular ligament and ramus of the mandible to enter the mandibular foramen. It lies at a distance of 17.4 mm (range 15–20 mm) from the sigmoid notch and the average length before it enters the mandibular foramen is 31.1 mm (range 13–44 mm). The lingual and inferior alveolar nerves are excellent road maps for navigating the ITF. The lingual nerve at its position close to the mandibular third molar, along the inferior aspect of the anterior border of the mandibular ramus, and the inferior alveolar nerve, just before it enters the mandibular foramen, should both be identified. Dissection along the lateral aspect of the nerves, transecting the lateral pterygoid muscle, leads to the foramen ovale and to the adjacent lateral pterygoid plate in the roof of the ITF. Early removal of the coronoid process of the mandible (coronoidectomy) will significantly improve access to the nerves and ease dissection of the ITF. This manoeuvre, along with blunt dissection along the stylohamular plane from the pterygoid hamulus to the tip of the styloid, allows safe dissection of the contents of the ITF, avoiding injury to the adjacent internal carotid artery (see Figs 9.4, 9.6;
The otic ganglion is located immediately below the foramen ovale, medial to the mandibular nerve and lateral to tensor veli palatini. It supplies secretomotor, parasympathetic fibres to the parotid gland. Preganglionic fibres are derived from the lesser petrosal nerve (a branch of the glossopharyngeal nerve that arises from the tympanic plexus in the middle ear). Postganglionic fibres, together with the sensory fibres from the auriculotemporal nerve and postganglionic sympathetic fibres from the plexus on the middle meningeal artery, reach the parotid gland via the auriculotemporal nerve.

The posterior boundary of the ITF is related laterally to the deep lobe of the parotid gland and medially to the styloid apparatus and its muscle attachments. The deep lobe of the parotid gland occupies varying amounts of the space between the mastoid and styloid processes, the stylomandibular and sphenomandibular ligaments, and the posteromedial mandible and medial pterygoid. The inelastic ligaments have to be detached to enable safe removal of deep-lobe parotid tumours without spillage, which in some cases can extend medially to the parapharyngeal space. Though the vast majority of these tumours can be removed with a transcervical approach, additional access in the form of a mandibular osteotomy may be required on occasion (Video 9.5). A similar approach can also be used to access high cervical internal carotid lesions at the skull base, deep to the styloid process.
Pterygopalatine fossa

Clinical anatomy

The pterygopalatine fossa (PPF) is an inverted pyramidal space with its base superiorly and apex inferiorly. It is located below the apex of the orbit, between the ITF laterally and nasopharynx medially. The body of the sphenoid forms the roof; the posterior boundary is the root of the pterygoid process and adjoining anterior surface of the greater wing of the sphenoid; and the anterior boundary is the superomedia tried part of the infratemporal surface (posterior wall) of the maxilla (see Fig. 9.5).\textsuperscript{1–3,8} The perpendicular plate of the palatine bone, with its orbital and sphenoidal processes, forms the medial boundary, and the pterygomaxillary fissure is the lateral boundary. There are two openings in the posterior wall of the pterygopalatine fossa: the foramen rotundum, which transmits the maxillary nerve, and the pterygoid canal (Vidian canal), which transmits the nerve of the pterygoid canal (Vidian nerve) and the Vidian vessels. The space between the body of the sphenoid and the superior perpendicular plate of the palatine bone forms the sphenopalatine foramen. The PPF communicates with the nasopharynx medially through the sphenopalatine foramen and laterally with the ITF through the pterygomaxillary fissure. It also communicates with the orbit via the medial end of the inferior orbital fissure, with the middle cranial fossa through the foramen rotundum and Vidian canal, and with the oral cavity via the greater palatine canal (see Fig. 9.6).

The PPF contains the pterygopalatine ganglion, maxillary nerve, Vidian nerve and the pterygopalatine (third) part of the maxillary artery. The maxillary artery and its branches are located anteriorly, and the pterygopalatine ganglion and maxillary and Vidian nerves are located posteriorly, conceptually creating an anterior vascular and a posterior neural compartment (Fig. 9.7; see Fig. 9.5).
The pterygopalatine ganglion (sphenopalatine ganglion; the ‘ganglion of hay fever’) is the largest parasympathetic ganglion. It is located inferior and medial to the foramen rotundum and the maxillary nerve, and lateral to the sphenopalatine foramen. Its primary function is parasympathetic secretomotor supply to the mucosa of the nasal cavity and paranasal sinuses. Preganglionic fibres run initially in the greater petrosal branch of the facial nerve, which becomes the nerve of the pterygoid canal (Vidian nerve) after it is joined by the deep petrosal nerve (postganglionic sympathetic). Postganglionic parasympathetic fibres are largely distributed via branches of the maxillary nerve. A pterygopalatine ganglion block is employed to treat a variety of painful and allergic conditions.

The maxillary nerve (second division of the trigeminal nerve) is purely sensory; it exits the foramen rotundum and enters the superior part of the PPF. All the extracranial branches of the nerve arise in the PPF and are described as arising from the main nerve and those associated with the ganglion. The zygomatic branch enters the orbit via the inferior orbital fissure, before dividing into a zygomaticofacial and zygomaticotemporal nerve. The posterior superior alveolar nerve runs along the posterior wall of the maxilla and pierces it to supply the adjacent mucosa and teeth.

The infraorbital nerve, the largest branch of the maxillary nerve, runs laterally in the PPF for about $13 \pm 2.5$ mm, before entering the orbital via the inferior orbital fissure. It is a very useful landmark in the superior aspect of
the PPF, especially for the foramen rotundum, cavernous sinus and ICA, and it defines the boundary between the PPF medially and the ITF laterally. The ganglionic branches include the orbital, nasopalatine, posterior superior nasal, greater and lesser palatine, and pharyngeal nerves.

In endoscopic approaches to the PPF (Video 9.6), the sphenopalatine vessels are exposed and ligated, and the pterygoplatine ganglion is identified posteriorly and traced medially to the Vidian nerve and the Vidian (pterygoid) canal. Further dissection along the canal leads to the second genu of the ICA, with the Vidian nerve passing superiorly and lateral. The cartilaginous pharyngotympanic tube can be followed posteriorly to its entry into the bony canal, with the first genu of the ICA lying just posterior to the bony–cartilaginous junction. Intraoperative navigation and Doppler can aid identification of the ICA. The infraorbital nerve is located lateral to the pterygopalatine ganglion, coursing anterosuperiorly to the orbital floor, and can be traced posteriorly to the foramen rotundum. This is another vital landmark separating the PPF medially from the ITF laterally. The pterygoid plates are located posterolaterally; the foramen ovale is located just lateral to the lateral pterygoid plates (see Figs 9.5, 9.7).

The arcade of foramina formed by the foramen rotundum anteriorly and the foramina ovale and spinosum more posteriorly in the floor of the middle cranial fossa represents the medial boundary of the ITF and PPF, and can be used as a landmark when a superior intracranial approach to the ITF is considered (Fig. 9.8).
The close relationship of the PPF to several anatomical structures (both extra- and intracranial) facilitates the spread of infection and tumours, especially perineural spread.

**Tips and Anatomical Hazards**

**Infratemporal Fossa**

Use the lingual and inferior alveolar nerves as navigational road maps.
Early coronoidectomy will improve access to the lingual and inferior alveolar nerves and ease dissection of the ITF.
Ligate the maxillary artery at the condylar neck early during ITF clearance.
The internal carotid artery is protected when using the stylohamular plane as a guide during ITF clearance via a lateral approach.
Choose paramedian mandibulotomy for maxillary tumours involving the ITF.
Consider endoscopic transnasal/transpterygoid/transmaxillary access.
Anatomical hazards to avoid are the maxillary and internal carotid arteries, the lingual and inferior alveolar nerves, and the pterygoid venous plexus.

**Pterygopalatine Fossa**

Use the infraorbital and Vidian nerves as navigational road maps.
Remember that vascular structures are anterior to neural elements.
Use the pharyngotympanic tube and Vidian nerve as landmarks for the internal carotid artery.
Make use of intraoperative navigation and Doppler.
Anatomical hazards to avoid are the sphenopalatine and internal carotid arteries and the maxillary/infraorbital nerves.
References


Further Reading


Single Best Answers

1. Which one of the following statements is FALSE?
   A. The maxillary artery enters the infratemporal fossa between the neck of the mandibular condyle and the sphenomandibular ligament
   B. The maxillary artery runs deep to the lateral pterygoid muscle
   C. The middle meningeal artery is located lateral to the mandibular nerve as they course through the skull base
   D. Flaps based on the sphenopalatine artery are often used in endoscopic skull base surgery
   E. The descending palatine artery can be damaged during Le Fort I osteotomy

Answer: B. The maxillary artery, one of the two terminal branches of the external carotid artery, enters the infratemporal fossa between the neck of the mandibular condyle and the sphenomandibular ligament. Early identification and ligation of the artery in this well-defined location can significantly improve haemostasis and visibility in dissections of the infratemporal fossa (see Fig. 9.3B). The artery is traditionally divided into mandibular, pterygoid and pterygopalatine segments and runs a variable course in relation to the lateral pterygoid muscle (see Fig. 9.5B).

The middle meningeal artery originates from the second (pterygoid) part and enters the skull base through the foramen spinosum, located lateral to the foramen ovale (through which the mandibular division of the trigeminal nerve exits the skull base). The middle meningeal artery is a useful landmark when using a lateral approach to access this area. The sphenopalatine artery is the largest of the terminal branches of the maxillary artery and is a major source of blood supply to the nasal cavity (Ch. 8). Ligation of the vessel may be required for
significant epistaxis and can be performed endonasally at the sphenopalatine foramen, which is located just inferior to the posterior end of the middle turbinate. Axial pattern flaps based on this artery are commonly used in endoscopic skull base surgery. The descending palatine artery can be injured at the posterior limit of the lateral nasal bone cuts when carrying out a Le Fort I osteotomy. Incomplete sectioning of the bony canal and retraction of the artery can make achievement of haemostasis difficult (see Fig. 9.5B).
Clinical Case

1. A 46-year-old female presented to the outpatient clinic with discomfort in her left ear, the sensation of a lump in her throat and a tingling sensation in her left lower lip of a few months’ duration. Clinical examinations confirmed reduced sensation in the lip and chin and demonstrated a large smooth submucosal mass in the left lateral pharyngeal wall. The orthopantomogram (OPG, Fig. 9.9) and coronal MRI (Fig. 9.10) demonstrate the imaging findings.

![Orthopantomogram](image1)

**FIG. 9.9** Orthopantomogram.

![Coronal MRI scan](image2)

**FIG. 9.10** Coronal MRI scan.

A. Describe the salient features demonstrated on Figs 9.9 and 9.10.
The OPG (see Fig. 9.9) is a rotational tomogram, which provides a panoramic view of the maxilla, mandible and teeth. It demonstrates an enlarged inferior dental canal on the left, when compared to the right (arrows). The inferior dental canal extends from the mandibular foramen on the medial aspect of the ramus to the mental foramen on the lateral aspect of the parasympophysial region of the mandible. The inferior dental (alveolar) nerve, a branch of the mandibular nerve, enters the canal at the mandibular foramen, then courses through the canal, supplying the lower teeth; its mental branch, which supplies the skin of the lower lip and labial gingivae, exits at the mental foramen.

The coronal MRI (see Fig. 9.10) demonstrates a well-defined hyper-intense mass lesion extending from the middle cranial fossa, through the skull base to the floor of the mouth, on the medial aspect of the mandible. The lateral pharyngeal wall is displaced medially.

B. Name the numbered structures on the axial MRI scan (Fig. 9.11) and describe any mass effects of the lesion.

![Fig. 9.11 Axial MRI scan.](image)

The structures are: 1, medial pterygoid; 2, lateral pterygoid; 3, mastoid air cells; 4, internal carotid artery; 5, pharyngotympanic (Eustachian) tube.
The mass is displacing lateral pterygoid medially and medial pterygoid laterally. It seems to be compressing the pharyngotympanic tube, which cannot be visualized on the left, and there are features of obstructive fluid levels in the mastoid air cells. The internal carotid artery, located posterior to the mass lesion, is not displaced.

The mandibular nerve exits the skull base through the foramen ovale and descends between medial and lateral pterygoid. It divides into a large posterior and a smaller anterior division. The inferior alveolar, lingual and auriculotemporal nerves and the nerve to mylohyoid originate from the posterior division. The inferior alveolar nerve subsequently enters the mandible through the mandibular foramen (see Fig. 10.2). The sensory disturbances described by the patient are a consequence of pathological changes in the branches of the mandibular nerve that have been affected by the schwannoma.

C. Why is the relationship of the lesion to the styloid apparatus an important consideration?

The parapharyngeal space is located on the medial aspect of the infratemporal fossa and is traditionally divided into pre- and post-styloid compartments. The location of lesions relative to the styloid apparatus can provide important clues to the differential diagnosis and the surgical access that may be required; the precise location of pathology in this region can occasionally prove a challenge.

Lesions located in the prestyloid region most commonly arise from the deep lobe of the parotid/aberrant salivary tissue. A smaller proportion arise from the mandibular nerve and lymph nodes.

The post-styloid compartment contains the internal carotid artery, internal jugular vein, sympathetic chain, cranial nerves IX, X, XI and XII, and lymph nodes. Neurogenic tumours and paragangliomas form the bulk of the pathology in this region.

Clinical examination, supplemented by imaging studies (CT, MRI) and angiograms (as necessary), is helpful in arriving at a diagnosis. Displacement of the adjacent structures, vascularity and other imaging characteristics further aid the diagnostic process. Image-guided cytology/biopsy can also be considered.

The clinical signs, symptoms and imaging features of this lesion suggest a diagnosis of a mandibular nerve schwannoma.
Temporomandibular joint

Andrew J Sidebottom, Benjamin Gupta

Core Procedures

Closed Procedures

• Arthrocentesis
• Arthroscopy

Open Joint Procedures

• Discectomy
• Disc plication
• Eminoplasty
• Total joint replacement
• Open reduction and internal fixation of fractured condyle

The temporomandibular joint (TMJ) is a bilateral diarthrodial, ginglymoid synovial joint, which is mobile independent of the motion of the contralateral joint. Upper and lower joint spaces within each joint are separated by an articular disc of fibrocartilage.

The TMJ is unique in that the articulating surfaces of the teeth lie between the two joints, which means that minor changes in joint structure can lead to changes of the occlusion. The main functions of the TMJ are to permit mastication and to aid swallowing and speech articulation.
Embryology

The TMJ develops in membrane as two separate condensations of neural crest mesenchyme between the eighth and twelfth weeks in utero; a recognizable joint is present at 12 weeks. The articular disc is initially cellular, vascular and rich in elastic fibres. The growth centre, located just inferior to the condylar head, may be active until the third decade. Prolonged growth activity can be seen in the form of condylar hyperplasia and usually manifests in the second to third decade of life. Lack of growth will be evident in the first decade of life, e.g. in hemifacial microsomia. The growth centre can be damaged by trauma; arrest may also be induced with a high condylar shave procedure following excess growth.
Clinical anatomy

The condylar head is the most proximal aspect of the mandible and forms the lower part of the TMJ. The head and part of the neck (approximately 1 cm) are contained within the capsule. On mouth opening there is an initial hinge-type movement due to rotation of the condylar head against the articular disc in the lower joint space; this relates clinically to mouth opening of approximately 26 mm. The disc–condyle complex is then able to translate anteriorly on to the articular eminence, permitting mouth opening of over 35 mm; this translation is facilitated within the upper joint space, which also allows for protrusion and lateral movements. Limited mouth opening can be due to an extra-articular issue, such as spasm in the muscles of mastication, or an intra-articular problem usually involving the upper joint space or disc. Degenerative changes of the TMJ manifest mainly on the condylar head with the presence of osteophytes, subchondral cysts and abnormal bony sclerosis. Intracapsular fractures of the condylar head can occasionally result in avascular necrosis from disrupted blood supply.

The glenoid fossa (part of the temporal bone) is the thin roof of the TMJ and has a sigmoidal shape (Ch. 14). The articular eminence is anterior and the retro-articular prominence, which is in continuity with the bony external auditory canal (EAC, external acoustic meatus), is posterior. An anterior dislocation results when the condylar head rests superior and anterior to the articular eminence, as is seen in hypermobility of the TMJ.

The joint capsule is formed of fibroelastic tissue that surrounds the condylar head; it is attached to the glenoid fossa superiorly and the articular eminence anteriorly. The lateral ligament is a thickening of the capsule that is attached to the condylar neck up to 1 cm from the joint (Fig. 10.1). The TMJ is innervated by branches from the mandibular division of the trigeminal nerve, mostly through the auriculotemporal branch, together with branches from the masseteric and deep temporal nerves. Postganglionic sympathetic nerves supply the tissues associated with the capsular ligament and the looser posterior bilaminar extension of the disc. The capsule of the TMJ, lateral ligament and retroarticular tissue contain mechanoreceptors and nociceptors: proprioceptive input from mechanoreceptors helps to control mandibular posture and movement.
The articular disc divides the joint space into a superior (discotemporal) space and an inferior (discomandibular) space, both filled with synovial
fluid. It is composed of multidirectional type I fibrocartilage and is smooth, biconcave and avascular. The disc is attached medially and laterally to the condylar head, anteriorly to the lateral pterygoid muscle and posteriorly to the retrodisca1 tissues. The latter can be stretched in cases of internal derangement, resulting in a loss of disc mobility and (potentially) surface damage. In sagittal section, the disc has three distinct parts: an anterior band, a thinner intermediate zone and a posterior band. The disc becomes avascular soon after birth and is then incapable of repair.

The synovial membrane lines the inside of the capsule: it does not cover the disc or the articular surfaces. The membrane contains free nerve endings, which may explain why synovitis manifests with pain. Synovial fluid produced by the synovial membrane provides protection and nutrition to the articular surfaces and is the sole supplier of nutrients to the avascular disc; it contains surface-active phospholipids and hyaluronic acid that lubricate the joint. Repeated bruxism can cause extrusion of joint fluid and adhesions of the joint surfaces. Anchored disc phenomena can result from loss of lubrication, leading to an acute loss of joint mobility. Relubrication can be achieved by washing out the inflammatory mediators and hydrodissection with an arthrocentesis procedure. The cells of the synovial membrane can then recover, secreting lubricating fluid that facilitates joint movement.

Ligaments

The lateral ligament is a thickening of the lateral capsule that is encountered as it is incised to enter the joint during TMJ surgery. Some believe that closure of the capsule is essential to prevent subluxation. The sphenomandibular ligament is attached to the spine of the sphenoid and the lingula of the mandible. It limits lateral movement of the mandible and can calcify after trauma, which could lead to limited mouth opening. The stylomandibular ligament is a thickening of the deep cervical fascia and runs from the tip of the styloid process to the angle of the mandible. It limits mandibular protrusion.

The otomandibular ligaments connect the malleus with the disc (discomalleolar ligament) and the malleus with the lingula (malleolar–mandibular ligament). Studies have suggested that they are intrinsic ligaments of the TMJ but their clinical significance has not yet been fully determined.
Muscles of mastication

The major jaw-closing muscles are masseter and temporalis. Protrusion and lateral deviation are achieved predominantly by the pterygoid muscles. Jaw opening is achieved by the weaker mylohyoid, geniohyoid and digastric muscles, assisted by lateral pterygoid.

Temporalis is attached to the superior temporal line of the temporal bone and the coronoid process of the mandible. It is fan-shaped superiorly and forms a tendon inferiorly at its attachment to the anterior ramus of the mandible. This attachment is useful when palpating for muscular tenderness intraorally in the diagnosis of myofascial pain. Temporalis is covered by temporal fascia, which splits just above the zygomatic arch into superficial and deep layers with an intervening fat pad (Ch. 5). The temporal branch of the facial nerve lies in the superficial layer; hence, dissection deep to this into the fat pad allows for safe retraction of the nerve. Temporalis is innervated by the mandibular division of the trigeminal nerve and receives its blood supply via deep temporal branches from the maxillary artery (MA).

Masseter is a multipennate muscle attached to the maxillary process of the zygomatic bone and to the zygomatic arch; its fibres pass downwards and backwards, to insert into the angle and lower posterior half of the lateral surface of the ramus of the mandible. Masseter is innervated by the mandibular division of the trigeminal nerve and receives its blood supply from the masseteric branch of the MA and periosteal branches. The muscle is readily palpable on clinical examination for assessment of muscle spasm and myofascial pain.

Medial pterygoid mirrors masseter on the medial aspect of the mandible. It consists of a deep head that arises from the medial aspect of the lateral pterygoid plate and a smaller, superficial head attached to the maxillary tuberosity and pyramidal process of the palatine bone: both heads are inserted into the medial angle of the mandible. Contraction of both medial pterygoids helps to elevate the mandible; acting with the lateral pterygoids, the medial pterygoids protrude the mandible. Contraction of one medial pterygoid produces lateral excursion to the contralateral side. The pterygomasseteric sling at the angle can prevent surgical lengthening of the ramus and limit superior dissection up the ramus during the retromandibular approach to the ramus. Medial pterygoid is innervated by the nerve to medial pterygoid directly from the trigeminal nerve and receives its vascular supply from the MA.

Lateral pterygoid has two heads. The inferior head arises from the lateral
surface of the lateral pterygoid plate and is attached to the pterygoid fovea on the condylar neck. The superior head arises from the infratemporal surface and infratemporal crest of the greater wing of the sphenoid bone and is attached to the disc. It is involved with anterior disc movement during mouth opening and protrusive jaw movements. Restriction of mouth opening and locking can be associated with lateral pterygoid spasm, leaving the disc in a more anterior position relative to the condylar head and resulting in anterior disc displacement without reduction. Lateral pterygoid is innervated by the mandibular division of the trigeminal nerve and receives its blood supply from the MA.

**Vascular supply**

The terminal branches of the external carotid artery, the superficial temporal artery (STA) and MA, divide approximately 2 cm proximal to the condylar head and deep to the posterior ramus to provide the local blood supply (**Fig. 10.2**).

![FIG. 10.2 The vascular supply and innervation of the temporomandibular joint: posterior view.](image)

In dissections superficial to the joint, the STA and vein are at risk of injury.
They lie on the superficial aspect of the temporal fascia and will be encountered at the superior part of the external ear if a temporal extension is continued from the pre-auricular incision. In a standard pre-auricular incision, the vessels are retracted anteriorly during the dissection. The pterygoid venous plexus can also be a source of problematic bleeding during deeper dissection. It is encountered on the lateral pterygoid muscle, medial to the disc and capsule during disectomy and joint replacement procedures. The retromandibular vein may be encountered either on the medial ramus towards the angle of the mandible or at the inferior extent of the pre-auricular incision. Control of the bleeding is often achieved by ligation via the retromandibular incision.

Dissection into the infratemporal fossa for condylectomy may encounter the masseteric branch of the MA traversing the sigmoid notch. The MA lies superficial to the lateral pterygoid and can also be encountered in the base of the wound. The middle meningeal artery lies deeper and can be at risk of injury at the medial aspect of the disc and lateral pterygoid muscle. The MA may be in closer proximity to an ankyloitic mass and so vascular imaging, including preoperative selective embolization, may be essential. Intraoperative arterial haemorrhage that cannot be controlled locally may need ligation of the external carotid artery either in the neck, at its bifurcation, or in the retromandibular groove deep to the posterior belly of the digastric. More distal ligation is preferable: ligation below the linguo-facial trunk reduces blood flow by only 40%. Ligation above this level reduces flow by 73% and ligation at the origin of the posterior auricular trunk and above reduces flow by 99.2%.

**Innervation**

The TMJ derives its sensory innervation from articular branches of the auriculotemporal and masseteric nerves (mandibular division of the trigeminal nerve). The auriculotemporal nerve travels along the posterior border of the lateral pterygoid muscle and gives off branches to the medial aspect of the joint (see Fig. 10.2). It passes between the sphenomandibular ligament and the neck of the mandible, and then runs laterally behind the TMJ, related to the upper part of the parotid gland. It traverses the posterior aspect of the joint and progresses superiorly; its cutaneous branches supply sensation to the tragus, part of the adjoining auricle and the posterior part of the temple.
Although the facial nerve is not directly involved with the TMJ, it is a cause of anxiety during surgery in this area due to its close proximity to the joint. The two branches that are likely to be encountered are the temporal and marginal mandibular branches.

The temporal branch lies in the superficial temporal fascia and crosses the zygomatic arch 8–35 mm (average 20 mm) anterior to the bony external auditory canal. Subperiosteal dissection of the base of the zygomatic arch through the superficial layer of the temporal fascia (Fig. 10.3) will protect this branch of the facial nerve from direct injury, although a neuropraxia can be sustained as a result of retraction. The superficial fascia can then be released in a line running from 5 mm anterior to the bony external auditory canal to 2 cm superior to the lateral canthus, which is the ‘safe zone’ of dissection (Fig. 10.4).
The temporal branch of the facial nerve in the superficial temporal fascia: coronal view. The planes of dissection are demonstrated, along with the location of the facial nerve relative to the zygomatic arch and the temporal fat pad (a landmark in this dissection). Dissection to the arch in a subperiosteal plane allows for safe retraction of the facial nerve. Identification of the temporal fat pad provides a landmark in this dissection. Key: SMAS, superficial muscular aponeurotic system; TF, temporalis fascia or deep temporal fascia; TPF, temporoparietal fascia or superficial temporal fascia; VII, branch of facial nerve.
The marginal mandibular nerve is found passing anteriorly from the posterior border of the ramus within the substance of the parotid gland. Careful blunt dissection through the parotid, once the parotid capsule has been entered, is needed to avoid direct nerve injury. The branch can be seen passing in a posterior–superior to anterior–inferior direction in the surgical wound. It is often found lying on the epimysium of masseter. It can be carefully mobilized and retracted out of the surgical wound with minimum risk of neuropraxia. In the majority of cases, this branch will be above the angle of the mandible; however, it may sometimes be found below the angle, posterior to the point where the nerve crosses the facial artery and vein. Care must be taken when undertaking a submandibular approach to the ramus: a subplatysmal dissection should stay superficial to the investing layer of deep cervical fascia which contains the nerve. It can then be identified, dissected and retracted out of the surgical wound superiorly.
Inferior Alveolar and Lingual Nerves

The inferior alveolar and lingual nerves lie deep to the lateral pterygoid muscle and can be stretched during medial dissection, especially if there is significant joint ankylosis. When placing the ramus component of a joint replacement prosthesis, the lingula is often close to the position of the most anterior screws and can be damaged if the prosthesis is not seated correctly.

Mastoid Air Cells and External Auditory Canal

The glenoid fossa has a sigmoid shape, limited anteriorly by the articular eminence and posteriorly by the retro-articular prominence (which is in continuity with the bony EAC). On approach to the joint, the inexperienced surgeon can mistake the EAC for the joint and inadvertently enter the canal: it is therefore advisable to move the joint before making any bone cuts.

The zygomatic process of the temporal bone, especially the articular eminence, and the roof of the glenoid fossa may be pneumatized. In studies, preoperative imaging with cone beam computed tomography (CBCT) found a significant prevalence of both the pneumatized articular eminence and the glenoid fossa. Eminence reduction procedures can lead to perforation into the mastoid air cells which are present within the eminence in 2–5% of cases. If perforation occurs during the procedure, there may be spread of infection into the joint or exposure of intracranial contents. The glenoid fossa is relatively thin and inadvertent puncture can lead to perforation into the middle cranial fossa. This is more likely in closed procedures such as arthroscopy when directing the scope superiorly on joint puncture.

Arthroscopy and Arthrocentesis

The main hazard is the need to avoid the superficial temporal vessels and temporal branch of the facial nerve on entry. If the glenoid fossa is thin, it can be penetrated, as can the middle ear with poor direction. Medial penetration of instruments can lead to fluid leaking into the
lateral pharyngeal wall and may potentially cause a limited-time airway obstruction. The ideal entry points are shown in Fig. 10.5.

Pre-Auricular Approach
The pre-auricular approach is shown in Fig. 10.6.
A pre-auricular incision is made, often in a skin crease, and continued in the pre-cartilaginous ‘avascular plane’.
This is deepened at the superior extent until the superficial layer of the deep temporal fascia is identified (white layer).
The dissection is continued at this depth until the base of the zygomatic arch is palpated.
The base of the arch can then be incised on to; during this manœuvre, however, a vessel is often encountered, which should be cauterized.
A 45° incision through the fascia superiorly from the base of the arch directed to 2 cm above the lateral canthus allows subperiosteal anterior dissection of the zygomatic arch.
The articular eminence should be identified anteriorly and the joint should be moved to determine its position.
The capsule is exposed with a blunt periosteal elevator by sweeping away the overlying tissues.
The joint can then be accessed by two incisions: a vertical incision on the
posterior aspect of the condylar neck (up to the level of the joint) that is connected to a horizontal incision that exposes the disc and joint spaces. Closure should include the lateral capsule and temporalis fascia.

Retromandibular Approach

The incision is made 1 cm beneath the ear lobe and posterior to the ascending ramus of the mandible. The skin is incised and undermined. The parotid capsule is then identified and entered, although it may be thin at this point. Careful blunt dissection in a bloodless field is required to identify the branches of the facial nerve in the parotid and on the masseteric epimysium. If present, they can be dissected free and retracted out of the surgical site. The pterygomasseteric sling can then be cauterized on the posterior and inferior border and subperiosteal dissection up to the sigmoid notch can be performed. The retromandibular vein may be encountered medial to the ascending ramus, leading to problematic bleeding. The main trunk of the external carotid artery can be found deep to the posterior belly of digastric in cases of uncontrolled arterial bleeding (Fig. 10.7).
The parotid capsule should be identified and water-tight closure achieved to prevent the formation of a sialocele.
References


Single Best Answers

1. When performing discectomy, which one of the following vessels is at risk of damage?
   A. Common carotid artery
   B. Superficial temporal artery
   C. Maxillary artery
   D. Middle meningeal artery
   E. Retromandibular vein

   **Answer: B.** The superficial temporal artery can be at risk during approach to the temporomandibular joint via a pre-auricular incision. The middle meningeal artery lies on the deep aspect of the disc and so can be at risk, although this is unlikely due to its depth.

2. Which one of the following structures is NOT at risk during temporomandibular joint arthroscopy?
   A. Temporal branch of the facial nerve
   B. Superficial temporal vessels
   C. Cartilaginous meatus of the ear
   D. Marginal mandibular nerve
   E. Middle cranial fossa

   **Answer: D.** The marginal mandibular nerve runs in the masseteric epimysium close to the angle of the mandible, not near the joint space, which is where the access points for arthroscopy are located.

3. Which one of the following nerves provides the sensory supply to the temporomandibular joint?
   A. Great auricular nerve
B. Zygomatic branch of the facial nerve
C. Auriculotemporal branch of the trigeminal nerve
D. Temporal branch of the facial nerve
E. Inferior alveolar nerve

**Answer:** C. The sensory nerve supply to the temporomandibular joint is via the auriculotemporal branch of the mandibular division of the trigeminal nerve.

4. Which one of the following structures should NOT be at risk during eminoplasty?
   A. Cartilaginous meatus
   B. Mastoid air cells
   C. Middle meningeal artery
   D. Temporal branch of the facial nerve
   E. Articular disc

**Answer:** C. All of the structures listed, except the middle meningeal artery, can be encountered during the approach to the joint and eminoplasty procedure. The middle meningeal artery lies deep to the medial surface of the disc and should not be encountered.

5. Which one of the following vessels is most at risk during condylectomy?
   A. Superficial temporal artery
   B. Internal carotid artery
   C. Retromandibular vein
   D. Facial artery
   E. Maxillary artery
Answer: E. The masseteric branch of the maxillary artery traverses the sigmoid notch and is most at risk of injury during a condylectomy procedure without appropriate use of subperiosteal dissection and placement of retractors. The superficial temporal artery can also be encountered during an approach via a pre-auricular incision.
Clinical Cases

1. A 54-year-old female was referred to Oral and Maxillofacial Surgery complaining of headaches, pain and swelling, with an area of numbness at the left temporomandibular joint (TMJ). Left TMJ exploration had previously been performed elsewhere for what was considered to be synovial chondromatosis, but further surgical excision was halted due to the skull base involvement. Pain levels varied from 2/10 to 7/10 and were worse on function. On examination, she had mouth opening of 43 mm with lateral extrusions to the left and right of 9 and 3 mm, respectively. She was unable to protrude her jaw and suffered pain on this movement. The muscles of mastication were non-tender; the joint line was tender. CT scanning revealed the extent of bony involvement and degree of erosion of the skull base (Fig. 10.8). An MRI scan, taken to assess whether there was dural involvement, showed a thickening of the left joint lining, with areas of radiolucency indicating multiple small masses (Fig. 10.9).
FIG. 10.8  Coronal (A) and sagittal (B) CT scans showing perforation (white arrow) of the articular fossa with an encapsulated lesion invading through the skull base and multiple radio-opaque foreign bodies.
The findings were suggestive of synovial chondromatosis eroding the articular fossa. A three-dimensional model was created to show the perforation of the skull base at the base of the zygomatic arch (Fig. 10.10). Following a multidisciplinary team (MDT) meeting with Neurosurgery, surgery was considered to offer the chance of reduced pain and improved function. Treatment stages involved gaining access, exploring the joint and removing the tumour, with reconstruction of the areas of bony erosion. A left open joint procedure via the Bramley–Al Kayat approach involved a subperiosteal exposure of the temporal fossa through temporalis vertically at the level of the auricle, along the zygomatic arch, with exposure of the very thin temporal bone at the base of the arch. Temporalis was retracted anteriorly (Fig. 10.11).
The next stage involved left TMJ exploration with removal of foreign bodies. The lower joint space was seen to be clear with no disc perforation. There was marked enlargement of the upper joint space.
Multiple fragments of translucent, cream-coloured, nodular tissue, including bone, were removed from the site (Fig. 10.12).

Left temporal craniotomy was performed, opened via the perforating lesion in the articular fossa at the base of the zygomatic arch. The lesion was seen to extend into the left middle cranial fossa, where it appeared cystic and to be pushing, but not penetrating, the dura. Further nodular remnants were removed (Fig. 10.13).
Split calvarial bone graft was used to reconstruct the fossa, with titanium cranioplasty repair to cover the craniotomy defect (Fig. 10.14). The joint capsule was irrigated and closed; the temporalis fascia was closed to reconstitute temporalis; the skin was closed.
A. What does limitation of movement to the contralateral side indicate? 
Limitation of movement to the contralateral side is indicative of upper joint space pathology.

B. What are the main findings on the CT scans? 
The main findings are a lesion penetrating from the left articular fossa, through the skull base into the left middle cranial fossa and behind the root of the left zygomatic arch, expanding into the left infratemporal fossa. The lesion is well encapsulated but with multiple radio-opacities, also present in the TMJ.

C. What does Fig. 10.9 show? 
An intracranial mass in the left middle cranial fossa.

D. What risks would be discussed at the MDT meeting? 
The risks of facial nerve weakness, dural tear or an intracranial bleed.

E. Why was temporalis retracted? 
To permit access to the temporal fossa for craniotomy and to allow for possible interposition of the fascia or muscle as a reconstructive option for the dura or cranial base.
2. A 37-year-old male was referred to Oral and Maxillofacial Surgery complaining of progressive restriction of mouth opening and pain on function over the left TMJ. Pain levels varied from 6/10 to 9/10 and were worse on function. On examination he had mouth opening of 11 mm with lateral extrusions to the left of 5 mm and to the right of 0 mm. He was unable to protrude his jaw and suffered pain on this movement. The muscles of mastication were non-tender but the joint line was tender.

A. What do progressive limitation of opening and pain on function imply?
Degenerative disease causes pain on function. Limitation of opening may be related to pain, but progressive limitation with lack of lateral deviation implies developing joint ankylosis.

CT scanning (Fig. 10.15) revealed the extent of bony involvement and degree of ankylosis of the skull base. The findings were of an ankylosis limited to the region of the articular fossa.
B. What other investigations might have needed to be considered if the ankylosis had extended medially along the skull base?

Angiography and potential embolization of the maxillary artery. If the artery were running into the ankylosic mass, it would bleed when the mass was removed and this would be difficult to control because the artery lies within bone.
The differential diagnosis was ankylosis of the left TMJ limited to the fossa (Fig. 10.16). The treatment option was resection of the ankylosic mass in order to permit mobilization.

C. If mouth opening did not improve on the table, what alternatives would need to be considered?

Ipsilateral coronoidectomy to achieve 30 mm opening. If limitation of movement remained, a contralateral coronoidectomy (Kaban protocol) would have to be considered.

D. What options would you consider for reconstruction of the joint?

Reconstructive options include leaving a gap arthroplasty; placing an interposition of temporalis fascia or buccal fat pad; adding a costochondral graft; or total alloplastic joint replacement.

E. What risks would you discuss with the patient preoperatively?

The main risk is damage to the facial nerve, particularly the frontal branch. If the ramus is accessed for a costochondral graft or alloplastic reconstruction, there is a risk of marginal mandibular division weakness. Bleeding is always a risk with ankylosis and revision TMJ surgery, with the attendant issues associated with blood transfusion and opening of the neck.
to tie the external carotid artery.

There is a small risk of sialocele with access via the parotid gland.

Recurrence of ankylosis is most likely with gap arthroplasty alone and least likely with alloplastic reconstruction.

Treatment stages involved gaining access, resecting the ankylosis and reconstructing the joint (in the Western world) with an alloplastic total joint prosthesis.

A right open joint procedure via pre-auricular incision with temporal extension is the standard technique described in this chapter (see Fig. 10.6). The ankylotic mass was exposed from above (Fig. 10.17) and the proximal condyle, disc remnant and capsule were removed with careful medial dissection to reduce bleeding, particularly from the pterygoid venous plexus and branches of the maxillary artery.

A left retromandibular incision to permit condylectomy and placement of the ramus prosthesis is the standard approach described in this chapter. The condylectomy was completed from below (Fig. 10.18) and the fossa prosthesis was placed from above. The patient was placed and held in occlusion and the ramus prosthesis (TMJ Concepts total alloplastic prosthesis) secured in place (Fig. 10.19). If desired, a free fat graft could be placed around the prosthetic articulation to reduce the risk of re-ankylosis. The temporalis fascia was closed to permit easier function and the parotid fascia was closed to reduce the risk of sialocele.
The patient was discharged at 48 hours and immediate mobilization followed. He was pain-free with 30 mm opening at 6 weeks, with further improvement to 34 mm and a relatively normal diet at 1 year.
CHAPTER 11
Mouth

Niall MH McLeod, Elizabeth A Gruber

Core Procedures

- Cleft lip and palate repair
- Submandibular calculi and sublingual gland removal
- Maxillary access for trauma or orthognathic surgery
- Mandibular orthognathic surgery and trauma surgery
- Anaesthesia for dentistry
Embryology

The oral cavity is demarcated as early as the fourteenth day of fetal development by the appearance of the prechordal plate.¹ The endodermal thickening of the prechordal plate contributes to the oropharyngeal membrane, a temporary membrane that separates the ectoderm forming the mucosa of the mouth and the endoderm forming the pharynx. It sits at the depth of the stomodeum, a shallow depression in the centre of the developing face, which constitutes the primitive mouth. The stomodeum is surrounded by five prominences: the frontonasal process and the paired maxillary and mandibular prominences (Fig. 11.1). Medial and lateral nasal processes form at the tip of the frontonasal process and fuse with each other and the maxillary prominence, forming the maxilla, lip, tip of the nose and primary palate. Failure of this fusion process produces clefts of the lip and premaxilla.² The mandibular prominences are derived from the first branchial arch, merging to form the lower lip and mandible.

The primitive stomodeum deepens with the growth of the surrounding prominences; by the twenty-eighth day, the oropharyngeal membrane has usually disintegrated, creating a continuous passage between the mouth and
pharynx. The frontonasal and maxillary prominences develop horizontal extensions into the stomodeum; these initially sit on either side of the tongue, which is developing from the floor of the cavity. In the eighth week, these shelves reorientate horizontally and then fuse, separating the oral and nasal cavities. Failure of reorientation or fusion of the palatal plates produces a cleft palate.²

The three divisions of the trigeminal nerve provide sensory innervation to the frontonasal, maxillary and mandibular parts of the face. The muscles of mastication, mylohyoid, anterior belly of digastric and tensor veli palatini are all innervated by the motor branch of the mandibular division of the trigeminal nerve. The anterior two-thirds of the tongue develop in the first (mandibular) pharyngeal arch from a small median elevation, the tuberculum impar or median tongue bud, and paired lateral lingual swellings distally. This part of the tongue is innervated by the lingual branch of the mandibular nerve (the nerve of the first arch), and by the chorda tympani of the facial nerve. The posterior, pharyngeal part of the tongue is innervated by the glossopharyngeal nerve, the nerve of the third arch; this nerve also invades and innervates the tissue immediately distal to the sulcus terminalis, including the circumvallate papillae. The intrinsic and extrinsic muscles of the tongue arise from occipital somites; all except palatoglossus are innervated by the hypoglossal nerve. Palatoglossus is innervated by motor branches of the pharyngeal plexus.

The mandible forms from intramembranous bone lateral to Meckel's cartilage. A single ossification centre for each half of the mandible arises in the sixth week in utero in the region of the bifurcation of the inferior alveolar nerve and artery into their mental and incisive branches. At this stage, the tooth germs lie above the developing mandible; near the end of the second month of fetal life, the alveolar processes develop as a trough in response to the tooth buds and become superimposed on the basal bone of the maxillary and mandibular bodies. Odontogenic tissue can be identified as early as the twenty-eighth day in utero as ectodermal thickenings at the superolateral margins of the developing frontonasal, maxillary and mandibular prominences. Local proliferation of the dental lamina into the subjacent mesenchyme forms the primordia of the enamel organs. Ten tooth germs, representing the 10 deciduous teeth, form initially; the tooth germs of the permanent teeth form lingually to the primary tooth germs at a later stage.
Clinical anatomy

The mouth can be divided into two parts. The peripheral portion, the vestibule, is the narrow space between the lips and cheeks and the teeth and gingivae. The anterior boundary is formed by the lips. The inner oral cavity proper is bounded anteriorly and laterally by the teeth and gingivae (Fig. 11.2). The roof is formed by the hard and soft palates, and the floor by the anterior two-thirds of the tongue and the floor of the mouth, on to which the submandibular and sublingual salivary ducts open. The posterior boundary of the oral cavity is the oropharyngeal isthmus, bounded by the tongue at the sulcus terminalis (the boundary of the anterior two-thirds and posterior third of the tongue), the palatoglossal arch and the soft palate.
The dental alveolus and hard palate are covered by keratinized epithelium, which is tightly adherent to the underlying bone. The remainder of the oral cavity (soft palate, ventral surface of the tongue, floor of the mouth, alveolar processes (except the gingivae) and the internal surfaces of the lips and cheeks) is lined with a mucous membrane that has a non-keratinized stratified squamous epithelium that is more pliable and able to move with the underlying muscles of the cheek and tongue. The anterior surface of the hard palate is marked by folds of mucosa, the palatine rugae. In addition to the major salivary glands, many minor salivary glands open on to the non-keratinized lining of the oral cavity, providing lubrication. These are mostly serous, similar to the lingual glands, in contrast to the parotid and submandibular glands which produce more mucus saliva.

The mucous membrane of the superior aspect of the vestibule is innervated by the infraorbital branch of the maxillary division of the trigeminal nerve; the lower aspect is innervated by the buccal and mental branches of the mandibular nerve.

**Lips and cheeks**

The upper and lower lips form a muscular valve that maintains an oral seal. The bulk of the lips are formed by orbicularis oris, into which the elevator and depressor muscles of the lip and the buccinator muscle of the cheeks are inserted (Fig. 11.3). The lips are covered externally by skin and internally by mucous membrane, which fuse on the exterior surface at the vermilion border. The vascular supply is from the superior and inferior labial branches of the facial artery and vein. Folds of mucosa in the midline of the upper and lower lips, labial frenulae, are attached to the anterior aspect of the maxillary and mandibular alveoli, respectively.
Cleft lips are the result of a separation of all, or part, of the upper lip and the maxillary alveolus either unilaterally or bilaterally, creating a communication between the oral and nasal cavities. The associated loss of orientation of the muscles of the lip affects speech and eating. Repair of a cleft lip requires dissection and reorientation of orbicularis oris and the muscles that insert into it in order to restore continuity of the lip and normal function.\(^2\)

The sensory supply to the upper lip is from the infraorbital branch of the maxillary division of the trigeminal nerve. The nerve emerges from the infraorbital foramen, approximately along a line from the canine tooth to the pupil. It is at risk from trauma following a fractured zygoma or maxilla, where the fracture line often passes through its foramen, or during surgical access procedures of the midface, which involve dissection of the mucoperiosteum from the anterior wall of the maxilla through an incision in
the upper buccal sulcus.

The lower lip is supplied by the mental nerve, a terminal branch of the inferior alveolar nerve (a branch of the mandibular division of the trigeminal nerve). This nerve is vulnerable to injury as it passes through the mandible, from fractures or osteotomies that divide the bone between the lingula on the inner aspect of the ramus and the mental foramen. The nerve passes close to the roots of the teeth and so may also be injured during dentoalveolar surgery, particularly the extraction of impacted wisdom teeth, enucleation of mandibular cysts and dental implant placement. Access incisions for the mandible are often located immediately inferior to the mucosal–mucoperiosteal junction; the periosteum is dissected, taking care not to damage the mental nerve as it emerges from the mental foramen between the apices of the lower first and second premolar teeth.

Terminal branches of the facial nerve, predominantly the zygomatic, buccal and marginal mandibular branches, innervate the muscles of facial expression, mainly from their deep aspect. Injury to the facial nerve from trauma or surgery will produce weakness of the associated muscles; while this is most noticeable during function, compensatory action of the opposing muscles may also render weakness visible at rest.

Many minor salivary glands lie beneath the mucous membrane of the lips. They are most numerous near the labial sulcus and do not extend beyond the region where the lips come into contact passively, creating the wet–dry demarcation line of the lip.

The cheeks are formed largely by buccinator. The parotid duct passes through buccinator and emerges in the oral cavity opposite the maxillary second molar tooth. The inner surface of the cheeks is covered by mucous membrane that reflects at the upper and lower buccal sulci, passing loosely over the basal bone of the maxilla and mandible, respectively, before merging into the mucoperiosteum covering the alveolar components. The buccal branch of the mandibular division of the trigeminal nerve is sensory to the lower buccal gingiva, lower buccal sulcus and cheek mucosa, and may also provide some minor sensory innervation to the cutaneous surface of the cheek.

The maxilla and anterior mandible lie in the vascular bed of the ipsilateral facial artery. Blood supply is via both periosteal and intrabony vessels: care must be taken when accessing the maxilla – particularly for orthognathic surgery, where this intrabony supply will be interrupted – not to divide the periosteal blood supply completely; incisions are therefore usually limited up
to the first molar teeth. The main arterial supply to the anterior mandible is
the sublingual artery, which may be a branch of either the lingual or the
submental artery. The dependence of the mandible on intrabony or periosteal supplies varies with age: the periosteal supply is said to be more
important at older ages.

Floor of mouth

The floor of the mouth is a space bounded by the mandible laterally and the
tongue medially (see Fig. 11.2A). The physical floor of the space is formed
principally by the two mylohyoids, which interdigitate in a midline raphe.
They originate from the mylohyoid lines on the medial aspect of the body of
the mandible and insert along a median raphe and into the hyoid bone. The
floor of the mouth contains the deep lobe of the submandibular gland, which
wraps around the posterior free edge of mylohyoid and the sublingual gland.
The submandibular ducts arise from the hilum of each submandibular gland
and pass anteriorly to drain saliva just posterior to the lower incisor teeth on
either side of the lingual frenulum. The ducts typically pass superficial and
medial to the sublingual glands, which either drain through small ducts
opening directly on to the floor of the mouth or connect to the
submandibular duct and drain with it. The submandibular and anterior
sublingual salivary glands receive a parasympathetic, secretomotor
innervation via the chorda tympani, submandibular ganglion and
postganglionic filaments (Ch. 15).

The lingual nerve is sensory to the mucosa of the floor of the mouth,
mandibular lingual gingivae and mucosa of the presulcal part of the tongue
(excluding the circumvallate papillae). The nerve arises from the posterior
trunk of the mandibular nerve in the infratemporal fossa, where it is joined
by the chorda tympani branch of the facial nerve and often by a branch of the
inferior alveolar nerve (Ch. 9). It passes below the mandibular attachment of
the superior pharyngeal constrictor and pterygomandibular raphe, closely
applied to the periosteum of the medial surface of the mandible, where it lies
opposite the distal root of the third molar, covered only by gingival
mucoperiosteum. It continues downwards and forwards on the deep surface
of mylohyoid, lying on the deep portion of the submandibular gland, passes
below the submandibular duct, which crosses it from medial to lateral, and
curves upwards, forwards and medially to enter the tongue by medial and
lateral branches. Inadvertent perforation of the bone lingual to the third
molar during its extraction, or retraction of the tight soft tissues lingually puts the lingual nerve at risk of either nerve transection or a crushing injury. The nerve is also vulnerable to injury during surgery to excise the sublingual glands, as a result of tumours or chronic infection. The surgical approach is typically from immediately lingual to the mandible, lateral to these structures, to permit their retraction medially. For hilar dissection of the submandibular gland for salivary duct stones (sialolithiasis), the dissection tends to start medially because the lingual nerve will then be more lateral.

Palate

The palate separates the oral cavity from the nose and pharynx (see Fig. 11.2C). It is subdivided into two regions: the hard and soft palates. The hard palate is vault-shaped and formed by the palatal processes of the maxillae and the horizontal plates of the palatine bones. It is bounded anteriorly and laterally by the alveolar margin of the maxillae and is continuous posteriorly with the soft palate. The soft palate is a mobile flap suspended from the posterior border of the hard palate, sloping down and back between the oral and nasal parts of the pharynx. Its oral surface is covered in stratified squamous epithelium while the pharyngeal surface is covered with respiratory-type mucosa.

Several muscles lying between the mucosal surfaces act to tighten and raise the soft palate for speech and swallowing (Fig. 11.4). Tensor veli palatini arises from the skull base and tents between the pterygoid plates; the expanded tendons of the two tensor veli palatini muscles form the palatine aponeurosis. Levator veli palatini arises from the petrous temporal bone and inserts into the superior surface of the palatine aponeurosis, acting to elevate the soft palate. Palatopharyngeus arises from the superior surface of the palatine aponeurosis and inserts into the pharyngeal wall; palatoglossus arises from the inferior surface and inserts into the tongue (see below). Both muscles act to depress the soft palate. Tensor veli palatini is innervated by the mandibular division of the trigeminal nerve via the nerve to medial pterygoid; all the other palatal muscles are innervated by the vagus nerve via the pharyngeal plexus.
A cleft palate may involve only the muscles of the soft palate; this is a submucous cleft. More commonly, the full thickness of the soft palate is separated and the fibres of tensor veli palatini are rotated to insert directly into the posterior aspect of the palatine bone. Correct repositioning of these muscles is important to restore the function of the soft palate. A cleft palate may extend all the way to the alveolar margins.
General sensation from the hard palate is carried by the greater palatine and nasopalatine branches of the maxillary nerve, which all pass through the pterygopalatine ganglion. General sensation from most of the soft palate is carried by branches of the lesser palatine nerve (a branch of the maxillary division of the trigeminal nerve) and from the posterior part of the palate by pharyngeal branches from the glossopharyngeal nerve and from the plexus around the tonsil (formed by tonsillar branches of the glossopharyngeal and lesser palatine nerves). A small disc of mucosa palatal to the upper incisors is innervated by the nasopalatine nerve.

**Tongue**

The tongue is a mobile, muscular structure covered by epithelium. The anterior two-thirds lie in the oral cavity and the posterior third within the oropharynx (see Fig. 11.2B). The tip is free but the root is anchored to the hyoid bone and mandible by muscles. Functionally, the tongue is important for taste, food manipulation and deglutition, and in speech.

The anterior two-thirds and posterior third of the tongue are separated by the sulcus terminalis, a V-shaped groove on the dorsal surface. A shallow depression at the apex of this groove, the foramen caecum, is the site of embryological origin of the thyroid gland. The dorsal mucosa is somewhat thicker than the ventral and lateral mucosae, is directly adherent to underlying muscular tissue with no discernible submucosa, and is covered by numerous papillae. The dorsal epithelium consists of a superficial stratified squamous epithelium, which varies from non-keratinized stratified squamous epithelium posteriorly to fully keratinized epithelium overlying the filiform papillae more anteriorly. Lingual papillae, projections of the mucosa covering the dorsal surface of the tongue, are limited to the presulcal part of the tongue. They produce its characteristic roughness and increase the area of contact between the tongue and the contents of the mouth. There are four principal types: filiform, fungiform, foliate and circumvallate papillae. The filiform papillae do not bear taste buds. Fungiform papillae appear as small, smooth dots across the rough dorsal surface. Circumvallate papillae are slightly raised, round structures just anterior to the sulcus terminalis, which contain almost half of the taste buds on the tongue. Foliate papillae may be visible as slightly raised folds on the lateral aspect of the tongue just anterior to the palatoglossal reflection. Small glands are scattered throughout the submucosa of the dorsum of the tongue; they are
predominantly serous anteriorly and mucous posteriorly.

The lingual nerve provides general sensory innervation to the anterior two-thirds of the tongue; special sensory innervation to the taste buds, other than those on the circumvallate papillae, is provided by the chorda tympani. The glossopharyngeal nerve provides both general sensory innervation to the posterior third of the tongue and special sensory innervation to the taste buds on the circumvallate papillae.

The mucosa of the posterior third of the dorsal surface of the tongue contains lymphoid follicles aggregated into dome-shaped groups often called the lingual tonsils. The lymphatic drainage of the tongue can be divided into three main regions: marginal, central and dorsal. The anterior tongue drains into marginal and central vessels; the posterior tongue behind the circumvallate papillae drains into the dorsal lymph vessels. The more central regions may drain bilaterally: this must be borne in mind when planning to remove malignant tumours of the tongue that are approaching the midline. If the tumour has a propensity for lymphatic spread, both cervical nodal chains may be involved.

The ventral surface of the tongue is covered by a smooth shiny epithelium that forms a midline fold, or frenulum, anteriorly. The lingual veins can be seen prominently on either side of the frenulum because the mucosa here is very thin. The lingual artery and lingual nerve lie medial to the vein but are not visible. A fringed fold of mucous membrane, the plica fimbriata, lies lateral to the vein. The orifices of the submandibular ducts open on either side of the base of the frenulum.

The tongue is divided by a median vertical fibrous septum, evident as a shallow groove on its dorsum. The intrinsic muscles run in vertical, longitudinal and transverse bundles and act to alter the shape of the tongue. The extrinsic muscles (genioglossus, hyoglossus, styloglossus and palatoglossus) move the tongue as a whole. Genioglossus arises from a short tendon attached to the superior genial tubercle behind the mandibular symphysis, above the origin of geniohyoid, and its fibres fan out backwards and upwards to enter the whole length of the ventral surface of the tongue from root to apex, intermingling with the intrinsic muscles; it protrudes the tongue. Hyoglossus arises from the whole length of the greater cornu and front of the body of the hyoid bone, and passes vertically upwards to enter the side of the tongue between styloglossus laterally and the inferior longitudinal muscle medially: it depresses the tongue. Styloglossus is attached to the anterolateral aspect of the styloid process near its apex and to
the styloid end of the stylomandibular ligament, and passes down to enter the tongue dorsolaterally: it draws the tongue up and backwards. Palatoglossus arises from the oral part of the palatine aponeurosis and passes forwards, downwards and laterally in front of the palatine tonsil to the side of the tongue; it acts to narrow the oropharynx on swallowing. All of these muscles are innervated by the hypoglossal nerve, except palatoglossus, which is innervated via the pharyngeal plexus.

**Dentition and alveolar processes**

The alveolar processes lie on the oral surface of the basal bone of the mandible and maxilla, and support the teeth. Two developmental processes – tooth eruption and growth of the alveolar process – are interdependent: the height of the alveolus is controlled by the height of eruption of the teeth, which is controlled in turn by factors that include the development of occlusion of opposing teeth. In the absence of an opposing tooth against which to occlude, teeth may over-erupt with consequent excessive alveolar growth. This can occur during eruption of the teeth or be a consequence of extraction of the opposing teeth in later life. Conversely, if teeth do not form, the alveolus does not develop. After the extraction of teeth, the alveolus will gradually resorb, until only the flattened basal bone is left.

Teeth are made of specialized mesenchyme: dentine forms the core of the tooth, enamel covers the part of the tooth that is exposed in the mouth, and the roots have a thin covering of cementum. The periodontal ligament is an aligned fibrous network that connects the tooth root and alveolar bone, and functions to retain the teeth securely.

The blood supply of the maxillary alveolus comes from the third part of the maxillary artery, mostly via periosteal branches of the greater palatine and infraorbital arteries, but also through intrabony branches of the posterior superior alveolar and infraorbital arteries. The maxillary alveolus and teeth are innervated by the infraorbital nerve via the posterior superior, middle superior and anterior superior alveolar branches of the maxillary division of the trigeminal nerve.

The mandibular alveolus receives its blood supply from the inferior alveolar branch of the maxillary artery; the periosteum also receives some supply via branches from the lingual artery (lingual gingiva and alveolar mucosa) and buccal artery (buccal gingiva and alveolar mucosa in the molar region). The contribution from periosteal vessels is said to increase with
advancing age, although in some mandibular resections performed for oral cancer the inferior alveolar artery can bleed profusely, even in patients older than 75 years. The sensory supply of the mandibular alveolus and teeth is from the inferior alveolar nerve; the buccal branch of the mandibular nerve, which supplies the buccal gingivae of the molar teeth, may also possess a branch that passes through a small retromolar foramen to supply the molar teeth.
Local anaesthesia

Most exodontia and other surgical procedures on the dentoalveolar process are undertaken under local anaesthesia. A clear understanding of the anatomy of the sensory innervation of the alveolus is important in undertaking these procedures successfully.\(^\text{13}\)

Local anaesthesia may be administered as local infiltration, nerve block or periodontal ligament injection. Local infiltration implies the supraperiosteal deposition of local anaesthetic solution, which subsequently infiltrates the periosteum and bone surrounding the relevant tooth. Factors that will determine the success of this technique include the biochemical properties of the chosen local anaesthetic solution and the thickness of the bone surrounding the teeth. Most infiltration is administered buccally or labially to the teeth. It will effectively anaesthetize the teeth for dental restorations but will not anaesthetize the palatal or lingual mucosa, and therefore exodontia requires either further infiltration of the tissues palatally or lingually, or the use of a nerve block.

A nerve block of the inferior alveolar nerve by infiltration of local anaesthetic solution close to the lingula of the mandible effectively anaesthetizes the mandibular teeth, and by virtue of the very close proximity of the lingual nerve to the lingula, it normally also effectively anaesthetizes the lingual tissues. For exodontia of mandibular teeth, infiltration at the anterior aspect of the ramus of the mandible, midway between the occlusal surface of the mandibular teeth and the maxillary tuberosity, will anaesthetize the buccal nerve, a branch of the mandibular division of the trigeminal nerve that is given off more proximally and supplies the buccal mucosa of the mandibular alveolus behind the first premolar.

A posterior superior alveolar nerve block, placed posterior to the maxillary tuberosity, will anaesthetize the posterior maxillary alveolar teeth, particularly the palatal roots of the teeth, while infiltration high in the buccal sulcus between the canine and first premolar teeth will anaesthetize the anterior superior alveolar nerve. For exodontia, infiltration palatally of the greater palatine nerve posteriorly or the nasopalatine nerve between the canines is necessary to anaesthetize the palatal mucosa.

Periodontal intraligament anaesthesia can be very effective but requires specific equipment with a fine needle and the ability to infiltrate the anaesthetic solution under pressure. Devices have also been described that penetrate the buccal bone and permit intrabony infiltration of local
**Tips and Anatomical Hazards**

The infraorbital nerve is at risk from trauma following a fractured zygoma or maxilla, where the fracture line often passes through its foramen, or during surgical access procedures of the midface that involve dissection of the mucoperiosteum from the anterior wall of the maxilla through an incision in the upper buccal sulcus.

The mental nerve is vulnerable to injury from fractures or osteotomies that divide the bone between the lingula on the inner aspect of the ramus and the mental foramen.

Inadvertent perforation of the bone lingual to the third molar during its extraction, or retraction of the tight soft tissues lingually puts the lingual nerve at risk of either nerve transection or a crushing injury. When the maxilla is accessed, particularly for orthognathic surgery, incisions are usually limited up to the first molar teeth.
References


Single Best Answers

1. Which one of the following soft palate muscles is NOT innervated by the vagus nerve (X)?
   A. Palatopharyngeus
   B. Palatoglossus
   C. Levator veli palatini
   D. Tensor veli palatini
   E. Musculus uvulae

   **Answer: D.** All muscles of the palate are innervated by the vagus nerve except tensor veli palatini, which is innervated by the mandibular division of the trigeminal nerve via the nerve to medial pterygoid.

2. If taste sensation to one side of the tongue is absent but general sensation is preserved and there is no facial palsy, which one of the following nerves is affected?
   A. Lingual nerve
   B. Chorda tympani
   C. Nerve to digastric
   D. Greater petrosal nerve
   E. Nerve to stylohyoid

   **Answer: B.** The chorda tympani carries taste sensation from the anterior two-thirds of the tongue (but not from the taste buds on the circumvallate papillae). It also carries preganglionic parasympathetic secretomotor innervation to the submandibular ganglion. If general sensation is preserved and there is no facial palsy, the nerve supply must be interrupted at the chorda tympani, after the nerve leaves the facial nerve but before it joins the lingual nerve.
3. When extracting a lower first molar tooth, which one of the following nerve combinations must be anaesthetized?

A. Lingual nerve and buccal nerve  
B. Lingual nerve and inferior alveolar nerve  
C. Inferior alveolar nerve and buccal nerve  
D. Buccal, lingual and inferior alveolar nerves  
E. Lingual and inferior alveolar nerves and nerve to mylohyoid

**Answer: D.** The sensory supply of the mandibular teeth is the inferior alveolar nerve, while the buccal gingiva is supplied by the buccal nerve and the lingual mucosa by the lingual nerve, all of which must be anaesthetized to permit exodontia.

4. In cleft lip, which of the following embryological processes fail to fuse?

A. Maxillary process and mandibular process  
B. Mandibular process and lateral nasal process  
C. Medial nasal process and lateral nasal process  
D. Medial nasal process and mandibular process  
E. Maxillary process and medial nasal process

**Answer: E.** Fusion of the maxillary process and the medial nasal process provides continuity for the upper lip and maxilla.
1. A 13-year-old female patient requires removal of a ranula in the left floor of the mouth.

A. Describe the anatomical structures that overlie the sublingual salivary gland in the floor of the mouth.
   The submandibular duct overlies the sublingual gland, running posteriorly to anteriorly. The drainage of the sublingual gland may communicate with the submandibular duct or may run directly into the floor of the mouth. The lingual nerve will also overlie the sublingual gland posteriorly as it crosses from the inner aspect of the mandible to the tongue. It normally passes to the medial side of the submandibular duct in the region of the first molar tooth.

B. How can the surgical approach avoid damage to these structures?
   If the incision is made lateral to the submandibular duct and not extended posterior to the first molar tooth, the lingual nerve should be avoided. Careful retraction of the medial margin of the incision should allow dissection between the ranula and the sublingual gland and submandibular duct under direct vision.

C. How does this surgical approach need to differ if approaching the hilum of the submandibular gland to remove a stone?
   Posterior to the first molar, the lingual nerve will be lateral to the submandibular gland and so the surgical approach should be medial to the duct.

2. A 25-year-old male presents after an alleged assault, complaining of swelling of the left side of his mandible and difficulty opening his mouth. On examination there is tenderness and swelling of the left mandible and derangement of his occlusion. He has paraesthesia of the left side of his lower lip. An X-ray (Fig. 11.5) reveals a fracture of the left body of the mandible.
A. **Why is a haematoma of the floor of the mouth considered pathognomonic of a fracture of the mandible?**

The floor of the mouth is relatively protected in maxillofacial trauma as it is surrounded by the mandible. Unless there is an injury of the upper neck that penetrates mylohyoid or a wound from a foreign body in the mouth, the tissues of the floor of the mouth are unlikely to bleed. The mandibular bone will bleed if fractured and this will track into the floor of the mouth.

B. **Why does the patient have paraesthesia of the lip and chin?**

The mental nerve supplies the mucosa and skin of the ipsilateral lip and chin. This is a terminal branch of the inferior alveolar nerve, which passes through the body of the mandible, where it is at risk of injury from fractures and surgery. In this case, the displacement of the bone will have caused stretching and possible compression of the nerve between the fractured ends.

C. **Why does the surgical management of this fracture put the patient at further risk of paraesthesia?**

There are two reasons why a patient with a fracture of the body of the mandible may develop paraesthesia in the territory of the mental nerve postoperatively. Firstly, manipulation of the fracture to reduce it may further stretch or compress the mental nerve between the fracture ends. Secondly, access to the fracture to undertake open reduction and internal fixation will be via an incision just beneath the reflection of the alveolar mucoperiosteum on to the mucosa of the buccal sulcus. The mental nerve exits the mandible via the mental foramen between the apices of the first and second premolar teeth: the incision and exposure in this case must not be developed further forward than necessary to obtain adequate exposure.
Salivary glands

Adal H Mirza, Emma V King

Core Procedures

- Parotid gland: superficial parotidectomy, total parotidectomy
- Submandibular gland: excision of submandibular gland
- Sublingual gland: excision of sublingual gland, excision of ranula

The salivary glands are exocrine glands that discharge saliva via a duct into the oral cavity. Grossly, these can be divided into three major pairs of glands, including the parotid, submandibular and sublingual glands, and over 400 minor glands, including those in the tongue, palatine tonsils, palate, lips and cheek. The main differentiator between major and minor salivary glands is the location of the glandular portion of the tissue: major glands lie some distance from the oral cavity, connected by their respective ducts, whereas minor glands are often found within the mucosa or submucosa itself.

Saliva functions to lubricate food in anticipation of deglutition, provide vital enzymes necessary for digestion, and confer vital protection to the oral cavity from desiccation. The actions of the salivary glands are largely comparable, though their excretory compositions are not similar. The parotid gland, for example, delivers a largely serous composition, the sublingual gland a predominately mucinous, and the submandibular gland a combination of both, i.e. seromucinous.
Embryology

The development of all salivary glands, both major and minor, is similar and involves interactions between the oral ectoderm and the underlying neural crest mesenchyme. Each gland develops, by branching morphogenesis, into secretory acini with the original epithelial invagination elongating to form a duct. The neural crest mesenchyme differentiates into all of the surrounding connective tissue.

The parotid gland appears first (35–36 days post fertilization), followed by the submandibular gland (after 42 days post fertilization) and the sublingual gland (about 47 days post fertilization). Other cells that secrete saliva develop later in the submucosa of the wall of the oral cavity without significant branching.

As the salivary glands and ducts enlarge, they become interwoven with the local tissues. The parotid gland surrounds the branches of the facial nerve, local lymphoid tissue and the parotid duct (of Stensen). The duct of the submandibular gland (of Wharton) originates lateral to the tongue; its final orifice is below the tip of the tongue close to the median plane. The sublingual glands are made up of a series of anatomically distinct glands that combine to form one structural unit. Their individual ducts are retained and persist in adult life as the ducts of Rivinus, though typically a select few fuse to form a major sublingual duct, the so-called duct of Bartholin.
Surgical surface anatomy

Parotid glands

Of the three major salivary glands, the parotid glands are the largest. The parotid gland is found inferior to the zygomatic arch and directly anteroinferior to the external auditory canal (EAC) (external acoustic meatus) and temporomandibular joint. The surface markings of the parotid duct (Stensen’s duct) correspond to the middle third of a line drawn between the lower border of the tragus and a point between the nasal ala and the labial margin.

Although not absolute, the approximate location of the gland can be established by defining its borders: anteriorly, a line extending from the mandibular condyles, via the midpoint of the ipsilateral masseter to a point approximately 2 cm below the angle of the mandible; and posteriorly, a curved line extending from the tragus of the pinna, extending inferiorly below the ear lobule dorsally to the mastoid process.

To palpate the gland clinically, the patient is required to clench the jaw and the physician passes a finger intraorally and in a posteromedial direction, in the area of the vestibule. The masseter can be felt in its tonic state and the parotid gland rolled on top of it by moving the examining finger back and forth.

Submandibular glands

The submandibular gland is a small gland measuring up to 4 cm in length. It is found in the anterior triangle of the neck: specifically, the submandibular triangle in level Ib (Fig. 12.1). The largest part of the gland is usually found between the body of the mandible and mylohyoid in the floor of the mouth and is readily palpable via bimanual examination. The gland is composed of two parts – deep and superficial – joined posteriorly around the free edge of mylohyoid.
Sublingual glands

The sublingual glands are flat, narrow structures, measuring up to 2 cm in length. They are the smallest of the major salivary glands and are found directly beneath the oral mucosa, above both geniohyoid and mylohyoid.

The sublingual glands can be readily identified on intraoral examination by asking the patient to raise the tongue to the palate. Parallel to the line of the inferior dentition is a raised raphe known as the sublingual fold (plica fimbriata), on to which the multiple excretory ducts of the sublingual glands open. The gland itself lies directly below this mucosa, just posterior to the mandibular symphysis and anterior to the deep lobe of the submandibular gland.

Relations of the sublingual glands can be described as follows: superior, the mucosa of the floor of the mouth; inferior, submandibular gland and mylohyoid; anterior, lingual nerve; and posterior, lingual nerve and submandibular duct.
Clinical anatomy

Superficial parotidectomy

The goal of successful parotid surgery is the identification and dissection of the facial nerve and subsequent resection of the parotid lesion. There are several important areas of anatomy for the surgeon and these are detailed as they are encountered during the operation.

Superficial muscular aponeurotic system

The superficial muscular aponeurotic system (SMAS) refers to a fibrofatty layer enclosing the facial muscles, adhering them tightly to the overlying dermis. The SMAS attachment serves to transmit the muscle forces requisite for facial expression. In its simplest description, the SMAS extends from the platysma inferiorly to the zygomatic arch superiorly. It is confluent with the superficial temporal fascia posterosuperiorly and the galea aponeurotica anterosuperiorly. Posteroinferiorly, it is in continuity with the fascial envelope of sternocleidomastoid.2

In the lower face, branches of the facial nerve pass deep to both the SMAS and platysma.3 Dissection in this area is therefore safest above the SMAS and platysma. When dissecting in the neck, however, in the region of the marginal mandibular branch of the facial nerve, meticulous dissection in the subplatysmal plane (just on the muscle) protects the nerve because it is invested in fascia and remains in the neck to be subsequently identified and preserved. Above the zygomatic arch, the SMAS (extending as the superficial temporal fascia) splits to enclose the temporal branch of the facial nerve; while this area should not be encountered routinely in parotid surgery, the relationship of the facial nerve to the SMAS should be borne in mind.

Facial nerve

The facial nerve is the single most important structure to dissect in a parotidectomy (Fig. 12.2). Grossly, it exits the stylomastoid foramen between the mastoid process and tympanic ring and immediately enters the parotid gland.4 Within the parotid gland, usually within 2 cm, the main trunk divides at the pes anserinus to give the zygomaticotemporal and cervicofacial trunks (Fig. 12.3).3,5 These subsequently divide within the parotid gland once again to give the five final branches: the temporal, zygomatic, buccal, marginal
mandibular and cervical nerves (Video 12.1), respectively. For the most part, the gland substance covers the nerve entirely; for surgical purposes, the gland is divided into superficial and deep, relative to its position next to the facial nerve. Radiologists, on the contrary, subdivide the gland based on its relationship with the retromandibular vein. It should be noted that there is no anatomical distinction between the superficial and deep parotid lobes.³

**FIG. 12.2** Facial nerve following right-sided parotidectomy. Key: B, facial nerve branches; MT, main trunk of facial nerve.

**FIG. 12.3** Facial nerve following left-sided parotidectomy. Key: MT, main trunk of facial nerve; PA, pes anserinus.
The facial nerve may be identified in an anterograde or a retrograde fashion. Typically, the anterograde approach is favoured and so is discussed first. Several important structures can alert the surgeon to the position of the facial nerve trunk as it exits the stylomastoid foramen and they are discussed subsequently.

The tympanomastoid suture is a palpatory landmark found distal to the cartilaginous EAC and is a relatively reliable landmark. Although it is rarely visualized, dissection reveals a hard ridge at the end of the EAC. Typically, the nerve is located up to 6 mm below the tympanomastoid suture.

The tragal pointer (of Conley) is a small cap of cartilaginous tissue that extends below the helix of the auricle in a parotid dissection (Fig. 12.4). Anteromedially, the tissue forms a blunt ‘pointer’, from which it derives its name. The facial nerve is classically described as 1 cm medial and inferior to this pointer. However, this structure is not consistently reliable and at best should be considered as a guide.

Another important marker for facial nerve identification is the posterior belly of digastric as it arises from its origin, the mastoid process (see Fig. 12.4). Working from inferior to superior along the superior aspect of the posterior belly, the facial nerve can be identified as a 2–3 mm diameter structure just above the muscle.

If identification of the main facial nerve trunk is difficult, due to either tumour location or previous surgery, a retrograde approach can be
undertaken. Distal branches are identified and followed in a retrograde fashion back to the main trunk. Several surface markings can help with branch identification in a retrograde dissection. A line drawn from approximately 1 cm inferior to the tragus to 1.5 cm superolateral to the eyebrow, the so-called Pitanguy line, approximates the location of the temporal branch of the facial nerve.6

Surface markings for the marginal mandibular nerve are documented in detail below. There is limited reliable literature relating to the surface markings of the other three branches of the facial nerve (Fig. 12.5).

Miscellaneous parotid tissue structures

The superficial temporal and occipital arteries are the two terminal branches of the external carotid artery and both are found deep in the parotid viscera. The superficial temporal and maxillary veins join in the substance of the parotid gland to form the retromandibular vein. This large vein subsequently bifurcates after formation: an anterior division joins the facial vein to form the common facial vein (a tributary of the internal jugular vein), and a posterior division joins the posterior auricular vein, forming the external jugular vein. The deepest of these structures is the external carotid artery, followed by the facial nerve and finally the retromandibular vein (Fig. 12.6).
Total parotidectomy

Surgical removal of the entire parotid gland is a procedure that is not commonly performed, in comparison to the more frequently performed superficial parotidectomy. Most commonly, its indication is for the removal of deep lobe benign tumours and metastatic malignancies that have spread to intraparotid nodes deep to the facial nerve, a reminder of the absence of an anatomical barrier delineating ‘superficial’ and ‘deep’ lobes. An average of one to two lymph nodes exist deep to the facial nerve. Primary parotid malignancy is rare.

Total parotidectomy can encompass preservation or sacrifice of the facial nerve and is often performed in conjunction with a neck dissection. For simplicity, only the radical dissection is discussed, involving sacrifice of the facial nerve.

Wherever possible, branches of the facial nerve are preserved for future nerve grafting, though it is important to send nerve endings as frozen sections to ensure tumour clearance. A temporal bone resection can also be included, which may encompass excision of the temporomandibular joint, mastoid process and EAC. If there is any involvement of the lateral temporal bone, a lateral bone resection is imperative. If appropriate and macroscopically clear of disease, the proximal intra-aural portion of the facial nerve can be grafted to uninvolved nerve branch endings, using harvested nerve grafts.
Submandibular gland excision

Excision of the submandibular gland is a common operation; the most frequent indications include chronic sialadenitis and sialolithiasis. Importantly, however, excision of the gland is also part of a level 1 neck dissection (see Fig. 12.1). Three important nerves are encountered as part of a routine submandibular gland excision: the marginal mandibular branch of the facial nerve, the hypoglossal nerve and the lingual nerve. Other important clinical structures include digastric and mylohyoid.

The gland itself is anatomically divided into two parts by mylohyoid, forming a ‘J’ shape, with a larger superficial part and a smaller deep portion. From the deeper aspect, the submandibular duct (Wharton’s duct) extends anteriorly for approximately 5 cm, terminating in the floor of the mouth just lateral to the frenulum linguae. Posteriorly, a continuation of its enclosing fascial sheath, the stylomandibular ligament, continues posterolaterally to make contact with the parotid gland at its inferior portion (Fig. 12.7).

![FIG. 12.7](image-url) Demonstration of the site for the incision utilized for submandibular gland excision. Key: 1, ramus of mandible; 2, skin crease incision two fingers’ breadths below mandible.

Marginal mandibular nerve

The initial location of a cervical incision is important in order to avoid encountering the marginal mandibular branch of the facial nerve. This nerve
innervates the depressor anguli oris, used to contract the angle of the mouth inferiorly. It commonly leaves the inferior border of the parotid gland as a single branch but can sometimes be found as two or more divisions.\textsuperscript{10}

The marginal mandibular nerve normally lies less than 1.75 cm from the inferior border of the mandible.\textsuperscript{10} If the facial artery is palpated (at the anterior border of masseter over the ramus of the mandible), the surgeon can be confident that the marginal mandibular nerve is superior to the inferior border of the mandible while dissecting anterior to this artery. Posterior to the facial artery, the position of the nerve is more variable and therefore the initial transcervical incision should be directly on to the gland at a distance of at least 2 cm below the mandible, commonly measured as two fingers’ breadths.\textsuperscript{8}

Of note, the facial vein can also be used to ‘protect’ the marginal mandibular nerve. If the vein is ligated at the lower border of the submandibular gland and the cranial portion is reflected superiorly, this will retract and protect the marginal mandibular nerve in the majority of cases.

**Hypoglossal nerve**

The hypoglossal nerve supplies all muscles within the tongue except palatoglossus (supplied by the vagus nerve).\textsuperscript{11} Having exited the skull base via the hypoglossal canal, the nerve emerges from between the internal carotid artery and internal jugular vein. From here, it is accompanied by C1/C2 nerve fibres, which descend within its sheath and subsequently give rise to the ansa cervicalis. Clinically, this is thought to occur at the level of the occipital artery.\textsuperscript{12} The ansa is composed of two neural loops: the descendens hypoglossi (superior root derived from C1 spinal nerve) and the descendens cervicalis (inferior roots derived from C2 and C3 spinal nerves).\textsuperscript{12}

At the level of the occipital artery, the hypoglossal nerve becomes horizontal and passes anteriorly, superior to the surfaces of both the internal and the external carotid arteries and medial to the posterior belly of the digastric muscle en route to the digastric triangle. Most frequently, the hypoglossal nerve is encountered as it crosses level I in an anterosuperior direction from just posterior to the hyoid bone. To identify the nerve, the inferior third of the submandibular gland is retracted and the nerve is seen coursing below the posterior belly of the digastric muscle.

Of clinical note, the nerve is accompanied by the ranine veins (venae comitantes), arising from the lingual veins of the tongue. Clinically, these
veins can be troublesome, causing obscuring bleeding if disrupted. Extreme care must be taken if diathermy is to be used for haemostasis because the hypoglossal nerve can be easily damaged, either temporarily or permanently.

**Lingual nerve**

The lingual nerve is a branch of the mandibular division of the trigeminal nerve. It has a distinctive appearance, being a large, flat nerve found in the lateral aspect of the floor of mouth. Its location is related intimately to the submandibular gland duct (Wharton's duct) and it should be identified during a routine submandibular gland excision. The submandibular duct extends anteriorly from the anterior aspect of the deep lobe of the parotid gland, for 5 cm parallel to the tongue. At its exit, the lingual nerve is found superior to the submandibular duct. As it continues forwards, however, the nerve passes from medial to lateral (passing underneath the submandibular duct), en route to the medial border of the mandible, and at this point it is found inferior to the duct (Fig. 12.8).

**FIG. 12.8** The relationship of the lingual nerve (LN) to the submandibular duct (SMD). Other abbreviations: MH, mylohyoid; SMG, submandibular gland.
The lingual nerve must be identified during dissection and is not always apparent. Often, the submandibular gland must be retracted inferiorly and the mylohyoid retracted superiorly in order to visualize the nerve and confirm its position.

**Digastric and mylohyoid**

Digastric is important in that it forms the anteroinferior and posteroinferior limits to the digastric triangle, i.e. level I (see Fig. 12.1). In the context of submandibular gland surgery, the posterior belly of digastric is a useful landmark, as there are no structures to be wary of superficial to it. Important structures, including the facial artery and the hypoglossal nerve, lie directly deep to the posterior belly.

Mylohyoid is an important landmark for the surgeon, as it demonstrates the oral and cervical portions of the submandibular gland. While superior to the muscle, the surgeon should not encounter any significant neurovascular structures, since both the lingual and the hypoglossal nerves are deep to mylohyoid.

**Excision of the sublingual gland/a ranula**

A ranula (from the Latin *rana*, frog) refers to a collection in the floor of the mouth that originates from the sublingual gland; importantly, it is both extraductal and extraglandular in location. The collection can be treated via a number of approaches and the subject of best practice is not for discussion here. The following text refers to the anatomical areas of importance that arise during the excision of a simple ranula and sublingual gland.

**Intraoral excision of a ranula**

The overlying mucosa is incised without breaching the cyst itself. A submucosal dissection takes place. The submandibular duct and lingual nerve are deep to the cyst. The submandibular duct is most at risk as it crosses lateral to medial, opening just lateral to frenulum of the tongue bilaterally.

**Excision of the sublingual gland**

Sublingual gland excision can proceed following successful ranula excision. The sublingual gland is found just anterior to the submandibular duct,
immediately below the mucosa of the floor of the mouth. Its size can be deceptive and is often larger than expected, extending to the midline anteriorly and crossing the deep lobe of the submandibular gland posteriorly. As before, the submandibular duct is most at risk, being the most superficial structure of note in the floor of mouth. More posteriorly, as the lingual nerve crosses the submandibular duct, an ‘X’ is formed and represents an area for careful dissection (see Fig. 12.8). Rather as with parotid surgery, the surgeon should attempt to identify and dissect around the submandibular duct to be sure of avoiding complications.

Tips and Anatomical Hazards

Owing to its strictly inelastic nature, the tough, uncompromising and fibrous SMAS can account for the considerable pain associated with acute parotitis. Additionally, patients with chronic and insidious growths may present late, as a result of concealment under the fascia. The marginal mandibular nerve is a motor nerve, serving three muscles related to depression and protrusion of the lower lip. Damage to the nerve is often iatrogenic (during surgical procedures) and results in flattening and inversion of these muscles. The resulting cosmetic deformity means that the lower lip cannot move inferiorly or laterally, most evident when baring the teeth. This results in functional symptoms, such as drooling, and presents a cosmetic morbidity for the patient.

The hypoglossal nerve is a motor nerve. If it is damaged, the protruded tongue deviates towards the side of the lesion, the result of unopposed action of the ipsilateral genioglossus. Over time, the tongue on the side of the lesion atrophies due to a loss of muscle tone. Assessment of speech reveals a loss in the ability to form refined sounds such as ‘la’ and ‘ti’. Speech seems slurred and the patient may describe the tongue as ‘heavy’.

The lingual nerve is a sensory nerve and injury typically causes anaesthesia or paraesthesia in the ipsilateral anterior two-thirds of the tongue. Injury during submandibular gland surgery is rare and this lesion is most typically seen in patients undergoing dental surgery.
The Facial Nerve in Parotidectomy

Although the three midfacial branches of the nerve enjoy multiple cross-innervations, this is not the case for the temporal or marginal mandibular branches: damage to these nerves is much more likely to result in a palsy than elsewhere.

The posterior auricular artery crosses the main trunk of the facial nerve at the stylomastoid foramen and not only alerts the operator to the presence of the nerve, but also must be ligated for haemostasis and further careful dissection.

The Submandibular Duct in Sublingual Gland Surgery

The submandibular duct runs in an oblique direction from medial to lateral, superficially in the floor of the mouth. It follows a line from the frenulum of the tongue to the ipsilateral retromolar trigone. The surgeon should be aware of this pathway during initial dissection to avoid injury.
References

12. Chhetri DK, Berke GS. Ansa cervicalis: review of the
Single Best Answers

1. Following sublingual gland surgery, a patient presents again with symptoms of numbness along the anterolateral aspect of the tongue. Which one of the following structures is most likely to have been damaged?
   A. Hypoglossal nerve
   B. Glossopharyngeal nerve
   C. Inferior alveolar nerve
   D. Lingual nerve
   E. Facial nerve

   **Answer: D.** Numbness along the anterolateral aspect of the tongue is most likely to be caused by damage to the lingual nerve. The hypoglossal nerve is a motor nerve, the glossopharyngeal nerve supplies sensory sensation to the posterior third of the tongue only, and the facial nerve supplies special sensation to the anterior two-thirds of the tongue.

2. How is the lingual nerve best described, in relationship to the submandibular gland?
   A. A superficial structure curving under the body of the mandible
   B. A flat structure found alongside the deep lobe of the gland and intimately related to its duct
   C. A tortuous structure passing under the posterior aspect of the gland
   D. A round-bodied structure passing across the digastric triangle
   E. A motor nerve innervating muscles of the tongue

   **Answer: B.** The lingual nerve, in relationship to the submandibular gland, is best described as a flat structure found alongside the deep lobe of the gland and intimately related to its
duct. A and C describe the marginal mandibular nerve and the facial artery, respectively, and D and E describe the hypoglossal nerve.

3. Which one of the following muscles is NOT supplied by the hypoglossal nerve?
   A. Palatoglossus
   B. Genioglossus
   C. Styloglossus
   D. Hyoglossus
   E. Stylopharyngeus

   **Answer:** A. Palatoglossus is innervated by the vagus nerve.

4. For which of the following is the posterior belly of digastric an important surgical landmark?
   A. Submandibular gland
   B. Parotid gland
   C. Parotid gland and submandibular gland
   D. Facial nerve and submandibular gland
   E. Facial nerve

   **Answer:** E. Identifying the posterior belly of digastric is a highly important step in identifying the facial nerve in parotid surgery. It is usually found superior to the superior border of the muscle.

5. Which of the following structures is NOT a means of identification of the facial nerve trunk?
   A. Posterior belly of digastric
   B. Anterior belly of digastric
   C. Tympanomastoid suture
   D. Tragal pointer of Conley
Answer: B. Anterior belly of digastric is supplied by the nerve to mylohyoid, a branch of the mandibular division of the trigeminal nerve.
Clinical Cases

1. A 62-year-old female presents with a new lump on the side of her face. Her GP is concerned it may be related to an existing tumour in her parotid gland.

A. Describe the anatomy of the parotid duct.
The parotid duct is eponymously known as Stensen's duct. It is 5 cm in length and exits anteriorly from the parotid passing superficial to masseter. It continues through buccinator and opens into the oral cavity. The duct ampulla can be seen under a fold of mucosa lateral to the upper second molar.

B. Imaging and a fine needle aspiration support a diagnosis of a benign parotid tumour. The patient opts to undergo a superficial parotidectomy. Discuss important points of consent for the operation.

There are several important points to mention during consent. Complications can be divided into immediate and late.

Immediate:
- Bleeding, infection, scar
- Contour defect following resection
- Need for drain
- Temporary facial nerve paralysis

Late:
- Numbness to ear lobe and cervical skin
- Salivary fistula
- First bite syndrome
- Permanent facial nerve paralysis
- Frey's syndrome

C. Describe how to identify the main trunk of the facial nerve at operation.

There are several structures used to identify the facial nerve as it exits the stylomastoid foramen.

- The tragal pointer (the tip of the cartilage of the external auditory canal) is approximately 1 cm superficial and lateral to the trunk.
• The posterior belly of the digastric attaches to the mastoid bone. The nerve can be found 1 cm deep to the medial aspect of this attachment.
• The tympanomastoid suture (found between the mastoid and tympanic bones) is easily palpable intraoperatively. The facial nerve can be found inferior to this suture.

D. Several weeks after the operation, the patient notes that the ipsilateral side of her face sweats when she eats. Why is this?
The synkinetic mechanism for auriculotemporal (Frey) syndrome is erroneous reinnervation of denervated sweat glands and cutaneous blood vessels by regenerating parasympathetic postganglionic nerves travelling in the auriculotemporal nerve.

2. A 62-year-old female presents with a swelling under her jaw that arises after eating. Her GP is concerned it may be related to a calculus in her submandibular duct.

A. Describe the anatomical position of the submandibular gland.
The submandibular gland consists of a larger superficial and a smaller deep part, continuous with each other around the posterior border of mylohyoid. The superficial part of the gland is situated in the digastric triangle. Above, it extends medial to the body of the mandible. Below, it usually overlaps the intermediate tendon of digastric and the insertion of stylohyoid.

B. Describe how you would safely identify the marginal mandibular nerve on excision of the gland.
The marginal mandibular nerve is found just deep to the superficial layer of the deep cervical fascia. Most commonly it passes along and parallel to the inferior border of the mandible, though not uncommonly it can droop lower into the neck. To avoid the nerve, make an incision two fingers' breadths below the mandible and dissect in a subcapsular plane on the gland.

C. During her operation, an assisting junior doctor wants to know if there are any important structures related to the gland that are important surgically. Can you describe them and their important anatomical relationships to the submandibular gland?
• Facial artery: found immediately deep to the medial border of the posterior belly of the digastric, posteromedial to the gland. It can commonly be identified by its tortuous path.
• Facial vein: a large vessel that passes posterior to the gland, heading in an anteroinferior direction to join the internal jugular vein.
• Hypoglossal nerve: found inferior and deep to the gland, and deep to the tendon of the digastric.
• Lingual nerve: found just superior and deep to the gland in the lateral portion of the oral cavity. The chorda tympani nerve (a branch of the facial nerve) travels in the lingual nerve, carrying taste fibres from the anterior two-thirds of the tongue and the preganglionic parasympathetic supply to the submandibular ganglion.
Core Procedures

Surgical approaches

- Transcanal
- Endaural
- Retroauricular

Canaloplasty

- Osteoma/exostosis
- Middle meatal stenosis

Tympanic membrane

- Myringotomy tube
- Myringoplasty.
- Tympanoplasty: small, medium and large perforations

Ossiculoplasty

- Basic situation one: malleus and stapes present, incus missing
- Basic situation two: incus and stapes missing; mobile versus fixed footplate
- Basic situation three: stapes only – mobile stapes; mobile footplate; fixed footplate
Stapedotomy
Mastoidectomy: canal wall up versus canal wall down

A note on terminology
Three synonyms are used to describe the cartilaginous and bony tube that connects the external and middle ears: the terms ‘external acoustic meatus’, ‘external auditory meatus’ and ‘external auditory canal’ all appear in approximately equal measure in the anatomical and clinical literature. In the Terminologia Anatomica (used by anatomists), the entire tube is called the external acoustic meatus. Clinically, the terms ‘external acoustic meatus’ (EAM) or ‘external auditory/acoustic canal’ (EAC) may be used to define the entire tube; alternatively, the term ‘meatus’ may be confined to the round lateral opening of the EAC. In this chapter and in Chapter 14, the term external auditory canal refers to the entire tube and the term external acoustic meatus is confined to the round lateral opening of the EAC.

Introduction
The primary function of the external and middle ear is to amplify sound. The anatomical structure of the outer ear, the auricle, reflects this primary function by gathering, amplifying and directing sound into the EAC. The EAC is a closed-ended cylinder in which resonances occur at a wavelength that is four times the length of the cylinder. For the EAC, this corresponds to a resonance frequency of 2.6–3 kHz, which contributes a 10 dB gain. The entire external ear produces a broad band 15–20 dB gain between 2 and 5 kHz, which includes the important speech frequencies.

Sound waves reach the tympanic membrane and are amplified by the ossicular chain, consisting of the malleus, incus and stapes. The middle ear transformer mechanism, formed by the middle and inner layers of the tympanic membrane and ossicles, serves as an impedance matching device. Acoustic energy in air is transferred to the fluid-filled cochlea. Impedance matching is effected by the relative size difference between the tympanic membrane and the stapes footplate. The lower two-thirds of the tympanic membrane, the pars tensa, is the most important area for vibration response to sound waves. The ratio of the vibrating portion of the tympanic membrane to that at the stapes footplate results in a 17 times amplification in sound energy. The lever action of the ossicular chain results in an additional 1.3-fold
amplification of sound energy. Smaller amounts of energy transference are
effected by the fluid wave created within the cochlea as transmissions are
initiated in the oval window and travel to the round window membrane.\(^1\)

The ear surgeon’s primary role is in the extirpation of disease and re-
establishment of the natural impedance matching characteristics of the outer
and middle ear.
External ear

Surgical surface anatomy

The auricle is composed of elastic cartilage, whereas the cartilaginous portion of the EAC is composed of fibrocartilage. The auricle is attached to the EAC by an extension of cartilage from the meatus and by three ligaments. The anterior ligament is attached to the auricle from the root of the zygoma to the tragus and helical crus; the superior ligament extends from the EAC to the spine of the helix; a posterior ligament extends from the mastoid bone to the posterior portion of the concha. The auricle is attached to underlying periosteum by anterior, superior and posterior auricular muscles.

The auricle and lateral EAC are perfused by the superficial temporal and posterior auricular arteries. The medial EAC is perfused by the deep auricular artery, a branch of the first portion of the maxillary artery, which enters the EAC at the bony cartilaginous junction and extends branches along the superior bony EAC to supply the tympanic vascular ring: this surgically important portion of the superior posterior EAC is termed the ‘vascular strip’. The sensory innervation of the outer ear is variable. The EAC is innervated by branches of the trigeminal, facial, glossopharyngeal and vagus nerves. The auricular conchal bowl and posterior EAC are innervated by branches of the facial, glossopharyngeal and vagus nerves. The numerous sources of sensory innervation explain clinical findings such as the vesicular eruption with facial paralysis caused by herpetic infection of the geniculate ganglion (Ramsay Hunt syndrome) and hypeaesthesia of the conchal bowl caused by facial nerve compression from a cerebellopontine angle mass (Hitselberger's sign).

The lateral third of the EAC is cartilaginous except in its superior border, where dense fibrous tissue attaches it to the squamous portion of the temporal bone. This superior defect, the incisura, is the surgical landmark for the endaural surgical approach to the EAC and middle ear. The medial two-thirds of the EAC are composed of a complete cylinder of bone lined only with periosteum and skin, with no intervening subcutaneous tissue. The anterior and inferior walls are composed of the tympanic portion of the temporal bone, and the superior and posterior walls are formed by the squamous and mastoid portions of the temporal bone. The salient surgical landmark, the tympanomastoid suture line, runs along the posterior inferior portion of the EAC and is evident when elevating a tympanomeatal flap. The surgical boundaries of the EAC are demarcated anteriorly by the mandibular
fossa; inferiorly by the parotid gland; superiorly by the epitympanic recess (medially) and the cranial cavity (laterally); and posteriorly by the mastoid bone, forming the posterior wall.

**External ear core surgical procedures**

**Local anaesthesia**

Infiltration with local anaesthesia is useful in intraoperative vasoconstriction and managing postoperative pain. One per cent lidocaine and 1 : 100,000 parts adrenaline (epinephrine) is routinely used to inject the EAC in quadratic fashion, as well as the incisura for transcanal and endaural approaches. Preoperative antiseptic cleansing of injection sites is useful in decreasing skin flora. Comprehensive surgical site preparation is undertaken while the vasoconstrictive effects of the local infiltration are taking effect. The use of a tuberculin (TB) syringe and 25-gauge 38 mm needle is favoured. Haemostasis and the establishment of a ‘cadaveric’ appearance to the EAC following injection are important in maintaining haemostasis in a microscopic surgical environment. Postauricular infiltration of local anaesthesia is likewise useful in intraoperative vasoconstriction and management of postoperative pain. A total of 10–15 mL of 1% lidocaine with 1 : 100,000 parts adrenaline is usually injected through a 10 mL control syringe along the postauricular sulcus. Anterior inferior advancement of the needle is useful in initial hydrodissection of the postauricular fibrous attachments.

**Surgical approaches**

**Transcanal approach**

In this approach, surgery is performed through an ear speculum and requires either the surgeon’s hand to stabilize the speculum (resulting in reduced bimanual dexterity) or a speculum holder (which is cumbersome and restricts head and table mobilization during the procedure) (**Fig. 13.1**). A transcanal approach can be used with sufficiently wide EACs but is contraindicated when the anterior sulcus cannot be clearly visualized. The benefit of avoiding an endaural or postauricular skin incision must be weighed against the surgeon’s ability to visualize the entire tympanic membrane completely and ease of instrumentation in a sufficiently wide speculum, typically more than 7 mm in diameter.
Endaural approach
This is the favoured route for otological surgical access. In this approach, a small incision is made in the incisura between the tragus and helix. With the use of a number 15 scalpel, skin and subcutaneous tissue are divided, exposing the root of the zygoma. A Lempert periosteal elevator is used to skeletonize the zygoma. Bipolar Adson forceps are used to control bleeding. Curved retractors (Fisch endaural retractors) are used to provide adequate access to the entire EAC, tympanic membrane and middle ear. The wide surgical field thus afforded allows for easy use of bimanual otological instruments, including the pneumatic drill and CO₂ laser.

Postauricular approach
The postauricular sulcus is incised with a number 10 scalpel through skin and subcutaneous tissue. The anatomical plane lateral to the temporalis fascia is identified and developed inferiorly with monopolar cautery and then anteriorly by dividing the postauricular muscles. Special care is required to identify, clamp, divide and ligate the superficial temporal artery if it is encountered superiorly. A posterior flap is elevated just lateral to the mastoid periosteum and retractors can be used to maintain clear visualization of the mastoid bone periosteum and posterior external auditory wall. The operating microscope is brought into the field, and with the use of a Freer elevator, the posterior external auditory wall skin is raised off the bony EAC and sharply divided with a number 11 scalpel to allow visualization of the medial EAC.
and tympanic ring, which can be obscured by anterior bowing of the bony EAC in other approaches.

**Canaloplasty**

The EAC is lined by keratinizing stratified squamous epithelium that is in continuity with the lateral surface of the tympanic membrane. The skin of the cartilaginous lateral portion of the EAC contains sebaceous glands, superficial dermis and hair follicles, whereas the skin of the bony EAC is thin, of the order of 30–50 µm in thickness. Cerumen is a mixture of the secretory products of the sebaceous glands and ceruminous glands. The goal of canaloplasty is to achieve a full view of the entire tympanic membrane within one position of the operating microscope. This requires removal of bone or soft tissue while maintaining the epithelial lining of the EAC.

Indications for canaloplasty include recurrent otitis externa leading to impaction and retention of debris, conductive hearing loss, and interference with amplification. Obstructions of the EAC can be either bony or soft tissue in nature. Osteomas are benign bony protuberances that are usually single and occur along suture lines. In contrast, exostoses are benign bony overgrowths that are usually multiple and frequently associated with cold water exposure. Medial canal fibrosis (MCF) is an uncommon soft tissue concentric narrowing of the EAC characterized by an active progressive infected stage followed by formation of a mature fibrous plug. Maximal medical management for MCF includes local debridement, topical antimicrobials and cauterization in the active stage. When the process becomes fibrotic, surgical intervention in the form of canaloplasty, with split thickness skin grafting, is indicated.

In order to visualize bony protuberances of the EAC adequately, either exostoses or MCF, EAC skin needs to be elevated in the form of laterally or medially based flaps. The most common of these is the tympanomeatal flap, which is the standard surgical approach to the tympanic membrane and middle ear. Incisions extending from medial to lateral at 12 and 6 o'clock are gently curved into a blunt point or delineated at right angles with a tab knife; a sickle knife or roller knife is suitable for the linear incisions. Anterior extension of the superior limb to 1 o'clock on the tympanic sulcus allows anterior retraction of the tympanomeatal flap so as to visualize the lateral handle of the malleus, and the anterior malleolar ligament. Gentle palpation of the ossicles is critical in assessing ossicular mobility. A calcified anterior malleolar ligament is an important cause of conductive hearing loss due to
malleolar fixation and is the leading alternative pathology found in failed stapes surgery.\textsuperscript{2} The tympanomeatal flap is elevated off periosteum with the primary directive of ‘get on bone and stay on bone’. Otological instruments should not come into direct contact with the subcutaneous surface of the skin of the EAC: dissection should be performed using a tab knife and cotton pledget. In this way, the tab knife is in direct contact with EAC bone and cotton ball, preserving the 30–50 µm-thick EAC skin.

The endaural approach is favoured for canaloplasty with split thickness skin grafting. A split thickness skin graft is harvested from the ipsilateral shoulder or thigh using an electric dermatome (Zimmer air dermatome) set at 0.8 mm thickness. A 3 × 5 cm piece of split thickness skin graft is sufficient. A circumferential incision is made in the skin of the EAC just lateral to the stenotic plug, and the skin lining the EAC, together with the stenotic plug, is dissected from lateral to medial. Occasionally, it is necessary to remove the fibrotic plug in piecemeal fashion to gain visual access to the deeper recesses of the anterior sulcus. The dissection extends to the bony anulus of the tympanic membrane. The fibrotic tissue that includes the superficial epithelial layer of the tympanic membrane is separated from the underlying fibrous and endothelial layers of the tympanic membrane. Meticulous dissection under high-power magnification is essential to avoid entering the middle ear cleft and to prevent recurrence. Once the tissue plane of the fibrous outer epithelial layer of the tympanic membrane is identified, the dissection can be carried out from superiorly to inferiorly. If a perforation of the tympanic membrane occurs, it can be addressed with lateral placement of the split thickness skin graft, which is still performed on an intact tympanic membrane. Once the EAC has been denuded of the fibrotic plug, a 2 mm diamond drill is used to widen the bony canal to achieve visualization of the complete tympanic ring and to facilitate subsequent skin grafting. Caution is exercised to avoid transgression of the mastoid air cells posteriorly and temporomandibular joint anteriorly. Once the EAC has been adequately widened, the split thickness skin graft is cut into strips and placed on the denuded EAC bone in radial fashion. The skin graft for the tympanic membrane, if required, is separate from the radial graft used to line the bony EAC. Once the EAC has been lined with split thickness skin graft, strips of Gelfoam are placed to pack the anterior sulcus in order to minimize the risk of anterior blunting.\textsuperscript{3}

**Exostoses and osteomas**
A releasing endaural incision is typically sufficient to visualize the involved portions of the EAC. A tympanomeatal flap is elevated to expose the rounded bony overgrowth. The 2 mm diamond drill is most appropriately used to perform canaloplasty. Retaining a bony shell by drilling into the core of the osteoma can be useful in protecting overlying skin. With progressive hollowing-out of the osteoma, the bony shell can be curetted away to protect the overlying skin. More than one flap can be elevated to afford the surgical exposure necessary to complete canaloplasty for exostoses or osteomas. Anterior and laterally based exostosis can be addressed by elevating meatal flaps that are based both laterally and medially.
Middle ear

Surgical anatomy

The middle ear is an air-filled space bounded by the medial wall of the tympanic membrane laterally and the labyrinthine wall medially. Anteriorly, the carotid wall and pharyngotympanic tube (Eustachian tube, auditory tube) are important anatomical landmarks. Posteriorly, the tympanic cavity is confluent with the mastoid air cells. Superiorly, the tympanic cavity is bounded by the tegmen tympani dividing it from the middle cranial fossa, and inferiorly the cavity is bounded by the jugular wall and styloid prominence.

Sensory innervation is provided by branches of the auriculotemporal nerve (mandibular division of the trigeminal nerve) and by the tympanic branch of the glossopharyngeal nerve (Jacobson's nerve). The tympanic plexus ramifies on the surface of the cochlear promontory: it contains Jacobson's nerve (sensory and preganglionic parasympathetic fibres) and caroticotympanic nerves (postganglionic sympathetic fibres).

The external carotid artery supplies the majority of middle ear perfusion via the anterior tympanic artery and the superior tympanic and superficial petrosal branches of the middle meningeal artery. The caroticotympanic artery, derived from the internal carotid artery, anastomoses with branches from the stylomastoid, maxillary and ascending pharyngeal arteries, which are all branches of the external carotid artery. The long process of the incus is the most poorly perfused element in the middle ear and consequently is the most frequently necrosed bone in chronic middle ear disease.

The three middle ear ossicles, the malleus, incus and stapes, perform as a coordinated lever conferring mechanical advantage. Landmarks along the malleus include the head, neck and manubrium. The head of the malleus projects into the epitympanic recess and articulates with the body of the incus; the manubrium is in direct contact with the majority of the tympanic membrane. The long crus of the incus articulates directly with the head of the stapes (capitulum). The short process of the incus is an important surgical landmark in delineating the boundaries of the epitympanic space and is a most important landmark for the second genu of the facial nerve and development of the surgical facial recess. The stapes consists of a posterior and anterior crus and a footplate.

Four ligaments suspend the malleus in its anatomical position and are important surgical determinants. The anterior malleolar ligament extends from the neck of the malleus to the petrotympanic fissure; a calcified anterior
malleolar ligament is the most common cause of failure to improve conductive hearing loss in stapes surgery. The ligament for tensor tympani extends from the medial surface of the upper end of the manubrium to the cochleariform process. The latter is highly resistant to cholesteatoma and infections, and serves as an important anatomical landmark for the tympanic portion of the facial nerve. The lateral malleolar ligament extends from the malleolar neck to the tympanic notch and forms a ligamentous fold that delineates the boundaries of Prussak's space (a potential route for cholesteatoma migration). The fold forms the anterior, superior and posterior boundaries of Prussak's space. The inferior border of the space is defined by the lateral process of the malleus, and the medial border is the neck of the malleus. Laterally, a potential area of weakness in the tympanic membrane, Shrapnell's membrane, is visible on otoscopy. The superior malleolar ligament anchors the head of the malleolus to the roof of the epitympanum.

The stapedial tendon extends from the apex of the pyramidal process to the posterior surface of the neck of the stapes or posterior crus. This is an important surgical landmark because visualization of the pyramidal process is required for middle ear surgery involving the ossicles or footplate of the stapes. When stimulated, the stapedial tendon pulls the stapes posteriorly, thereby increasing the resonant frequency of the ossicular chain and attenuating sound. The stapes is about one-quarter of the mass of the other ossicles: this difference facilitates transmission of high frequencies.

**Clinically relevant applied acoustics**

Impedance matching is conferred by the following elements:

1. The full tympanic membrane surface area is of the order of 85–90 mm² whereas the stapes footplate is 3.2 mm². Despite the relatively large surface area of the tympanic membrane, only its lower two-thirds effectively vibrate. The ratio of the area of the vibrating portion of the tympanic membrane to that of the footplate of the stapes produces a 17 to 1 increase in sound energy.
2. The handle of the malleus is approximately 1.3 times longer than the long process of the incus, increasing the pressure received at the footplate of the stapes by a factor of 1.3 to 1. The transformer ratio of the middle ear is of the order of 22 to 1, a product of the combined amplification effects of the tympanic membrane and middle ear.
ossicles: this advantage translates to a gain of approximately 25 dB.
3. The natural resonance of the outer and middle ears is of the order of 500–3000 Hz.
4. The fluid wave that is established within the cochlea from the oval window to the round window establishes a phase difference with a gain of approximately 4 dB.

The hearing threshold, defined as a reference sound pressure level (SPL), is of the order of $10^{-12}$ W/m$^2$ ($W = \text{watt}$). The SPL needed to produce hearing at 1000 Hz is 20 µPa, defined as N/m$^2$ ($\text{Pa} = \text{pascal}; \text{N} = \text{newton}$). The decibel is defined as $10 \log \text{SPL}$ over the reference SPL. For comparison, normal conversational levels are typically in the order of 60 dB, whereas a gunshot measures at 140 dB. The minimum change in SPL required to give rise to a detectable change in loudness sensation is of the order of 0.2–0.4 dB. Conductive hearing loss is primarily low in frequency because a pathological state in the middle ear either increases impedance or decreases mobility: the increased resistance of the drum and ossicular chain produces a greater ‘pushback’, termed elastic recoil. In these states the natural resonant frequency of the spring-loaded system is higher and is more tightly wound, favouring the coherent transmission of higher frequencies. The maximum conductive hearing loss is an ossicular discontinuity behind an intact tympanic membrane: maximum impedance is afforded by the intact tympanic membrane, and the discontinuous ossicles provide minimal mobility. The maximal conductive hearing level is 57 dB.$^4$

**Middle ear core surgical procedures**

**Myringotomy and tympanostomy tube placement**

Otitis media with effusion is the most frequent indication for ventilation tubes and is one of the most common surgical procedures performed internationally. Chronic otitis media refers to inflammatory middle ear effusion of 30 days’ duration or more.

Tympanostomy tube placement is also performed in patients with pharyngotympanic tube dysfunction, in which chronic negative middle ear pressure results in tympanic membrane retraction. Associated conductive hearing loss, underlying incus erosion, and development of unsafe retraction pockets are relative indications for tympanostomy tube insertion.
Tympanostomy tube insertion is typically performed via the transcannal route. An anterior inferior myringotomy is performed parallel to the radial orientation of the fibres of the tympanic membrane. The middle ear should be evacuated of secretions with small-diameter microsuction. Insertion of the tympanostomy tube is then performed, with attention paid to eversion of the myringotomy edges.

**Clinical decision-making**

Selection of a tympanostomy tube has been considered a compromise between longer-duration ventilation tubes that have higher associated perforation rates, and short-duration tubes that can increase the need for repeat surgeries. Recently, intermediate-duration tympanostomy tubes have been proposed to combine the most desirable qualities of both types, by conferring control over duration of ventilation to the surgeon while maintaining low residual perforation rates.

**Myringoplasty**

Myringoplasty refers to patching a tympanic membrane perforation, without elevating a tympanomeatal flap or exploring the middle ear. Myringoplasty is indicated in small to medium, safe perforations and can be performed in an office setting. The transcannal approach is favoured in myringoplasty procedures. Perforation margins can be defistulized with use of a Rosen pick and Micro Cup forceps. The middle ear is packed with Gelfoam and a small sheet of gel film is placed in underlay fashion. Adipose tissue from the ipsilateral lobule can also be used.

**Tympanoplasty**

Tympanoplasty refers to the surgical reconstruction of the tympanic membrane after elevation of a tympanomeatal flap. This represents definitive management in the form of defistulization of perforation margins, evaluation of middle ear status, and positioning of a graft on the medial wall of the native tympanic membrane.

The majority of tympanic membrane perforations can be accessed via the endaural approach. A canaloplasty can be performed in conjunction with tympanoplasty in order to gain complete visualization of the tympanic anulus. Grafting material can be harvested from either tragal perichondrium or temporalis fascia. In the former procedure, a number 15 scalpel is used to
cut through skin and subcutaneous tissue on the medial aspect of the tragus. Tragal perichondrium is harvested off the intact tragus and pressed with Gelfoam to confer rigidity and aid placement. When the perforation involves the tip of the umbo or the handle of the malleus, dissection of these regions off the handle of the malleus is required.

Following elevation of the tympanomeatal flap, the middle ear is explored in order to lyse adhesions and to confirm the mobility of the ossicles. Gelfoam soaked in Optimyxin is then used to pack the middle ear to create a medial buttress that immobilizes the underlay graft. Tragal perichondrium is cut to an appropriate size and placed in underlay fashion to occlude the perforation in the tympanic membrane completely. The tympanomeatal flap is returned to its native position and a Gelfoam disc and a silastic disc are placed laterally to immobilize the graft and to prevent adhesions to the anterior sulcus.

A postauricular approach is indicated for large perforations of the tympanic membrane, marginal perforations, and cases that require a canaloplasty. The postauricular skin incision is carried out in the postauricular sulcus through skin and subcutaneous tissue, and elevated anteriorly. The periosteal flap is then elevated, based anterior to the tissues of the posterior EAC. The skin of the posterior wall of the EAC is then incised 2 mm deep to the external auditory meatus. This enables retraction of the auricle with periosteal flap anteriorly. The incision is then extended along the anterior meatal wall to approximately 2 o'clock, allowing elevation of the skin of the lateral wall of the EAC, in an ascending spiral tympanomeatal flap. Micro-scissors are then used to debride the remaining ascending tympanomeatal flap in an ascending spire, with retention of the tympanic anulus and its skin 2 mm laterally. The pedicle of the meatal skin flap can then be retracted inferiorly and the tympanic anulus can be elevated along its entirety (other than between 2 and 4 o'clock). Preservation of the anterior tympanomeatal angle at this point is essential to reduce blunting of the anterior sulcus and lateralization of the graft. If extensive dissection is required along the handle of the malleus, then the incudostapedial joint can be disarticulated. Perforations of the anterior and inferior quadrant of the drum are underlay-grafted above the anterior inferior tympanic sulcus, beneath the handle of the malleus, and above the posterior tympanic sulcus. Perforations that reach the anterior superior quadrant of the drum require meticulous middle ear support with Gelfoam. Elevating the tympanic anulus between 12 and 2 o'clock can allow the surgeon to pull the upper edge of the
medial graft through the resulting gap for greater support. The positioning of the graft is facilitated by division of the tympanic anulus at 6 o'clock, allowing for swinging of the tympanomeatal flaps anteriorly like wings anchored on to the remnant of the tympanic membrane. Meticulous debridement of the tip of the malleus is important to avoid burying epidermal nests. A new tympanic sulcus can be drilled along the inferior posterior edge of the EAC.  

In larger perforations of the tympanic membrane, when insufficient tragal perichondrial tissue is available, temporalis fascia can be harvested by sharp incision of the fascia with a number 15 scalpel and subfascial blunt dissection with the Freer elevator. Non-toothed Adson's forceps are used to grasp one corner of the elevated temporalis fascia, and iris micro-scissors are used to harvest a piece of tissue of sufficient size. The graft can be placed on the cutting block and an incision is made with a number 15 scalpel in the expected position for the handle of the malleus. In these cases, fascia is harvested immediately prior to use and is introduced, with the medial side facing laterally, under the anterior margin of the perforation and under the handle of the malleus. Gelfoam packing in the middle ear is essential to maintain correct positioning. The ‘swing doors’ of the tympanomeatal flap are then returned to their native position and the meatal skin flap is replaced into its normal position; Gelfoams soaked in Optimyxin are placed along incision margins. The postauricular incision is reapproximated with 3-0 Vicryl sutures and skin staples.

**Ossiculoplasty**

Upon elevation of the tympanomeatal flap to the level of chorda iter, the tympanic sulcus and chorda tympani are visible. It is preferable to enter the middle ear with use of a Rosen pick at the level of the chorda iter by dissecting the tympanic anulus free from the chorda tympani and developing this plane superiorly with a Rosen pick. Elevation of the tympanic anulus with preservation of the chorda tympani is best achieved inferiorly with a facial nerve excavator. The tympanic membrane can be retracted forward and the mesotympanum assessed. In order to gain full visibility of the middle ear, the scutum is drilled with a 2 mm diamond. Once this has been accomplished, the chorda tympani can be retracted inferiorly to access the long process of incus, stapes, stapedial tendon and the tympanic portion of the facial nerve. Drilling of the scutum is considered complete when a full view of the pyramidal process and stapedial tendon is afforded. This is
required for ossiculoplasty and stapes surgery.

Increasing barriers to impedance matching by progressive amounts of middle ear pathology are recognized. Commonly, the malleus and stapes are present, but effective articulation with the incus is missing; this is the most common finding in chronic ear disease and is due to the precarious perfusion of the lenticular process of the incus. The endaural approach is preferred in order to afford free mobility of both hands and greatest visualization. A tympanomeatal flap is raised to expose the anterior malleolar ligament and the mobility of the malleus is assessed. Preservation of the attachment of tensor tympani is prioritized in order to prevent anterior migration of the handle of the malleus. The otologist should strive to preserve the chorda tympani to prevent osseous fixation of a graft to the posterior superior canal wall.

The distance from the stapedial head to the handle of the malleus is approximately 2.5 mm. In cases of an intact but eroded incus, the remaining incus can be sculpted in autograft fashion and repositioned to provide articulation with the stapedial head: the residual long process of the incus can be rotated to point toward the geniculate ganglion, articulating under the neck of the malleus (Fig. 13.2). Notching of the long process with a small drill bit can be useful in optimizing the articulation. The residual short process of the incus would then be expected to point towards the round window. A 2 mm diamond drill can be used to sculpt a cradle into the body of the incus: a C wire serter drill (Linvatec Corporation) is useful in drilling a deep but narrow bony seat for the capitulum of the stapes. The chorda tympani can be used to stabilize this. Titanium partial ossicular replacement prostheses (PORP) can be used: they can be cut to an appropriate length and placed directly on to the capitulum of the stapes with an offset oval portion that is most effectively placed pointing towards tensor tympani for maximum mechanical advantage. Split thickness tragal cartilage is useful to cap the portion of the prosthesis that is in direct opposition to the underside of the tympanic membrane. In standard fashion, middle ear packing with Gelfoam-soaked fluoroquinolone drops is an appropriate stabilizing mechanism for ossicular reconstruction. Assessment of the stapedial tendon and division, if it is felt to be sclerotic, can be useful in increasing mechanical advantage.
Current titanium prostheses designed with a helical wire at right angles to the capitulum of the stapes (Krauss K-helix) are a notable advance. The helical pattern of titanium wire is positioned on to the residual incus, and the cap can be placed on the capitulum (Fig. 13.3). In these cases, the body and short process of the incus, with its articulation to the malleolar head, are kept intact; the deficient portion of the lenticular process is effectively reconstituted by placing bone cement on the titanium scaffolding along the expected anatomical course of the long process of the incus. The cooling time for bone cements is of the order of 4 minutes, allowing placement and moulding with a facial nerve excavator (Fig. 13.4).
FIG. 13.4  A reconstruction of an eroded left incus with bone cement placed within the helix of the titanium spiral prosthesis (arrow).
Depending on clinical indications such as middle ear status, comorbidities and age, combined or staged procedures can be planned in conjunction with tympanoplasty.

Absent or eroded incus and stapes are often encountered. When the footplate is palpated and found to be mobile, a single-step reconstruction is typically performed with a titanium total ossicular replacement prosthesis (TORP). Positioning of the TORP is similar to that of a PORP but is done directly on to a mobile stapes, with the lateral extent secured under the malleolar neck. In cases where the stapedial footplate is fixed, malleolostapedotomy can be performed by positioning a TORP into a stapedotomy (Fig. 13.5).
Stapedotomy

A limited central perforation of the footplate (stapedotomy) has largely replaced the partial or total removal of the stapedial footplate (stapedectomy). During stapes surgery, the prosthesis is typically attached to the incus, but in the context of an absent incus, a malleostapedotomy, as previously discussed, can be performed with an extended-length prosthesis (Fig. 13.6).
Surgical treatment of otosclerosis

Otosclerosis is a bone disorder restricted to the otic capsule that can progress from an early state of resorption and loose spongy bone to a more mature state of sclerotic bone. It is characterized clinically by progressive unilateral conductive hearing loss with absent stapedial reflexes. Vestibular symptoms are uncommon, but when present they constitute a contraindication to stapes surgery. Vestibular symptoms in conductive hearing loss patients should alert the surgeon to the possibility of a third window phenomenon, such as perilymphatic fistula or superior semicircular canal dehiscence, which should be investigated with high-resolution CT of the temporal bones. Otosclerosis shows a familial tendency, and a positive family history can be obtained in 50–60% of patients. Increased vasculature across the cochlear promontory can sometimes manifest as a bluish tinge on otoscopy, representing increased vascular spaces in the periosteal layer. Audiometrically, a depression (Carhart’s notch) in the bone conduction threshold at 1000 or 2000 Hz can be observed: this is eliminated after a successful stapedotomy, suggesting that it is not truly sensorineural in nature, but rather that a fixed footplate impairs bone conduction testing.

Stapes surgery employs a small opening of the stapedial footplate, removal of fixed stapedial superstructure, and attachment of the prosthesis to the
long process of the incus. Current techniques typically include an endaural incision, a CO$_2$ laser, and heat-responsive metal alloy prostheses with a fluoroplastic piston.

With the patient and all staff following CO$_2$ laser safety precautions (including wet towels to the patient's eyes and confirmation of the laser alignment beam), an endaural approach is utilized with tympanomeatal flap elevation and palpation of the anterior malleolar ligament to confirm malleolar mobility. The chorda tympani is typically identified, preserved and retracted inferiorly. The scutum is drilled down with a 2 mm diamond drill to provide a full view of the pyramidal process and stapedial tendon. In the majority of cases, laser stapedotomy can be performed with placement of the prosthesis while the native stapes and superstructure are still intact: this effectively reduces the risk of incus subluxation (Fig. 13.7).

![Fig. 13.7](image)

**FIG. 13.7** A left endaural laser stapedotomy. Key: a, chorda tympani; b, tympanic portion of the facial nerve; c, prosthetic stapes; d, long process of the incus; e, cochlear promontory.

Meticulous microdissection of any middle ear adhesions and exposure of the complete bony anulus of the oval window are integral to stapes surgery. Pre-emptive division of perforating arteries along the cochlear promontory, common in otosclerosis, is useful.

The CO$_2$ laser alignment beam is focused on the stapedial footplate.
Optimal optical working distance and defocus settings in order to achieve the desired spot size (typically of the order of 0.6 mm) should be predetermined. Stapedotomy is performed in continuous wave mode, at 2 watt for 100 msec. The bony margin is smoothed manually with a 0.6 mm Fisch perforator. A titanium stapes prosthesis is placed directly into the stapedotomy and heat-crimped on to the long process of the incus. This is done with a manual heating device or laser firing with the setting at 200 mW, 100 msec, to ensure that the heat-activated shape memory design closes gently around the incus. The incudostapedial joint can then be disarticulated, and the stapedial tendon and posterior crus are ablated with the CO$_2$ laser set at 3 W and 50 msec. This allows safe and easy down-fracture of the remaining anterior crus. Three small pieces of connective tissue are placed around the stapedotomy in order to ensure against perilymphatic leak, and the tympanomeatal flap can be returned to its native position.

**Tympanomastoidectomy**

Surgery for chronic ear disease involving the mastoid is collectively termed a tympanomastoidectomy. A canal wall up tympanomastoidectomy is performed when the posterior superior canal wall is preserved. Canal wall down tympanomastoidectomy implies removal of the posterior superior canal wall and complete exenteration of the mastoid and epitympanum. The most common indication for these procedures is the presence of keratinizing squamous epithelium, cholesteatoma, found within the middle ear or pneumatized areas of the temporal bone. Cholesteatoma can be classified as congenital or acquired. Congenital cholesteatomas occur when keratinizing squamous epithelium is retained in the middle ear, often in the region of the pharyngotympanic orifice. Acquired cholesteatoma occurs after birth as a result of invasion of the middle ear by keratinizing squamous epithelium originating from the lining of the EAC or the tympanic membrane. The term ‘primary acquired cholesteatoma’ refers to development of a cholesteatoma behind an intact tympanic membrane, whereas a secondary acquired cholesteatoma develops in the middle ear through a marginal perforation of the tympanic membrane. Acquired cholesteatomas typically arise as a result of the formation of a retraction pocket in the posterior superior attic, associated with chronic negative middle ear pressure. Retraction pocket formation leads to epithelial migration with scutum erosion and osteitis of the middle ear. Although benign, cholesteatoma can grow to destroy ossicles and threaten the facial nerve, cochlea and vestibular apparatus (Figs 13.8,
FIG. 13.8 A left canal wall up tympanomastoidectomy. A, A postauricular view of a pars flaccida cholesteatoma in a left canal wall up mastoidectomy. B, A postauricular view of incus erosion following removal of the cholesteatoma. Note the tympanic portion of the facial nerve and the intact stapes. C, The intact external auditory canal wall (arrow). D, Placement of a partial ossicular replacement prosthesis on to the capitulum of the stapes (arrow).
The goal of surgical treatment is the extirpation of the squamous epithelium and a safe, dry ear. In canal wall up tympanomastoidectomy, the combined approach to the middle ear via tympanomeatal flap and transmastoid routes permits removal of disease that is confined laterally to the incus.

The surgical steps of canal wall up tympanomastoidectomy begin with the postauricular approach, division of the auricular muscles and retraction of the auricle anteriorly. The periosteum is sharply divided along the linea temporalis and intersected at right angles extending to the mastoid tip. Periosteal elevators are then used to skeletonize the mastoid cortex. The skin of the posterior wall of the EAC is next sharply incised, allowing the auricle to be retracted with umbilical tape and retractors in order to facilitate visualization of the entire tympanic anulus. A tympanomeatal flap is elevated and the middle ear explored: surgical decision-making is based on the size and extent of the cholesteatoma (Fig. 13.10).
Middle ear cholesteatomas, in which the superior and lateral boundaries are unclear, can be assessed with rigid endoscopes. To examine the hypotympanum, sinus tympani and epitympanic space, 30° and 45° endoscopes can be inserted into the middle ear (Fig. 13.11). The decision to limit surgery depends on visual confirmation that there is no residual squamous epithelium. In the majority of cases, a canal wall up tympanomastoidectomy should be performed to confirm the status of the epitympanum, and to provide aeration by development of the facial recess. Division of the incudostapedial joint is a necessary first step to preserve sensorineural hearing when working along the ossicles.
The initial burr cut is made along the linea temporalis marking the lowest point in the dura of the middle cranial fossa. The second burr cut is along a line perpendicular to the first cut and parallel to the posterior canal wall. These burr cuts outline a triangular area, the spine of Henle, which correlates with an area directly over the lateral semicircular canal and is the surgical safe site for drilling, bounded by the dura superiorly and the sigmoid sinus posteriorly. Drilling focused deep to this region allows the antrum to be entered and identification of the lateral semicircular canal. Drilling saucerization of the margins allows deeper exposure with adequate visualization. The middle fossa dural plate is an important landmark, characterized by a non-aerated bony plate that shifts the drilling site higher. The dissection is carried forward and deep to uncover the epitympanum. Posterior saucerization allow skeletonization of the dural plate superiorly and sigmoid sinus posteroinferiorly. Cholesteatoma removal from the
epitympanum can proceed in stepwise fashion, remembering that the tympanic portion of the facial nerve lies inferior to the lateral semicircular canal. Nipping the malleolar head at its neck, with preservation of the attachment of tensor tympani, is a critical step in exenterating the epitympanum and identifying the tympanic portion of the facial nerve. The residual incus, which is usually eroded by cholesteatoma, can be removed via the epitympanum to provide a view of the second genu of the facial nerve. Nerve integrity monitoring is typically used throughout this procedure. Retrofacial air cells are exenterated. The lateral and posterior semicircular canals are identified and the retrolabyrinthine cells can be exenterated. In cases of bulky cholesteatomas, the matrix can be incised with micro-scissors and the content evacuated by suction; the cholesteatoma sac can be peeled off surrounding bone. Viewing the sac from its medial surface also permits evaluation of the condition of the lateral semicircular canal: a dark blue colour can indicate the presence of a semicircular canal fistula.

In most cases of middle ear cholesteatoma, the long process of the incus is eroded by disease. Drilling the scutum with preservation of the chorda tympani is useful in further delineation of the extent of the cholesteatoma; cortical mastoidectomy is then carried out with the use of progressively smaller drill bits.

In cases of semicircular fistula, the squamous epithelium overlying the fistula is left to the end of the procedure to minimize damage to the inner ear. In fistulas less than 3 mm, the matrix and epithelium can routinely be removed, leaving an intact endosteum. Bone dust and temporalis fascia can be used to seal a fistula.

The facial recess of the middle ear is bounded by the chorda tympani laterally and by the descending portion of the facial nerve medially. Superiorly, a ridge of bone, the fossa incudis, lodges the short process of the incus. The bone is saucerized in this area with a small diamond burr using drill movements parallel to the direction of the descending portion of the facial nerve. The superior boundary of the fossa incudis protects the second genu of the facial nerve. The facial recess is opened to remove disease from the sinus tympani and oval window, and to facilitate aeration in the mastoid. This is a key step in a canal wall up tympanomastoidectomy.

Protecting the integrity of the facial nerve and its adjacent anatomy by positively identifying the tympanic and mastoid segments of the facial nerve is an important principle in chronic ear surgery. The tympanic portion of the facial nerve extends from the geniculate ganglion to the second genu at the
level of the pyramidal eminence. Its course is delineated by important anatomical landmarks: proximally, it passes just above and medial to the posterior edge of the cochleariform process and the tendon of tensor tympani; distally, it lies above the oval window niche, just anterior and inferior to the prominence of the lateral (horizontal) semicircular canal; it passes under the base of the cog and is anterior to it. The ‘cog’ is a transverse ridge of bone demarcating the boundary between the anterior and posterior epitympanum, which extends inferiorly from the tegmen tympani and lies immediately above and slightly posterior to the cochleariform process and anterior to the head of the malleus.  

When cholesteatoma extends medial to the head of the malleus or the incus, the wall of the EAC typically requires removal (Fig. 13.12). In canal wall down tympanomastoidectomy, the bony wall of the EAC is drilled down to the level of the mastoid portion of the facial nerve. Cortical mastoidectomy by drilling deep to the spine of Henle, identification of the lateral semicircular canal and development of the epitympanum, in the same manner as in an intact canal wall up procedure, is similar. Involvement of supralabyrinthine, apical and retrofacial mastoid cells by cholesteatoma are indications for a canal wall down procedure. Bone is removed from the root of the zygoma and the anterior epitympanum. This should be continuous with the mesotympanum. The final result is a rounded kidney bean-shaped space in which the mastoid air cell, mesotympanum, epitympanum and ear canal are converted into a single smoothly contoured cavity. Reconstruction of the ossicular chain is possible when the tendon of tensor tympani and the pars tensa portion of the tympanic membrane are intact (Fig. 13.13).

Tips and Anatomical Hazards

Red flag: chlorhexidine-based preparations can lead to ototoxicity. Care must be taken to prepare the ear with safe topical preparations such as povidone-iodine. Otological surgery is uniquely dependent on patient positioning to gain an optimal binocular field of view with minimal microscope adjustment. In the manipulation of a 0.4 mm field that is routine in
otological surgery, the importance of each millimetre of binocular vision cannot be overstated. Proper positioning of the patient typically begins with mobilization of the head on a gel-filled doughnut to prevent slippage. A gel-filled shoulder roll is placed vertically under the ipsilateral shoulder to extend the neck to approximately 105° degrees to gain superior and posterior visualization. Trendelenburg positioning by 5–10° with the bed tilting both away and toward the surgeon and a remote control mechanism that is accessible during the procedure is critical in visually and manually accessing all parts of the external and middle ear.

Hair clipping above and behind the ear is useful in the postauricular approach but is not required for transcanal or endaural approaches. Perioperative intravenous antibiotics are used when operating on infected ears, or whenever the inner ear is exposed (for example in a perilymphatic fistula), or in procedures lasting more than 2 hours. A chief objective of otological surgery is a bloodless field. Small cotton balls soaked in 1 : 100,000 parts adrenaline (epinephrine) are useful otological tools and should be considered an important component of the otological instrumentation. Focused blunt dissection, such as is required in elevation of the tympanomeatal flap, elevation of the tympanic anulus, dissection of the chorda tympani, and elevation of cholesteatoma from adjacent structures, is aided by judicious use of cotton balls, which serve to protect vital structures.

In the operating theatre, use the Trendelenburg position: tilt to the side; elevate the table; angle the scope; choke up on the drill and hold it like a pen firmly close to the tip.

It is important to evaluate nasopharyngeal patency with flexible nasopharyngoscopy in patients with middle ear ventilation disorders. Adenoid hyperplasia can be associated with physical obstruction of the orifice of the pharyngotympanic tube and can serve as a bacterial reservoir for middle ear pathogens. Congenital or acquired abnormalities of the nasopharynx should be ruled out in patients with chronic middle ear ventilatory dysfunction because medical and surgical treatments can improve middle ear surgery outcomes.

The approach to successful ossiculoplasty needs to recognize the importance of the position of the tympanic membrane; integrity of the attachment of tensor tympani to the neck of the malleus; the state of the anterior malleolar ligament; and the stability of the reconstruction.
References

Further Reading


Nadol JB Jr. Causes of failure of mastoidectomy for chronic


Self-Assessment Questions

1. Which middle ear ossicle receives the least blood supply and is therefore most frequently necrosed?
   a. Stapes
   b. Malleus
   c. Incus
   d. Spine of Henle

   **Answer: (C)** The long process of the incus. The inferior tympanic artery to the middle ear is a branch of the ascending pharyngeal artery.

2. List the three standard surgical approaches to the middle ear.
   a. Endaural, transcanal, post auricular
   b. Translabyrinthine, trans canal, endaural
   c. Post auricular, endoscopic, translabyrinthine
   d. Retrocochlear, post auricular, middle fossa

   **Answer: (A)** Endaural, transcanal and postauricular. An endaural approach is favoured in middle ear surgery: an incision is performed through the skin and subcutaneous tissue of the incisure until the root of the zygomatic bone is reached and then exposed with a Lempert periosteal elevator. A transcanal approach is used when a restricted region of the tympanic membrane is accessed through the lumen of an ear speculum which is typically limited to 7-9mm in diameter. This approach requires manual traction of the speculum or the use of a specialized retractor to hold the speculum. A post auricular approach affords good access to the anterior sulcus of the external auditory canal but requires a large skin incision. The other surgical approaches are used to access the
3. Name the four fibrous structures that suspend the malleus. Which is considered the most important in ossicular surgery?
   a. Stapedial tendon, tensor tympani, lateral malleolar ligament, superior malleolar ligament
   b. Cochleariform process, anterior malleolar ligament, round window membrane, superior malleolar ligament
   c. Anterior/lateral/superior malleolar ligaments and the tensor tympani tendon
   d. Tensor tympani tendon, Schrapnell's membrane, pars flaccida, superior malleolar ligament

**Answer:** (C) The anterior, lateral and superior ligaments and tensor tympani tendon suspend the malleus. The tendon is inserted into the medial surface of the proximal manubrium and is critical in maintaining the anatomical position of the malleus in procedures that resect the malleolar head. The anterior malleolar ligament is attached onto the head of the malleus from the anterior epitympanic wall and can be abnormally calcified leading to malleolar fixation. This is the most common cause of persistent conductive hearing loss in patients who have undergone stapedotomy surgery for otosclerosis. The lateral malleolar ligament is attached to the neck of the malleus from the tympanic notch. The superior malleolar ligament is attached to the head of the malleus from the roof of the middle ear cavity.

4. Why is the nasopharynx important in middle ear disease?
   a. It can act as a reservoir for middle ear pathogens
   b. It can disrupt pharyngotympanic (Eustachian) tube function
   c. It can affect mouth breathing
   d. A and B
Answer: (D) The nasopharynx can act as a reservoir for middle ear pathogens. Nasopharyngeal obstruction can lead to pharyngotympanic tube dysfunction and poor aeration of the middle ear. As negative pressure increases in a closed middle ear due to the obstruction, fluid extravasates from the middle ear mucosa and presents as an effusion. Bacterial infection of the effusion leads to suppurative otitis media. In children who require repeat tympanostomy tube insertion, an adenoidectomy is often performed in order to optimize the middle ear status.

5. What are the chief differences in types of tympanostomy tubes?
   a. Composition material of the tympanostomy tube
   b. Shape of the tympanostomy tube
   c. Colour of the tympanostomy tube
   d. A and B

Answer: (D) Longer duration tubes are associated with an increased risk of residual perforation, possibly due to pressure-induced changes to the margins of the perforation. Shorter duration tubes can extrude before therapeutically indicated. Intermediate duration tubes with longer flanges, which employ soft materials and are designed with variable rigidities, can offer physician-guided implant duration with lower perforation rates.

6. Describe the borders of the facial recess.
   a. Chorda tympani, round window niche, lateral semicircular canal
   b. Fossa incudis, oval window niche, manubrium of malleus
   c. Descending portion of the facial nerve, tympanic portion of the facial nerve, body of incus
   d. Chorda tympani, fossa incudis, descending portion of the facial nerve
Answer: (D) The borders of the facial recess are the chorda tympani, laterally; the descending portion of the facial nerve, medially; and the fossa incudis, superiorly. These are critical landmarks in the identification of the facial nerve in patients with cholesteatoma induced erosion of normal middle ear anatomy.

7. Describe the anatomical landmarks for the tympanic portion of the facial nerve.
   a. Cochleariform process superiorly, stapes inferiorly, round window superiorly, tensor tympani tendon laterally
   b. Geniculate ganglion distally, internal auditory canal medially, fossa incudis laterally, stylomastoid foramen
   c. Pyramidal eminence rostrally, pharyngotympanic (Eustachian) tube medially, lateral semicircular canal superiorly, short process of the incus laterally
   d. Geniculate ganglion medially, cochleariform process inferiorly, stapes inferiorly, lateral semicircular canal superiorly

Answer: (D) The tympanic portion of the facial nerve extends from the geniculate ganglion to the second genu near the pyramidal eminence. Proximally, it passes above and medial to the posterior edge of the cochleariform process and extends above the oval window niche, inferior to the lateral semicircular canal. These bony landmarks are generally preserved despite chronic infection or cholesteatoma induced changes.
1. A 40-year-old healthy male presents with a 5-day history of progressive left otalgia and hearing loss. On examination, there is delay in left rapid eye blinking and a protruding left auricle, with postauricular erythema and tenderness but no bogginess. Tuning fork testing shows negative Rinne on the left (bone conduction greater than air conduction) and left referring Weber (perceived as louder on the left). Micro-otoscopy shows acute suppurative otitis media with perforation and granulation tissue.

A. Describe the most likely diagnosis and give recommendations for treatment.

The symptoms and clinical findings are suggestive of early mastoiditis. Serial micro-debridement, administration of ototopical drops through a tympanostomy tube, and intravenous antimicrobials are required. Investigations should include a complete blood count with differential analysis, C-reactive protein as a marker of inflammatory severity over time, blood cultures, and ear-specific culture and sensitivity. Broad-spectrum intravenous antimicrobials with cerebrospinal fluid penetration are indicated; they can be modified, based on culture and sensitivity results. High-resolution CT scan of the temporal bones can help to delineate the extent of disease and the possibility of cholesteatoma. Close clinical follow-up is required in the first 48–72 hours to ensure that disease does not progress. Clinical deterioration, for example, heralded by persistent fever, disproportionate pain and mastoid bogginess, should be surgically addressed. Mild lower motor facial nerve weakness is commonly due to irritation of the tympanic portion of the facial nerve, which can be dehiscent in up to 20% of the population. Progressive facial weakness, meningismus or nystagmus is an urgent surgical indication. A canal wall up mastoidectomy with facial nerve monitoring is performed for extirpation of infected bone and re-establishment of aeration.
The temporal bone contains the organs of hearing and balance. The facial nerve, internal carotid artery, sigmoid sinus and jugular bulb passage through it or adjacent to it. These are all very important or vital structures and a thorough knowledge of temporal bone anatomy is necessary for those who operate on or around it. Variants of the normal anatomy are not uncommon and can take the surgeon by surprise, even with seemingly good preoperative scan data.\(^1\) This is particularly the case when chronic infection or a tumour has destroyed much of the normal anatomy, particularly in regard to the path of the facial nerve within the facial (Fallopian) canal. In this chapter, the surgical anatomy of the temporal bone, tympanic cavity (middle ear) and mastoid are described with reference to anatomical variants. The detailed anatomy of the inner ear is not included because of constraints on length.
Embryology

The temporal bone develops from four main sources: the petromastoid part of the temporal bone, the squamous part, the tympanic part and the styloid process. The embryonic brain is supported by a sheet of condensed mesenchyme that surrounds the notochord and extends laterally to surround the invaginated otic vesicles. These mesenchymal otic capsules differentiate into cartilage by the end of stage 20 (47–50 days post fertilization). On each side, several ossification centres develop in the cartilaginous otic capsule during the fifth month and they fuse, so that this structure, destined to be the petromastoid part of the temporal bone, is almost completely ossified by the sixth month. The squamous part of the temporal bone begins to ossify from a single centre near the zygomatic root during stage 23 (53–58 days post fertilization). The tympanic part ossifies from a solitary centre around the third month and is an incomplete ring of bone at birth, deficient superiorly but already containing a groove to house the anulus of the tympanic membrane. The tympanic ring unites with the squamous part shortly before birth, and the petromastoid part fuses with it during the first year. The styloid process is derived from the cranial end of the second pharyngeal arch cartilage and ossifies from two centres, one at each end of the process, around the time of birth. The styloid process is not completely ossified until after puberty. The mastoid tip continues to elongate in early life under the influence of the pull of sternocleidomastoid as neck posture improves. As a result, in neonatal and early life, the facial nerve is very superficial, almost subcutaneous at the stylomastoid foramen and at risk when approaching the parotid gland or retromandibular region.

Facial canal

The tympanic part of the primitive facial canal, the facial sulcus, develops anteroposteriorly from the geniculate fossa to enclose the facial nerve. The mesenchyme that forms the facial sulcus undergoes endochondral ossification, while the bone that caps or closes the sulcus develops in membrane. Permanent elliptical congenital dehiscences, about 1 mm in length and caused by incomplete closure of the canal, may be found in the tympanic segment, most commonly at the second genu. These dehiscences leave the nerve vulnerable to iatrogenic damage, particularly during stapedotomy. The facial nerve, unprotected by bone, may overhang the stapes
superstructure and foot plate, or sustain heat damage if lasers are used to perforate the footplate (Fig. 14.1). The unwary mastoid surgeon can also traumatize a dehiscent facial nerve when peeling cholesteatoma matrix from the surrounding structures.\(^2\) Oval window atresia has been described in a few patients who present with non-progressive unilateral or bilateral mixed-type hearing loss. In this anomaly, the facial nerve is found to occupy the entire oval window area and the stapedial crura are absent. Surgical interventions to correct the conductive element of hearing loss have been described in which a fenestra into the vestibule is drilled immediately below the facial nerve and the incus extended with cements on which a piston can be placed.\(^3\) The provision of hearing aids is as effective and without risk of morbidity. More significant variants of the course of the facial nerve through the temporal bone have been described in detail and are often associated with other morphological abnormalities.\(^4,5\)

![FIG. 14.1](image)

An operative view of a left-sided oval window with an overhanging facial nerve that made access to the window unsafe. The patient was a middle-aged female with a history of slowly progressive, bilateral conductive hearing loss secondary to otosclerosis. Overhanging facial nerves are often bilateral.

**External auditory canal**

The external auditory canal (external acoustic meatus) develops from the dorsal end of the first pharyngeal cleft. The groove extends inwards as a funnel-shaped primary meatus, and from this the cartilaginous element and a small part of the roof develop. The dorsal end of the first pharyngeal pouch,
the tubotympanic recess, becomes filled with a solid plug of epidermal tissue and extends along the floor of the recess. The central cells of this plug degenerate to produce the inner part of the canal and the tympanic membrane. The osseous part of the external auditory canal is derived from the tympanic ring of the temporal bone.

Congenital aural atresia is often associated with dysmorphic features of the auricle (pinna), middle ear, cochlea, labyrinth and facial nerve, e.g. in Treacher Collins’, Crouzon’s and Moebius’ syndromes. These anomalies, which are often bilateral, vary in severity from partial to complete atresia and rudimentary middle ear ossicles. There is often a so-called ‘atretic plate’ of bone between the mastoid component and the cartilaginous, fibrous and epidermal elements of the dysplastic external canal.6

**Inner ear**

Development of the inner ear is extremely complex and a detailed account is outside the remit of this chapter. The process is dependent on genetic patterning and a cascade of transcription signals expressed by its intrinsic and adjacent tissues. Otic placodes, areas of neurectoderm remaining in the ectodermal epithelium after neurulation, appear lateral to the hindbrain at stage 9 (25–27 days post fertilization). Both invaginate as pits adjacent to the fifth and sixth rhombomeres of the hindbrain dorsal to the second pharyngeal cleft. At stage 12 (30–32 days post fertilization), each pit is nipped off from the surrounding ectoderm to form the otic vesicle. Regions of the vesicles differentiate to form the labyrinth and, slightly later, the cochlea, undergoing an intricate process of elongation and infolding. The surrounding mesenchyme chondrifies to become the otic capsule. Dehiscences of the otic capsule overlying the superior and posterior semicircular canals are not uncommon and can give rise to Minor's syndrome, which is characterized by autophony, a conductive hearing loss and vertigo in the presence of loud sounds, the Tullio phenomenon.7

Congenital structural anomalies of the ear are seen in 2–6/1000 births and are associated with conductive, mixed or sensorineural hearing losses. About two-thirds are non-syndromic and caused by genetic factors that are increasingly being identified. Most are associated with sensorineural hearing loss and some children can be helped by cochlear implantation.8,9 CT and MRI have played a significant part in the classification and management of these anomalies, particularly the cochlear and labyrinthine dysplasias.10
Inner ear anomalies, usually unilateral, are also associated with an increased risk of cerebrospinal fluid leaks and bacterial meningitis, from which there is a significant morbidity and mortality.\textsuperscript{11}

**Vascular anomalies**

An anomalous course of the internal carotid artery may result from abnormal development of the stapediohyoid and cervical carotid arteries of the neck. It may enter the temporal bone in the hypotympanum and turn forwards beneath the oval window (fenestra vestibuli). The stapedial artery normally atrophies during the third month of fetal life; the hyoid remnant becomes the caroticotympanic artery that anastomoses with the inferior tympanic artery over the promontory. If the stapedial artery persists, it passes between the crura of the stapes, turns anteriorly and either replaces the middle meningeal artery or joins the arteries that accompany the three divisions of the trigeminal nerve.\textsuperscript{12,13}

The height of the jugular bulb, which may not be covered by bone, is variable and occasionally is extremely high.\textsuperscript{1} It can fill the middle ear cleft and give the otoscopic appearance of a blue drum. In some, it is in contact with the tympanic anulus and puts these patients at risk of serious haemorrhage when the anulus is lifted during a tympanoplasty. Undertaking a myringotomy if the appearance of the drum is misdiagnosed as a cholesterol granuloma can be disastrous. The position of the sigmoid sinus or height of the jugular bulb must be considered carefully before undertaking a transtemporal approach to the internal auditory canal. The surgeon should be aware that the sigmoid sinuses may vary in size, one being dominant or even solitary (Fig. 14.2).\textsuperscript{14}
An MRV (A) and T1 Gd enhanced axial MRI (B) showing a high right jugular bulb that has filled the right middle ear and blocked the right mastoid antrum. The left sigmoid sinus was rudimentary. The otoscopic appearances were those of a blue drum, which the clinician mistook for a cholesterol granuloma. The patient was a child of 8 years and a myringotomy was undertaken. Only then was the correct diagnosis realized. The clinician and patient were fortunate that the myringotomy blade did not perforate the jugular bulb, as the resulting haemorrhage and outcome could have been fatal.
Surgical surface anatomy

The asterion is palpable as a depression 1–2 cm behind the auricle at a level that approximates the junction of the upper one-third and lower two-thirds of the auricle. It marks the junction of the occipitomastoid, parietomastoid and occipitoparietal sutures, and denotes the approximate position of the transverse sinus where it turns inferiorly to become the sigmoid sinus. It is a useful landmark when making the incision for a retrosigmoid approach to the cerebellopontine angle, when it is important to have the sigmoid sinus as the most anterior element of the exposure. Similarly, in a translabyrinthine approach to the angle or an infratemporal approach to the jugular fossa, as in jugular paraganglioma surgery, it ensures that the incision is sufficiently posterior to the sigmoid sinus to enable good exposure and facilitates safe ligation of the sinus.

Studies have been undertaken to examine the relationship of surgical landmarks on the lateral surface of the mastoid and external auditory canal with deeper structures. The temporal line, external auditory canal, mastoid tip, occipitomastoid suture and the suprameatal spine (Henle's spine) have been correlated with a low-lying dura mater, an anteriorly located sigmoid sinus and a more lateral course of the facial nerve. However, fine-cut temporal bone CT, which should be available to every surgeon before operation, renders this information largely academic.
Clinical anatomy

The temporal bone is divided conventionally into four component parts. This reflects its embryological development and primary ossification sites, i.e. squamous, petromastoid, tympanic and styloid process. The lateral, medial and inferior aspects of the temporal bone are illustrated in Figs 14.3–14.5, respectively.

**FIG. 14.3** The lateral aspect of a left temporal bone.
Squamous part
This overlies the lateral and part of the inferior aspect of the temporal lobe. It
fuses with the petromastoid portion inferiorly and is separated from the parietal bone anterosuperiorly by a suture. The anteroinferior border adjoins the greater wing of the sphenoid bone. Its internal surface is concave and contains depressions that correspond to the convolutions of the temporal gyri; it is grooved by the middle meningeal vessels. The external squamous temporal surface is smooth and slightly convex; it forms part of the temporal fossa, to which tempoparietalis is attached. The supramastoid crest curves backwards and upwards across the posterior element to give attachment to the temporal fascia. The zygomatic process projects anteriorly from the squamous part. The anterior part of the zygomatic process is thin and flat, and provides attachment for the temporal fascia on its superior border. Its inferior border gives origin to part of masseter; the remainder of the muscle is attached to the concave medial surface. Anteriorly, the zygomatic process articulates with the temporal process of the zygomatic bone to form the zygomatic arch. Immediately posterior to the zygomatic process is the mandibular fossa, limited anteriorly by the articular tubercle or eminence of the zygomatic process. The articular surface of the mandibular fossa is smooth, oval and concave. The fossa contains the articular disc of the temporomandibular joint, and posteriorly is separated from the tympanic part of the temporal bone by the squamotympanic fissure.

**Petromastoid part**

The petromastoid part of the temporal bone contains the middle and inner ear, facial nerve, internal carotid artery and sigmoid sinus.

**Petrous element**

The petrous element lies wedged between the sphenoid and occipital bones. It is pyramidal in shape with a base, apex and three surfaces: anterior, posterior and inferior. The base adjoins the squamous portion of the temporal bone and forms part of the skull base itself. The apex lies between the posterior border of the greater wing of the sphenoid and the basilar part of the occipital bone, and contains the anterior opening of the carotid canal. The anterior surface forms part of the floor of the middle cranial fossa and is in continuity with the internal surface of the squamous part of the temporal bone. The trigeminal ganglion leaves an impression on this surface just behind the apex. Bone anterolateral to the trigeminal impression provides the roof of the carotid canal, internal auditory canal, cochlea and labyrinth.
The most conspicuous landmark is an eminence – the arcuate eminence, which is raised by, but not directly over, the superior semicircular canal. Laterally, the anterior surface roofs the vestibule of the inner ear and part of the facial nerve canal. A thin region of this surface, the tegmen tympani, roofs the mastoid antrum and middle ear, extending forwards to contribute to the bony part of the pharyngotympanic tube (Eustachian tube) and the canal for tensor tympani. A groove on the tegmen tympani houses the greater petrosal nerve (greater superficial petrosal nerve) as it courses forwards towards the foramen lacerum. The posterior surface of the petrous element contributes to the anterior part of the posterior cranial fossa. The internal auditory canal opens on to this surface and contains the vestibulocochlear and facial nerves and the labyrinthine artery. The opening of the vestibular aqueduct, which contains the endolymphatic duct and sac, is posterior to the internal auditory canal. The inferior surface of the petrous element is part of the external surface of the skull base. An area of bone towards its apex on this surface gives some attachment to levator veli palatini and the cartilaginous part of the pharyngotympanic tube. Behind this area is the opening of the carotid canal and further posteriorly is the jugular fossa. The stylomastoid foramen lies posterolateral to the jugular fossa and posterior to the base of the styloid process.

**Mastoid element**

The mastoid element forms the posterior aspect of the temporal bone. Its outer surface provides attachment for occipitofrontalis and auricularis posterior. An emissary vein of very variable size exits from a foramen near its posterior border. The mastoid process projects downwards to a tip that provides attachment on its lateral surface for sternocleidomastoid, splenius capitis and longissimus capitis. The posterior belly of digastric is attached to its medial surface in a deep notch. A wide, curved groove on the internal surface of the mastoid indicates the site of the sigmoid sinus.

**Tympanic part**

The tympanic part of the temporal bone is a curved plate of bone below the squamous part and anterior to the mastoid process. It fuses with the petrous and squamous parts, and its concave posterior surface forms the anterior wall, floor and part of the posterior wall of the external auditory canal, while its concave anterior surface is the posterior wall of the mandibular fossa. Its
rough lateral border forms most of the margin of the osseous part of the external auditory canal. The tympanic membrane lies in a narrow groove on its medial surface, the tympanic sulcus. The petrotympanic fissure is anteromedial; it contains the anterior malleolar ligament, the anterior tympanic branch of the maxillary artery and the chorda tympani nerve.

**Styloid process**

This projects anteroinferiorly from the inferior aspect of the temporal bone. Its length is extremely variable. In some individuals it can be 3–4 cm in length, while in others it is very rudimentary. Its base is ensheathed by a split in the lateral aspect of the tympanic plate, the vaginal process. The styloid process provides attachment for stylopharyngeus, stylohyoid and styloglossus. The stylomastoid foramen lies between the styloid and mastoid processes; the facial nerve emerges from the skull into the parotid gland together with the stylomastoid artery through the stylomastoid foramen.

**External auditory canal**

The external auditory canal runs from the concha of the auricle to the tympanic membrane and is about 2.5 cm in length. The lateral one-third is cartilaginous and is continuous with the auricular cartilage, and the medial two-thirds are bony. Initially directed medially, anteriorly and slightly upwards, the canal then runs posteromedially and finally anteromedially and slightly downwards. In some patients, this sigmoid course can be quite pronounced and obstruct a view of the entire tympanic membrane. Generally oval in cross-section, it has two constrictions: one is at or near the junction of its cartilaginous and bony parts, while the other lies within the bony canal closer to the tympanic membrane and is called the isthmus. The floor and anterior wall of the canal are longer than the roof and posterior wall, causing the tympanic membrane to be obliquely positioned at the medial end of the canal. This obliquity is most marked in the neonate, where the tympanic membrane is almost horizontal.

MacEwan’s triangle is a surgical landmark just posterosuperior to the external auditory canal, which marks the lateral wall of the mastoid antrum. It is defined as the area beneath the supramastoid crest, behind the posterosuperior margin of the external auditory canal and a line tangential to the posterior margin of the canal.
The posterior auricular artery, deep auricular branch of the maxillary artery and the auricular branches of the superficial temporal artery supply the external auditory canal. Veins drain into the external jugular and maxillary veins and the pterygoid plexus. Lymphatics drain into pre- and postauricular nodes. The auriculotemporal branch of the mandibular nerve provides sensation to the anterior and superior walls, while the auricular branch of the vagus and sensory component of the facial nerve supply the posterior and inferior walls.

**Tympanic membrane**

This is thin, semi-transparent and almost oval in shape. It forms part of the lateral wall of the tympanic cavity. It is thickened peripherally to form a fibrocartilaginous ring – the anulus, which lies in the tympanic sulcus. This sulcus is incomplete and deficient superiorly in the attic, leaving a notch. The anterior and posterior malleolar folds extend from the edges of this notch to the lateral process of the malleus, defining a visible border between the upper and thinner part of the tympanic membrane – the pars flaccida – from the thicker and taut inferior part – the pars tensa. The handle of the malleus is firmly attached to the medial surface of the tympanic membrane as far as its centre – the umbo, which projects towards the tympanic cavity. The external surface of the tympanic membrane is therefore concave, centred on the umbo. The tympanic membrane has a trilaminar structure composed of an outer cuticular layer, an intermediate fibrous layer and an inner mucous layer. The fibrous element has an outer layer of radiating fibres that emerge from the handle of the malleus and a deeper, sparser layer of circular fibres. The tympanic membrane is mainly innervated by the auriculotemporal nerve with contributions from branches of the facial, glossopharyngeal and vagus nerves.

**Tympanic cavity**

This has a roof, floor and lateral, medial, posterior and anterior walls. It contains air, is lined by a mucous membrane, and communicates with the nasopharynx through the pharyngotympanic tube, and with the mastoid air cells posteriorly through the aditus of the mastoid antrum. It measures approximately 15 mm wide both anteroposteriorly and vertically, 6 mm superiorly and 4 mm inferiorly, narrowing to 2 mm at the level of the umbo.
The tympanic cavity contains three small bones or ossicles: the malleus, incus and stapes. They form a connecting chain – the ossicular chain, which conducts auditory vibration from the tympanic membrane to the inner ear (Ch. 13). By convention, the tympanic cavity is divided into three zones. The zone above the tympanic segment of the facial nerve is called the epitympanum; the zone between the tympanic segment of the facial nerve and the inferior margin of the tympanic membrane is the mesotympanum; and the zone beneath the mesotympanum is the hypotympanum.

The roof of the tympanic cavity is a very thin plate of compact bone – the tegmen tympani. It separates the cranial and tympanic cavities; veins pass through it to drain into the superior petrosal sinus. The floor is a thin, convex plate of bone raised by the jugular bulb and is often deficient in places. The tympanic branch of the glossopharyngeal nerve exits through a foramen adjacent to the medial wall. The tympanic membrane, surrounded by a ring of bone, forms the lateral wall. The superior aspect of this wall is shaped like a shield – the scutum – and constitutes the lateral aspect of the attic of the middle ear.

The most conspicuous landmark in the anterior wall of the tympanic cavity is the opening of the pharyngotympanic tube. Below this opening, the bone is relatively thin and covers the posterior aspect of the internal carotid artery. Tympanic branches of the artery and caroticotympanic nerves perforate this wall. The internal carotid artery turns forwards at the entrance of the pharyngotympanic tube and runs medial to it. The canal for tensor tympani runs in the roof of the pharyngotympanic tube, ending in the cochleariform process, which marks the geniculate ganglion at the first genu of the facial nerve. At this point, the tendon of tensor tympani emerges to attach itself to the upper part of the handle of the malleus. Both the pharyngotympanic canal and the canal for tensor tympani pass anteriorly, pursuing a downward and anteromedial course and eventually opening in the angle between the squamous and petrous parts of the temporal bone. They are separated by a thin partition of bone throughout their course.

The medial wall of the tympanic cavity is dominated by the promontory – the dense bone that is the otic capsule – overlying the basal turn of the cochlea. The tympanic plexus of nerves runs in small grooves on its surface. The oval window lies posterior to the promontory and is sealed by the footplate of the stapes sitting in an anular ligament. Below this is the round window (fenestra cochleae), within a deep niche that often contains mucosal folds and is overhung by the promontory.
The tympanic part of the facial nerve canal (Fallopian canal) runs horizontally across the medial wall just above the promontory, from the cochleariform process (marking the first genu) to the oval window (the second genu), where it turns into the posterior wall of the tympanic cavity, coursing inferiorly towards the stylomastoid foramen. The sinus tympani lies deep to the facial nerve canal in the posterior wall. Lateral to the facial nerve and posterior to the oval window is a small projection of bone – the pyramidal process – through which the stapedial tendon passes towards the capitulum of the stapes. Above and behind the facial nerve at the second genu is a prominence, formed by the part of the otic capsule that surrounds the lateral semicircular canal. It is at this point that the middle ear communicates with the mastoid air cells via the aditus of the mastoid antrum. The short process of the incus sits in a depression – the fossa incudis – in the anteroinferior part of the aditus, to which it is attached by ligaments.

**Mastoid air cell system**

This is variable in its extent, both between sides and between individuals. It is rudimentary at birth and develops progressively until puberty. In some individuals, the air cells extend into the apex of the temporal bone and even into the zygomatic process. Air cells that develop in the squamous part of the temporal bone become separated by a bony septum – Körner's septum – from those deeper in the petrous bone. At surgery, this septum can be mistaken for the posterior entrance to the mastoid antrum. In other individuals, the entire bone may be almost devoid of air cells. The mastoid air cells open into the middle ear through the aditus. The descending part of the facial nerve canal lies in the anterior wall; the posterior semicircular canal within the otic capsule lies medially. The sigmoid sinus is posterior, running towards the jugular bulb; in well-pneumatized bones numerous air cells are often found posterior to the sigmoid sinus. The roof of the mastoid air cell system is formed by a continuation of the tegmen tympani. The attachment of the posterior belly of the digastric is denoted by a conspicuous ridge of bone – the digastric ridge – in the mastoid tip. The anterior limit of this ridge is a very valuable surgical landmark for the facial nerve at the stylomastoid foramen (**Fig. 14.6**).
Chorda tympani

The chorda tympani is a branch of the facial nerve that emerges from the facial nerve about 6 mm above the stylomastoid foramen. It travels in its own canal just lateral to the main trunk of the facial nerve and enters the middle ear at a variable level that is always 3–4 mm below the oval window. The chorda tympani is easily visible behind the tympanic membrane as it arcs across the middle ear cavity passing between the handle of the malleus and long process of the incus, and finally leaving the middle ear through the petrotympanic fissure.

Tips and Anatomical Hazards

It is important to be aware that the facial canal (Fallopian canal) may not be complete throughout the temporal bone. Congenital or acquired
dehiscences are not uncommon. Congenital dehiscences that result from incomplete closure of the encircling mesenchyme in the embryo are most common around the oval window and tympanic segment. It is here that the facial nerve is susceptible to heat injury during laser stapedectomy. Extensive dehiscences around the oval window may allow the facial nerve to prolapse over the oval window.

An aberrant course of the entire facial canal may be heralded by, or associated with, an abnormal auricle or craniofacial abnormality. In these patients, the facial nerve may run across the promontory and be completely uncovered, appearing like a thickened and flattened area of mucosa.

Bifurcation of the facial nerve may be found in the mastoid segment of the nerve just above the stylomastoid foramen and may be mistaken for the main trunk and chorda tympani.

Erosion of the canal by cholesteatoma or tumour is often a factor that predisposes to iatrogenic damage by the unwary surgeon exploring the middle ear and mastoid. Facial nerve monitoring helps to avoid this but is no substitute for a sound anatomical knowledge.

The mastoid process is absent or underdeveloped in the neonate or young child. As a result, the facial nerve is very superficial as it exits the stylomastoid foramen: surgeons operating on the parotid in children must be aware of this possibility.

The jugular bulb is of variable height and can fill the tympanic cavity rather than be restricted to the hypotympanum. Its bluish appearance through the tympanic membrane resembles the ‘blue drum’ of a cholesterol granuloma. Surgeons have been known to perform a myringotomy on the jugular bulb!

Aberrations of the course of the internal carotid artery may partially obstruct the pharyngotympanic tube and be visible through the tympanic membrane. A persistent stapedial artery – part of the developmental anatomy of the internal carotid artery – may also be encountered and appear as a vessel running across the promontory, through the crura of the stapes and across the facial nerve to replace the middle meningeal artery.
References


Further Reading


1. Which one of the following statements concerning the facial canal and facial nerve is correct?
   A. Dehiscences are most common around the first genu
   B. The anterior part of the digastric ridge marks the stylomastoid foramen
   C. They contain secretomotor fibres to the lacrimal and parotid gland
   D. Bifurcation of the facial nerve in its mastoid segment is often encountered
   E. The landmark for the geniculate ganglion is the cochleariform process at the second genu

   Answer: B.

2. Which one of the following statements concerning the internal carotid artery is correct?
   A. It runs lateral to the pharyngotympanic (Eustachian) tube
   B. It does not give off branches in the temporal bone
   C. It may be mistaken for a tympanic paraganglioma on otoscopic examination
   D. It gives a vascular supply to the facial nerve

   Answer: C.

3. Which one of the following statements concerning the tympanic membrane is correct?
   A. It is a bilaminar structure composed of an outer cuticular layer and an inner mucosal layer
   B. A thickened area peripherally sits in a groove in the tympanic bone
C. The auriculotemporal nerve is the sole provider of sensory innervation
D. The chorda tympani traverses the middle ear medial to the pars flaccida
E. The jugular bulb is seen as a bluish area in the hypotympanum on otoscopic examination

Answer: B.
Self-Assessment Question

1. Identify the structures labelled in the CT scan (Fig. 14.7).

Answer: a, head of the malleus; b, short process of the incus; c, tympanic segment of the facial nerve; d, posterior semicircular canal; e, basal turn of the cochlea; f, vestibule.
Clinical Case

1. A 55-year-old female presented with a sudden conductive hearing loss in her right ear that developed after a fit of coughing a few weeks earlier. It had not resolved spontaneously and there was neither discharge, otalgia nor any other ontological history. She was referred to an ENT surgeon who arranged a CT scan of her temporal bones (Fig. 14.8).

![Coronal CT scans of the patient's temporal bones.](image)

**A. What does the CT scan show?**

The CT scan shows a collection of fluid in her right mastoid and middle ear.

**B. What is the likely diagnosis?**

Secretory otitis media or CSF. The tegmen tympani is extremely thin and deficient in places on both sides. Her episode of coughing and associated increased intracranial pressure might have provoked a dural tear and CSF leakage. The otologist failed to consider this and performed a myringotomy with the insertion of a ventilation tube. CSF flowed freely and did not stop. A middle fossa repair of her fossa floor was necessary that both stopped her CSF leak and restored her hearing. There was no recurrence.
Neck

Core Procedures

- Neck dissection (selective (also called functional), modified radical and radical)
- Submandibular gland excision
- Branchial cyst excision
- Lymph node biopsy
- Access for microvascular anastomosis

The anterior neck extends from the skull base (inferior surface of the clivus) above to the root of the neck below. From a surgical perspective, it may be divided into anterior and posterior triangles (Fig. 15.1A), which are further subdivided into levels that are useful for conveying information about lymph node location, particularly in oncology practice (Fig. 15.1B; Table 15.1). The posterior neck lies behind trapezius, extending from the level of the superior nuchal line above to the level of the vertebra prominens (the seventh cervical vertebra) below. It contains seven cervical vertebrae, the cervical portion of the spinal cord, the vertebral arteries and veins, cervical postvertebral muscles and associated soft tissues. This area is rarely operated on by head and neck surgeons and is usually the remit of the spinal surgeon (Ch. 32). The root of the neck (the cervicothoracic junction) is the area bounded by the two first ribs on either side, the sternal notch anteriorly, and the upper border of the first thoracic vertebral body posteriorly.
Splenius capitis
Sternoceleidomastoid
Levator scapulae
Trapezius
Scalenus medius
Scalenus anterior
Inferior belly of omohyoid
Clavicle
FIG. 15.1  Triangles of the neck. A. The anterior and posterior triangles of the neck, left lateral aspect. The interval between the upper attachments of sternocleidomastoid and trapezius is not normally as extensive as shown here. B. The neck triangles are subdivided clinically into levels; the posterior triangle is divided into level Va (the area above the accessory nerve) and Vb (the area below the accessory nerve). (Adapted with permission from R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray’s Anatomy for Students, second ed., Elsevier, Churchill Livingstone. Copyright 2010.)
### TABLE 15.1

## Surgical levels of the neck

<table>
<thead>
<tr>
<th>Level</th>
<th>Boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>The submental triangle, formed by the anterior bellies of the digastric and mylohyoid muscles.</td>
</tr>
<tr>
<td>Ib</td>
<td>The submandibular triangle, formed by the anterior and posterior bellies of digastric and the body of the mandible.</td>
</tr>
<tr>
<td>IIa</td>
<td>The region anterior to the accessory nerve, bounded by the digastric muscle superiorly and either the hyoid bone (clinical landmark) or the carotid bifurcation (surgical landmark) inferiorly, down to the prevertebral fascia.</td>
</tr>
<tr>
<td>IIb</td>
<td>The region above and posterior to the accessory nerve, extending to the skull base.</td>
</tr>
<tr>
<td>III</td>
<td>Extends from the carotid bifurcation superiorly to either the cricothyroid notch (clinical landmark) or the omohyoid muscle (surgical landmark). Note that the position of omohyoid moves with head position and so the inferior extent of this level can be arbitrary.</td>
</tr>
<tr>
<td>IV</td>
<td>Extends from omohyoid superiorly to the clavicle inferiorly and contains the lower jugular nodes.</td>
</tr>
<tr>
<td>V</td>
<td>The posterior triangle, bounded posteriorly by the anterior border of trapezius, anteriorly by the posterior border of sternocleidomastoid and inferiorly by the clavicle. Divided into level Va (above) and Vb (below) by the accessory nerve as it crosses the posterior triangle.</td>
</tr>
<tr>
<td>VI</td>
<td>The anterior neck compartment, extending from the level of the hyoid bone superiorly to the suprasternal notch inferiorly. On each side, the lateral boundary is the medial border of the carotid sheath.</td>
</tr>
</tbody>
</table>
Embryology

During the fifth week, the second, third and fourth pharyngeal clefts form part of a retrohyoid depression, the cervical sinus. This sinus is bordered by the hyoid arch cranially, a ridge formed by the ventral extensions of the occipital myotomes dorsally, and by mesenchyme that will encompass sternocleidomastoid and trapezius. The fusion of the hyoid arch with the ectoderm covering the pericardium excludes the lower arches from the skin of the neck and results in platysma, bounded both superficially and deep with superficial fascia, passing along the neck to the anterior thoracic wall. The presence of remnants of the cervical sinus, termed branchial cleft cysts, is of surgical relevance. These cysts present at an average age of 20–30 years, usually as soft neck lumps, and typically located anterior to sternocleidomastoid. Branchial cleft cysts may be either superficial or deep to the carotid tree; most are located lateral to the carotid space. It is important to differentiate between a branchial cyst and metastatic squamous cell carcinoma, particularly in patients over the age of 40 years at presentation.
Surgical surface anatomy

Evidence-based surface anatomy gives a guide to the surgical levels of the neck (Fig. 15.2; see Table 15.1).\(^2\) The hard palate lies at the level of the anterior arch of the atlas (C1); the angle of the mandible is easily felt and lies at the level of C2. The body of the hyoid bone is located approximately 2 cm directly superior to the thyroid notch at the level of the body of C3. The midline thyroid notch is readily palpable and often visible (particularly in the male): it lies at the level of the upper border of the fourth cervical vertebra (C4), or the intervertebral disc between C3 and C4. The superior borders of the thyroid laminae can be felt on either side of the thyroid notch. The anterior arch of the cricoid cartilage lies approximately 1 cm directly below the lower border of the thyroid cartilage at the level of C6; the interval between the thyroid and cricoid is bridged by the tough median (anterior) cricothyroid ligament, which is the thickened central portion of the conus elasticus. At this level, the rather prominent transverse processes of C6 may be palpated on either side of the midline and can sometimes be confused with a neck lump; ultrasound or a cervical X-ray will readily confirm it to be bone. The sternal notch of the manubrium sterni is at the level of the upper part of the third thoracic vertebra (T3).
FIG. 15.2  Surgically relevant surface anatomy of the neck. A, The parotid gland and duct, cranial nerves VII and XI, cutaneous branches of cervical plexus and internal
jugular vein. Key: 1, porion line; 2, zygomatic sutural line; 3, zone of location of the (fronto)temporal nerve; 4, parotid gland; 5, zone of location (white) of the parotid duct (green line): sits within 1.5 cm of the middle half of a line passing from the lower tragus to the chelion; 6, lower tragus–chelion line; 7, marginal mandibular nerve; 8, zone of emergence of the cutaneous branches of the cervical plexus (white), posterior to the middle third of sternocleidomastoid; 9, zone of location of the accessory nerve, from 3–10 cm below the tip of the mastoid process to 1–10 cm above the insertion of trapezius into the clavicle; 10, hyoid bone; 11, thyroid cartilage (laryngeal prominence); 12, cricothyroid ligament/membrane; 13, cricoid cartilage; 14, external jugular vein; X (blue), angle of the mandible; X (red), facial artery and anterior border of masseter crossing the lower border of the mandible; X (orange), superficial temporal artery. B, The anterior and posterior triangles of the neck. Key: 1, thyroid notch with thyrohyoid ligament (indented region) above; 2, laryngeal prominence; 3, median cricothyroid ligament; 4, cricoid cartilage; 5, isthmus of thyroid gland; 6, greater supraclavicular fossa (of posterior triangle); 7, sternal head of sternocleidomastoid; 8, common carotid artery; 9, lesser supraclavicular fossa overlying the internal jugular vein; 10, clavicular head of sternocleidomastoid; 11, course of brachial plexus (upper trunk); 12, subclavian artery; 13, trapezius. (A, Adapted from R.L. Drake, A.W. Vogl, A. Mitchell, et al (eds), Gray’s Atlas of Anatomy, Elsevier, Churchill Livingstone. Copyright 2008. B, From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 26.11.)

The approximate course of the (spinal) accessory nerve can be mapped by dividing sternocleidomastoid into thirds and drawing a line from the junction of the upper and middle thirds to a point on the anterior border of trapezius about 5 cm above the clavicle: it is important to appreciate that both points vary considerably. The accessory nerve also lies approximately 1 cm above the point at which the great auricular nerve comes round the posterior border of sternocleidomastoid. The great auricular nerve (C2,3) can be mapped prior to raising a skin flap for neck dissection, face lift or parotidectomy by marking the midpoint of sternocleidomastoid approximately 6.5 cm below the external acoustic meatus. The nerve is approximately 1 cm posterior to the external jugular vein (EJV) and can readily be found once the EJV has been identified; its root is also seen when dissecting deep to sternocleidomastoid (Fig. 15.3A) and this should be preserved when possible to maintain earlobe sensitivity.
FIG. 15.3  A, Left neck dissection showing the phrenic nerve (C3,4,5) at the end of the tissue forceps deep to the prevertebral fascia, crossing from lateral to medial on scalenus anterior. The sympathetic chain is shown with white arrows and the great auricular nerve root with a blue arrow. The accessory nerve (asterisk) can be seen entering the retracted sternocleidomastoid. B, Vessels and nerves of the neck, left lateral view. Sternocleidomastoid and the greater part of omohyoid and the internal jugular vein have been removed. The brachial plexus emerges between scalenus anterior and medius more laterally in the posterior triangle. (B, With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)
Clinical anatomy

Muscles of the neck

Muscles in the anterior region are organized into supra- and infrahyoid groups, and, with one exception (sternothyroid), have an attachment to the hyoid bone. The suprahyoid muscles, which connect the hyoid bone to the mandible and the base of the skull, include mylohyoid, geniohyoid, stylohyoid and digastric. The infrahyoid (strap) muscles connect the hyoid to the thyroid cartilage, sternum, clavicle and scapula, and are arranged in two planes: a superficial plane consisting of sternohyoid and omohyoid, and a deep plane consisting of sternothyroid and thyrohyoid. Omohyoid is relevant surgically because it is always superficial to the internal jugular vein (IJV).

The muscles that form part of the musculoskeletal column in the neck are best considered in three groups that, very broadly speaking, lie anterior, lateral or posterior to the cervical vertebrae. The anterior and lateral groups include longus colli and longus capitis; recti capitis anterior and lateralis; and scaleni anterior, medius, posterior and minimi (when the latter is present).

The posterior muscle group is composed of the cervical components of the intrinsic muscles of the back, overlaid by some of the extrinsic ‘immigrant’ muscles of the back that run between the upper limb and the axial skeleton (trapezius, levator scapulae) (Chs 30 and 32). These muscles are not usually encountered during head and neck surgery because they lie deep to the prevertebral fascia, a relatively dense layer of tissue that forms a useful barrier to deeper dissection. To avoid inadvertently breaching this fascia, the loose fibrofatty tissue can readily be dissected off using a damp swab in a sweeping motion.

Deep to the prevertebral fascia are the phrenic nerve (C3,4,5), which crosses from lateral to medial on scalenus anterior (see Fig. 15.3A), and the brachial plexus (Fig. 15.3B), which emerges between scalenus anterior and scalenus medius more laterally in the posterior triangle. The transverse cervical artery and vein run superficial to the prevertebral fascia across the posterior triangle inferiorly; the artery arises from the subclavian artery and the vein drains into either the subclavian vein or the IJV. The nerves from the cervical plexus that penetrate and emerge from the prevertebral fascia (i.e. become superficial to the prevertebral fascia) are almost all sensory, the exception being the cervical root of the ansa cervicalis (C2,3), which is motor to the infrahyoid strap muscles. The sensory components of the cervical plexus are the lesser occipital (C2), great auricular (C2,3), transverse cervical
(C2,3) and supraclavicular nerves (C3,4). If possible, these should be preserved during neck dissection surgery in order to maintain sensation in their respective dermatomes.

**Tissue planes and fascial layers in the anterior part of neck**

Details of the attachments and distribution of the fascial layers in the neck vary within surgical, radiological, oncological and anatomical literature: the persistent confusion probably reflects the difficulties of defining not only what constitutes fascia but also the limits of layers that split to ensheathe muscles and neurovascular bundles and then merge with other fascial layers.5

The skin is thinner and generally more mobile over the anterior triangle than it is over the posterior triangle. The superficial fascia – essentially a layer of subcutaneous fat arranged circumferentially around the neck – is immediately deep to the neck skin and is also generally thinner anteriorly. Platysma is a relatively thin, wide sheet of muscle that lies immediately deep to the subcutaneous fat on either side of the anterior midline and is usually confined to the anterior and anterolateral parts of the neck (Fig. 15.4); typically, it consists of three parts (pars mandibularis, labialis and modiolaris). As platysma fades away in the posterior triangle, raising skin flaps in this region becomes more difficult, which means that care should always be taken to avoid damage to the relatively superficial accessory nerve in the posterior triangle, particularly in a thin patient. Superiorly, platysma is loosely attached to the lower border of the mandible before crossing superficial to the mandible to become continuous with the superficial musculo-aponeurotic system (SMAS) layer of the face (Ch. 5). Inferiorly, platysma crosses superficial to the clavicle and blends with the fascia overlying pectoralis major, about 1–2 cm below the clavicle. Above the level of the hyoid bone, the two platysma muscles often either merge across the midline or lie edge to edge. In some patients, a dehiscence between the two muscles results in more prominent jowls in later life; platysma plication is an aesthetic technique that can be used to improve this appearance. Platysma is innervated by the cervical branch of the facial nerve; it receives a good blood supply from the facial and transverse cervical vessels (and sometimes others) and can be used as a broad pedicled flap for reconstruction.6
Deep to platysma, the superficial or investing layer of deep cervical fascia invests the neck like a collar. As its name implies, it is the most superficial of the three layers of the deep cervical fascia (the other layers being the middle and deep layers, which are further subdivided according to their location) (Fig. 15.5). The marginal mandibular and cervical branches of the facial nerve lie within the investing layer of deep fascia. While the cervical branch of the facial nerve is not so important and is often sacrificed during surgery, care should be taken to locate the marginal mandibular nerve (often two branches) to preserve lip depressor function. The nerve can readily be found crossing the facial vessels: it descends into the neck proper only in about 20% of cases and is therefore sometimes not found. Twitching of the lower lip is often seen when cutting through platysma anteriorly: this can confuse the surgeon into thinking that the marginal mandibular nerve is nearby, which will not usually be the case when operating below the mandible and anterior to the facial vessels. Rarely, the great auricular nerve can anastomose with the marginal mandibular nerve, again potentially confusing the surgeon.\(^7\)
Superiorly, the investing layer of deep cervical fascia is attached to the entire length of the lower border of the mandible, from the midline to the angle of the mandible on either side. Traced posteriorly from the angle of the mandible, the fascia is attached to the mastoid process and superior nuchal line bilaterally and to the external occipital protuberance in the posterior midline. In the interval between the angle of the mandible and the mastoid process (a distance of 5–6 cm), the investing layer of deep cervical fascia splits to enclose the parotid gland, becoming the parotid fascia or parotid capsule. Stretching of the parotid fascia results in the severe pain associated with acute parotid enlargement.

Inferiorly, from anterior to posterior, the deep cervical fascia is attached to the sternal notch, the upper surface of the clavicle, the acromion and the spine of the scapula. It splits to enclose sternocleidomastoid, continues posterolaterally as the fascial roof of the posterior triangle, and then splits again to enclose trapezius.

All the cervical viscera, major blood vessels and nerves of the neck, and all the cervical muscles (except platysma) lie within the investing layer of deep cervical fascia. The common and internal carotid arteries, IJV, vagus nerve and ansa cervicalis are enclosed to varying degrees within the carotid sheath, a condensation of deep fascia that is thicker around the arteries than the vein. Peripherally, the sheath is connected to adjacent fascial layers by loose areolar tissue. The middle layer of deep cervical fascia is usually subdivided...
into a muscular layer that surrounds the infrahyoid strap muscles, and a visceral layer that includes both the pretracheal and buccopharyngeal fasciae. The deepest layer of the deep cervical fascia is the prevertebral fascia, a relatively dense layer that runs across the neck from one side to the other, anterior to the prevertebral musculature and the cervical vertebral column (Ch. 3). The prevertebral fascia protects the brachial plexus and phrenic nerve, which lie immediately deep to it: a useful tip to remember is ‘go through the prevertebral fascia at your peril’.

**Delineation of lymph node levels in the neck**

Lymph nodes in the head and neck are distributed in terminal and outlying groups. The terminal group is related to the carotid sheath and the nodes it contains are the deep cervical lymph nodes. All lymph vessels of the head and neck drain into this group, either directly from tissues or indirectly through nodes in the outlying groups. Efferents of the deep cervical nodes form the jugular trunk. The right jugular trunk collects lymph from the right arm, the right half of the thorax and the right head and neck, and may end in the jugulosubclavian junction or the right lymphatic duct. The left jugular trunk usually enters the thoracic duct but it may join the internal jugular or subclavian vein. A summary of the widely used surgical neck lymph node classification system is shown in Table 15.1 and in Fig. 15.1B. (For a concise description of the main anatomical boundaries of each nodal group, the normal structures juxtaposed to these nodes, and the main tumour sites at risk for harbouring metastases in each level, see Grégoire et al. 8)

**Suprahyoid area (level I)**

Above the hyoid bone, the paired mylohyoid muscles interdigitate in the anterior midline at the mylohyoid raphe, forming a mobile muscular sheet that constitutes the floor of the mouth. This muscular diaphragm extends between the inner aspects of the right and left halves of the mandible: it is an important surgical landmark because it demarcates the neck below from the oral cavity above. Mylohyoid is innervated by the nerve to mylohyoid, the only motor branch of the anterior division of the mandibular division of the trigeminal nerve (Fig. 15.6). The nerve pierces the sphenomandibular ligament and runs superficially on mylohyoid, where it can sometimes be preserved during neck dissection; it also supplies the anterior belly of
digastric and is sensory to the skin of the inferior part of the chin. Cutting this nerve on both sides during a bilateral neck dissection can result in difficulty in swallowing post surgery.

The stylohyoid and digastric muscles lie on the neck side of mylohyoid. As its name implies, digastric has anterior and posterior bellies and an intermediate tendon. The two digastric bellies and the lower border of the mandible together form an inverted triangular outline known as the digastric or submandibular triangle. Mylohyoid forms the floor (or deep limit) of this triangular area (Fig. 15.7). Level Ia nodes are located in the submental triangle, between both anterior bellies of digastric.
The submandibular gland and level Ib lymph nodes lie within the submandibular triangle. The submandibular gland wraps around the free posterior border of mylohyoid, arbitrarily separating the gland into superficial and deep parts. The submandibular duct exits the hilum in the deep part of the gland and passes along mylohyoid on its deep (oral) side. The submandibular gland receives a parasympathetic, secretomotor innervation via filaments from the submandibular ganglion, which lies on the upper part of hyoglossus, superior to the deep part of the submandibular gland and inferior to the lingual nerve, to which it is connected by several filaments. The posterior filament carries preganglionic secretomotor fibres from the superior salivatory nucleus in the brainstem via the facial, chorda tympani and lingual nerves to the ganglion, where they synapse. Several postganglionic branches supply the submandibular gland and its duct by travelling either through the anterior filaments that connect the submandibular gland to the lingual nerve or along adjacent blood vessels to their targets. The fibres enter the gland towards its posterior aspect, usually accompanied by a small vein that can be stubborn and bleed even following diathermy, so some surgeons tie off the ganglion and associated fibres when removing the submandibular gland. Having usually passed through the submandibular gland, the facial artery emerges on its superior pole (typically
posteriorly), where it then crosses the lower border of the mandible (see Fig. 15.7).

The anterior belly of digastric receives a blood supply from the submental artery, a branch of the submandibular artery, which originates from the facial artery and runs superficially on mylohyoid. These vessels can cause troublesome bleeding if not formally identified during neck dissection or submandibular gland excision, and are used when lifting a submental island flap (Fig. 15.8). The marginal mandibular branch of the facial nerve may sometimes be seen in the submandibular triangle (below the lower border of the mandible): it is found in the deep cervical fascia and crosses superficial to the facial vessels (Fig. 15.9). Ligation and upward retraction of these vessels can be a useful method of protecting this nerve.

FIG. 15.8 A left submental island flap pedicled on the submental vessels (arrow).
The digastric muscle is a helpful surgical and anatomical guide when operating on the neck. It can be dissected along its course with relative ease, safety and confidence because no vital structures cross it. However, care should be taken to avoid a number of important structures that lie close to the muscle: the lingual and hypoglossal nerves (both deep and inferior, respectively); branches of the external carotid artery (deep and located anteriorly); and the internal carotid artery (deep to the posterior belly of digastric). The IJV and accessory nerve are deep to the posterior belly of digastric and superficial to the carotid tree. The main trunk of the facial nerve lies approximately 1 cm superior to, and in the same plane as, the posterior belly of digastric near its origin on the mastoid process.

The posterior auricular and occipital arteries supply the posterior belly of digastric. The facial artery initially passes deep to the posterior belly of digastric but then crosses over its superior border before entering the submandibular gland. Even when the facial artery does not course through the submandibular gland (see Fig. 15.7) it invariably gives off a submandibular branch. During microvascular surgery, the facial artery is often identified and isolated as it enters the submandibular gland in order to provide as much length as possible to facilitate anastomosis. When it is not suitable, the lingual artery can readily be found in the forgotten Piragoff's (also spelled Pirogov's) triangle (formed by the intermediate tendon of
digastric, the posterior border of mylohyoid and the hypoglossal nerve, Fig. 15.10).

![Fig. 15.10](image)

**FIG. 15.10** The right neck showing Piragoff’s triangle (dashed line), formed by the intermediate tendon of digastric, the free edge of mylohyoid (retracted) and the hypoglossal nerve (arrow). Dissection through hyoglossus will locate the lingual artery.

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**Anatomy deep to sternocleidomastoid: upper neck (levels II and III)**

Sternocleidomastoid is key to understanding the organization of the deeper structures of the neck because it divides the neck into anterior and posterior triangles (Video 15.1). The investing layer of deep cervical fascia can be cut and raised anteriorly along the whole length of the muscle. The external jugular vein (EJV) crosses the muscle from medial to lateral and can be a useful guide for finding the great auricular nerve, which lies approximately 1 cm posterior to the vein. As sternocleidomastoid is retracted posteriorly on a broad front, the posterior belly of digastric will be found. The accessory nerve is located between these two muscles, deep to digastric (Fig. 15.11). The nerve usually lies superficial to the IJV; less commonly, it is found deep to the vein; and on rare occasions, it penetrates the vein. Several anatomical variants of the accessory nerve have been documented, e.g. where the nerve splits, one branch supplying sternocleidomastoid and the other passing deep to that muscle, travelling onwards to supply trapezius (Fig. 15.12).
Level IIb is superior to the accessory nerve and extends to the skull base.
Once the nerve and IJV have been found, level IIb can be dissected with confidence to its floor. The occipital artery runs along the inferior aspect of the digastric and can sometimes cause unexpected bleeding. Rarely, a tortuous internal carotid artery can pass more superficially than expected and will be seen in this level. Further dissection along sternocleidomastoid inferiorly will find another surgeon's friend, omohyoid, which crosses the posterior triangle en route to the hyoid bone. The IJV lies deep to its intermediate tendon. As with the digastric muscle, omohyoid can be used as a surgical guide with confidence because no vital structures cross it.

The carotid sheath, a condensation of connective tissue around the major blood vessels in the neck, lies lateral to the prevertebral fascia and is readily found by mobilization of sternocleidomastoid; as already mentioned, it is wise to dissect the muscle on a broad front. The carotid sheath contains the laterally based IJV and common carotid artery; the vagus nerve lies between them, often on the posterolateral aspect of the artery (Fig. 15.13). The internal carotid artery runs within the carotid sheath above the level of the common carotid bifurcation. The ganglionated cervical sympathetic chain lies posteromedial to (and outside) the carotid sheath and anterior to the prevertebral fascia (Fig. 15.14). The chain can occasionally be damaged during neck dissection surgery, resulting in a unilateral Horner's syndrome (ipsilateral ptosis, miosis and anhidrosis).
FIG. 15.13  Left neck dissection with the internal jugular vein removed. The vagus nerve (shown with the black scissors) is posterolateral to the common carotid artery (asterisk) and posterior to the internal carotid (white arrow), with the hypoglossal nerve (arrowheads) and vagus seen intimately related to the carotid superiorly. The accessory nerve enters the retracted sternocleidomastoid. The C1 (descendens) branch of the ansa cervicalis is shown with a yellow arrow.
The hypoglossal nerve crosses the internal and then the external carotid arteries (see Fig. 15.13), and is usually found inferior and deep to the posterior belly of digastric. It runs with a delicate plexus of veins that will bleed if provoked: this can be troublesome during more limited-access neck surgery such as submandibular gland excision. Care should always be taken when using diathermy in this area to avoid damaging the hypoglossal nerve itself. The hypoglossal nerve carries a motor branch of C1, the descendens hypoglossi, which runs inferiorly to join branches of C2 and C3, forming the ansa cervicalis (C1,2,3). The ansa passes anteriorly, crossing the IJV. Although the descending branch runs anterior to the IJV, the inexperienced eye can confuse it with the vagus nerve; a nerve stimulator can be used to confirm the ansa. Anatomical variants of this C1 branch are well known, e.g. the nerve may supply sternocleidomastoid (Fig. 15.15). Care should always be taken when dissecting the branches of the ansa because these variants can occur in up to 4% of neck dissections.\textsuperscript{11}
FIG. 15.15  The right neck showing an anatomical variant of the C1 branch of the ansa cervicalis. There is a presumed C1 branch (yellow arrow) arising from the hypoglossal nerve (asterisk), which crosses the internal jugular vein to enter sternocleidomastoid. The descendens hypoglossi (white arrows) can be seen arising from this variant, passing around the black scissors to follow the internal jugular vein.

The IJV receives several tributaries on its anterior surface including (from superior to inferior) the facial, lingual and thyroid veins. It is often written that no veins enter the posterior wall of the IJV, but we have not found this to be the case: small veins can be encountered, often when least expected, which can result in unexpected bleeding.

**Inferior neck (level IV)**

At operation, level IV is separated from level III superiorly by omohyoid: it is important to note that this muscle moves with head positioning and so its position is not constant.\(^{12}\) The relationships of the great blood vessels and the vagus nerve are essentially unchanged from the more superior levels II and III, although surgical access becomes more difficult the more inferiorly
any dissection is taken. It is usually not advisable to dissect behind the sternum or clavicle because the subclavian vessels can be closer than expected. Indeed, on occasion the subclavian vessels may pass above the clavicle, so careful dissection is advisable when working in the inferior aspect of the posterior triangle.

The thoracic duct is found on the left side of the neck in level IV and can easily be damaged during dissection (Ch. 3). It exhibits considerable anatomical variation, although it usually courses along the medial border of scalenus medius. The terminal arch of the duct can lie between 0.5 and 4 cm above the clavicle, terminating as one or more delicate, thin-walled ducts that join the venous system: most commonly, the IJV.

The centrally located cervical visceral compartment contains the pharynx and its distal continuation, the oesophagus, most posteriorly; the pharyngo-oesophageal junction is typically at the level of the lower border of the cricoid cartilage (corresponding to the lower part of the body of C6). The pharynx is an elongated chamber that extends from the clivus superiorly to the pharyngo-oesophageal junction inferiorly (Ch. 16). From above downwards, it lies successively behind the nasal cavity (nasopharynx), the oral cavity (oropharynx) and the larynx (laryngopharynx). The larynx lies anterior to the lower third of the pharynx, has a skeletal framework made up entirely of cartilages (including the thyroid and cricoid cartilages), and is continuous with the trachea at the level of the lower border of the cricoid cartilage. The laryngotracheal junction is thus at the same horizontal level as the pharyngo-oesophageal junction (approximately the body of C6). The thyroid isthmus lies on the anterior aspect of the upper trachea and joins the two thyroid lobes (Ch. 18).

**Posterior triangle (level V)**

The most important structure in the posterior triangle is the (spinal) accessory nerve; it passes obliquely from medial to lateral at the level of levator scapulae and divides the triangle into level Va (above) and Vb (below). As it exits sternocleidomastoid, the accessory nerve becomes superficial and is vulnerable during any procedure in the posterior triangle. The nerve is accompanied by a chain of lymph nodes, a point that should always be remembered when undertaking a node biopsy in the posterior triangle (Ch. 36).

Apart from the subclavian vessels, which occasionally pass above the
clavicle and appear in the posterior triangle superficial to the prevertebral fascia, the only other vessels seen are the transverse cervical artery and vein. They are superficial to the prevertebral fascia, which separates them from the brachial plexus. Supraclavicular nerves (C3,4) will be found traversing the fat of the posterior triangle. The lesser occipital nerve (C2), which carries sensation from the occipital region, can sometimes be found at the apex of the posterior triangle.

Tips and Anatomical Hazards

The great auricular and accessory nerves are located superficially. The accessory nerve is superficial in the posterior triangle and can be easily damaged. It may have more than one branch before entering sternocleidomastoid. Damage to the accessory nerve causes limitation of shoulder abduction, winging of the scapula and troublesome pain at the sterno-clavicular joint as a result of muscle imbalance.

The marginal mandibular nerve is thin and can be found up to 2cm below the angle of the mandible in the deep cervical fascia. The nerve is easily damaged in the submandibular triangle: damage results in lower lip weakness with unopposed pulling by the muscles of the upper lip (which are supplied by the buccal branch).

Damage to the hypoglossal venous plexus can lead to troublesome bleeding and the hypoglossal nerve can be damaged if care is not taken when using diathermy, resulting in deviation of the tongue to the affected side on protrusion.

Damage to the lingual nerve results in altered sensation or anaesthesia of the affected side of the tongue (anterior two thirds).

The phrenic nerve and the brachial plexus are located deep to the thin prevertebral fascia.

The thoracic duct is readily damaged in the root of the neck and therefore an attempt should always be made to check for clear fluid after any surgery in this area. It is important to appreciate that a chyle leak is often clear or straw coloured (because the patient is starved) at surgery. Chyle becomes milky following ingestion of a fatty meal post operatively.

Ligation of both internal jugular veins during a bilateral neck dissection
is to be avoided because this usually results in severe facial and neck swelling. However, as a staged procedure it is sometimes possible to sacrifice both internal jugular veins.

Injury to the brachial plexus can result in varying degrees of arm dysfunction depending on the severity of damage.

Damage to the phrenic nerve results in a raised hemi-diaphragm and possible difficulty in breathing: bilateral phrenic nerve damage can be fatal.

It is important to insert suction drains when operating in the neck, even if there is little bleeding. This is particularly important after bilateral neck surgery.

There are no vital structures on the digastric or omohyoid muscles, so they can be used as anatomical guides to progress dissection and to find other structures (e.g IJV, facial artery).

Tissue planes around nerves should be opened by following the nerves instead of working at right angles as that can lead to neuropraxia.

Damp swabs (sponges) are recommended when working around nerves to avoid abrasion.

Level IIb contains the occipital artery and, rarely, a tortuous internal carotid artery: it should be dissected with care.

Occasionally the subclavian vessels may pass above the clavicle, where they can be damaged when blind dissecting at the inferior aspect of level V.

A summary of the main types of neck dissection are shown in Table 15.2. In addition, there is a postero-lateral neck dissection (levels II-V), and central neck dissection (levels VI +/- VII).
### TABLE 15.2

#### The different types of neck dissection

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radical neck dissection (RND)</td>
<td>Excision of lymph node levels I-V</td>
</tr>
<tr>
<td></td>
<td>Resection of sternocleidomastoid (SCM), internal jugular vein (IJV) and accessory nerve</td>
</tr>
<tr>
<td>Modified radical neck dissection (MRND)</td>
<td>Excision of lymph node levels I-V</td>
</tr>
<tr>
<td></td>
<td>MRND Type 1: preservation of one of the following structures: SCM, IJV or accessory nerve</td>
</tr>
<tr>
<td></td>
<td>MRND Type 2: preservation of two of the following structures: SCM, IJV or accessory nerve</td>
</tr>
<tr>
<td></td>
<td>Types 1 and 2 MRND should be documented as: MRND with preservation of one or two structures, respectively, from the list above</td>
</tr>
<tr>
<td></td>
<td>MRND Type 3: preservation of SCM, IJV and accessory nerve</td>
</tr>
<tr>
<td>Selective neck dissection (SND)</td>
<td>Excision of varying lymph node levels</td>
</tr>
<tr>
<td></td>
<td>SND should be documented as: SND levels * to ** (where * and ** indicate lymph node levels)</td>
</tr>
</tbody>
</table>

The surgeon should be wary of anatomical variants.  
Dissection must be meticulous at all times.  
Adequate haemostasis should be ensured.
References


Single Best Answers

1. Which one of the following statements is correct?
   A. Damage to the marginal mandibular nerve can produce an ipsilateral numb chin
   B. The brachial plexus and phrenic nerve lie superficial to the prevertebral fascia
   C. Pirogoff's triangle is formed by the intermediate tendon of digastric, the posterior border of mylohyoid and the hypoglossal nerve
   D. The internal jugular vein lies superficial to the intermediate tendon of omohyoid
   E. The subclavian vessels never pass above the clavicle

   **Answer: C.** During microvascular surgery, when the facial artery is not suitable for anastomosis, the lingual artery may serve as an alternative. It can be found in Pirogoff's triangle.

2. Which one of the following statements concerning the accessory nerve is correct?
   A. It is most often located deep to the internal jugular vein as it exits the jugular foramen
   B. Elective sacrifice always results in shoulder weakness
   C. On rare occasions it may pass through the internal jugular vein
   D. It exits sternocleidomastoid inferior to the great auricular nerve
   E. Before entering sternocleidomastoid, the nerve is usually superficial to the posterior belly of digastric

   **Answer C:** Rarely, the accessory nerve can pass through the internal jugular vein. It usually crosses the vein superficially and
then passes deep to the posterior belly of digastric before entering sternocleidomastoid. On exiting sternocleidomastoid, it is found superior to the great auricular nerve.

3. Which one of the following statements concerning the facial artery is correct?
A. It occasionally does not pass through the submandibular gland
B. When it crosses the angle of the mandible, the marginal mandibular nerve lies deep to it
C. It enters the submandibular gland by passing inferiorly to the posterior belly of digastric
D. It is crossed by the hypoglossal nerve
E. It is usually superficial to platysma as it crosses the mandible

**Answer: A.** When the facial artery does not pass through the submandibular gland, it will always give a branch to the gland. The marginal mandibular nerve is always superficial to the artery, and the artery lies deep to platysma. The artery enters the submandibular triangle by passing over the superior aspect of the posterior belly of digastric.

4. Which one of the following statements regarding the internal jugular vein is NOT correct?
A. The C2,3 branch of the ansa crosses superficial to the vein
B. It receives the thoracic duct on the left side of the neck
C. Omohyoid is superficial to the internal jugular vein
D. It passes deep to the posterior belly of digastric
E. The vagus nerve usually lies anteromedial to the vein

**Answer: E.** The vagus nerve usually lies posterolateral to the carotid artery, between the internal jugular vein and the carotid.
The internal jugular vein is deep to both digastric and omohyoid, a useful fact that can guide safe and rapid dissection along these muscles without fear of damaging the internal jugular vein or indeed any other structures.

5. Which one of the following statements regarding the surgical levels of the neck is correct?

A. Level IIb lies below and anterior to the accessory nerve as it enters sternocleidomastoid
B. Level Vb lies superior to the accessory nerve as it crosses the posterior triangle
C. Level Ia contains the submandibular gland and associated lymph nodes
D. At operation, the carotid bifurcation can be useful in delineating the upper border of level III
E. Omohyoid serves as a useful landmark for the lower border of level IIa

Answer: D. The carotid bifurcation serves to delineate the lower border of level IIa and upper border of level III. Level IIb lies above and posterior to the accessory nerve, which forms the superior boundary of level Vb.
Clinical Case

1. A 75-year-old patient has a fungating right neck metastasis (Fig. 15.16) following failure of radiotherapy to the right tongue and neck for a squamous cell carcinoma and requires a salvage neck dissection.

FIG. 15.16  Large right neck metastatic squamous cell carcinoma involving the skin (primary cancer site was right tongue).

A. What structures are most likely to be damaged when making the skin incisions in this case?

The great auricular nerve (C2,3) and external jugular vein are superficial, but both lie deep to platysma. Care should be taken in a conventional neck dissection to try to preserve these structures where possible. Clearly, this is not going to be achievable in this case. In the posterior triangle, the accessory nerve is always superficial and can be displaced by pathology.

B. How can the dissection proceed safely inferiorly?

In a modified radical neck dissection, such as in this case, omohyoid can be transected and taken anteriorly to locate the internal jugular vein. Omohyoid is superficial to the great vessels and this fact can be utilized to help locate the internal jugular vein, particularly in cases like this where the vein may be compressed and not readily visible. In this case, the internal jugular vein was tied off and secured using transfixion sutures through the vessel wall to
facilitate dissection. **Fig. 15.17** shows the transected omohyoid superficial to the ligated internal jugular vein, which has dilated. The vagus nerve (white arrow) can be seen on the posterolateral aspect of the common carotid.

![Image](image_url)

**FIG. 15.17** Excision of mass with overlying skin as part of a Type I modified radical neck dissection (preservation of the accessory nerve). The internal jugular vein has been ligated and divided with the omohyoid visible on its superficial aspect in the lower neck.

Even with a large tumour metastasis, and when oncologically safe to do so, it is possible to preserve the C2,3 branch of the ansa cervicalis (blue arrow). The internal jugular vein is passed under this branch. The main ansa cervicalis is shown with a black arrow.

**C. How important is preservation of the accessory nerve?**

When possible, it is always preferable to preserve the accessory nerve. While trapezius may receive a dual motor innervation from both the accessory nerve and the cervical plexus in up to half of patients, shoulder weakness and pain following accessory nerve sacrifice can be debilitating. The dropped lateral clavicle can result in rotation at the sternoclavicular joint, resulting in marked pain on arm movement. In this case, despite a large metastatic deposit in the neck, it was possible to preserve the accessory nerve. **Fig. 15.18** shows a completed modified radical neck dissection type 1: sternocleidomastoid and the internal jugular vein have been sacrificed. The accessory nerve (white arrow) can be seen passing from medial to lateral
across the posterior triangle. The carotid tree is clearly visible with the hypoglossal nerve (black arrow) crossing it, and the vagus nerve (yellow arrow) is posterolateral. The patient made a full recovery and was discharged after 5 years’ follow-up.

**FIG. 15.18** Completed neck dissection. The intact accessory nerve is clearly visible passing from medial to lateral, and the hypoglossal nerve can be seen crossing the carotid tree.
Pharynx

Eitan Prisman, Yotam Shkedy

Core Procedures

• Tonsillectomy
• Transoral robotic surgery
• Adenoidectomy
• Nasopharyngectomy
Embryology

Lymphoid tissues develop at several sites around the oro- and nasopharynx. In each case the endodermal epithelium proliferates and grows into the surrounding neural crest mesenchyme as solid buds, which form fossae and crypts. Lymphoid cells accumulate around the crypts from the fifth month and become grouped into lymphoid follicles. Four pairs of invaginations form the tubal tonsils, the adenoid (pharyngeal) tonsil, the palatine tonsils and the lingual tonsils: collectively, these accumulations of mucosa associated lymphoid tissue (MALT) are termed the pharyngeal lymphoid ring (Waldeyer's ring).

The embryonic pharynx is broad laterally and compressed dorsoventrally. From stage 13 (31–33 days post fertilization) the lateral extensions of the pharyngeal pouches with thickening endodermal epithelium can be seen, whereas the pharyngeal roof is still thin. The first pharyngeal pouch gives rise laterally to the tubotympanic recess, which forms the middle ear cavity and the pharyngotympanic tube. The orifice of this tube lies above the palate in the nasopharynx and is the site of the tubal tonsil. The pharyngeal tonsil (adenoid) develops in the roof and posterior wall of the nasopharynx and grows rapidly after birth. The adenoid is large relative to the volume of the nasopharynx at 5 years and undergoes some involution from 8 to 10 years. The second pharyngeal pouch gives rise to the palatine tonsils, which form in the lateral wall of the oropharynx. They grow rapidly in size for the first 5–6 years of life, developing a branching crypt system, and undergo involution at puberty. The lingual tonsils develop on the posterior third of the tongue and form deep crypts in the submucosa.

Most of the pharyngeal content develops from the third, fourth and sixth pharyngeal arches. The third arch gives rise to stylopharyngeus and most of the hyoid bone, and is innervated by the glossopharyngeal nerve. The fourth arch gives rise to the three constrictor muscles and its innervation is based on the superior laryngeal nerve, while most of the laryngeal musculature develops from the sixth arch, which is innervated by the recurrent laryngeal nerve.
Clinical anatomy

The pharynx is divided into three parts: nasopharynx, oropharynx and hypopharynx (Fig. 16.1). It is enveloped by three constrictor muscles (superior, middle and inferior) arranged in a palisading structure, such that each one lies external to the one above it. Between the superior constrictor and base of skull is the sinus of Morgagni, which is closed by the pharyngobasilar fascia. The pharyngobasilar fascia is attached to the basilar part of the occipital bone, the petrous temporal bone, the posterior medial pterygoid plate, the pterygomandibular raphe and the median pharyngeal raphe. The intervals between adjoining constrictor muscles allow the passage of various anatomical structures that are important orientating aids during surgical procedures, especially endoscopic and robotic ones.
The pharyngotympanic tube (Eustachian tube), tensor veli palatini, levator veli palatini and the ascending palatine artery all lie above the superior constrictor. Stylopharyngeus and the glossopharyngeal nerve pass between the superior and middle constrictors. The internal laryngeal nerve and the laryngeal branch of the superior thyroid artery pass between the middle and inferior constrictors. Below the inferior constrictor, the recurrent laryngeal nerve and internal branch of the inferior thyroid artery pass towards the larynx (Fig. 16.2).
The nasopharynx is bordered superiorly and posteriorly by the body of the sphenoid and basilar part of the occipital bone. Anteriorly, the nasopharynx communicates with the nasal cavity through the choanae; inferiorly, it is connected to the oropharynx, with the soft palate serving as the inferior border. The lateral nasopharyngeal wall features the opening of the pharyngotympanic tube. The mucosal covering of the tube is the torus tubarius. The fossa of Rosenmüller behind the torus tubarius is a common area for the development of nasopharyngeal carcinoma.

Three muscles are associated with the pharyngotympanic tube: salpingopharyngeus, tensor veli palatini and levator veli palatini. The foramen lacerum is above the cartilaginous part of the tube and the foramen ovale is lateral to the tube. The medial pterygoid plate will be revealed after
removal of the cartilaginous part of the pharyngotympanic tube. During endoscopic nasopharyngectomy, these anatomical features are important in identifying the internal carotid artery (ICA) and thus preventing inadvertent damage to the vessel. Usually, the ICA lies 2 cm and 30° posterolaterally to the medial pterygoid plate, 2 cm posterolateral to the anterior margin of the foramen lacerum, 5 mm posterior to the isthmus of the pharyngotympanic tube (the point where the cartilaginous part connects to the bony part) and 2 cm posterior to the lateral pterygoid plate (Figs 16.3 and 16.4).¹

The oropharynx is bounded superiorly by the soft palate, anteriorly by the anterior tonsillar pillars and circumvallate papillae of the tongue, and inferiorly by the superior edge of the epiglottis and lateral glossoepiglottic folds. It is divided into four subsites: the palatine tonsils, base of tongue, soft palate and uvula, and posterior pharyngeal wall.

With the advent of transoral robotic surgery (TORS), a thorough understanding of the ‘inside-out’ anatomy of the oropharynx is mandatory. On approach to the pharynx, the first structures encountered are the palatine tonsils resting on the tonsillar capsule. The tonsils are bounded by the anterior and posterior folds (pillars), which contain the palatoglossal and palatopharyngeal muscles, respectively. Deep to the tonsils is the superior constrictor. Lateral to it is the parapharyngeal space: it has the shape of an inverted pyramid bounded superiorly by the skull base and inferiorly by the hyoid bone. Bilaterally, the medial border is the superior constrictor, the lateral border is the parotid fascia, and medial pterygoid forms the...
anterolateral border. The posterior border is the prevertebral fascia, where the parapharyngeal space becomes continuous with the retropharyngeal space.

Two structures are encountered initially in the parapharyngeal space: the stylohyoid ligament, which is directed inferiorly and slightly medially, and styloglossus, which has a more inferolateral course. Between these two structures, and located deep to them, is the glossopharyngeal nerve. The middle constrictor muscle is deep and medial to the stylohyoid ligament. The greater cornu of the hyoid may be encountered inferiorly (Fig. 16.5). Medial pterygoid is lateral to styloglossus. The submandibular gland is inferolateral to styloglossus, which explains the occurrence of a connection (fistula) between the pharynx and neck after extensive inferior resection in the tonsillar fossa, especially when combined with neck dissection in the submandibular area (level Ib). During base of tongue operations, styloglossus is the important anatomical landmark. Both the lingual artery and hypoglossal nerve are located lateral to it, which means that a resection medial to the muscle is safe; however, the dorsal lingual branch of the artery has a more medial course, so it might be encountered (and, as need arises, ligated) during resection. Since the lingual artery is situated medial to the hypoglossal nerve, the vessel is more susceptible to injury.
The borders of the hypopharynx are the top of the epiglottis and the lateral glossoepiglottic folds superiorly, the thyroid cartilage laterally, the aryepiglottic folds medially and the oesophagus inferiorly. The hypopharynx is divided into three subsites: the piriform sinuses, post-cricoid region and posterior pharyngeal wall (Video 16.1). Its close contact with the larynx (especially in the post-cricoid region) makes surgery in this area challenging.

The lymphatic drainage of the pharynx is to the deep cervical nodes in the lateral neck (levels 2–4; Ch. 15) and the retropharyngeal space; nasopharyngeal malignancies also spread to level 5 nodes. The pharynx has a rich bilateral drainage and thus malignancies tend to have a high propensity for bilateral regional lymph node spread. While lateral neck dissection is performed frequently and with minimal morbidity, the retropharyngeal space is infrequently addressed in the surgical treatment of the neck. The retropharyngeal space is bounded anteriorly by the buccopharyngeal fascia and posteriorly by the alar fascia of the deep layer of the deep cervical fascia.
Its superior border is the base of skull and it extends inferiorly to the level of the carina (T4 vertebra). Laterally, it is bounded by the carotid sheath and, in the midline, it is bounded by the median pharyngeal raphe; infection in this space is therefore frequently unilateral (as opposed to bilateral danger space and prevertebral infections). The retropharyngeal lymph nodes are divided into two groups: the lateral nodes (also known as Rouvière nodes), 2–5 mm in size, and the medial group, which are rarely present in adulthood.

**Tips and Anatomical Hazards**

During endoscopic nasopharyngectomy, identification of the pharyngotympanic tube is the first step in identification of other anatomical landmarks (e.g. medial pterygoid plate, foramen lacerum). The limiting factor in radical tonsillectomy is the ICA. If identification of the ICA is problematic, either the vessel should be controlled from the neck before commencement of resection or non-surgical treatment options should be considered. In base of tongue resection, styloglossus is medial to the lingual artery, which in turn is medial to the hypoglossal nerve. Knowledge of these relationships can help prevent inadvertent iatrogenic injury to both artery and nerve. Lateral dissection in the nasopharynx can endanger the ICAs. Identification of the medial pterygoid plate, foramen lacerum and isthmus of the pharyngotympanic tube assists in identification of the ICA.

During radical tonsillectomy, the ICA is at risk from deep lateral dissection. A layer of parapharyngeal fat overlies the artery: if uninvolved, it need not be disturbed and therefore the artery can be protected. On resection of stylopharyngeus, care needs to be taken not to extend the cut too far laterally, in order to prevent injury to the ICA ([Fig. 16.6](#)).
An orocervical fistula can be created from a dissection that extends too far inferiorly during radical tonsillectomy, especially when combined with level I neck dissection. In the event of such an occurrence, and depending on the soft tissue deficit, the fistula can be closed primarily, with a rotational muscle flap (e.g. sternocleidomastoid or a strap muscle) or with a free flap.

Base of tongue resections can endanger the lingual artery and hypoglossal nerve. Surface features that aid in preventing injury to these structures include the insertion of palatoglossus into the tongue, the foramen caecum and the circumvallate papilla. It is important to note that distances between these surface landmarks and the lingual artery may shorten as a result of retraction of the tongue during
operation (Fig. 16.7). 4

The posterior extent of hypopharyngeal tumours should be assessed pre- and intraoperatively during resection. If there is considerable posterior involvement, there might not be enough normal mucosa available for primary closure: reconstruction with a regional or free flap might be appropriate.
References


Single Best Answers

1. Which one of the following structures gives rise to the pharyngeal constrictors?
   A. Third pharyngeal arch  
   B. Fourth pharyngeal arch  
   C. Fifth pharyngeal arch  
   D. Sixth pharyngeal arch  

   **Answer: B.** The third pharyngeal arch gives rise to stylopharyngeus and most of the hyoid bone, while the fourth arch gives rise to the constrictor muscles. The fifth arch involutes early after its formation and the sixth is involved in laryngeal musculature development.

2. Which one of the following structures passes between the superior and middle constrictors?
   A. Internal laryngeal nerve  
   B. Recurrent laryngeal nerve  
   C. Glossopharyngeal nerve  
   D. Tensor veli palatini  

   **Answer: C.** Stylopharyngeus and the glossopharyngeal nerve pass between the superior and middle constrictors. The pharyngotympanic tube, tensor veli palatini, levator veli palatini and the ascending palatine artery all pass above the superior constrictor. The internal laryngeal nerve and the laryngeal branch of the superior thyroid artery pass between the middle and inferior constrictors, and the recurrent laryngeal nerve and internal branch of the inferior thyroid artery can be found below the inferior constrictor.

3. The internal carotid artery can be found closest to which one of
the following anatomical landmarks?
A. Isthmus of the pharyngotympanic tube
B. Anterior margin of the foramen lacerum
C. Lateral pterygoid plate
D. Medial pterygoid plate

**Answer: A.** There are a few important landmarks for the identification of the internal carotid artery during endoscopic nasopharyngectomy. The internal carotid artery lies 2 cm posterolateral to the medial pterygoid plate and the anterior margin of the foramen lacerum, 5 mm posterior to the isthmus of the pharyngotympanic tube, and 2 cm posterior to the lateral pterygoid plate.

4. While performing base of tongue resection, the surgeon resected styloglossus and the structure that was immediately lateral to it. Which one of the follow scenarios best describes what will happen as a result of this resection?
A. Nothing important is found in this area and there will be no untoward consequences
B. The patient will feel numbness in the tongue after the operation
C. The surgeon will encounter major bleeding
D. There will be deviation of the tongue postoperatively

**Answer: C.** Styloglossus is an important landmark in transoral base of tongue operations. The lingual artery and the hypoglossal nerve lie immediately lateral to styloglossus, the artery coursing in a more medial position. The lingual nerve courses along the medial aspect of the mandible and crosses the submandibular gland and duct on its way to the tongue; it is less likely to be injured in operations in the base of tongue area than the lingual
artery.

5. In malignancies, in which of the following locations are neck metastases to level V most likely?
   A. Palatine tonsil
   B. Base of tongue
   C. Piriform sinus
   D. Nasopharynx

   **Answer: D.** While malignancies in all locations of the pharynx have a tendency to spread to the lateral neck (levels II–IV) and the retropharyngeal space, only the nasopharynx has a high frequency of level V involvement.
Clinical Case

1. A 52-year-old male presents to your clinic with a 1-year history of base of tongue discomfort and dysphagia. Two months prior to being seen in your clinic he was evaluated by another otolaryngologist, who visualized a 2.5 cm mass in the right lateral aspect of the base of the tongue. CT was performed, which showed a 2.6 cm exophytic mass in the right base of tongue and no suspicious neck lymphadenopathy. The patient then underwent a transoral biopsy, which debulked most of the mass. Pathology revealed invasive squamous cell carcinoma.

A. What features are important in the pathology report?
   The most important feature is human papillomavirus (HPV)/p16 status because it has a significant effect on patient outcome. Although current management of the disease is similar in both p16-negative and p16-positive patients, ongoing trials are looking at the option of de-escalation treatment for p16-positive tumours. Other important features are margin status, extent of lymphovascular and perineural invasion, degree of differentiation and aggressive pathological subtypes.

B. The pathology report showed positive staining for p16. Margins were involved since the operation consisted of debulking only. What details interest you in this patient's history?
   Regarding the current illness, it is important to assess for symptoms of spread of the disease, e.g. impaired tongue movement or sensation, haemoptysis, referred pain, dysphagia or aspirations, and also for classic risk factors for oropharyngeal cancer (smoking, alcohol abuse) because p16-positive patients with a history of smoking have a worse prognosis than those without a history of smoking. It is important to enquire about general medical conditions, especially those that may contraindicate some forms of treatment (e.g. severe heart disease as a contraindication to surgery, kidney disease as a contraindication to cisplatin therapy).
   The patient's past medical history was significant for hypertension and gout. He had not undergone previous surgical procedures other than the above-mentioned biopsy. He denied smoking or alcohol abuse. On examination, he appeared to be his stated age. There was no suspicious lymphadenopathy. On direct examination and flexible endoscopy, no mass could be seen in the base of tongue. Palpation failed to reveal a discrete
C. What are the treatment options for this patient?
The patient has presented with a cT2N0M0 tumour. He is a candidate for either primary radiotherapy (with no need for chemotherapy) or surgical resection. In both cases, there is a need to address the neck (either with radiation or neck dissection).

The patient underwent transoral robotic resection of the right base of tongue (Video 16.2). Frozen sections showed that the tumour was close to the lateral margin and thus an additional margin was taken from the lower right tonsil. He also underwent right neck dissection. The postoperative course was uneventful: the patient was able to resume a full diet and he was discharged on postoperative day 4.

Pathology revealed a focus of invasive non-keratinizing squamous cell carcinoma, p16-positive. The tumour was 4 mm in size and reached the lateral border of the original specimen. However, the additional lateral margin was negative for malignancy. Neck dissection showed no involved nodes. The final staging was T2N0M0. After consultation with the institutional tumour board, it was decided that there was no need for further adjuvant treatment.
### Core procedures

#### Outpatient
- Transnasal flexible diagnostic endoscopy
- Transoral rigid diagnostic endoscopy
- Vocal fold medialization injection
- Vocal fold biopsy via channelled endoscope

#### Inpatient
- Diagnostic ± therapeutic rigid laryngoscopy/pharyngoscopy
- Laryngeal framework surgery
- Total laryngectomy/pharyngolaryngectomy
- Partial laryngectomy
Outline of voice production

The primary function of the larynx is to act as a sphincter to prevent the entry of foreign material into the tracheobronchial tree. To achieve this, the vocal folds close tightly (as do the false vocal folds (vestibular folds)) during swallowing. In addition, the larynx facilitates expulsion of secretions from the trachea and lungs during a cough: the act of coughing requires the vocal folds to abduct rapidly during exhalation, causing an explosive release of air and expulsion of material. A further function of the larynx is to increase the intrathoracic and/or intra-abdominal pressure (the so-called Valsalva manoeuvre); the vocal folds tightly adduct during attempted expiration, as in straining to lift weights or to increase intra-abdominal pressure during defecation or parturition.

The final function of the larynx is phonation. With the vocal folds adducted, increasing subglottic air pressure overcomes the muscular force of adduction and pushes the vocal folds apart; a fraction of a second later, the vocal folds then come together again. This is achieved partly because of the elastic recoil of the vocal folds and partly because of the Bernoulli effect (the flow of air through the rima glottidis causes a negative pressure, drawing the vocal folds together). This cyclical movement of the vocal folds causes movement of air, which is perceived as sound (Fig. 17.1 and Video 17.1). The sound generated by the vocal folds is then modulated by the changing shape of the rest of the vocal tract (pharynx, oral cavity and so on) to produce intelligible voice.
In order for the epithelium of the vocal folds to vibrate in a cyclical way, the vocal folds must be pliable. The layered microstructure of the vocal folds means that the epithelium is separated from the vocal ligament by a loose collagenous layer known as ‘Reinke's space’. The superficial layer of the lamina propria forms Reinke's space, while the intermediate and deep layers of lamina propria constitute the vocal ligament. The smooth, regular cyclical vibration of the vocal epithelium over the ligament, with the two separated by Reinke's space, is known as the ‘mucosal wave’ and can be seen with stroboscopic examination techniques (Fig. 17.2).
FIG. 17.2  
A, A coronal view of the laryngeal cavity, showing the distribution of the mucous membrane in the laryngeal cavity. B, The structure of the true vocal folds at low power, × 40, stained with Movat's pentachrome stain. C, The true vocal folds at high power, × 100; Movat's pentachrome stain. The non-keratinized squamous epithelium is shown forming a mucosal layer over the superficial part of the lamina propria, along with the three layers of the lamina propria, with thyroarytenoid and vocalis lying deep to the deep layer of the lamina propria. At higher magnification, the deeper yellow staining of the collagen in the deep layer of the lamina propria, compared to the superficial layer, indicates a greater degree of cross-linking. (A, From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 35.7a. B, C, Modified with permission from M.S. Courey, The professional voice, in: C.W. Cummings et al (eds), Otolaryngology: Head and Neck Surgery, vol. 4, third ed., Mosby, St Louis, pp. 3003–3025.)
Surgical approaches and considerations

Historically, the larynx would have been examined with a mirror held in the oropharynx. This technique was devised by Manuel Garcia in the mid-19th century. In modern practice, examination of the vocal folds is usually achieved with a flexible endoscope (either a fibreoptic endoscope or a distal chip endoscope) introduced through the nose and passed into the pharynx. This gives the view seen in Fig. 17.3.\textsuperscript{1,2} Examination of epithelial pliability relies on seeing the vocal fold epithelium moving in slow motion. In clinical practice, this is achieved using stroboscopic techniques.
In broad terms, voice disorders fall into the categories listed in Table 17.1. Normal phonation relies on vocal folds with straight edges, adequate glottic closure and pliability of the vocal folds. Laryngeal surgery may aim to achieve any or all of these goals. There are several different approaches to laryngeal surgery.
TABLE 17.1

Voice disorders

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoplastic</td>
<td>Benign (e.g. polyp, cyst, nodules, papilloma)</td>
</tr>
<tr>
<td></td>
<td>Malignant</td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>Vocal fold paralysis</td>
</tr>
<tr>
<td></td>
<td>Spasmodic dysphonia (focal laryngeal dystonia)</td>
</tr>
<tr>
<td></td>
<td>Other neurological conditions (e.g. Parkinson’s disease, multiple sclerosis)</td>
</tr>
<tr>
<td>Inflammatory</td>
<td>Laryngitis (bacterial, viral, fungal)</td>
</tr>
<tr>
<td></td>
<td>Reflux-induced changes</td>
</tr>
<tr>
<td></td>
<td>Reinke’s oedema</td>
</tr>
<tr>
<td>Behavioural</td>
<td>Muscle tension dysphonia, poor vocal hygiene</td>
</tr>
</tbody>
</table>

Transoral laryngeal surgery

The majority of benign vocal fold lesions are amenable to surgery through the mouth using a laryngoscope. Under general anaesthetic, with the neck extended at the craniocervical junction and flexed at the thoracocervical junction (the so-called ‘sniffing the morning air’ position), the laryngoscope is introduced through the mouth. The laryngoscope can then be fixed to a jig, which allows the surgeon to operate with both hands (Figs 17.4, 17.5).
FIG. 17.4 Demonstration of the correct positioning for microlaryngoscopy. A, Neutral position. B, Flexion of the thoraco-cervical junction and flexion of the cranio-cervical junction – a poor laryngeal view. C, Flexion of the thoraco-cervical junction and extension of the cranio-cervical junction giving a good laryngeal view, aligning the oral axis, the laryngeal axis and the pharyngeal axis.
This approach gives an excellent view of the vocal folds, and microsurgical instruments can then be used to excise lesions (Figs 17.6, 17.7).

**FIG. 17.5** Microlaryngoscopy setup. Note that the laryngoscope is suspended on a jig to allow for two-hand operating.

**FIG. 17.6** An endoscopic view of the vocal folds under general anaesthetic using a laryngoscope. Note the endotracheal tube, which sits posteriorly in the larynx between the arytenoid cartilages, and hence does not significantly impede the view of the vocal folds. This image demonstrates bilateral anterior vocal fold swellings consistent with nodules.
Transoral laryngeal surgery also allows for excision of many malignant laryngeal lesions, often using the carbon dioxide laser. The extent of removal of vocal fold tissue (or ‘cordectomy’) is graded I–V (Fig. 17.8), with shallow, grade I cordectomy reserved for benign superficial lesions, and more complete resections for malignancy. In general, oncological and functional outcomes are similar for transoral resection of the larynx (TORL) and radiotherapy, and the decision as to which modality to use is based on discussion with the patient and on the opinions of the clinical team regarding the operability of each individual tumour.
In addition, the transoral approach allows for injections into the vocal fold(s), particularly when there is a vocal fold paralysis.

**Tips and Anatomical Hazards**

Ensure that an adequate selection of laryngoscopes is available: in general, it is best to start with a large laryngoscope (e.g. Lindholm) to give optimal exposure. If the patient's anatomy makes it difficult to use a large scope, others should be tried. If the exposure is very difficult, a narrow ‘anterior commissure’ scope may be needed; it is rare for this to be required, however, and this type of narrow laryngoscope limits the movement of instruments, making surgery difficult.

During laryngoscopy if it is difficult to see the anterior commissure (see below), lift the head of the patient (somewhat counter-intuitively) to accentuate the ‘sniffing the morning air’ position.
In treating benign lesions of the larynx, try to preserve the pliability of the vocal fold (i.e. maintain the mucosal wave). This is achieved by avoiding excessive dissection in Reinke's space: any procedure that breaches the superficial lamina propria and extends to the vocal ligament is likely to result in loss of epithelial pliability, and hence a poor mucosal wave and a suboptimal voice outcome.

**External approaches to the larynx**

Vocal fold paralysis can confer a breathy quality on the voice as a result of incomplete closure of the vocal folds on phonation. It may also cause aspiration of ingested material. Surgical procedures aim to medialize the paralysed vocal fold to allow for better glottic closure. One means of achieving this is to approach the larynx through a neck incision in ‘laryngeal framework’ surgery. (These techniques were developed by Isshiki in the 1970s, when four different surgical procedures were described. The most common of these is a ‘type I thyroplasty’ or ‘medialization laryngoplasty’.) This is performed under local anaesthetic (often with some sedation) so that the voice can be checked during the surgery. A skin-crease incision is made over the thyroid lamina, and a subplatysmal layer is developed. The strap muscles are separated in the midline and the thyroid and cricoid cartilages are exposed.

Markings are made to delineate the position of the vocal folds: the anterior commissure is located exactly halfway between the upper and lower borders of the thyroid cartilage. A window in the thyroid cartilage is fashioned at the level of the paralysed vocal fold; the position of the window is then checked by passing a transnasal flexible endoscope. At this point, an implant material (which may be silastic, Gore-Tex ribbon, metal or other) is placed through the window into the paraglottic space. The position of the medialized vocal fold is checked endoscopically and the patient is asked to phonate to check the quality of voice.\(^3,6\)

**Tips and Anatomical Hazards**

The positioning of the cartilage window is critical: if it is too high, the false vocal fold will be medialized and the voice will not improve. To
avoid this, mark the position of the anterior commissure at the midpoint of the thyroid cartilage (halfway down between the laryngeal prominence and the lower border of the thyroid cartilage). Then mark out a horizontal line parallel to the lower border of the thyroid cartilage. This line now marks the position of the vocal fold and will form the upper border of the cartilage window (Fig. 17.9).
Other laryngeal framework procedures include the type IV thyroplasty, which mimics the action of the cricothyroid muscle to increase tension on the vocal folds and hence elevate the pitch of the voice. This is typically performed for male-to-female gender reassignment (Fig. 17.10).
Outpatient endoscopic procedures

In some circumstances, it is possible to perform procedures on the vocal folds in the outpatient setting under local anaesthetic with the patient awake. These techniques are especially helpful in patients whose medical comorbidities preclude them from having a general anaesthetic.

In particular, for patients with a unilateral vocal fold paralysis, the technique of vocal fold medialization under local anaesthetic has become increasingly popular. The needle may be introduced through the thyrohyoid membrane (hence approaching the vocal folds from above) or via the cricothyroid membrane (approaching from below) (Figs 17.11, 17.12).
FIG. 17.11 A, B, Transthyrohyoid (A) and transcricothyroid (B) approaches to vocal cord injection under local anaesthetic.
Transnasal endoscopic techniques may also be used to undertake biopsies of the larynx or to perform some laser procedures.

**External approaches to treat laryngeal malignancy**

While many laryngeal cancers are treated with either radiotherapy or transoral microsurgery, as described above, there remains a large cohort that is too advanced or unsuitable for this modality and must therefore be excised via an external approach. While descriptions of surgical technique are beyond the scope of this book, thorough knowledge of the structural anatomy of the larynx is vital in achieving adequate resection margins while maintaining function as much as possible (Fig. 17.13).
Total laryngectomy and pharyngolaryngectomy

In both of these operations, the larynx is removed in its entirety along with varying amounts of the hypopharynx/upper oesophagus. The trachea is brought out as a tracheostomy at the base of the neck and therefore there is no communication between the mouth and respiratory tract. To ensure a complete resection, the trachea is sectioned anywhere below the first ring and direct visualization from below confirms a macroscopic margin. Superiorly, the suprathyroid musculature is resected from the hyoid bone and the pharynx entered over the epiglottis, again with visualization to ensure that the tumour is clear. In this way, as much normal mucosa as possible can be preserved in the piriform fossae to allow a more tension-free closure and better functional outcome. The exact location and size of the tumour will determine the extent of pharyngeal resection. If disease is limited purely to the larynx, then the pharynx may be closed primarily; however, for hypopharyngeal/more extensive disease, it may be necessary to reconstruct
the missing segment using a free tissue flap (Fig. 17.14).
FIG. 17.14 Steps in total laryngectomy. A, The thyroid cartilage is dissected free from the inferior constrictor muscles. B, The trachea is divided well below the tumour and an endotracheal tube placed through the tracheotomy. C, The trachea is freed from the oesophagus. D, The larynx is excised, leaving a defect in the pharynx.
Partial laryngectomy
The operations described above have an understandably significant impact on quality of life: not only are there effects on speech and swallowing but also there are psychosocial and functional impacts in terms of daily activities. To counter this, an alternative is to perform a partial resection of the larynx, removing the tumour while preserving the integrity of larynx and therefore preventing the need for a stoma.

Vertical partial laryngectomy
Vertical partial laryngectomy (VPL) is employed either as salvage treatment (where the tumour has recurred following radiotherapy) or for small tumours (where access difficulties prevent adequate excision via a transoral route). In this operation, the thyroid cartilage is divided in the midline and opened (a ‘laryngofissure’), giving access to the internal larynx. The entire vocal cord, with or without a cartilage cuff, may then be resected. Reconstruction in its simplest form involves suturing the false cord to the subglottic mucosa (Fig. 17.15).
Supracricoid partial laryngectomy

Supracricoid partial laryngectomy (SCPL) refers to a group of operations employed to treat laryngeal malignancy surgically while preserving organ function, where the disease is not amenable to VPL. There are two types of SCPL, depending on the degree of resection needed to remove the tumour.

Cricohyoidoepiglottopexy (CHEP) is usually performed for glottis carcinomas. The entire thyroid cartilage, both true and false cords, and the paraglottic spaces are removed (Fig. 17.16). The cricoid is sutured to the hyoid and epiglottis.

Cricohyoidopexy (CHOP) is a more extensive procedure than CHEP and includes the additional resection of the pre-epiglottic space and epiglottis. It is used for selective supraglottic and transglottic tumours. Reconstruction is achieved by suturing the cricoid to the hyoid/infrahyoid musculature directly.

Understandably, the postoperative internal view of these patients is complex, with significantly distorted anatomy.

Tips and Anatomical Hazards

Remember that any decision on what operation to undertake should be
made after detailed consideration of the tumour location, as well as the implications of a full resection margin, and should include detailed discussion with the patient, taking their expectations into account.

Reassess the tumour fully on table prior to starting a partial laryngectomy by performing a comprehensive endoscopy of the upper aerodigestive tract; if there is any doubt as to the ability to obtain clear margins, then a total laryngectomy should be performed instead, after counselling the patient appropriately.

Always aim to divide the fibres of the cricopharyngeus muscle (i.e. perform a cricopharyngeal myotomy) to aid swallowing.

For partial laryngectomy, preserve the superior laryngeal nerves to keep sensation to the remaining larynx, as well as an intact cricoarytenoid unit, which will aid postoperative laryngeal function.
References

Single Best Answers

1. A patient presents with a 3-month history of hoarseness; he is a lifelong smoker. In the first instance, which one of the following would be the most appropriate modality for laryngeal evaluation?
   A. Head light and tongue depressor
   B. General anaesthetic laryngoscopy
   C. Mirror laryngeal examination
   D. Flexible fibreoptic examination
   E. Flexible bronchoscopy

   **Answer: D.** Examination with a head light and tongue depressor will not give a view of the larynx. Although it may ultimately be necessary to perform an examination and biopsy of the larynx under general anaesthetic, it is important to evaluate the vocal folds in clinic, ideally with a flexible nasal endoscope – either a chip-tip endoscope or a fibreoptic endoscope.

2. **Fig. 17.17** shows an intraoperative image of a larynx. Which one of the following diagnoses is correct?
   A. Vocal fold nodules
   B. Laryngeal papillomatosis
   C. Carcinoma
D. Vocal fold polyp
E. Vocal process granuloma

**Answer: A.** This image shows bilateral symmetrical swellings at the junction of the anterior third and posterior two-thirds of the vocal folds; these are typical of vocal fold nodules. These are subepithelial fibrotic swellings caused by chronic vocal abuse. Treatment is typically with voice therapy but surgery is sometimes required.

3. When laryngoscopy is being performed under general anaesthetic, which one of the following describes the most appropriate position for the head?
   A. Neutral position
   B. Neck fully extended (extension at the thoracocervical junction; extension at the craniocervical junction)
   C. Neck flexed
   D. ‘Sniffing the morning air’ (flexion at the thoracocervical junction; extension at the craniocervical junction)
   E. Extension at the thoracocervical junction; flexion at the craniocervical junction

**Answer: D.**

4. Which one of the following may cause unilateral vocal fold paralysis?
   A. Thyroid surgery
   B. Cervical spine surgery
   C. Lung surgery
   D. All of A, B and C
   E. None of A, B and C
**Answer:** D. Unilateral vocal fold paralysis results from interruption of the recurrent laryngeal nerve; any surgery near (or on) the vagus nerve (e.g. anterior cervical discectomy and fusion; carotid endarterectomy; carotid body tumour excision; glomus tumour excision) or the recurrent laryngeal nerve (thyroid or parathyroid surgery; oesophageal or lung surgery; heart surgery) may cause a unilateral vocal fold paralysis.

5. A 55-year-old male presents to clinic with a 6-month history of hoarseness. He is a lifelong non-smoker. Flexible chip-tip laryngeal examination is performed (**Fig. 17.18**). Which one of the following options describes the most likely diagnosis and next step?

A. Vocal fold granuloma; monitor in clinic
B. Laryngeal papillomatosis; perform microlaryngoscopy
C. Carcinoma; perform diagnostic microlaryngoscopy
D. Carcinoma; perform radiological imaging and review in clinic
E. Vocal fold nodules; monitor in clinic
Answer: C. The appearances at the anterior commissure are suspicious for dysplasia or carcinoma; a diagnostic microlaryngoscopy and biopsies should be performed, along with CT scanning to establish whether cartilage invasion is present.

6. Which one of the following nerves is at risk when dissecting the greater cornu during total laryngectomy?
A. Vagus nerve
B. Phrenic nerve
C. Facial nerve
D. Hypoglossal nerve
E. Superior laryngeal nerve

Answer: D. Care must be taken when freeing the greater cornua, and it is usually recommended to use sharp scissor dissection, as opposed to electrocautery, for this part. The hypoglossal nerve lies in close proximity to the greater cornu and, unless identified, may be injured during resection.

7. Which one of the following is a contraindication to supracricoid laryngectomy?
A. Mucosal involvement of both arytenoid cartilages
B. Subglottic origin of the tumour
C. Invasion of the hyoid bone
D. Invasion of the pre-epiglottic space
E. All of the above

Answer: E. All of the above are contraindications to supracricoid laryngectomy, as they will compromise the ability to clear tumour while maintaining function.
1. A 45-year-old female has recently had a left hemithyroidectomy; postoperatively, she has a weak and breathy voice.

   A. What is the most likely aetiology and why?
   The most likely cause is a vocal cord paralysis as a result of injury to the recurrent laryngeal nerve. The proximity of the recurrent laryngeal nerve to the thyroid means that it is vulnerable to injury in the tracheo-oesophageal groove or around the cricothyroid joint, where it enters the larynx.

   B. What are the clinical features of a unilateral vocal fold paralysis?
   The inability to achieve closure of the vocal folds on phonation results in a breathy voice. In addition, the patient may have a weak (‘bovine’) cough, with ineffective expectoration. Failure of glottic closure on swallowing leaves the patient at risk of aspiration. The combination of aspiration and an ineffective cough can lead to aspiration pneumonia.

   C. Describe the management of a patient in this situation.
   In the first instance, the patient should be assessed by a speech and language therapist to establish whether the swallow is ‘safe’ or whether the patient should be placed nil-by-mouth to avoid aspiration. Swallow therapy techniques can be employed to minimize the risk of aspiration. Surgical procedures can be employed to medialize the paralysed vocal fold: these might involve a medialization injection (either transcutaneously or perorally) or external-approach laryngeal framework surgery (so-called Isshiki thyroplasty type 1).

2. A 25-year-old football fan loses his voice after shouting energetically during a match. In subsequent weeks, his voice comes back, but does not return to normal and remains moderately hoarse.

   A. What is the possible aetiology?
   It seems likely that an episode of phonotrauma has occurred – possibly a haemorrhage into the vocal fold, leaving a residual vocal fold subepithelial lesion such as a polyp.

   B. What examination technique should be employed?
   In the clinic a laryngoscopy is mandatory – either using a flexible transnasal endoscope or a rigid (Hopkins rod) endoscope perorally. Ideally,
the movements of the vocal folds should be inspected using stroboscopy to give information about the pliability of the vocal folds.

C. The patient's larynx appears as shown in Fig. 17.19. Describe what is shown.

![Fig. 17.19](image)

This is a polyp of the right vocal fold.

D. What is the anatomical explanation for this polyp?

The episode of phonotrauma probably led to an acute haemorrhage into the subepithelial layer of the mid part of the right vocal fold. After the haemorrhage resolved, this was replaced with a deposition of collagen.

E. What treatment should be offered?

This is a benign lesion and the patient may choose not to have any treatment. However, the lesion is unlikely to resolve spontaneously. Surgical excision (during microlaryngoscopy) is likely to be curative, and speech therapy should be offered to ensure that better vocal habits are instigated, and to provide advice during the perioperative period.

3. A 30-year-old female presents to the voice clinic with an insidious onset of a hoarse voice and, more recently, noisy breathing. Her larynx appears as shown in Fig. 17.20.
A. Describe what is shown.

Both vocal folds are grossly abnormal, with irregular masses arising from both sides; the airway is compromised because of the size of these masses. Clinically, this appears to be laryngeal papillomatosis (recurrent respiratory papillomatosis, caused by human papillomavirus (HPV)).

B. What treatment would you offer?

Urgent surgery is required to prevent any further airway compromise. The papillomatous lesions should be debulked during microlaryngoscopy. A variety of techniques is available, including microdebrider, laser and coblation.

4. A 55-year-old smoker presents via his primary care doctor with a 3-month history of hoarseness and increasingly noisy breathing.

A. Fig. 17.21 is an endoscopic view of the larynx as seen in clinic. Describe what is shown.
This photograph demonstrates a large exophytic tumour of the left hemilarynx, which is obscuring a view of the true vocal folds. It is affecting the left side of the epiglottis (indeed, it crosses the midline to the right), the left aryepiglottic fold, the left arytenoid and the medial aspect of the left piriform fossa.

**B. What is the most likely diagnosis and what steps should now be taken?**

Given the history of smoking, this is probably a squamous cell carcinoma (SCC). The patient should undergo cross-sectional imaging of the neck and thorax (probably a CT scan). This will help to establish the extent of the tumour and any invasion of local structures (cartilaginous invasion is overwhelmingly likely, given the clinical appearance). A tissue diagnosis should be taken under general anaesthetic (microlaryngoscopy), and the rest of the pharynx and larynx should be assessed to stage the tumour.

**C. What treatment will be offered?**

In general terms, two modalities can be used in treatment of SCC of the larynx: radiotherapy (with or without chemotherapy) and surgery. In this case, the size of the tumour and the likely invasion of cartilage make it very unlikely that non-surgical treatment will be an option; a total laryngectomy is likely to be required.
Thyroid and parathyroid glands

Sam M Wiseman

Core Procedures

- Thyroid lobectomy and isthmusectomy
- Total thyroidectomy/near-total thyroidectomy
- Sistrunk procedure (resection of a thyroglossal duct cyst)
- Parathyroidectomy
- Subtotal parathyroidectomy and transcervical thymectomy
- Parathyroid autotransplantation
- Parathyroid cryopreservation
- Central neck dissection

The thyroid gland takes its name from the Greek words ‘thyreos’ (shield) and ‘edidos’ (form) because of its shape and position in the anterior central neck. The parathyroid glands are named for their location adjacent to the thyroid. It is because of their intimate anatomical relationship that any operation performed on the thyroid should also be considered an operation on the parathyroids, and vice versa. Therefore the surgical anatomy of the thyroid and parathyroid glands will be reviewed together in this chapter, and within the context of a thyroidectomy, because of their significant anatomical and technical overlap. Thyroid and parathyroid operations require meticulous surgical technique, obsessive attention to detail and thoughtful consideration of anatomical nuances. Perhaps this is why thyroidectomy was described by William Halsted, one of the fathers of modern surgery, as the ‘supreme triumph of the surgeon's art’. It is not surprising that multiple studies have reported that a surgeon's experience has a significant impact on the outcomes of patients undergoing thyroid and parathyroid operations.

One of the greatest barriers that exists to understanding surgical anatomy, especially true for thyroid and parathyroid surgical anatomy, is an
appreciation of the significant differences that are observed when comparing *in situ* normal anatomy and operative anatomy. These observed differences are primarily encountered as a consequence of changes in the location and orientation of anatomical structures that occur during the operation itself, as well as the distortions of normal anatomy that are caused by the underlying pathology that is being treated. During thyroidectomy and parathyroidectomy, anteromedial rotation of the thyroid gland out of the central neck and through an arc of approximately 120° is essential for adequate surgical exposure ([Fig. 18.1](#)). It is this exposure of the central neck compartment that facilitates both the identification and the preservation of important structures, including the recurrent laryngeal nerves (RLNs) and the parathyroid glands, and removal of pathological structures, such as a parathyroid adenoma or central neck metastatic lymph nodes. Operative anatomy is further distorted as a consequence of the underlying pathology that involves the gland(s) themselves, such as goitrous growth or malignancy of the thyroid, or the parathyroid enlargement that is observed as a consequence of hyperplasia. Though a variety of minimal access approaches are currently utilized for thyroidectomy and parathyroidectomy, this chapter focuses on the classic ‘open’ operative approach, and specific technical advice is presented within the context of the anatomical review of the operations.
FIG. 18.1  The differences between in situ normal anatomy (above) and operative anatomy (below) may be appreciated in cross-section.
Embryology and congenital anomalies

The thyroid gland appears at about 30–31 days post fertilization (stages 11–12) as a median endodermal thickening in the floor of the primitive pharynx, located between the first and second pharyngeal pouches, which invaginates into the surrounding neural crest mesenchyme. As the lower pharyngeal arches form and the heart descends, the diverticulum extends as the thyroglossal duct, anterior to the developing hyoid bone and laryngeal cartilages. The original site of invagination, the foramen caecum, is located at the junction of the anterior two-thirds (oral portion) and posterior one-third (pharyngeal portion) of the tongue. The thyroid gland is bilobed, forming thyroid lobes and an isthmus by stage 14 (32–34 days post fertilization), and is near the rostral border of the aortic sac at stage 15 (35–36 days post fertilization). As it extends caudally to its pretracheal position, it fuses laterally with cells of the caudal pharyngeal complex (fourth pharyngeal pouch and ultimobranchial body) that become incorporated into the lateral aspect of the developing thyroid gland, and is the origin of the calcitonin-secreting parafollicular or ‘C’ cells.

Complete failure of descent of the thyroglossal duct leads to the development of thyroid tissue within the tongue, which is referred to as a lingual thyroid. The persistence of thyroid tissue along its path of migration may also lead to entirely ectopic thyroid glands (sublingual, prelaryngeal and pretracheal glands) or ectopic thyroid tissue deposits, also referred to as small accessory thyroid glands. The surgeon should be aware that an ectopic thyroid gland may easily be mistaken for a thyroglossal duct cyst and if removed will lead to hypothyroidism. Thus, preoperative imaging (radioactive iodine uptake scan or neck ultrasound) should be considered to determine if additional thyroid tissue is present. Persistence of the most distal portion of the thyroglossal duct occurs in approximately 50% of individuals, and gives rise to the pyramidal thyroid lobe and the levator glandulae thyroideae. The pyramidal lobe is a tongue of thyroid tissue extending from the superior border of the isthmus, usually at its junction with the left lobe, towards the hyoid bone, to which it is connected by a fibrous band, the levator glandulae thyroideae, which may contain muscular fibres. During total thyroidectomy, care must be taken to remove the entire pyramidal lobe in order to avoid persistence of an excessively large thyroid remnant. The thyroglossal duct atrophies, but remnants may persist anywhere along its path of migration and lead to the
development of a thyroglossal duct cyst (see Fig. 18.2). The latter may become infected, require drainage and fistulize through the overlying skin; uncommonly, these cysts may even give rise to thyroid malignancy.\(^5\) During resection of a thyroglossal duct cyst, also referred to as the Sistrunk procedure, the cyst and its associated duct, as well as the central portion of the hyoid bone, are removed en bloc in order to reduce the risk of recurrence.\(^6\)

Prelaryngeal lymph nodes may commonly be found along the course of the pyramidal lobe. Calcitonin-producing parafollicular cells, or C cells, arise within the paired ultimobranchial bodies that are derived from the fourth branchial pouch during the fifth week of gestation, and become incorporated into the developing thyroid. The Zuckerkandl tubercle (ZT), a posterolateral projection of the thyroid gland, located adjacent to the junction of the thyroid and cricoid cartilages, is a remnant of the ultimobranchial body. The ZT is present in approximately 70% of individuals and usually is less than 1 cm in diameter.\(^7\) When present, it constitutes a useful anatomical landmark for identification of the RLN and the superior parathyroid gland. The ZT has been described as being shaped like an ‘arrow that points towards the RLN’. This is because the RLN travels posteromedially to a well-developed ZT in more than 80% of people, and in this location the nerve may often be mistaken as travelling intrathyroidally (Fig. 18.3). The RLN may, through gentle dissection and with medial retraction of the ZT, be gradually exposed up to its entry into the larynx. Like the ZT, the superior parathyroid glands are also derived from the fourth pharyngeal pouch; their common embryological origin explains the consistent posterior and superior location of the superior parathyroid gland in relation to the ZT.\(^8\) Thus, the superior parathyroid gland should be routinely identified and its blood supply carefully preserved during thyroidectomy, especially when dissecting the ZT. Midline thyroid tissues that extend inferiorly into the thyrothymic ligament are referred to as thyrothymic thyroid rests (TTR) (see Fig. 18.2). TTR also represent remnants of the developing thyroid gland that may be present in more than half of individuals, and during surgery may be mistaken for lymph nodes or parathyroids.\(^9\)
FIG. 18.2  Arrest of descent of the thyroglossal duct leads to development of an ectopic thyroid gland or a thyroglossal duct cyst. The pyramidal thyroid lobe and thyrothymic thyroid rests also arise from the thyroglossal duct.
The parathyroid glands develop at about stage 14 (32–34 days post fertilization) as interactions between the dorsal endodermal epithelium and the underlying neural crest mesenchyme of the third and fourth pharyngeal pouches. The ventral epithelium of these pouches gives rise to the thymus and lateral thyroid tissue, respectively. Parathyroid III (inferior parathyroid gland) migrates earlier and moves further caudally than parathyroid IV (superior parathyroid gland), which becomes anchored to the developing lateral lobes of the thyroid gland. This leads to the inferior parathyroids having a more variable location than the superior. Congenital anomalies in parathyroid development include variations in gland number, shape, size, weight, colour, and the development of a cystic component.
Surgical surface anatomy and approach

The thyroid gland straddles the trachea anteriorly. It consists of two conically shaped lobes that are connected to each other by a narrow bridge, or isthmus, which may also have an ascending pyramidal lobe. The thyroid normally extends from the level of the fifth cervical vertebra to the body of the first thoracic vertebra. A normal thyroid gland weighs approximately 25 g in an adult, and each lobe on average measures 5 cm in length, 3 cm in width and 2 cm in thickness. The isthmus measures approximately 1.3 cm in length and usually overlies the second and third tracheal cartilages. Critical palpable surface landmarks for thyroid/parathyroid operations include the suprasternal notch, the cricoid cartilage, the thyroid notch and the hyoid bone. Normal anatomical surface landmarks may be significantly distorted or even lost because of enlargement of the thyroid itself or because of the patient's body habitus. In obese, ‘short-necked’ older patients, the thyroid tends to be positioned lower in the neck and may be almost entirely retrosternal (Fig. 18.4). An enlarged thyroid gland may extend inferiorly into the mediastinum or superiorly into the submandibular region, and may even encroach on the lateral neck compartments and displace the carotid arteries and the internal jugular veins (Fig. 18.5).
The patient undergoing a thyroidectomy/parathyroidectomy is usually positioned in some degree of neck extension in order to displace the thyroid anteriorly and superiorly. The precise location of the neck incision is important, and optimal placement requires consideration of both patient cosmesis and surgical access. Ideally, a gently curving, symmetrical, transverse incision that is placed along the skin lines of Langer, travelling either through or parallel to a neck crease, is preferred. As natural creases may be lost with extension, it is helpful to mark out the incision while the patient is in a neutral sitting position, even prior to anaesthesia. Traditional teaching has classically described placement of the thyroidectomy/parathyroidectomy incision ‘two fingers’ breadths above the suprasternal notch’. However, for individuals with long necks, such incisions are often too low and may hamper exposure of the superior pole. Conversely, for individuals with short necks, such incisions may be too high and limit access to their inferior pole, especially if a substernal goitre is present (see Fig. 18.4). Placement of the incision 1–2 cm below the cricoid cartilage, a landmark that consistently correlates with the location of the thyroid isthmus, will facilitate exposure and permit access to both superior and inferior thyroid poles. Exposure of the thyroid/parathyroid may be challenging in patients who are obese, or who have short necks or limited
extension due to kyphoscoliotic deformities or other neck pathology, especially when in a position of fixed flexion. The actual length of the thyroidectomy incision really must be tailored to both the individual patient and their clinical presentation. During thyroidectomy/parathyroidectomy, the adequacy of surgical exposure of critical structures, including the RLNs and parathyroid glands, must not be compromised for incisional cosmesis.

Platysma lies beneath the skin and subcutaneous fat, and is often deficient in the midline (Ch. 15). The working space for thyroidectomy is usually created by raising flaps along the subplatysmal plane, superiorly to the level of the top of the thyroid notch, and inferiorly to the level of the suprasternal notch. When creating these flaps, care must be taken to avoid the bleeding that may occur as a result of injury to the anterior jugular veins or one of their tributaries. The anterior jugular veins run along the surface of the infrahyoid strap muscles, often paralleling the midline, but have a somewhat variable course. They also may communicate with each other through bridging vessels that cross the midline, especially lower in the neck. The anterior jugular veins usually empty into the internal jugular veins, but may also empty directly into the subclavian veins. The strap muscles are encountered beneath the platysma. They are paired muscles encased by the superficial layer of the deep cervical fascia and either originate or insert on to the hyoid bone; they function either to depress or to stabilize the hyoid bone during deglutition, and to stabilize the larynx. Individual strap muscles are each named according to site of origin and insertion. The inner strap muscles are the thyrohyoid more superiorly, and the sternothyroid more inferiorly. The thyrohyoid originates from the lamina of the thyroid cartilage above the insertion of sternothyroid (oblique line) and inserts on to the lower border of the greater cornu of the hyoid bone. The outer strap muscles are sternohyoid and omohyoid. Sternohyoid originates from the posterior aspect of the manubrium, the adjacent clavicle and the posterior sternoclavicular ligament, and inserts on to the medial aspect of the lower border of the body of the hyoid bone. The omohyoid has an inferior belly that originates from the upper border of the scapula and the superior transverse scapular ligament, a central tendon enclosed by a band of cervical fascia that crosses the carotid sheath, and attaches to the clavicle and the first rib, and a superior belly that extends alongside sternohyoid to insert on the lateral aspect of the hyoid bone (Ch. 15). All the strap muscles, except thyrohyoid, are innervated by the ansa cervicalis, derived from the cervical plexus (C1, C2, C3); thyrohyoid is innervated by fibres from C1 that travel with the hypoglossal nerve. The
superior root of the ansa cervicalis appears as a branch of the hypoglossal nerve and descends along the lateral border of sternothyroid, innervating that muscle near its lower third. If the strap muscles must be transected during thyroidectomy to facilitate surgical exposure of a large goitre, this should be carried out at the level of the cricoid cartilage or higher up in order to preserve the nerve supply to the muscles. Occasionally, for suspected or known thyroid cancers that are located anteriorly within the gland and may invade the overlying strap muscles, leaving an island of muscle in continuity with the tumour as part of the surgical specimen may facilitate clearance at its anterior margin. Division of sternothyroid at its insertion is a manoeuvre that may facilitate exposure of the superior pole of the thyroid. During thyroidectomy, the strap muscles are separated along their midline fascia; care must be taken when operating for suspected or confirmed thyroid malignancy because there may be pretracheal and prelaryngeal lymph node metastases present that should also be removed.

The thyroid gland is enveloped by an outer false capsule and an inner true capsule. The false capsule (surgical capsule, perithyroidal sheath) is continuous with the deep (pretracheal) layer of the middle or visceral layer of the deep cervical fascia. It is well developed anteriorly and laterally but thin posteriorly, although it thickens medially into the posterior suspensory ligament of the thyroid, commonly referred to as the ligament of Berry (LB). The LB suspends each thyroid lobe from the cricoid cartilage and the first two tracheal rings, and extends along the posteromedial aspect of each lobe. The true capsule sends septa into the gland parenchyma and forms lobules.

The superior parathyroid glands are usually located between the true and false thyroid capsules. The inferior parathyroid glands may be located intrathyroidally, or between the true and false capsules, or on the outer surface of the false capsule. During thyroidectomy, the false capsule may be appreciated as being in continuity with the areolar tissue that is bluntly pushed off the true capsule towards the paratracheal region when entering the central neck compartment. This manoeuvre usually also mobilizes the parathyroid glands off, and away from, the thyroid. The importance of this capsular dissection technique, begun high on the surface of the true thyroid capsule and carried out in a medial to lateral direction, cannot be overstated because it facilitates preservation of the parathyroid glands by leaving their blood supply intact. When dissection is being performed within this plane, small terminal branches of the inferior thyroid artery that directly penetrate the surface of the thyroid gland are encountered and require careful
systematic ligation or clipping in order to avoid haemorrhage\textsuperscript{11} (Fig. 18.6).

The parathyroid glands may be differentiated from yellowish fat, dark brownish thyroid tissue and greyish to pinkish lymph nodes, on the basis of their pale tan to dark reddish brown colour; their appearance, with magnification, of being peppered with light-refracting pinpoint specks; and their characteristic flattened oblong shape with discrete rolled edges. Normal parathyroid glands weigh between 15 mg and 40 mg, measure approximately 2 mm × 3 mm × 5 mm, and are often enclosed by a small amount of fat.\textsuperscript{4} In 80\% of cases, the superior parathyroid glands are located on the posterior aspect of the thyroid at the level of the cricothyroid junction, corresponding to a position that is 1 cm superior to the point where the RLN crosses the inferior thyroid artery. The inferior parathyroid glands are more variable in their position, and in 50\% of cases may be found within 1 cm of the inferior
thyroid pole, located either inferiorly, laterally or posteriorly. The superior parathyroid glands tend to be located lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane, whereas the inferior parathyroid glands tend to be located medial to the RLN sagittal plane and anterior (ventral) to the RLN coronal plane (Fig. 18.7). During subtotal parathyroidectomy carried out for the treatment of multigland disease (which has an inherent associated risk of disease recurrence and need for reoperation), the inferior parathyroid glands are given preference over the superior parathyroid glands as the source of the remnant that remains in situ, on the grounds that removing disease recurrence anterior to the plane of the RLN may have a lower risk of nerve injury during reoperative parathyroidectomy. Tagging of the parathyroid remnant with coloured suture or clips may also be helpful if disease recurrence requires reoperation. However, the most important consideration is to ensure that the parathyroid remnant left in situ has an adequate blood supply. Similarly, in order to minimize the risk of the patient developing postoperative hypoparathyroidism, preservation of the blood supply of all of the parathyroid glands left in situ is absolutely critical during thyroid/parathyroid operations. Each parathyroid gland should be coveted and treated as if it is the only remaining parathyroid. Great care must be taken to preserve the branches of the inferior thyroid artery that supplies both the upper and lower parathyroid glands, and the superior thyroid artery that often also supplies the superior parathyroid glands.
The superior parathyroid glands tend to be located lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane, in contrast to the inferior parathyroid glands that tend to be located medial to the RLN sagittal plane and anterior (ventral) to the RLN coronal plane. Early identification of the parathyroid glands may facilitate RLN localization.
Intensive scrutiny of the viability of the parathyroids is important; devitalization should not be confused with the bruising or colour change that is observed due to development of a subcapsular haematoma. In circumstances where a normal parathyroid gland is intentionally or inadvertently removed or devitalized, parathyroid autotransplantation should be carried out. After intraoperative confirmation that the removed or devitalized tissue is indeed parathyroid, using either frozen section analysis or another technique, autotransplantation may proceed. The parathyroid tissue is initially placed in ice-cold saline while the autotransplantation implantation sites are prepared. Even though many different anatomical sites for parathyroid autotransplantation have been described, they may broadly be classified as being either subcutaneous or intramuscular. If the tissue to be autotransplanted is derived from a grossly normal-appearing parathyroid gland, removed during a thyroid operation from a patient with normal parathyroid function, immediate autotransplantation should be performed. In this setting, the sternocleidomastoid is an easily accessible, well-vascularized and commonly utilized autotransplant implantation site. However, if the parathyroid tissue being autotransplanted originates from a hyperparathyroid patient and/or appears grossly abnormal, if autotransplantation is warranted, a more distant host site, such as brachioradialis, should be selected. Should recurrent hyperparathyroidism develop in such a patient, preoperative localization and surgical re-exploration may be more straightforward, and have less associated morbidity, in a location that is remote from the neck. In renal failure patients, avoiding potential or existing arteriovenous fistula sites is an important consideration when selecting an autotransplant implantation site. Several tiny pockets are created within the host muscle to receive aliquots of the parathyroid tissue that has been diced into approximately 1 mm\(^2\) fragments. It is critically important for there to be no bleeding within the muscle pockets because bleeding and clot may prevent parathyroid tissue engraftment. The implantation sites are also each marked with clips or non-absorbable suture (Fig. 18.8). Injection of morcellated parathyroid tissue suspended in saline into the muscle is an alternative autotransplantation technique. If excessive parathyroid tissue is available, as is often the case in secondary or tertiary hyperparathyroid patients, parathyroid cryopreservation should be considered.\(^{13}\)
FIG. 18.8 After removal of a devitalized normal appearing parathyroid gland is confirmed by intraoperative frozen section autotransplantation is carried out. The parathyroid is diced into 1 mm$^3$ fragments (A and B), aliquots of the fragments are separated (C), and after using a small right angle clamp to create several pockets within the sternocleidomastoid (D), are carefully placed into each pocket using the tip of a scalpel (E), and the pocket is then closed with multiple clips that also serve to mark the transplantation site (F).

Due to goitrous enlargement, the lower pole of the thyroid may extend into the anterior superior mediastinum and cause tracheal compression at the thoracic inlet within the rigid space created by the surrounding bony structures (Fig. 18.9). The patient may be symptomatic as a consequence of significant segmental tracheal and oesophageal compression. However, the majority of such goitres may be removed through a standard transcervical approach, and usually just requires blind blunt finger dissection to allow for delivery of the substernal component out of the chest and into the neck (Fig. 18.10). In such cases, the RLN may be at increased risk of injury especially if it is adherent or splayed by the goitre, and not identifiable until the goitre has been delivered from the chest. Other techniques for delivery of a substernal goitre include the drawer manœuvre, where the surgeon grasps the goitre from the neck with two hands and pulls it out like a drawer; and
morcellation, which may be hazardous because it can lead to haemorrhage, dissemination of malignancy and retention of a substernal remnant. A partial sternotomy may be required for rare cases. Dumbbell-shaped goitres and reoperative substernal goitres are both at higher risk of requiring a sternotomy. Injury to the cupola of the pleura with a resultant pneumothorax is an uncommon complication that may occur during removal of a substernal goitre.

**FIG. 18.10** Blind blunt finger dissection is often necessary in order to deliver the substernal component of a goitre into the neck.
There has been widespread adoption of preoperative image-directed focused parathyroidectomy, usually carried out through a small incision, guided by intraoperative parathyroid hormone measurement, and performed as a same-day hospital discharge procedure for treatment of primary hyperparathyroidism. However, all surgeons who perform these focused procedures must also be able to perform a four-parathyroid gland exploration readily, should it become necessary when multiple abnormal parathyroid glands are identified. A four parathyroid gland exploration is also required for focused parathyroidectomy cases in which preoperative imaging studies fail to localize, misdirect or are incorrect, for treatment of secondary or tertiary hyperparathyroidism, lithium-related hyperparathyroidism and hereditary forms of hyperparathyroidism.

The major operative objective when performing a parathyroidectomy for the treatment of primary hyperparathyroidism is the identification and removal of one or more abnormal glands that are causing the disease. The objective when performing a subtotal parathyroidectomy for treatment of four-gland disease, whether for treatment of primary, secondary or tertiary hyperparathyroidism, is the removal of all parathyroid tissue except for one half of a normal gland, or leaving the patient with 50 mg of viable parathyroid tissue.\textsuperscript{12} Though often carried out through small incisions today,
the initial exposure of the central neck for parathyroidectomy is essentially the same as for thyroidectomy, with medial retraction on the thyroid lobe permitting adequate central neck exposure. Intraoperatively, based on their gross appearance, both normal and pathological parathyroid glands may be identified. Intraoperative localization of abnormal parathyroid glands is greatly facilitated by preoperative imaging studies. The superior parathyroid glands are usually more consistent in location than the inferior glands, which are situated along the posterior surface of the superior pole of the thyroid gland, lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane (see Fig. 18.7). The utility of the ZT in assisting with superior parathyroid gland localization has already been reviewed (see Fig. 18.3). The inferior parathyroid glands have a more variable position and generally are described as being medial to the RLN sagittal plane and anterior (ventral) to the RLN coronal plane (see Fig. 18.7). The RLN actually serves as a very useful anatomical landmark for correctly distinguishing between superior and inferior parathyroid glands.12

Correct designation of a parathyroid gland as being either superior or inferior is important because it helps to direct the surgical exploration for glands that have not yet been identified (Fig. 18.11). The inferior parathyroid glands may be located on the lateral, anterolateral or posterior aspect of the lower portion of the thyroid lobe, a short distance inferior to the lower pole of the thyroid, within the thyrothymic ligament, and may even be incorporated into the thymus. Multiple factors may contribute to difficulties with parathyroid gland identification during operation, including the limited experience of the surgeon, incorrect diagnosis, non-localized disease, patient characteristics (such as a short neck or obesity), normocalcaemic disease, the presence of a concurrent multinodular goitre or other thyroid pathology, central neck lymphadenopathy, and a history of a prior central neck compartment operation. Clear identification of the normal parathyroid glands is also often necessary to aid in deducing the side and type (superior versus inferior) of a missing gland, and may help to direct surgical exploration. Intensive scrutiny and comparison of the size and morphology of the normal parathyroid glands that have been identified during operation may allow for the diagnosis of what was not initially appreciated as being multigland disease. In this setting, intraoperative frozen section tissue analysis may be especially important for definitive parathyroid identification. The strategy for localization of a missing parathyroid gland may require exploration superior to the upper pole of the thyroid as high as the hyoid
bone, and inferior to the lower pole of the thyroid into the superior mediastinum. The exploration begins with careful inspection and palpation of the posterior and lateral aspects of the thyroid capsule. Removal of paratracheal tissue and delivery of the thymus gland into the neck with gentle upward traction, along with careful division of its vessels as they are encountered, may also be necessary. Further careful systematic exploration of the parapharyngeal and retropharyngeal spaces, and the para-oesophageal and retro-oesophageal spaces should follow. This exploration is carried out deep within the paratracheal space both anterior and posterior to the plane of the RLN. The missing parathyroid may even be located immediately anterior to the point at which the RLN enters the larynx. If the parathyroid continues to elude the surgeon, then opening the carotid sheath and exposing the common carotid artery for its course in the neck may expose the ectopic gland. When all sites have been explored, then either ligation of the inferior thyroid artery or thyroid lobectomy may be performed in order to devitalize or remove what may be an ectopic intrathyroidal gland. Sternotomy for mediastinal exploration should not usually be carried out at the initial operation if a missing parathyroid(s) has not been identified, but should be deferred until the diagnosis has been reconfirmed and further localization studies have been performed.\textsuperscript{15}
FIG. 18.11  The surgeon's view of large left superior parathyroid adenoma (green arrow) that is located lateral and posterior (dorsal) to the recurrent laryngeal nerve (yellow arrow) sagittal and coronal planes, respectively. Inset image shows parathyroid adenoma after removal.
Surgical anatomy and variants

Vascular supply and lymphatic drainage

**Arterial supply**

The thyroid gland has a very rich blood supply, receiving 5.5 ml per gram of tissue each minute. The arterial blood supply is from the superior and inferior thyroid arteries; occasionally, small perforating arteries may arise directly from the trachea, and in 10% of patients a thyroidea ima artery is present. There is tremendous variation in the thyroid gland's arterial anatomy. The superior thyroid artery supplies the upper half of the lobe and isthmus. It is the first branch of the external carotid artery, and arises above, below or at the carotid bifurcation. It passes superior and parallel to the external branch of the superior laryngeal nerve (EBSLN), deep to the superior belly of omohyoid and deep to sternothyroid. It has six branches: infrahyoid, sternocleidomastoid, superior laryngeal, cricothyroid, inferior pharyngeal constrictor, and terminal branches that supply the thyroid and parathyroid glands. It divides at the superior pole of the thyroid gland into an anterior branch that anastomoses with the contralateral artery, and a posterior branch that anastomoses with branches of the inferior thyroid artery, and that may give off a small branch that passes to the superior parathyroid gland, and a lateral branch. The inferior thyroid artery most commonly arises from the thyrocervical trunk but may arise directly from the subclavian artery (15%). It enters the central neck beneath the common carotid artery and internal jugular vein at the level of the cricoid cartilage, travels medially and posteriorly along the anterior surface of longus colli, and divides into ascending and descending branches as it crosses the RLN during its ascent towards the larynx.

Many different anatomical relationships have been reported between the RLN and the inferior thyroid artery. The surgeon must be aware that the RLN may be located anterior or posterior to, or may even pass between, the arterial branches. RLN identification may be facilitated by placing slight traction on a ligature or vessel loop that encircles the inferior thyroid artery as it emerges from behind the carotid artery. If the RLN passes through or anterior to the branches of the inferior thyroid artery, this manoeuvre will elevate the nerve and may assist with its identification. The ascending branch of the inferior thyroid artery usually anastomoses with the descending branch of the superior thyroid artery and supplies the posterior aspect of the
thyroid gland. The descending branch supplies the lower pole of the thyroid and also sends an arterial branch to the inferior parathyroid gland. The inferior thyroid artery therefore supplies both the superior and the inferior parathyroid glands; the superior thyroid artery may also supply the superior parathyroid\(^4\) (Fig. 18.12). The importance of taking great care to preserve the delicate and intricate parathyroid blood supply, in order to avoid gland ischaemia and postoperative hypoparathyroidism, cannot be overstated. As has already been discussed, in order to accomplish this, a capsular dissection technique is absolutely critical\(^11\) (see Fig. 18.6). When the parathyroid glands are mobilized off the surface of the thyroid, great care should be taken to limit the dissection only to the surface that is in contact with the thyroid capsule. Additional dissection of a parathyroid with disruption of its surrounding fat is usually not necessary, traumatizes the gland and may lead to ischaemia.
The thyroidea ima artery is an unpaired artery that is occasionally present (10%); it has a variable origin, arising from either the aortic arch, the brachiocephalic trunk or the right common carotid artery. It passes upwards anterior to the trachea and supplies the inferior portion of the thyroid gland.\(^\text{10}\) It is important to recognize and ligate this artery during thyroidectomy or tracheostomy in order to avoid haemorrhage (see Fig. 18.12).
Though uncommon, on the right side, located immediately at or above the suprasternal notch, a high-riding brachiocephalic trunk may present as a large, pulsatile, arching vessel that crosses the trachea and may also give rise to the carotid artery. Great care must be taken when this uncommon vascular anatomical variant is encountered during neck operations, as fatal haemorrhage may result from its injury.\textsuperscript{16}

**Venous drainage**

The thyroid gland has a rich venous plexus that is usually visible on its surface immediately beneath the true capsule. Venous drainage from the thyroid occurs through connections with the plexus at its superior pole (superior thyroid veins), lateral aspect (middle thyroid veins) and inferior pole (inferior thyroid veins). The superior thyroid vein travels with the superior thyroid artery. After it exits the superior pole of the thyroid, the vein runs superiorly and laterally, across the omohyoid and the common carotid artery, to enter the internal jugular vein, either alone or with the common facial vein. The middle thyroid vein arises from the lateral aspect of the thyroid, crosses the common carotid artery and drains directly into the internal jugular vein. The middle thyroid vein is especially vulnerable to injury that causes haemorrhage, obscuring the operative field; it usually requires ligation during thyroidectomy when the central neck is first exposed (Fig. 18.13). Occasionally, the fourth thyroid vein (of Kocher) may exit the gland between the middle and inferior thyroid veins and drain directly into the internal jugular vein.\textsuperscript{10}
FIG. 18.13  The surgeon’s view of the right central neck compartment during thyroidectomy. Medial retraction of the right lobe is critical in order to obtain the exposure needed to locate the recurrent laryngeal nerve and identify the parathyroid glands.

The inferior thyroid vein has the most variable venous anatomy. On the right side, it exits at the lower pole of the thyroid and passes anterior to the brachiocephalic trunk before it drains into the right brachiocephalic vein at its junction with the superior vena cava. On the left side, the vein exits the lower pole of the thyroid, crosses the trachea and then drains into the left brachiocephalic vein. Occasionally, the right inferior thyroid vein crosses the trachea to join the left inferior thyroid vein and forms a common trunk, the thyroidea ima vein, which drains into either the superior vena cava or the left brachiocephalic vein. The plexus thyroideus impar is a pretracheal venous plexus formed by the inferior thyroid veins below the level of the thyroid isthmus (see Fig. 18.12). The parathyroid glands are drained through tiny parathyroid veins that empty into the superior, middle and inferior thyroid venous plexuses.4

**Lymphatic drainage**
The thyroid has a rich and complex lymphatic drainage system, with its lymphatics generally following the same course as blood vessels and nerves.
The thyroid lymphatics usually drain initially into the central neck compartment via the prelaryngeal (Delphian) nodes just superior to the isthmus; pretracheal and prelaryngeal nodes in communication with the pretracheal plexus; right and left paratracheal nodes that are intimately related to the RLN; and the brachiocephalic nodes that are located in the anterior superior mediastinum. The superior lymphatics drain the isthmus and superomedial portions of the thyroid lobes into the digastric and prelaryngeal nodes, and eventually into the upper cervical lymph nodes located along the internal jugular chain. The median inferior lymphatics drain the middle and inferior portions of the thyroid gland, and drain into the pretracheal and brachiocephalic lymph nodes. The lateral lymphatics drain both superiorly and inferiorly into the internal jugular chain lymph nodes. Lateral lymphatics from the thyroid may also drain directly into the right subclavian vein, jugular veins or the thoracic duct. Posterior lymphatics from the inferomedial surface of the lateral thyroid lobes drain into lymph nodes that are located along the RLN. Posterior superomedial lymphatics may drain into retropharyngeal lymph nodes. The thyroid also has intraglandular lymphatics that allow for interlobar lymphatic drainage via the isthmus. It is controversial whether the multifocality and bilaterality commonly observed in papillary thyroid cancer (PTC) are a consequence of intraglandular lymphatic metastatic spread.

Cervical lymph node metastases from PTC are common, and clinically evident macroscopic disease may be found in up to 35% of patients; 80% of patients may harbour clinically undetectable lymph node micrometastases. A thorough understanding of the lymphatic drainage of the thyroid, and its consequential pattern of lymphatic metastases, is especially important for surgeons when carrying out thyroidectomy for cancer. A CND may also need to be performed concurrently with thyroidectomy. It is not surprising that, as a consequence of increased surgical dissection, a CND has been found to be associated with an increased risk of both hypoparathyroidism and RLN injury. The American Thyroid Association (ATA) considers the central neck to include both level VI and level VII lymph nodes. The ATA defines the boundaries of neck level VI as being the hyoid bone (superior), suprasternal notch (inferior), prevertebral fascia (posterior), superficial layer of the deep cervical fascia (anterior), and medial border of the carotid sheath (lateral). Level VII lymph nodes are associated with the brachiocephalic vein and brachiocephalic trunk in the anterior superior mediastinum, the inferior border on the right side being the brachiocephalic trunk at its point of
tracheal crossing, and on the left side being the corresponding axial plane\(^\text{19}\) (Fig. 18.14). The surgical anatomical landmarks of the central neck compartment, as defined by the American Head and Neck Society (AHNS), are a horizontal line at the inferior border of the cricoid and RLN insertion point (superior), and a plane on a level with the brachiocephalic trunk (inferior), prevertebral fascia (posterior), sternothyroid muscle (anterior), common carotid artery (lateral), and medial edges of the contralateral strap muscles (medial, in cases of unilateral CND). The lymph nodes of the central neck compartment have also been further separated by the AHNS into four anatomically discrete subcompartments: namely, prelaryngeal (Delphian), pretracheal, right paratracheal and left paratracheal lymph node groups. The AHNS defines a CND as being the comprehensive removal of the pretracheal and prelaryngeal nodes, along with removal of the left and/or right paratracheal nodes. A CND may therefore be described as being either unilateral or bilateral.\(^\text{18}\)
The pattern of thyroid cancer metastatic spread is generally reflective of its
lymphatic drainage pattern, and is described as being stepwise, or progressing initially to the central neck nodes (neck level VI), then to the nodes in the ipsilateral lateral neck (neck levels II, III, IV and V, and less commonly, neck level I), and eventually to the contralateral lateral neck nodes and the anterior superior mediastinal nodes (neck level VII) (Ch. 15). Skip nodal metastases, defined as being present in patients who have an ipsilateral central neck compartment that does not harbour nodal metastases but have lateral neck compartment(s) that do contain metastatic nodal disease, have been observed in more than 20% of PTC cases and may even be more prevalent when the cancer is located within the superior pole of the gland. In recent years, the extent of lymph node dissection that is performed at the time of thyroidectomy for thyroid cancer patients has become progressively more selective. A CND that is carried out for treatment of PTC rarely requires sacrifice of adjacent structures. When a CND is carried out to remove preoperatively or intraoperatively diagnosed gross metastatic nodal disease, it is described as being a therapeutic lymph node dissection. Alternatively, a CND performed in the setting of a thyroid cancer patient considered to be at high risk of harbouring micrometastatic lymph node disease, but with clinically uninvolved nodes, is described as being a prophylactic or elective lymph node dissection. When describing a CND, the surgeon must clearly specify if it is a unilateral or bilateral procedure; when unilateral, whether left- or right-sided; the neck levels (VI and/or VII) removed; and whether it is therapeutic or prophylactic.

**Innervation**

The thyroid is innervated by the sympathetic system from the superior, middle and inferior cervical ganglia. Postganglionic fibres from the inferior cervical ganglion form a plexus that encircles the inferior thyroid artery and communicates with the RLN, the EBSLN, the superior cardiac nerve, and the plexus on the common carotid artery. The parathyroid glands are innervated by the sympathetic system from the superior or middle cervical ganglia.

**Recurrent laryngeal nerve**

It is absolutely critical for surgeons who perform thyroid and parathyroid operations to have an excellent knowledge and understanding of the anatomy of the RLN. Identification and clear visualization of the RLN during
thyroidectomy/parathyroidectomy are both vital in reducing the risk of iatrogenic injury and preventing potentially devastating consequences for the patient (significant voice, respiratory and swallowing disability, and reduction in quality of life) (Ch. 17). During thyroidectomy, identification of the RLN must be considered mandatory; the procedure has been clearly demonstrated to reduce the risk of RLN injury.\textsuperscript{21} The anatomy of the RLN and its anatomical variations are largely dictated by the pattern of development of the blood vessels to which it is intimately related.\textsuperscript{22} The RLN arises from the vagus nerve in the thorax and initially passes posterior to the carotid sheath. It has a characteristic glistening whitish colour compared to adjacent vessels and it often has tiny blood vessels (vasa nervorum) running along its surface, which may assist with its identification. The right RLN branches from the vagus nerve as it travels anterior to the right subclavian artery, then loops around the artery from posterior to anterior, passes behind the right common carotid artery and recurs in the central neck, travelling either within or in close proximity to the tracheo-oesophageal (TE) groove as it ascends to innervate the larynx. The left RLN arises from the left vagus nerve as it crosses the aortic arch and hooks below the vessel, to the left and behind the ligamentum arteriosum, then ascends (recurs) on the right of the arch, entering the central neck posterior to the pretracheal fascia\textsuperscript{23} (Fig. 18.15). The differences in vascular anatomy on the right and left sides mean that the right RLN follows a more oblique course within the central neck, running more lateral to medial when compared to the left RLN, which has a more vertical ascent within the TE groove.\textsuperscript{23} It is also because of the differences in vascular anatomy between right and left sides that the right RLN is located more anteriorly then the left RLN\textsuperscript{18} (Fig. 18.16). These differences in the cervical course of the RLN have significant implications with respect to the location of central neck compartment lymph nodes and the performance of central neck lymph node dissection (CND). This is because the RLN on the right side has lymphatic tissue located both anteriorly and posteriorly, while on the left side the lymphatic tissue is primarily located anteriorly. Therefore, a CND performed on the right side is more precarious than on the left side because it may require nodal dissection both posterior and anterior to the RLN.\textsuperscript{18} Pathological parathyroid glands, especially the superior parathyroid gland on the right side, may also be found posterior to the plane of the RLN (Fig. 18.17).
FIG. 18.15  A. The usual anatomical course of the recurrent laryngeal nerve (RLN). B. The anatomical course of the non-recurrent laryngeal nerve (NRLN) with associated vascular variant arteria lusoria. (Adapted from P.W. Smith, et al, Thyroidectomy – partial or total. In: Essential Surgical Procedures. © 2016, Elsevier Inc. All rights reserved. Fig. 52-1-1a,b.)
FIG. 18.16 Differences in vascular anatomy in the chest mean that the right recurrent laryngeal nerve (A) follows a more oblique course within the central neck, running more lateral to medial and more anteriorly, when compared to the left recurrent laryngeal nerve (B), which has a more vertical ascent and tends to run more posteriorly within the tracheo-oesophageal groove.
During exposure of the TE groove, in order to facilitate RLN identification and preservation, excessive traction on the thyroid lobe may lead to RLN injury. Care must also be taken to avoid perforation or rupture of the thyroid parenchyma. Trauma to the thyroid gland itself during thyroidectomy may cause haemorrhage or dissemination of cancer cells within the operative field, and may even contribute to the persistence of a large thyroid remnant. Early careful ligation of the superior pole vessels, especially during thyroidectomy for treatment of large goitres, is an important manoeuvre that permits delivery of the gland out of the neck, reduces haemorrhage and facilitates exposure of the central neck for RLN identification. Even though
uncommon, early superior thyroid pole mobilization may lead to RLN injury on the right side if a non-recurrent laryngeal nerve (NRLN) is present.

Randolph has categorized the surgical technique of RLN identification into three separate approaches. The most common surgical approach to the RLN that is utilized today is the lateral approach. Upward and medial retraction of the thyroid gland, pulling it out of the central neck and rolling it over the larynx and trachea, along with simultaneous lateral retraction on the carotid artery and strap muscles, is required for central neck exposure (see Fig. 18.13). As already discussed, this occurs in conjunction with division of the middle thyroid vein, the capsular dissection technique, and usually after gross identification of the superior and inferior parathyroid glands. Any further mobilization of the parathyroid glands from the thyroid capsule should be limited until after the RLN is clearly identified, in order to reduce the risk of haemorrhage that may obscure the operative field. This approach is also further facilitated by dissection of the superior thyroid pole pedicle, and more limited dissection of the inferior thyroid pole pedicle. The RLN is identified at the thyroid midpolar level, travelling either within or in close proximity to the TE groove, as it ascends towards its insertion point in the larynx (see Fig. 18.16). The major advantages of this approach are that the length of RLN dissection required is limited, and preservation of the parathyroid blood supply is facilitated.12 Anatomical landmarks that may assist the surgeon with RLN identification when employing this approach include bracketing by the parathyroid glands, the crossing point with the inferior thyroid artery, the inferior edge of the inferior cornu of the thyroid cartilage, and the ZT.23

The inferior approach involves identification of the RLN at the thoracic inlet. As described by Loré, the RLN is identified within the RLN triangle, where it exists as a single trunk; nerve branching usually occurs superior to the level of the inferior thyroid artery. The apex of the RLN triangle is located inferiorly at the thoracic inlet, its medial wall is the trachea, its lateral wall is the retracted strap muscles, and its base is located superiorly at the lower edge of the inferior pole of the thyroid.24 Unlike the lateral approach, the inferior approach puts the RLN and parathyroid glands, especially the inferior parathyroid glands, at increased risk of injury because it requires a more extensive dissection. This approach is usually reserved for RLN identification when exposure of the central neck is distorted by scar from a prior operation or limited by goitrous enlargement of the thyroid itself.12

The superior approach involves identification of the RLN at its entry point.
into the larynx, which is the most consistent location of the RLN within the neck, and may be exposed after early dissection, ligation and retraction of the superior pole thyroid pedicle. The RLN may be identified in relation to the LB (see discussion later) as it enters the larynx inferior to the lower edge of cricopharyngeus (inferior pharyngeal constrictor). This approach may be best suited for RLN identification during reoperative thyroidectomy, or when operating on large substernal goitres after lateral and inferior approaches have failed. The inferior approach to the RLN is the technique surgeons utilize least commonly. Disadvantages of this approach include haemorrhage and trauma that may occur at the LB near the RLN laryngeal entry point, and also injury to the EBSLN and the superior parathyroid gland.\(^\text{12}\)

Awareness of the relationship of the RLN to the LB is important because this is a very common location for iatrogenic injury to occur, especially along the 2 cm terminal extralaryngeal course of the nerve.\(^\text{2}\) It has been suggested that two fascial layers, superficial vascular and deep fibrous, envelop the RLN at the LB. The superficial vascular fascial layer is derived from the thyroid/pretracheal fascia and contains the terminal branches of the inferior thyroid artery and vein. With medial rotation and retraction of a lobe during thyroidectomy, this layer becomes anterolateral to the RLN, and thus the terminal vessels it contains cross the surface of the RLN immediately prior to its point of entrance into the larynx. Great care must be taken to ligate these vessels meticulously during the final centimetres of RLN dissection, as this is a major surgical danger point during thyroidectomy, and attempts at haemostasis may lead to RLN injury. Once this layer has been divided, the RLN becomes visible lying on the deep fibrous fascial layer that further condenses medially into the true LB.\(^\text{2}\) The RLN often displays a small ‘knee’ or genu immediately prior to its entrance into the larynx, and this location is considered to be the most common site for nerve injury. An important posterior branch of the inferior thyroid artery, the inferior laryngeal artery, is often encountered passing posterior to the RLN just prior to its entry point into the larynx. The inferior laryngeal artery is commonly referred to as the ‘vessel of regret’ as a reminder to the surgeon of the difficulties that will be encountered when attempting to obtain safe haemostasis when this vessel bleeds if inadvertently injured, after it has retracted posteriorly or posteriorly to the RLN.

The true LB consists of two sheaves that may contain a variable amount of thyroid tissue. The presence of this thyroid tissue located anterior and/or posterior to the RLN, immediately before the nerve enters the larynx, may
also lead to direct or indirect nerve injury during dissection or attempts at haemostasis, and is another reason why the RLN is so vulnerable to injury at this site during thyroidectomy. At this point during the operation, the surgeon must decide, based on the patient's anatomy and underlying pathology, as well as his or her own experience, whether the benefit of removing the tiny amount of thyroid tissue that is intimately related to the laryngeal entry point of the RLN and performing a total thyroidectomy outweigh the potential risk of RLN trauma and injury. The surgeon may consider whether the most advantageous operative approach may be to leave a minuscule remnant of thyroid tissue adjacent to the RLN laryngeal entry point and perform a near-total thyroidectomy (Fig. 18.18).

Extralaryngeal RLN branches may supply the trachea (sensory), oesophagus (sensory and motor), inferior constrictor muscle (sensory and motor) and sympathetic chain. Randolph has reported that 50–60% of
patients may have small RLN branches to the trachea, oesophagus or inferior constrictor muscle. True extralaryngeal branching of the main RLN (causing electromyographic activity when the branch is stimulated) occurs in 30% of patients.\textsuperscript{12} A surgical pitfall is encountered if enlarged and anastomosing RLN branches are misidentified by the surgeon as being a NRLN because such an error may lead to RLN transection. Extralaryngeal motor branching of the RLN usually occurs along its distal 2 cm at the LB; preservation of all branches is imperative in order to avoid iatrogenic nerve injury.\textsuperscript{2} RLN branching may be unilateral or bilateral. Branching makes the RLN especially vulnerable to injury because the branches are thinner and more delicate, and therefore more easily traumatized by surgical dissection. Identification of a particularly thin main RLN trunk during thyroidectomy should prompt the surgeon to perform retrograde nerve dissection in order to ensure that a posterior RLN branch has not been misidentified as being the main RLN trunk. This pitfall may lead to injury of the anterior branch of the RLN, which contains, with the exception of the supply to cricothyroid, all of the functional motor branches supplying the laryngeal muscles.\textsuperscript{23} (Ch. 17).

The RLN enters the larynx approximately 1 cm below and just anterior to the readily palpable inferior cornu of the thyroid cartilage, just inferior to the lower edge of the inferior pharyngeal constrictor muscle; this is the most consistent RLN anatomical location in the neck.\textsuperscript{12}

True anatomical variations and distortions of the RLN that arise due to thyroid pathology must be thoroughly appreciated by the surgeon in order to avoid iatrogenic nerve injury during thyroidectomy. The course of the RLN may be significantly distorted when performing thyroidectomy for treatment of goitre or malignancy. Perhaps one of the least common, but potentially most precarious, of the anatomical variants of the RLN is the NRLN (Fig. 18.19). The incidence of a NRLN on the right side has been reported to range from 0.5 to 1.0%; it occurs much less commonly on the left side (0.04%), where it is always associated with situs inversus.\textsuperscript{23,25} The NRLN is a consequence of abnormal absorption of the fourth right pharyngeal arch, with associated development of a left-sided aortic arch and abnormal subclavian artery anatomy. Arteria lusoria is the name that has been given to this vascular anatomical variant, describing a right subclavian artery that arises as the fourth branch of the aortic arch and travels posterior to, or less commonly between, the trachea and oesophagus. Like the right subclavian artery, the right common carotid artery also arises directly from the aorta.
when this vascular variant is present. The right RLN therefore does not recur around the right subclavian artery and does not ascend into the neck from the thorax. Instead, it arises directly from the cervical vagus nerve posterior to the common carotid artery, and travels medially to enter the larynx at the same point as a normal RLN (see Fig. 18.15). A NRLN may arise at any point along the course of the cervical vagus nerve. Demonstration that a suspected NRLN originates from the vagus nerve through retrograde dissection and utilization of intraoperative nerve monitoring techniques, as well as an absence of the RLN in its usual location, allows for its identification and preservation. The surgeon should anticipate and be prepared to encounter a NRLN if arteria lusoria is identified by preoperative thyroid or parathyroid imaging.

FIG. 18.19 The surgeon's view of a right non-recurrent laryngeal nerve (yellow arrow) and right superior parathyroid gland (green arrow) after removal of the right thyroid lobe.
Superior laryngeal nerve

The superior laryngeal nerve (SLN) arises from the vagus nerve at the nodose ganglion at the level of the second cervical vertebra, 4 cm superior to the bifurcation of the common carotid artery. Approximately 1.5 cm inferior to its origin at the level of the cornu of the hyoid bone, the SLN divides into an external motor branch (EBSLN) and an internal sensory branch. The internal branch travels medial to the carotid sheath and enters the larynx through the posterior aspect of the thyrohyoid membrane; it provides sensation to the ipsilateral supraglottis and to the base of the tongue. The EBSLN travels anterior to the carotid sheath and then crosses medially, usually anterior to the superior thyroid artery and superior to the inferior pharyngeal constrictor muscle, prior to innervating cricothyroid, at the anterolateral aspect of the lower portion of the cricoid cartilage. Injury to the EBSLN causes paralysis of cricothyroid, impairing the ability to produce high tones and altering the fundamental voice frequency\(^{12,23}\) (Ch. 17). In order to avoid injury to the EBSLN, mass ligation should be avoided at the superior pole of the thyroid lobe, and the branches of the superior thyroid artery and vein should each be individually ligated immediately at the capsule of the gland. Though it is controversial whether routine identification of the EBSLN is necessary to avoid its injury, for the surgeon, awareness of its anatomy and anatomical variations is important. Based on its risk of injury during thyroidectomy, the Cernea classification system is used to describe EBSLN anatomical variation. This system classifies the EBSLN into three groups, based on its relationship to the plane of the superior edge of the superior pole of the thyroid lobe. A type 1 EBSLN crosses the superior pole vessels more than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2A EBSLN crosses the superior pole vessels less than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2B EBSLN crosses the anterior surface of the superior pole of the thyroid lobe below its superior edge (Fig. 18.20). Type 2A and type 2B EBSLNs are at the greatest risk of being injured during thyroidectomy. The frequency with which these anatomical variants of the EBSLN are encountered, and thus their risk of injury, are heavily dependent on the size of the thyroid gland, and specifically on the degree of goitrous expansion of its superior poles. The frequency with which type 1, type 2A and type 2B EBSLNs are encountered in association with normal-sized thyroid glands to small-sized goitres is 68%, 23% and 18%, respectively. For large goitres, type 1 and type 2A EBSLNs may be encountered less commonly, and type 2B EBSLNs may be encountered more
commonly, in 15%, 14% and 54% of cases, respectively.\textsuperscript{21,26}

**FIG. 18.20** Based on the risk of injury to the external branch of the superior laryngeal nerve (EBSLN) during thyroidectomy, the Cernea classification system is used to describe EBSLN anatomical variation. A type 1 EBSLN crosses the superior pole vessels more than 1 cm superior to the upper edge of the superior pole of the thyroid lobe. A type 2A EBSLN crosses the superior pole vessels less than 1 cm superior to the upper edge of the superior pole of the thyroid lobe. A type 2B EBSLN crosses the anterior surface of the thyroid pole below its upper edge. Type 2A and type 2B EBSLNs are at the greatest risk of being injured during thyroidectomy.

### Tips and Anatomical Hazards

Only attention to detail and meticulous surgical dissection technique will allow for anatomical and functional preservation of the RLNs and the parathyroid glands. Scrupulous haemostasis is absolutely imperative, as bleeding will obscure the view of critical structures, especially the RLNs and parathyroid glands, and may increase the risk of complications. Unipolar and bipolar electrocautery and vessel-sealing instruments, all of which produce electrical current and/or heat, should not be used in close proximity to the RLNs or parathyroid glands. During thyroidectomy, RLN identification is mandatory, and during parathyroidectomy the threshold for RLN identification should be
extremely low. No tissue that may be the RLN should ever be clamped, cauterized, clipped, sealed or divided until the RLN has been definitely identified. If total thyroidectomy is planned, the lobe that harbours the most significant disease should always be removed first. If injury to the RLN is suspected or confirmed after completion of this first side, the procedure should usually be terminated without removal of the remaining side in order to prevent bilateral RLN injury. NRLNs are rare; even in cases where the RLN is very difficult to identify, its course is usually recurrent/conventional. Most goitres may be removed, and most pathological parathyroid glands may be identified and removed, through a standard transcervical surgical approach. Each parathyroid gland should be preserved and treated as though it is the only parathyroid gland remaining in the neck, and should never be intentionally sacrificed. If a normal parathyroid gland is inadvertently devitalized or removed, after its identity is confirmed by frozen section analysis, immediate autotransplantation should be performed. When requesting frozen section analysis of what is potentially a parathyroid gland, the surgeon should want to know only if the specimen is, or is not, parathyroid tissue. Frozen section cannot guide the extent of surgical exploration based on a detailed histopathological diagnosis because it is unable to reliably distinguish an adenoma from hyperplasia.
References

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Single Best Answers

1. The thyroglossal duct may give rise to which one of the following?
   A. Lingual thyroid gland
   B. Thyrothymic thyroid rest
   C. Thyroglossal duct cyst
   D. All of the above

   **Answer: D.** The thyroid gland appears at about 30–31 days post fertilization (stages 11–12) as a median endodermal thickening in the floor of the primitive pharynx, between the first and second pharyngeal pouches, which invaginates into the surrounding neural crest mesenchyme. As the lower pharyngeal arches form and the heart descends, the diverticulum extends as the thyroglossal duct, anterior to the developing hyoid bone and laryngeal cartilages. Complete failure of descent of the thyroglossal duct leads to the development of thyroid tissue within the tongue, which is referred to as a lingual thyroid. The persistence of thyroid tissue along its path of migration may also lead to entirely ectopic thyroid glands (sublingual, prelaryngeal and pretracheal glands) or ectopic thyroid tissue deposits, also referred to as small accessory thyroid glands. The thyroglossal duct atrophies, but remnants may persist anywhere along its course and lead to the development of a thyroglossal duct cyst. Midline thyroid tissues that extend inferiorly into the thyrothymic ligament are referred to as thyrothymic thyroid rests (TTR). TTR also represent remnants of the developing thyroid gland that may be present in more than half of individuals, and during surgery may be mistaken for lymph nodes or parathyroid glands⁹ (see Fig. 18.2).

2. Which one of the following statements about the Zuckerkanld
tubercle is TRUE?
A. In 70% of people it is larger than 1 cm
B. It is a remnant of the thyroglossal duct
C. It constitutes a useful landmark that may assist with identification of the recurrent laryngeal nerve and the superior parathyroid gland
D. It represents a useful landmark that may assist with identification of the superior laryngeal nerve and the inferior parathyroid gland

Answer: C. The Zuckerkandl tubercle (ZT), a posterolateral projection of the thyroid gland located adjacent to the junction of the thyroid and cricoid cartilages, is a remnant of the ultimobranchial body. The ZT is present in approximately 70% of individuals and usually is less than 1 cm in diameter. When present, it constitutes a useful anatomical landmark for identification of the recurrent laryngeal nerve (RLN) and the superior parathyroid gland. The ZT has been described as being shaped like an ‘arrow that points towards the RLN’. This is because the RLN travels posteromedially to a well-developed ZT in more than 80% of people, and in this location the nerve may often be mistaken as travelling intrathyroidally. Like the ZT, the superior parathyroid glands are derived from the fourth pharyngeal pouch; their common embryological origin explains the consistent posterior and superior location of the superior parathyroid gland in relation to the ZT. Thus, the superior parathyroid gland should be routinely identified, and its blood supply carefully preserved, early on during thyroidectomy when dissecting the ZT (see Fig. 18.3).

3. Which one of the following statements about the embryological development of the parathyroid glands is FALSE?
A. The parathyroid glands develop at about stage 14 (32–34 days
post fertilization) as interactions between the dorsal endodermal epithelium and the underlying neural crest mesenchyme of the third and fourth pharyngeal pouches.

B. Congenital anomalies in parathyroid development include variations in gland number, shape, size, weight, colour, and the development of a cystic component.

C. The parathyroid glands develop at about stage 14 (32–34 days post fertilization) as interactions between the dorsal endodermal epithelium and the underlying neural crest mesenchyme of the fourth and fifth pharyngeal pouches.

D. The inferior parathyroid gland migrates earlier and moves further caudally than the superior parathyroid gland, which becomes anchored to the developing lateral lobes of the thyroid gland, causing the inferior parathyroids to have a more variable location than the superior parathyroids.

Answer: C. The parathyroid glands develop at about stage 14 (32–34 days post fertilization) as interactions between the dorsal endodermal epithelium and the underlying neural crest mesenchyme of the third and fourth pharyngeal pouches. The ventral epithelium of these pouches gives rise to the thymus and lateral thyroid tissue, respectively. Parathyroid III (inferior parathyroid gland) migrates earlier and moves further caudally than parathyroid IV (superior parathyroid gland), which becomes anchored to the developing lateral lobes of the thyroid gland. This causes the inferior parathyroids to have a more variable location than the superior.³ Congenital anomalies in parathyroid development include variations in gland number, shape, size, weight, colour, and the development of a cystic component.⁴

4. Which one of the following statements about the strap muscles is TRUE?
A. The strap muscles are innervated by the spinal accessory nerve
B. The outer strap muscles are thyrohyoid more superiorly and sternothyroid more inferiorly
C. The strap muscles are paired muscles encased by the superficial layer of the deep cervical fascia and either originate or insert on to the hyoid bone
D. The inner strap muscles are the sternohyoid and the omohyoid

Answer: C. The strap muscles are encountered below platysma. They are paired muscles encased by the superficial layer of the deep cervical fascia and either originate or insert on to the hyoid bone; they function either to depress or to stabilize the hyoid bone during deglutition, and to stabilize the larynx. Individual strap muscles are each named according to their sites of attachment. The inner strap muscles are thyrohyoid more superiorly and sternothyroid more inferiorly. The thyrohyoid originates from the lamina of the thyroid cartilage above the insertion of sternothyroid (oblique line) and inserts on to the lower border of the greater cornu of the hyoid bone. The outer strap muscles are sternohyoid and omohyoid. Sternohyoid originates from the posterior aspect of the manubrium, adjacent to the clavicle, and the posterior sternoclavicular ligament, and inserts on the medial aspect of the lower border of the body of the hyoid bone. Omohyoid has an inferior belly that originates from the upper border of the scapula and the superior transverse scapular ligament, a central tendon enclosed by a band of cervical fascia that crosses the carotid sheath, and attaches to the clavicle and the first rib, and a superior belly that extends alongside sternohyoid to insert on the lateral aspect of the hyoid bone. The strap muscles are innervated by the ansa cervicalis, derived from the cervical plexus (C1, C2, C3), with the exception of thyrohyoid, which is innervated by fibres from C1 that travel
with the hypoglossal nerve. The superior root of the ansa cervicalis appears as a branch of the hypoglossal nerve and descends along the lateral border of sternothyroid, innervating that muscle near its lower third.\(^4\)

5. Which one of the following statements about the location of the parathyroid glands is FALSE?

A. In 80% of cases, the superior parathyroid glands are located on the posterior aspect of the thyroid at the level of the cricothyroid junction, corresponding to a position that is 1 cm superior to the point where the recurrent laryngeal nerve (RLN) crosses the inferior thyroid artery.

B. The superior parathyroid glands tend to be located lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane.

C. The inferior parathyroid glands are more variable in their position than the superior parathyroid glands, and in 50% of cases may be found within 1 cm of the inferior thyroid pole, located either inferiorly, laterally or posteriorly.

D. The inferior parathyroid glands tend to be located lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane.

**Answer: D.** In 80% of cases, the superior parathyroid glands are located on the posterior aspect of the thyroid at the level of the cricothyroid junction, corresponding to a position that is 1 cm superior to the point where the RLN crosses the inferior thyroid artery. The inferior parathyroid glands are more variable in their position, and in 50% of cases may be found within 1 cm of the inferior thyroid pole, located either inferiorly, laterally or posteriorly.\(^12\) The superior parathyroid glands tend to be located lateral to the RLN sagittal plane and posterior (dorsal) to the RLN coronal plane, whereas the inferior parathyroid glands tend
to be located medial to the RLN sagittal plane and anterior (ventral) to the RLN coronal plane (see Fig. 18.7).\textsuperscript{12}

6. Which one of the following statements about the anatomical course of the recurrent laryngeal nerve (RLN) is TRUE?

A. The left RLN branches from the vagus nerve as it travels anterior to the left subclavian artery, then loops around the artery from posterior to anterior, passes behind the left common carotid artery and recurs in the central neck

B. The right RLN follows a more oblique course within the central neck, running more lateral to medial when compared to the left RLN, which has a more vertical ascent within the tracheo-oesophageal (TE) groove

C. The right RLN arises from the right vagus nerve as it crosses the aortic arch, hooks below the vessel, to the right and behind the ligamentum arteriosum, then ascends (recurs) on the right of the arch, entering the central neck posterior to the pretracheal fascia

D. It is because of differences in the vascular anatomy between right and left sides that the left RLN is located more anteriorly than the right RLN

\textbf{Answer: B.} The right RLN branches from the vagus nerve as it travels anterior to the right subclavian artery, then loops around the artery from posterior to anterior, passes behind the right common carotid artery, and recurs in the central neck, travelling either within or in close proximity to the TE groove as it ascends to innervate the larynx. The left RLN arises from the left vagus nerve as it crosses the aortic arch, hooks below the vessel, to the left and behind the ligamentum arteriosum, then ascends (recurs) on the right of the arch, entering the central neck posterior to the pretracheal fascia\textsuperscript{23} (see Fig. 18.15). The differences in vascular anatomy mean that the right RLN follows
a more oblique course within the central neck, running more lateral to medial when compared to the left RLN, which has a more vertical ascent within the TE groove. It is also because of differences in the vascular anatomy between the right and left sides that the right RLN is located more anteriorly then the left RLN (see Fig. 18.16).

7. Which one of the following statements about a non-recurrent laryngeal nerve (NRLN) is FALSE?

A. The NRLN arises as a consequence of abnormal absorption of the fourth right pharyngeal arch, with associated development of a left-sided aortic arch and abnormal subclavian artery anatomy

B. Arteria lusoria is the name that has been given to the vascular anatomical variant that is associated with an NRLN

C. The vascular anatomical variant that is associated with an NRLN is a right subclavian artery that arises as the fourth branch of the aortic arch and travels posterior to or, less commonly, between the trachea and oesophagus

D. The NRLN occurs more commonly on the left than the right side

Answer: D. Perhaps one of the least common, but potentially most precarious, of the anatomical variants of the RLN is the NRLN (see Fig. 18.20). The incidence of a NRLN on the right side has been reported to range from 0.5 to 1.0%; it occurs much less commonly on the left side (0.04%), where it is always associated with situs inversus. The NRLN is a consequence of abnormal absorption of the fourth right pharyngeal arch, with associated development of a left-sided aortic arch and abnormal subclavian artery anatomy. Arteria lusoria is the name that has been given to this vascular anatomical variant, describing a right subclavian artery that arises as the fourth branch of the aortic arch and
travels posterior to or, less commonly, between the trachea and oesophagus. Like the right subclavian artery, the right common carotid artery also arises directly from the aorta when this vascular variant is present. The right RLN therefore does not recur around the right subclavian artery and does not ascend into the neck from the thorax. Instead, it arises directly from the cervical vagus nerve posterior to the common carotid artery, and travels medially to enter the larynx at the same point as a normal RLN.

8. Which one of the following statements about the superior laryngeal nerve (SLN) is TRUE?
   A. The SLN arises from the vagus at the level of the carotid bifurcation
   B. The SLN divides into an internal motor branch and an external sensory branch
   C. The external branch of the SLN innervates the cricothyroid
   D. Type 2A and type 2B Cernea classification system external branch SLNs are at lower risk of injury during thyroidectomy than type 1 external branch SLNs

**Answer:** C. The SLN arises from the vagus nerve at the nodose ganglion at the level of the second cervical vertebra, 4 cm superior to the bifurcation of the common carotid artery. Approximately 1.5 cm inferior to its origin, at the level of the cornu of the hyoid bone, the SLN divides into an external motor branch (EBSLN) and an internal sensory branch. The internal branch travels medial to the carotid sheath and enters the larynx through the posterior aspect of the thyrohyoid membrane; it provides sensation to the ipsilateral supraglottis and to the base of the tongue. The EBSLN travels anterior to the carotid sheath and then crosses medially, usually anterior to the superior thyroid artery and superior to the inferior pharyngeal constrictor
muscle, prior to innervating cricothyroid, at the anterolateral aspect of the lower portion of the cricoid cartilage. Injury to the EBSLN causes paralysis of cricothyroid, impairing the ability to produce high tones and altering the fundamental voice frequency.\textsuperscript{12,23} In order to avoid injury to the EBSLN, mass ligation should be avoided at the superior pole of the thyroid lobe, and the branches of the superior thyroid artery and vein should each be individually ligated immediately at the capsule of the gland. Based on risk of injury during thyroidectomy, the Cernea classification system is used to describe EBSLN anatomical variation. This system classifies the EBSLN into three groups, based on its relationship to the plane of the superior edge of the superior pole of the thyroid lobe. A type 1 EBSLN crosses the superior pole vessels more than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2A EBSLN crosses the superior pole vessels less than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2B EBSLN crosses the anterior surface of the thyroid pole below its superior edge (see Fig. 18.21). Type 2A and type 2B EBSLNs are at the greatest risk of being injured during thyroidectomy.
Clinical Cases

1. A 38-year-old female presents with a long-standing history of a central neck mass that has slowly been enlarging for several years. She denies any symptoms of dysphagia, odynophagia or shortness of breath. She has no personal history of prior head and neck radiation exposure, and has no personal or family history of thyroid or other endocrine disease. Her thyroid stimulating hormone (TSH) is within the normal range, and a neck ultrasound reports a 2.9 × 2.3 × 4.7 cm nodule arising within the right thyroid lobe that is partly cystic and partly solid. The solid portion has an irregular margin and contains multiple microcalcifications. The rest of the thyroid appears otherwise normal by ultrasound, and the central and lateral neck lymph nodes also appear normal. An ultrasound-guided fine needle aspiration biopsy of the right thyroid nodule is carried out, and reported using the Bethesda System for Thyroid Cytopathology. The final cytological diagnosis is malignant, diagnostic of papillary carcinoma. You plan a total thyroidectomy.

A. Describe the potential surgical approaches, pros and cons of each approach, and critical anatomical landmarks for identification of the recurrent laryngeal nerve (RLN) in this case.

RLN identification during thyroidectomy may be carried out by employing one, or a combination, of three different surgical approaches: lateral, inferior and superior.

Approach 1: Lateral approach. The most common surgical approach to the RLN that is utilized today is the lateral approach. Upward and medial retraction of the thyroid gland, pulling it out of the central neck and rolling it over the larynx and trachea, along with simultaneous lateral retraction on the carotid artery and strap muscles, is required for central neck exposure (see Fig. 18.13). This occurs in conjunction with division of the middle thyroid vein, the capsular dissection technique, and usually after gross identification of the superior and inferior parathyroid glands. Any further mobilization of the parathyroid glands from the thyroid capsule should be limited until after the RLN is clearly identified, in order to reduce the risk of haemorrhage that may obscure the operative field. This approach is also further facilitated by dissection of the superior thyroid pole pedicle and more limited dissection of
the inferior thyroid pole pedicle. The RLN is identified at the thyroid midpolar level, travelling either within or in close proximity to the tracheoesophageal groove, as it ascends towards its insertion point in the larynx (see Fig. 18.16). The major advantages of this approach are that the length of RLN dissection required is limited, and preservation of the parathyroid blood supply is facilitated. The major disadvantage of this approach is that, in the reoperative setting, RLN identification may be difficult due to the presence of dense scar tissue. This approach may also be difficult when operating on a large substernal goitre. Anatomical landmarks that may assist the surgeon with RLN identification when employing this approach include bracketing by the parathyroid glands, the crossing point of the inferior thyroid artery and the RLN, the inferior edge of the inferior cornu of the thyroid cartilage, and the Zuckerkandl tubercle.

**Approach 2: Inferior approach.** The inferior approach involves identification of the RLN at the thoracic inlet. As described by Loré, the RLN is identified within the RLN triangle, where it exists as a single trunk; nerve branching usually occurs superior to the level of the inferior thyroid artery. The apex of the RLN triangle is located inferiorly at the thoracic inlet, its medial wall is the trachea, its lateral wall is the retracted strap muscles, and its base is located superiorly at the lower edge of the inferior pole of the thyroid. Unlike the lateral approach, the inferior approach puts the RLN and parathyroid glands, especially the inferior parathyroid gland, at increased risk of injury because it requires a more extensive parathyroid dissection. This approach is usually reserved for RLN identification when exposure of the central neck is distorted by scar from a prior operation or limited by goitrous enlargement of the thyroid itself.

**Approach 3: Superior approach.** The superior approach involves identification of the RLN at its entry point into the larynx, which is the most consistent location of the RLN within the neck, and which may be exposed after early dissection, ligation and retraction of the superior pole thyroid pedicle. The RLN may be identified in relation to the ligament of Berry (LB) as it enters the larynx inferior to the lower edge of cricopharyngeus (inferior pharyngeal constrictor). This approach may be best suited for RLN identification during reoperative thyroidectomy, or when operating on large substernal goitres after lateral and inferior approaches have failed. The superior approach to the RLN is the technique surgeons utilize least commonly. Disadvantages of this approach include haemorrhage and trauma that may occur at the LB near the RLN laryngeal entry point, and also injury to the external branch of
the superior laryngeal nerve and the superior parathyroid gland.\textsuperscript{12}

B. During thyroidectomy you identify several grossly abnormal-appearing lymph nodes along the course of the right recurrent laryngeal nerve within the tracheo-oesophageal groove. Intraoperative frozen section diagnosis confirms your suspicion that they contain metastatic papillary carcinoma. You decide to perform a central neck dissection. Would you describe this central neck dissection as being either prophylactic or therapeutic? Specify which neck nodal levels you would remove and review the anatomical boundaries of these levels, and thus the central neck, as currently defined by the American Thyroid Association (ATA).

This central neck dissection is therapeutic because you are removing grossly abnormal central neck lymph nodes. The ATA considers the central neck to include both level VI and level VII lymph nodes, and either or both of these lymph node groups would be removed during a central neck dissection. The ATA defines the boundaries of neck level VI as being the hyoid bone (superior), suprasternal notch (inferior), prevertebral fascia (posterior), superficial layer of the deep cervical fascia (anterior), and medial border of the carotid sheath (lateral). Level VII lymph nodes are associated with the brachiocephalic vein and brachiocephalic trunk in the anterior superior mediastinum, with the inferior aspect on the right side being the brachiocephalic trunk at its point of tracheal crossing, and on the left side being within the corresponding axial plane.\textsuperscript{19}

2. A 69-year-old female presents with a long-standing history of primary hyperparathyroidism. She has reduced bone density and there has been a recent episode of nephrolithiasis. She has no personal or family history of parathyroid or other endocrine disease and she does not take any medications or supplements. Her parathyroid hormone and calcium levels are both significantly elevated above the normal range. A 24-hour urine collection for calcium is also elevated. Preoperative imaging (sestamibi scan, ultrasound and four-dimensional CT scan) does not localize any parathyroid glands. You take her to the operating room for a bilateral neck exploration.

A. List some factors that may contribute to difficulties in parathyroid gland identification during operation.

Multiple factors may contribute to difficulties in parathyroid gland identification during operation, including the limited experience of the
surgeon, incorrect diagnosis, non-localized disease, patient characteristics (such as a short neck or obesity), normocalcaemic disease, the presence of a concurrent multinodular goitre or other thyroid pathology, central neck lymphadenopathy, and a history of a prior central neck compartment operation.

**B. During the operation, you identify normal-appearing left and right superior parathyroid glands but cannot find either of the inferior parathyroid glands. Review your surgical approach when faced with this scenario.**

Clear identification of the normal parathyroid glands is often necessary to aid in deducing the side and type (superior versus inferior) of missing gland(s), and may help to direct surgical exploration. Intensive scrutiny and comparison of the size and morphology of the normal parathyroid glands, which have been identified during operation, may allow for the diagnosis of what was not initially appreciated as being multigland disease. In this setting, intraoperative frozen section tissue analysis may be especially important for definitive parathyroid identification.

The strategy for localization of a missing parathyroid gland(s) may require exploration superior to the upper pole of the thyroid as high as the hyoid bone, and inferior to the lower pole of the thyroid into the superior mediastinum. The exploration begins with careful inspection and palpation of the posterior and lateral aspects of the thyroid capsule. Removal of paratracheal tissue and delivery of the thymus gland into the neck with gentle upward traction, and careful division of its vessels as they are encountered, may also be necessary. Further careful systematic exploration of the parapharyngeal and retropharyngeal spaces, and the para-oesophageal and retro-oesophageal spaces should follow. This exploration is carried out deep within the paratracheal space both anterior and posterior to the plane of the recurrent laryngeal nerve (RLN). The missing parathyroid may even be located immediately anterior to the point at which the RLN enters the larynx. If the parathyroid continues to elude the surgeon, then opening the carotid sheath and exposing the common carotid artery in its course in the neck may expose the ectopic gland. When all sites have been explored and no parathyroid has been identified, then either ligation of the inferior thyroid artery or thyroid lobectomy may be performed in order to devitalize or remove what may be an ectopic intrathyroidal gland. Sternotomy for mediastinal exploration should usually not be carried out at the initial operation if a missing parathyroid has not been identified, but should be
deferred until the diagnosis has been reconfirmed and further localization studies have been performed. If possible, the assistance of an experienced colleague may also be helpful when this surgical scenario is encountered.
Root of the neck and tracheostomy

Richard W Nason, Anupam Das, K Alok Pathak
Core Procedures

Percutaneous Access

Subclavian vein access:
  Supraclavicular or infraclavicular approach – temporary central venous access
Brachial plexus block:
  Interscalene approach – anaesthesia for shoulder and upper extremity
  Supraclavicular approach – anaesthesia for distal two-thirds of arm
  Infraclavicular approach – anaesthesia for distal two-thirds of arm

Thoracic Outlet Syndrome

  Transaxillary approach – first rib resection for neurological and venous decompression
  Supraclavicular approach – first rib resection when management of subclavian vessels is indicated
  Infraclavicular approach – first rib resection for venous decompression
  Posterior approach – reoperation requiring neurolysis of the brachial plexus

Superior Sulcus Tumour (also well known as Pancoast tumour)

  Anterior transcervical approach – tumours involving structures of the thoracic inlet
  Posterior approach – tumours located posteriorly
Trauma

Subclavian vessels:
- Median sternotomy – access to proximal right subclavian artery, brachiophecalic trunk (innominate artery) and carotid artery
- Left anterolateral thoracotomy – access to proximal left subclavian artery
- Supraclavicular approach ± claviculectomy – access to middle to distal subclavian artery

Brachial plexus:
- Supraclavicular approach ± claviculectomy – majority of brachial plexus lesions requiring repair

The root of the neck is at the confluence of the lower neck, upper thorax, upper limb and mediastinum and is variously referred to as the thoracic outlet or inlet, depending on one's perspective. This anatomical area is both literally and figuratively at the periphery of several surgical disciplines. The anatomy is compact, surgical exposure can be challenging, and both the pathology and treatment can have limb- and life-threatening consequences. The clinical conditions where surgery is considered are rare and the indications to proceed with surgery are even less frequent (see ‘Core procedures’). Satisfactory surgical outcomes depend on a thorough understanding of the complex interactions between the pathology and anatomy.

Clinical anatomy

The root of the neck is defined by the bony confines of the manubrium, the first ribs and the first thoracic vertebrae, forming an oval ring that is tipped anteriorly (Fig. 19.1). Scalenus anterior, a useful clinical landmark, inserts on the scalene tubercle on the upper surface of the first rib. The muscle lies anterolateral to the dome of the pleura and apex of the lung, which protrude into the root of the neck in the concavity formed by the first rib. The major structures traversing this zone of transition, passing over the first rib, are the subclavian vessels and the brachial plexus. The clavicle sits above the first rib and either protects or restricts access to the neurovascular bundle, depending on the circumstance.
The subclavian artery, arising on the right from the brachiocephalic trunk (innominate artery) and directly from the aorta on the left, enters the root of the neck posterior to the sternoclavicular joint. The artery arches in a superior and posterior direction behind scalenus anterior and then passes inferiorly over the first rib, transitioning to the axillary artery as it passes beneath pectoralis minor. The subclavian vein begins at the lateral border of the first rib and crosses the rib anterior to scalenus anterior. At the medial border of scalenus anterior and posterior to the medial end of the clavicle it
joins the internal jugular vein to form the brachiocephalic vein. It is at this junction that the thoracic duct on the left enters the venous system. The brachial plexus, formed by the ventral rami of C5–C8 and T1, emerges into the root of the neck between scalenus anterior and medius. The palpable interscalene groove, lateral to the cricoid cartilage at the posterior border of sternocleidomastoid, identifies this point. The roots combine to form the upper, middle and lower trunks. The trunks are located superior to the clavicle in the anterior and inferior portion of the posterior triangle. The subclavian artery lies anterior and inferior to the plexus at this point and the lung apex is a close medial relationship. The trunks divide into anterior and posterior divisions as the plexus passes over the first rib. With the arms at the side, the divisions are located behind the clavicle. Continuing laterally, the lateral, posterior and medial cords are defined and are named according to their relationship with the axillary artery. The cords give rise to the major nerves of the upper extremity.

Other nerves of clinical significance include the phrenic nerve, arising from the C3, C4 and C5 nerve roots. This nerve courses from a lateral to medial position on scalenus anterior, assisting with the clinical identification of this muscle. At the base of the neck the phrenic nerve is located over the medial edge of scalenus anterior, 3–4 cm lateral to the sternoclavicular joint. The long thoracic nerve, arising from the C5, C6 and C7 nerve roots, traverses scalenus medius and passes over the lateral edge of the first rib. The cervical sympathetic ganglia lie on the prevertebral fascia in front of the transverse processes of the cervical vertebrae.

Surgical approaches and considerations

Percutaneous procedures

Percutaneous access for subclavian vein cannulation and brachial plexus blocks are the most common indications for surgical intervention in this area. Subclavian vein catheters are commonly used for temporary central venous access. Brachial plexus nerve blocks are used for operative anaesthesia and postoperative analgesia. The interscalene block can anaesthetize the nerve roots of the cervical plexus and the upper and middle trunks of the brachial plexus, and therefore is used for surgery of the shoulder and upper extremity. The supraclavicular block can address the upper, middle and lower trunks and is useful for procedures of the distal
two-thirds of the upper extremity. The infraclavicular block works at the level of the cords, providing anaesthesia for the distal two-thirds of the arm, and blocks the axillary and musculocutaneous nerves as well. The landmarks for percutaneous procedures in this area are sternocleidomastoid, the suprasternal notch, the clavicle and the coracoid process (Table 19.1). Ultrasound guidance facilitates these procedures and reduces complications.⁶

**TABLE 19.1**
Landmarks for percutaneous techniques in the root of the neck

<table>
<thead>
<tr>
<th>Surgical indications</th>
<th>Approach</th>
<th>Landmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subclavian vein access</td>
<td>Infraclavicular</td>
<td>Midpoint of clavicle palpated. Needle inserted 2–3 cm inferior to this point and directed deep to suprasternal notch</td>
</tr>
<tr>
<td></td>
<td>Supraclavicular</td>
<td>Angle between lateral border of sternocleidomastoid and clavicle palpated. Needle inserted 1 cm behind sternocleidomastoid and 1 cm above clavicle. Needle directed upward behind medial head of clavicle toward contralateral nipple</td>
</tr>
<tr>
<td>Brachial plexus block</td>
<td>Interscalene</td>
<td>Interscalene groove palpated deep to lateral border of sternocleidomastoid at level of cricoid process (level of C6). Needle inserted at this point and directed to interscalene groove</td>
</tr>
<tr>
<td></td>
<td>Supraclavicular</td>
<td>Interscalene groove palpated and followed inferiorly until subclavian artery is palpated approximately 1 cm behind middle portion of clavicle. Needle directed posteriorly and superior to arterial pulsation</td>
</tr>
<tr>
<td></td>
<td>Infraclavicular</td>
<td>Coracoid process palpated. Needle inserted at a point 2 cm medial and 2 cm caudal to coracoid process and directed vertically</td>
</tr>
</tbody>
</table>

**Thoracic outlet syndrome**

Thoracic outlet syndrome refers to symptom complexes arising from compression of the brachial plexus and subclavian vessels as they pass from the neck to the axilla. A number of predisposing factors have been identified, including cervical ribs, fibrous bands extending from the transverse process of C7 to the first rib, variations in the insertion of scalenus anterior, and neurovascular structures which follow an atypical course.¹,⁷,⁸ Deformity from a clavicular fracture⁷ and hypertrophy of scalenus anterior from weightlifting¹ are examples of acquired factors. Repetitive overhead arm movements with occupational or athletic activity can contribute to the syndrome.⁸ The exact mechanism of compression in any individual is difficult to identify⁹ and the pathophysiology of the condition remains
controversial.\textsuperscript{8,10} Irrespective of this controversy, the majority of anatomical factors implicated in the pathophysiology of this disorder operate against the first rib, producing similar symptom complexes.\textsuperscript{9}

Three symptom complexes are described: neurogenic, arterial and venous thoracic outlet syndromes. The neurogenic symptom complex accounts for more than 90\% of cases.\textsuperscript{8,11} The compression usually occurs in the triangular area bound by scalenus anterior and scalenus medius and the first rib.\textsuperscript{1,7,8} The lower trunk of the brachial plexus is most frequently involved and patients present with chronic neck pain and paraesthesia in the distribution of the ulnar nerve.\textsuperscript{7,8} Symptoms of venous compression, swelling of the arm with cyanosis and pain,\textsuperscript{11} are the second most common symptom complex.\textsuperscript{7,11} These patients relate a history of repetitive activity of the upper extremities in a plane above the shoulders. Compression of the vein occurs medially as the vein crosses the first rib in the costoclavicular space, where hypertrophy of scalenus anterior, lateral insertion of the costoclavicular ligament, and positional factors can contribute to the syndrome.\textsuperscript{1} Arterial compression, often associated with bony abnormalities such as a cervical rib,\textsuperscript{1,7} is the least frequent expression of the thoracic outlet syndromes. Symptoms are the result of thromboemboli from mural thrombus in a subclavian artery aneurysm or post-stenotic area of dilation.\textsuperscript{1,11} Patients present with hand pain and digital ischaemia associated with coldness, pallor and paraesthesia.

The management of neurogenic thoracic outlet syndrome is conservative with physiotherapy. Surgery is a consideration for recalcitrant symptoms or progressive neurological deficit.\textsuperscript{9} Surgery is generally indicated to manage vascular symptoms.\textsuperscript{8} There is agreement that first rib resection is the appropriate surgical procedure to decompress the thoracic outlet.\textsuperscript{1,7,9,10} The surgical exposure for first rib resection varies by surgeon preference and anatomical considerations. The transaxillary approach is an expedient approach for complete removal of the first rib and is used for neurological and venous decompression. A supraclavicular approach is used for arterial lesions requiring control of the proximal subclavian artery. A posterior approach is reserved for reoperation requiring neurolysis of the brachial plexus and decompression of vascular structures.\textsuperscript{9} Endoscopic video-assisted approaches are being evaluated.\textsuperscript{12}

The transaxillary approach\textsuperscript{7} involves a relatively small incision in the axilla
with direct dissection to the chest wall, and then superiorly to expose the first rib. The first rib can be removed completely without retracting the brachial plexus and subclavian vessels. Dissection and scarring are minimal with less postoperative morbidity and a better cosmetic result. Exposure of the proximal subclavian artery is limited, however. The supraclavicular approach uses an incision above the clavicle to expose scalenus anterior and the phrenic nerve, the brachial plexus and scalenus medius.\textsuperscript{10} Scalenus anterior is divided from the first rib to expose the subclavian artery (Fig. 19.2). Scalenus medius is transected from its broad attachment to the first rib with careful attention to the long thoracic nerve. The brachial plexus and subclavian artery are retracted to expose the first rib. The supraclavicular approach provides direct visualization of structures compressing the neurovascular bundle and exposes the proximal subclavian artery. In the management of venous compression an infraclavicular exposure with a second transverse incision below the clavicle can facilitate removal of the medial aspect of the first rib.\textsuperscript{13} The posterior approach involves a high posterior thoracoplasty.\textsuperscript{1} This is the most morbid approach as a consequence of traversing the suspensory muscles of the scapula. Good exposure of the lower trunk of the brachial plexus is provided.\textsuperscript{8}
Superior sulcus tumours
The superior sulcus or Pancoast tumour is a tumour of the lung apex located at the superior aspect of the costovertebral gutter. In this location the tumour can invade the upper ribs, posterior neurovertebral elements, stellate ganglion, lower components of the brachial plexus and the more anteriorly situated subclavian vessels. These tumours are responsible for less than 5% of bronchogenic carcinomas.\textsuperscript{14} Symptoms and signs reflect the structures involved. Shoulder pain and pain radiating to the ulnar side of the arm and hand are common presenting symptoms. Horner's syndrome and weakness and atrophy of hand may be present. Pulmonary symptoms such as cough and haemoptysis are uncommon as a consequence of the peripheral location of the tumour.\textsuperscript{14,15}

Treatment with curative intent usually involves neoadjuvant concomitant chemoradiation followed by surgical resection with a negative margin.\textsuperscript{14,16–18} Surgical resection involves an upper lobectomy with an \textit{en bloc} resection of the chest wall, and other structures as appropriate, including the sympathetic chain and stellate ganglion, lower trunks of the brachial plexus, subclavian artery and components of the thoracic vertebrae.\textsuperscript{15,19} Contraindications to surgery include poor cardiopulmonary status, distant metastasis and local
Two surgical approaches for resection of superior sulcus tumours are described: the posterior and the anterior transcervical approach. Predominantly posterior lesions can be resected through the posterior approach. The anterior transcervical approach is favoured for tumours involving the structures of the thoracic inlet. Combined approaches may be necessary, with the understanding that operative risk is significantly increased.

The posterior approach, as initially described by Paulson, is an extension of the conventional posterolateral thoracotomy. The incision is extended around the tip of the scapula and continues superiorly in a paravertebral location to the level of C7. The scapula is mobilized, providing exposure of the posterior chest wall and the vertebrae and transverse processes. The thorax is entered through an intercostal space below the lowest rib to be resected. Resectability is assessed and the en bloc resection usually starts with resection of the chest wall. Good access is provided to the neurovascular elements and posterior elements of the brachial plexus. The major limitation of this approach is restricted exposure of the more anteriorly placed subclavian vessels lying above the tumour mass.

The anterior transcervical approach, as described by Dartavelle, and its modifications provide improved access to the anterior neurovascular elements (Fig. 19.3) and increase the rate of a complete resection. This approach uses an L-shaped incision starting at the mastoid process and extending along the anterior border of sternocleidomastoid, and then directed as a horizontal limb beneath the clavicle. Scalene anterior, the phrenic nerve and the brachial plexus are identified. The manubrium is transected and an osteomuscular flap that includes the intact clavicle is retracted laterally. The subclavian vein may be mobilized or resected. Scalene anterior and medius are detached from the first rib. The brachial plexus is dissected to the level of the spinal foramen. The subclavian artery and its branches can be successively controlled. Exposure is provided to assess the extent of the tumour. An upper lobectomy and chest wall resection below the second rib can be challenging and this can necessitate extended surgical exposure. Endoscopic video-assisted techniques have been combined with this approach to assist with the upper lobectomy. The major limitation of the anterior approach is the requirement for further exposure for resection of the posterior neurovascular elements. A second
posterior midline exposure by a spinal surgeon with multilevel laminectomy, nerve root division inside the spinal canal and hemivertebreal resection can be added to the anterior approach.\textsuperscript{14,15}

![Image of superior sulcus tumor and subclavian vessels](image)


**Trauma to the subclavian vessels**

Injury of the subclavian vessels accounts for 1–2% of all acute vascular trauma\textsuperscript{29,30} and yet is the most common cause of upper-extremity ischaemia.\textsuperscript{31} The most frequent causes are stab wounds, gunshot wounds and iatrogenic injuries. The injuries are associated with significant morbidity and mortality.\textsuperscript{29,31} Stable patients with isolated injuries are increasingly managed with endovascular stents.\textsuperscript{29,32,33} Patients with haemodynamic instability or multiple concomitant injuries, and stable patients who have undergone unsuccessful endovascular procedures are candidates for open
procedures. In general, prosthetic grafts are employed for proximal injuries, and direct repair or interposition vein grafts are used for distal injuries. Repair of major venous injuries is now accepted, with ligation reserved for unstable patients.

The principle of extensile exposure is applicable, with primary and distal control prior to direct approach to the injury. The major issue with injuries involving the root of the neck is proximal control as a consequence of the bony constraints. An understanding of all techniques of extensile exposure for this area is critical to a successful outcome. A median sternotomy provides access to the proximal right subclavian artery as well as the brachiocephalic trunk and proximal carotid artery. Exposure of the proximal left subclavian artery is difficult from this approach because of its relatively posterior origin from the aortic arch. The left subclavian artery is accessible for control with a high anterolateral thoracotomy performed through the third interspace. Others advocate an initial supraclavicular approach with addition of a median sternotomy if necessary. More extensive exposure of the proximal vessels, albeit with more morbidity, can be achieved by combining a partial median sternotomy with the supraclavicular and infraclavicular approach to create a trapdoor incision. The mid to distal aspect of the subclavian artery is approached through a supraclavicular incision (see Fig. 19.2). Using this approach, the clavicular head of sternocleidomastoid is transected, the carotid sheath is entered and the internal jugular vein is retracted to expose the carotid artery, with careful attention to the posteriorly located vagus nerve. On the left side the thoracic duct is controlled. With the phrenic nerve isolated and protected, scalenus anterior is transected to expose the subclavian artery. Exposure of the subclavian artery can be improved with resection of the mid portion of the clavicle. Recent reports suggests that the long-term functional disability from clavicular resection is minimal. Distal control may require an infraclavicular approach to the axillary artery with an incision in the deltopectoral groove. Pectoralis major is separated and pectoralis minor is divided to expose the axillary artery.

In summary, the basis of management of vascular injuries of the thoracic inlet is the appropriate use of median sternotomy, left anterolateral thoracotomy, the supraclavicular approach and claviculectomy, alone or in combination, to facilitate proximal and distal control. The brachial plexus is injured in 20–35% of patients with penetrating injuries to the thoracic
inlet\textsuperscript{30,33} and in surviving patients is the main cause of disability.\textsuperscript{30}

**Trauma to the brachial plexus**

Closed traction injuries are the most common lesions that the brachial plexus sustains (Ch. 37).\textsuperscript{3,36} Lesions of the supraclavicular plexus are the most frequent\textsuperscript{3,36,37} and occur with forces that move the shoulder downward and the neck to the contralateral side. Overt nerve transection may occur with high-energy impact, as associated with motor vehicle or industrial accidents. A permanent and disabling type of closed traction injury occurs when the primary roots are torn from the spinal cord. Root avulsions are problematic as they often involve multiple levels, and because the axons do not regenerate with these types of lesion successful surgical repair is not possible.\textsuperscript{3,38} Head trauma, chest injuries, and fractures and dislocations affecting the shoulder girdle and cervical spine are common associations.\textsuperscript{37,39} Isolated compression injuries are relatively rare because of the protection provided by the bony framework of the root of the neck. Transient focal force to the shoulder region with contact sports is the most frequent cause of nerve compression injury. Brachial plexus birth palsy caused by lateral traction on the fetal head at time of delivery is considered an iatrogenic type of closed traction injury.\textsuperscript{3} Open injuries from gunshot and knife wounds are less frequent. They are commonly associated with vascular injuries, which take precedence in management. The damage to the plexus may be secondary to expanding haematomas, pseudoaneurysms or arteriovenous fistulae involving the subclavian vessels.\textsuperscript{3}

Most brachial plexopathies present with varying degrees of weakness in the distribution of the affected component of the plexus. Pain is not a consistent system; it can, however, be severe with nerve root avulsions. Involvement of nerve elements in close proximity to the proximal brachial plexus, such as the long thoracic nerve from the C5–7 nerve roots and the cervical sympathetic plexus with resultant Horner's syndrome, should raise the level of suspicion for nerve root avulsions.\textsuperscript{3}

The treatment of brachial plexus lesions is specific to the disorder. In general, the initial approach to closed injuries is conservative. Injuries without or with partial axon loss have a good prognosis for recovery. The outcome of lesions secondary to more severe trauma associated with more complete axon loss is variable and is dependent on the area of plexus involved.\textsuperscript{40} Avulsion injuries do not recover and permanent neurological
sequelae are common after penetrating trauma.\textsuperscript{30} Most surgical interventions are performed after documenting no improvement over 3–4 months.\textsuperscript{3} The interventions are tailored to the particular pathology and include nerve grafts, neurolysis, nerve transfers and tendon and muscle transfers.\textsuperscript{41}

The majority of brachial plexus lesions can be exposed through a supraclavicular approach with the addition of clavicular osteotomy and infraclavicular incision if the injury involves the retro- and infraclavicular regions.\textsuperscript{42,43} Specific to this approach, the upper trunk of the brachial plexus is identified exiting under scalenus anterior. The phrenic nerve is identified on the anterior surface of scalenus anterior and followed superiorly to identify the contributions from C5 at the level of the cervical sensory plexus. The roots and trunks are then progressively identified. The emergence of the long thoracic nerve from the proximal aspect of the C5–7 nerve roots is identified and spared. More distally, at the upper level of the clavicle, the suprascapular nerve can be identified arising from the upper trunk. The neuropathology is assessed for management.\textsuperscript{42,44} The clavicle is divided at this point if further exposure is necessary.
Tracheostomy

Surgical access to the airway may be indicated for prophylactic or emergent management of airway obstruction, and for airway access for prolonged ventilation and facilitation of tracheobronchial toilet.\textsuperscript{45,46} The main procedures for surgical access are summarized in Table 19.2.

**TABLE 19.2**

Surgical airway access: advantages and disadvantages of core procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheostomy</td>
<td>Airway access for all emergent and elective indications Procedure of choice when other techniques cannot be used</td>
<td>Open operative procedure</td>
</tr>
<tr>
<td>Cricothyrotomy</td>
<td>Emergent airway access in selected cases Quick to perform</td>
<td>Conversion to tracheostomy when airway stabilization is necessary Contraindicated for airway obstruction from tumour Contraindicated in trauma when laryngotracheal dysjunction suspected Limited use in paediatric population</td>
</tr>
<tr>
<td>Percutaneous dilation tracheostomy</td>
<td>For elective indications may be more expedient and may have fewer complications than open tracheostomy</td>
<td>Relative contraindications, including head and neck cancer patients, midline neck mass, paediatric patients, emergent airway access, distorted anatomy, obesity, inability to extend neck</td>
</tr>
</tbody>
</table>

The trachea is a 10–11 cm tube of cartilage and fibromuscular membrane extending from the lower border of the cricoid at the level of the C6 vertebra to the carina corresponding to the sternal angle and the T5 vertebra. Its course runs slightly backward and to the right of the sagittal plane at the carina. Its rigid structure is imparted by 18–22 C-shaped cartilaginous rings that provide its characteristic shape. The trachea is flattened posteriorly as it lies anterior to the oesophagus. Lateral relations include the common carotid arteries, recurrent laryngeal nerves, inferior thyroid arteries and lobes of the thyroid gland. The thyroid isthmus is firmly adherent to the anterior trachea from the second to the fourth tracheal cartilages. In the paediatric population the trachea is softer, smaller and more mobile. The tracheal diameter is about 3 mm at birth, and as the child grows, the inner diameter of the trachea can be calculated using formulae that correlate age and weight with the size of the trachea.\textsuperscript{47} In children, the brachiocephalic trunk crosses obliquely in front of the trachea at a higher level than in adults and may extend a little
above the upper border of the manubrium.

Exposure for an open tracheostomy uses a transverse incision in the midline below the cricoid cartilage at the predicted level of the thyroid isthmus (Fig. 19.4A and B). Dissection in the midline avoids bleeding from the anterior jugular veins and injury to lateral related structures such as the carotid vessels. The tracheotomy is sited at the level of the second and third tracheal rings. Exposure of this area is facilitated by dividing the thyroid isthmus (Fig. 19.4C and D). The isthmus is adherent to the anterior wall of the trachea and cannot be easily retracted. If the isthmus is not divided and the tracheostomy is placed above the isthmus, there is a risk of erosion of the cricoid cartilage and subglottic stenosis. A low tracheostomy sited below the isthmus predisposes to a tracheobrachiocephalic trunk fistula (tracheo-innominate artery fistula). This complication is now uncommon with the use of high-volume, low-pressure cuffs. A vertical incision is made through the second and third cervical rings and the tracheostomy tube is inserted under direct vision (Fig. 19.4E and F). Care is necessary to avoid a false passage between trachea and sternum, as malposition of the tracheostomy tube can obstruct the airway. The use of tracheal flaps sutured to the skin is advocated by some to reduce this complication. Percutaneous dilational tracheostomy is performed following the same principles. A needle is inserted through the second and third tracheal rings with concomitant bronchoscopy to confirm an adequate position to prevent posterior tracheal wall injury. The tract is dilated and the tracheostomy tube introduced.
FIG. 19.4  Tracheostomy stages. **A**, Placement of the incision is below the cricoid cartilage at the level of the thyroid isthmus. **B**, The superficial layer of deep cervical fascia is divided in the midline to expose the thyroid isthmus. **C**, The thyroid isthmus
is elevated from the anterior wall of the trachea. **D**, The thyroid isthmus is divided to expose the first three tracheal rings. **E**, A vertical incision is made through the second and third tracheal rings. **F**, The tracheostomy tube is directed into the trachea with the cuff of the tracheostomy tube positioned immediately below the tracheotomy.

In summary, tracheostomy is a common operation that is usually straightforward, though at times challenging. The airway should be secured with endotracheal intubation before a tracheostomy is performed, if at all possible. Attention to dissection in the midline, adequate exposure, and accurate placement of the tracheostomy tube under direct vision will reduce complications.

**Tips and Anatomical Hazards**

**Optimizing Outcomes in Surgery of the Root of the Neck**

Procedures involving the root of the neck can be complex and are associated with significant morbidity and mortality. The challenges in addressing the clinical conditions in this area are reflected in the number of surgical exposures described and the lack of consensus on the ideal surgical exposure in many instances. The following are general considerations in avoiding complications and optimizing surgical outcomes:

A thorough understanding of the complex interactions between the anatomy and pathology from the history and physical exam, appropriate imaging studies, and pre-treatment biopsy where appropriate.

Knowledge of all surgical exposures applicable to a particular clinical situation is essential. The strength and limitations of all potential surgical approach needs to be adapted to the clinical presentation.

A multidisciplinary team can improve outcomes with major surgical procedures.

The benefit to risk assessment for these procedures is critical to decision making and realistic outcomes need to be understood by the patient.

The brachial plexus and the important phrenic nerve (C3,4, 5) are located deep to the prevertebral fascia, an important point to remember when dissecting in this area. Nerves above the fascia in the posterior triangle are the important accessory nerve, and sensory
nerves from the cervical plexus. The sensory nerves (and rarely the accessory nerve) are sometimes sacrificed during surgery in this region.

Tracheostomy

Some surgeons recommend removing a window of the trachea to facilitate cannulation with the tracheostomy tube and to aid re-insertion if the tube becomes displaced. The use of temporary stay sutures (3/0 silk is ideal) placed at time of tracheostomy and brought out through the skin incision can be invaluable for lifting the trachea towards the surface if the airway is lost.

Beware of anatomical variants such as a high brachiocephalic artery that can cross the trachea and cause catastrophic bleeding to the unwary. The subclavian vessels on occasion pass superior to the clavicle – always be careful when dissecting inferiorly the posterior triangle and don’t cut anything blindly.
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Single Best Answers

1. A 32-year-old male presents with a stab wound to the left supraclavicular fossa. He is haemodynamically unstable. Following resuscitation, he is taken to the operating theatre on an emergent basis. Which one of the following is the best surgical exposure for proximal control of the subclavian artery?
A. Supraclavicular incision
B. Supraclavicular incision with claviculectomy
C. Left anterolateral thoracotomy
D. Median sternotomy

Answer: C. The principle for management of vascular injuries is proximal and distal control of the vessel before directly approaching the injury site. The proximal subclavian artery lies behind the sternoclavicular joint and is relatively inaccessible. The left subclavian artery has a posterior origin from the aortic arch and follows the intrapleural surface on the left side of the mediastinum. The proximal artery is accessible using a high left anterolateral thoracotomy. The right subclavian artery, arising from the brachiocephalic trunk, has a more anterior position in the mediastinum and can be accessed with a median sternotomy. The middle to distal aspect of the subclavian artery is accessed using a supraclavicular incision resecting the central aspect of the clavicle if necessary.

2. A 50-year-old female presents with a painful cold hand and clinical findings of digital ischaemia. Which one of the following anatomical abnormalities is the most likely association?
A. Medial insertion of the costoclavicular ligament
B. Fibrous bands passing from the transverse process of C7 to the first rib
C. Hypertrophy of scalenus anterior
D. Cervical rib

**Answer: D.** The symptom complex described is consistent with arterial thoracic outlet syndrome. The pathophysiology involves thromboemboli from a post-stenotic area of dilation or a subclavian artery aneurysm. The list presented above describes congenital and acquired entities associated with thoracic outlet syndrome. In many cases of thoracic outlet syndrome the exact mechanism of compression of the neurovascular bundle is difficult to determine. The arterial form of thoracic outlet syndrome is usually associated with bone abnormalities such as a cervical rib.

3. A 70-year-old male with severe chronic obstructive pulmonary disease requires emergent central venous access for a pacemaker. Which one of the following approaches for central venous access would carry the most risk for this clinical scenario?
   A. Right subclavian
   B. Left subclavian
   C. Right internal jugular
   D. Left internal jugular

**Answer: B.** In a patient with severe chronic obstructive pulmonary disease it would be prudent to minimize any risk of pneumothorax. The lung apex is a close posterior and inferior relationship of the subclavian vein. The apex of the left lung can extend above the level of the first rib on the left but not commonly on the right. In theory, a right-sided approach would carry less risk for a pneumothorax. The risk of pneumothorax is significantly lower with internal jugular vein catheterization. The right internal jugular vein approach would carry the least risk for pneumothorax, and the left subclavian approach the highest, from an anatomical perspective.
4. A 24-year-old male was involved in a motor vehicle accident. He has neurological findings in his left arm and hand that indicate a brachial plexus injury. Additional neurological findings include a Horner's syndrome and winging of the left scapula. Which one of the following segments of the brachial plexus does the injury involve?

A. Roots  
B. Trunks  
C. Divisions  
D. Cords

**Answer:** A. The Horner's syndrome is a result of disruption of the cervical sympathetic plexus. The winging of the scapula is explained by interruption of the long thoracic nerve arising from the C5–7 nerve roots. The long thoracic nerve innervates serratus anterior. Both of these nerve elements are in close proximity to the cervical nerve roots. This constellation of findings would place the injury at the level of the cervical roots and should raise suspicion for nerve root avulsions.
A. Briefly describe the pertinent clinical anatomy relevant to surgical management of this case.

The major anatomical issue in the management of this case is the surgical relations of the tumour mass as it transgresses the root of the neck. The
major structures of concern are the neurovascular bundle passing over the first rib. A key clinical landmark is scalenus anterior, which inserts on the scalene tubercle on the upper surface of the first rib. The subclavian vein passes over the first rib anterior to scalenus anterior. The subclavian artery and brachial plexus are located posterior to scalenus anterior. The clavicle sits above the first rib, restricting access to the neurovascular bundle. Other nerves relevant to this case include the phrenic nerve, passing from a lateral to a medial position on the surface of scalenus anterior. The accessory nerve is in the operative field in the posterior triangle as it courses from the posterior border of sternocleidomastoid approximately 2 cm above the nerve point to pass into trapezius approximately 2 cm above the clavicle. The thoracic duct enters the venous system medial to the medial border of sternocleidomastoid.

B. What is the most likely aetiology of the symptoms described?

The symptoms described were attributed to compression of the neurovascular bundle in the root of the neck, i.e. a thoracic outlet syndrome. In contrast to most cases of thoracic outlet syndrome, the aetiology of the compression was obvious. The arm pain was attributed to compression of the brachial plexus and the shoulder discomfort was considered mechanical in nature, reflecting the bulk of the tumour mass. The swelling in the arm could be explained by venous compression.

C. Describe the surgical exposure or exposures necessary to resect this tumour.

Surgical exposure can be challenging in the root of the neck because of the bony constraints imposed predominantly by the clavicle. The surgical exposures in this area are usually described in relation to specific clinical entities, including the various forms of thoracic outlet syndrome, superior sulcus tumours and upper extremity revascularization. In general, the surgical exposures for this region can be broadly classified into posterior and anterior approaches. The posterior approaches are used for pathology in the posterior confines of the thoracic outlet and are not applicable to this case, which involves the anterior aspect of the root of the neck. The majority of anterior approaches are initiated with a supraclavicular incision or approach and extended with claviculectomy or infraclavicular incision if necessary.

In terms of management, this case was approached with a supraclavicular incision and claviculectomy (Fig. 19.6). The mid portion of the clavicle (MC) was reflected inferiorly as an osteomuscular flap based on pectoralis major (PM). (Other abbreviations: DC, distal portion of clavicle; SCM,
This permitted *en bloc* resection of the tumour mass with minimal or no trauma to the neurovascular bundle. Current opinion reports minimal disability from resection of the clavicle. For predominantly cosmetic reasons, the blood supply to the mobilized clavicular segment was preserved and the continuity of the clavicle was re-established with osteosynthesis (Fig. 19.7).

**FIG. 19.6** Operative field following resection of soft tissue tumour, left thoracic inlet. See text for description of operative exposure. DC, distal clavicle; MC, middle segment clavicle; PM, pectoralis major; SCM, distal sternocleidomastoid; SV, subclavian vein.
FIG. 19.7 Radiograph of left clavicle following resection of soft tissue tumour, left thoracic inlet. Anatomical continuity of left clavicle restored with reconstruction plate.
SECTION 3
Neuroanatomy

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CHAPTER 20
Neurosurgical anatomy

Peter C Whitfield

This chapter contains an overview of the surgical anatomy of the brain that will be amplified in later chapters. The use of cisternal anatomy to guide microsurgical procedures in the supratentorial and infratentorial compartments is emphasized. The pterional, transcallosal and telovelar approaches are described because they are standard procedures used to access a variety of intra-axial or intraventricular lesions.
Surgical surface anatomy

The pterion is the point where the frontal, parietal and temporal bones and the greater wing of the sphenoid meet. It is located 2.5 cm above the zygomatic arch and 1.5 cm behind the frontal process of the zygomatic bone. The asterion is the junction of the lambdoid, occipitomastoid and parietomastoid sutures and overlies the junction of the transverse and sigmoid sinuses.

The lateral sulcus (Sylvian fissure) is marked by a line drawn from the lateral canthus to a point 75% of the distance from the nasion to the external occipital protuberance. There is variability in the location of the central sulcus, which lies between the motor strip (anteriorly) and the primary sensory cortex (posteriorly): it lies approximately 4–5 cm posterior to the coronal suture. This is also at a point approximately 2 cm posterior to the mid position of the arc joining the nasion and the external occipital protuberance.

Placement of a ventricular catheter is usually via Kocher's point (Fig. 20.1). This is a burr-hole, usually on the right side, in the mid-pupillary line, 1 cm anterior to the coronal suture. The catheter is inserted by aiming toward the medial canthus of the ipsilateral eye in the coronal plane and toward the external auditory canal (external acoustic meatus) in the anterior–posterior plane. The ventricle is normally at a depth of around 5–5.5 cm. Keen's point lies 2.5–3 cm behind and 2.5–3 cm above the auricle (pinna) and may be used to access the trigone of the lateral ventricle. The Frazier burr-hole lies 3–4 cm from the midline and 6 cm above the external occipital protuberance: it can be used to tap the occipital horn.
FIG. 20.1 Landmarks for Kocher’s point, the most commonly used entry point for ventricular access.

The superior sagittal sinus runs posteriorly from the nasion to the external occipital protuberance and is a midline structure. The transverse sinus passes horizontally forward from the level of the external occipital protuberance toward the mastoid at the same level as a line projected posteriorly from the zygomatic arch.
Clinical anatomy

Surface anatomy provides useful landmarks for operative planning. The intracranial approaches require knowledge of neuroanatomy, including detailed knowledge of the hemispheres, the diencephalon, the brainstem, the cerebellum, the ventricles and the blood supply. The complex relationships between structures requires three-dimensional understanding. In the supratentorial compartment, the lateral sulcus (Sylvian fissure) and the central sulcus are key landmarks in identifying structures on the lateral aspect of the hemisphere. During a pterional approach, opening of the lateral sulcus enables identification of the optic nerve and carotid artery, providing a base for onward dissection. In the posterior fossa the midline structures are useful landmarks for initial orientation. In the cerebellopontine angle the relationship between the choroid plexus and cranial nerves VII and VIII enables accurate orientation.

Subarachnoid cisterns

Arachnoid mater invests the brain and forms a series of partially interconnecting cerebrospinal fluid (CSF) cisterns around the base of the brain (Fig. 20.2). Each cistern contains cranial nerves and/or blood vessels. Knowledge of the subarachnoid cisterns is of immense practical value during microsurgical approaches. The principal cisterns of operative importance, and their contents, are listed in Table 20.1.
FIG. 20.2 A schematic representation of the basal cerebrospinal fluid cisterns (Arabic numbers) as observed during microsurgical procedures. Note the intimate association with the cranial nerves (Roman numerals). Many of the cisterns are also intimately associated with cerebral arteries. Key: 1, olfactory cistern; 2a, callosal cistern; 2b, lamina terminalis cistern; 3, chiasmatic cistern; 4, carotid cistern; 5, Sylvian cistern; 6, crural cistern; 7, interpeduncular cistern; 8, ambient cistern; 9, prepontine cistern; 10, superior cerebellar–pontine cistern; 11, inferior cerebellar–pontine cistern (lateral cerebellomedullary); 12, anterior spinal cistern; 13, posterior spinal cistern. I, olfactory bulb; II, optic nerve; III, oculomotor nerve; IV, trochlear nerve; V, trigeminal nerve; VI, abducens nerve; VII, facial nerve; VIII, vestibulocochlear nerve; IX, glossopharyngeal nerve; X, vagus nerve; XI, accessory nerve; XII,
TABLE 20.1

The principal cisterns of operative importance and their contents

<table>
<thead>
<tr>
<th>Cistern</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamina terminalis</td>
<td>Anterior communicating artery and branches</td>
</tr>
<tr>
<td>Chiasmatic</td>
<td>Proximal anterior cerebral artery; optic nerves</td>
</tr>
<tr>
<td>Carotid</td>
<td>Internal carotid artery and origins of posterior communicating artery and anterior choroidal artery</td>
</tr>
<tr>
<td>Sylvian</td>
<td>Middle cerebral artery</td>
</tr>
<tr>
<td>Crural</td>
<td>Anterior choroidal artery, medial posterior choroidal artery</td>
</tr>
<tr>
<td>Interpeduncular</td>
<td>Bifurcation of basilar artery and posterior cerebral arteries; CN III</td>
</tr>
<tr>
<td>Ambient (with supratentorial and infratentorial components)</td>
<td>Posterior cerebral artery, superior cerebellar artery (SCA), basal veins; CN IV</td>
</tr>
<tr>
<td>Quadrigeminal</td>
<td>Vein of Galen, distal pericallosal arteries, distal posterior cerebral arteries and SCA; CN IV</td>
</tr>
<tr>
<td>Prepontine</td>
<td>Basilar artery, anterior inferior cerebellar artery (AICA), SCA; CN VI</td>
</tr>
<tr>
<td>Premedullary</td>
<td>Vertebral arteries, posterior inferior cerebellar artery (PICA); CN XII</td>
</tr>
<tr>
<td>Cerebellopontine</td>
<td>AICA; CN V, VII, VIII</td>
</tr>
<tr>
<td>Cerebellomedullary</td>
<td>Vertebral artery, PICA; CN IX, X, XI, XII</td>
</tr>
<tr>
<td>Cisterna magna</td>
<td>Distal PICA, craniospinal junction</td>
</tr>
</tbody>
</table>

Lobes of the brain

The frontal lobe lies anterior to the central sulcus (of Rolando) and comprises the precentral gyrus and the superior (F1), middle (F2) and inferior (F3) frontal gyri, as viewed laterally. The neocortex of the precentral gyrus gives rise to the descending motor projection fibres from the pyramidal cells of Betz in layer five of the primary motor cortex. The inferior frontal gyrus contains the fronto-orbital, triangular and frontal opercular regions: the latter two comprise the motor speech cortex in the dominant hemisphere. The medial aspect of the frontal lobe comprises mainly the F1 gyrus and part of the cingulate gyrus as it envelops the genu and rostrum of the corpus callosum. The basal aspect of the frontal lobe comprises the gyrus rectus medially and the orbital gyri laterally.

The lateral sulcus separates the frontal and temporal lobes. The sulcus is deep and is characterized by short anterior and ascending rami that demarcate the apex of the triangular portion of the inferior frontal (F3) gyrus.
The superior (T1), middle (T2) and inferior (T3) temporal gyri extend posteriorly toward the inferior parietal lobule. The superior temporal gyrus has a considerable surface area that forms the floor of the lateral sulcus and includes the primary auditory cortex located within Heschl's transverse temporal gyri. The medial surface of the temporal lobe comprises the parahippocampal gyrus, with the dentate gyrus and fimbria lying more superiorly. The posterior end of the parahippocampal gyrus is intersected by the calcarine sulcus, with the upper part merging with the cingulate gyrus and the lower part with the lingula. The collateral sulcus is fairly constant and defines the lateral margin of the lingula and the parahippocampal gyrus.

The parietal lobe lies posterior to the central sulcus. A line drawn from the parieto-occipital sulcus (best identified from the medial aspect of the hemisphere) to the inferiorly located preoccipital notch defines the posterior limit of the parietal lobe. A second line, drawn from the first line to the lateral sulcus, defines the boundary between the temporal and parietal lobes. The parietal lobe comprises superior and inferior lobules. The latter includes the supramarginal gyrus, which lies anterior to the angular gyrus. These gyri surround the posterior aspects of the lateral sulcus and the superior temporal sulcus (between T1 and T2); they are involved in language control.

The lateral aspect of the occipital lobe shows considerable variability. Medially, the occipital lobe is separated from the parietal lobe by the parieto-occipital sulcus. The calcarine sulcus begins near the occipital pole and courses forwards, joining the parieto-occipital sulcus. The cuneus lies above and the lingula lies below the sulcus. The primary visual cortex is located both above and below the calcarine sulcus.

The insula lies deep to the lateral sulcus. Although triangular in shape, it is bounded by the circular sulcus. The central sulcus of the insula demarcates a large anterior component containing several short gyri and a posterior part comprising two long gyri. The insula overlies many deep structures, including the lentiform nucleus and the internal capsule. The $M_2$ segments of the middle cerebral artery cross the insula. During resection of tumours involving the insula, the lenticulostriate perforators coming off the $M_1$ are vulnerable to injury and their damage can result in motor deficits. The most lateral lenticulostriate perforator acts as the medial margin of such a resection. The central grey matter of the hemispheres is considered in Chapter 29 (Fig. 20.3).
Posterior fossa

The posterior fossa contains the cerebellum, brainstem, cranial nerves VI to XII and much of the posterior circulation. The cerebellum comprises a midline vermis and two cerebellar hemispheres including the tonsils and the flocculi. Lesions within the cerebellar hemisphere are generally approached via a transcortical dissection. Lesions on the undersurface of the tentorium or in the region of the quadrigeminal cistern are usually approached via a supracerebellar, infratentorial route. The structures contained within the quadrigeminal cisterns are hazards to avoid. Lesions in the cerebellopontine angle are approached by retraction of the petrous aspect of the cerebellar hemisphere. Opening the cerebellopontine cistern and the cerebellomedullary cistern will enable identification of the anterior inferior cerebellar artery (AICA), posterior inferior cerebellar artery (PICA) and
cranial nerves VII to XII. Identification of choroid plexus protruding through the foramen of Luschka assists in identifying cranial nerves VII and VIII. The ascending fibres of the spinal accessory nerve are easily identified. The hypoglossal rootlets arise anterior to the olive, from the preolivary sulcus, while the rootlets of IX and X arise posterior to the olive.

**White matter fibres**

The white matter fibres are covered in considerable detail in Chapter 25. Understanding the spatial orientation of these tracts relative to each other in the lateral to medial (and medial to lateral) directions is crucial in planning safe operative corridors for tumours involving cortical and subcortical structures. The white matter contains association fibres, commissural fibres and projection fibres. The association fibres are of two types: short U or arcuate fibres interconnect adjacent gyri, and long fibres interconnect more distant gyri. Examples of long association fibres include the uncinate fasciculus between the temporal and frontal lobes; the cingulum interconnecting the cingulate and parahippocampal gyri and the septal region (subfrontal); the superior longitudinal fasciculus interconnecting the frontal, temporal, parietal and occipital lobes, which lies just superior to the insula, deep to the extreme and external capsules but superficial to the optic radiation and the internal capsule; and the inferior longitudinal fasciculus interconnecting the temporal and occipital lobes.

The inferior occipitofrontal fasciculus is formed by a group of fibres that traverse from the prefrontal region dorsal to the frontal fibres of the uncinate fasciculus and continue posteriorly towards the middle and posterior temporal region. The principal commissural fibres include the corpus callosum and the anterior commissure. The corpus callosum is subdivided into five parts: genu, rostrum, body, splenium and tapetum. The fibres of the forceps minor interconnect the frontal lobes via the genu. The fibres of the forceps major project to the tapetum and interconnect the occipital lobes via the splenium. The fibres of the tapetum lie in the lateral wall of the trigone and the temporal horn, and separate these parts of the ventricle from the more laterally placed optic radiation. The anterior commissure lies in the anterior wall of the third ventricle and interconnects the temporal lobes.

The principal projection fibres are those of the internal capsule and the optic radiation. The internal capsule contains descending corticothalamic, corticobulbar, corticonuclear and corticospinal fibres and ascending
thalamocortical fibres. The sublenticular part of the posterior limb includes auditory and optic radiation fibres. The optic radiation projects from the lateral geniculate body to the primary visual cortex. Fibres from the upper part of the lateral geniculate body course directly to the visual cortex superior to the calcarine sulcus. Fibres from the lower part of the geniculate body loop forwards into the temporal lobe (Meyer's loop) before turning posteriorly toward the inferior part of the primary visual cortex (Fig. 20.4).

**FIG. 20.4**  The uncinate fasciculus has been removed to expose the anterior commissure, and the lateral fibres of the anterior commissure have been removed to expose the optic radiation. Abbreviations: AntCom, anterior commissure; CoRa, corona radiata; GloPa, globus pallidus; IFOF, inferior fronto-occipital fasciculus; SagStr, sagittal stratum; SupLongFasc, superior longitudinal fasciculus; UncFasc, uncinate fasciculus. (Courtesy of Richard Gonczalo Párraga. Adapted from: R.G. Párraga, G.C. Ribas, L.C. Welling, et al., Microsurgical anatomy of the optic radiation and related fibres in 3-dimensional images, Neurosurgery. 71[ONS Suppl 1] (2012) ons160–ons172.)

Cerebral hemispheres
Surgical access to lesions in the cerebral hemispheres is governed by the location of the lesion and the proximity of eloquent tissue. Preoperative functional MRI can be used to assist in the assessment of eloquence. Diffusion tensor imaging can help demonstrate the location of association, commissural and projection fibres which are commonly displaced by space-occupying lesions.

Hemispheric lesions may be approached by a transgyral or a trans-sulcal approach. A pterional approach provides excellent access to the lateral sulcus. A craniotomy is elevated in the region of the pterion which opens directly over the lateral sulcus. Dissection of the sulcus, from lateral to medial, carefully separating the adherent frontal and temporal lobes, provides access to the anterior circulation and the insula (Fig. 20.5). Initial opening of the Sylvian fissure leads to opening of the chiasmatic and carotid cisterns. An extended pterional and/or subtemporal approach can be directed posteriorly via the crural cistern to the interpeduncular cistern and anterior brainstem.
FIG. 20.5  Pterional approach. Cadaveric (A) and intra-operative (B) dissection of the right Sylvian fissure showing the internal carotid artery (ICA), posterior to the optic nerve. A, Shows a wide dissection of the internal carotid, M1 segment of the middle cerebral artery (M1MCA) and A1 segment of the anterior cerebral artery (A1ACA). B, Shows a posterior communicating artery aneurysm (PCAA) just distal to the posterior communicating artery (PCoA), the anterior choroidal artery (AChA) is seen proximal to the bifurcation. (Human anatomical specimen picture provided by Dr Kumar Abhinav under the supervision of Dr Juan C Fernandez-Miranda at the Surgical Neuroanatomy Laboratory, Department of Neurosurgery, University of Pittsburgh Medical Center, Pittsburgh, USA.)

**Accessing the lateral ventricles**

Entry into the lateral ventricles can be accomplished via a number of different routes (Fig. 20.6).
The transcortical approach via the middle frontal gyrus is commonly employed in patients with hydrocephalus (e.g. while resecting a colloid cyst). For lesions in the posterior part of the body or the atrium of the lateral ventricle a transcortical approach through the superior parietal lobule is preferred.

If the ventricles are not significantly dilated, the transcallosal route provides excellent access to the frontal horn and body of the lateral ventricle and to lesions in the region of the foramen of Monro. The exposure can be extended to provide access to the third ventricle. An interhemispheric approach is employed, carefully avoiding inadvertent injury to the
callosomarginal and pericallosal arteries and to any bridging veins more superficially. A 2 cm incision is made in the corpus callosum, providing immediate access into the lateral ventricle. The lateral relationship of the thalamostriate vein to the choroid plexus helps confirm the laterality of the ventricle. Rarely, a featureless cavum septum pellucidum may be entered initially.

If access to the third ventricle is required, this is best achieved by gently retracting the choroid plexus laterally and opening the relatively avascular taenia fornici from the foramen of Monro posteriorly for a distance of 1 cm. This is described as the transchoroidal approach and provides a wide view of the third ventricle. Care should be taken to avoid injury to the paired internal cerebral veins in the roof of the third ventricle; a route between these vessels is usually adopted (Figs 20.7, 20.8).
FIG. 20.7  The lateral and third ventricles: coronal section. The third ventricle is usually entered via opening the taenia fornicens – the medial attachment of the choroid plexus – extending posteriorly from the foramen of Monro. (With permission from S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016.)
FIG. 20.8 Coronal MRI images at the level of the anterior roof of the third ventricle.

Note the location of the choroid plexus (CP); access to the third ventricle can be achieved via the taenia fornix on the medial aspect of the choroid plexus. Note also the position of the paired internal cerebral veins (asterisks), lying beneath the double layer of tela choroidea in the velum interpositum of the roof of the third ventricle. The variable positions of the fornices (F) are also shown. A, Symmetrical fornices unifying in a long segment (yellow circle). B, Symmetrical fornices unifying in a short segment (yellow circle). C, Asymmetrical fornices unifying in a short segment (yellow circle). D, Asymmetrical fornices unifying in a short segment. E, Cavum septum pellucidum (CSP). (With permission from S. Tsutsumi, H. Ishii, H. Ono, Y. Yasumoto, The third ventricle roof: an anatomical study using constructive interference in steady-state magnetic resonance imaging, Surg. Radiol. Anat. 40 (2018) 123–128.)

**Brainstem**

There are a number of approaches to brainstem lesions. The most commonly used approaches are a midline suboccipital telovelar approach to access the floor of the fourth ventricle; a retrosigmoid approach to the lateral pons; and a lateral supracerebellar infratentorial approach to the dorsal midbrain. Rarely, anterior approaches (e.g. to the cerebral peduncles) can be performed via an extended pterional approach.

The suboccipital approach is used for tumours within the fourth ventricle or lesions in the floor of the fourth ventricle. Midline division of the vermis
can expose this region but may be associated with neurological deficits, including truncal ataxia and potential temporary speech disturbance.

A telovelar approach enables access with less risk of complication. If the cerebellar tonsils are both retracted laterally and superiorly, taking care not to occlude the PICA, the roof of the fourth ventricle is exposed. This consists of the tela choroidea inferiorly and the inferior medullary velum superiorly; the foramen of Magendie is evident just inferior to this point.

After completion of a suboccipital craniotomy and exposure of the cerebellum and brainstem, the dissection needs to proceed towards the uvulotonsillar space and the cerebellomedullary fissure. In order to visualize the tela choroidea, the uvulotonsillar space is exposed by retracting the uvula superomedially and the tonsil laterally. A paramedian incision through the tela, just lateral to the uvula of the vermis, enables good visualization of the floor of the fourth ventricle. The incision can then be extended superiorly into the inferior medullary velum (the telovelar approach) to access the upper reaches and lateral recess of the fourth ventricle. Care should be taken to avoid damaging the inferior and superior cerebellar peduncles when exposing the lateral recess of the fourth ventricle. During this approach, the PICA and its branches are vulnerable to injury, particularly as the artery courses medially into the cerebellomedullary fissure. If the surgical target lies within the brainstem, an opening is usually made at the site of pial presentation of the lesion. If the lesion lies deep to the pial surface, a safe entry zone using the shortest route possible through the normal parenchyma is adopted to minimize the risk of collateral damage. The preferred zones for entry posteriorly are the supra- and infracollicular approaches above and below the facial colliculus, respectively. Where possible, the midline longitudinal sulcus should be avoided because of its proximity to the medial longitudinal fasciculus, which is responsible for the coordination of eye movements.

Other adjuncts that may help in making surgery in the brainstem safer include use of neurophysiological monitoring (including cranial nerves, motor and brainstem auditory evoked responses) and diffusion tractography. The latter may guide the operator regarding the spatial orientation of an affected tract and thereby influence the trajectory.

**Tips and Anatomical Hazards**
Pterional Approach

Open the lateral sulcus from lateral to medial.
Identify the chiasmatic cistern to expose the optic nerve.
Open the carotid cistern to expose the ICA.
Follow distally to identify the posterior communicating artery and anterior choroidal artery.
Identify the bifurcation and follow the anterior cerebral artery or middle cerebral artery, according to pathology.
Take care to avoid injury to the perforating vessels.
Hazards include all vessels of the anterior circulation; lenticulostriate perforators.

Transcortical Approach

Remember that functional MRI scan, awake craniotomy and cortical stimulation all aim to minimize the neurological deficit.
Hazards include eloquent cortex.

Transcallosal Approach to Third Ventricle

Avoid fixed retractors – use cottonoids or small wool balls.
Visualize the callosomarginal and pericallosal vessels.
Once in the lateral ventricle, take care to orientate using the lateral relationship of the thalamostriate vein to the choroid plexus (in the right lateral ventricle, the thalamostriate vein is to the right of the choroid plexus).
Open the taenia fornica (attachment of the choroid plexus to the fornix) on the medial aspect of the choroid plexus, to enter the roof of the third ventricle. Going through the taenia thalami (attachment of the choroid plexus to the thalamus) risks injury to the thalamostriate vein. This facilitates the opening of the choroidal fissure. The internal cerebral veins lie between the upper and lower layers of tela choroidea in the velum interpositum.
Visualize both internal cerebral veins and take a midline approach between them to avoid any injury. Terminal branches of the medial posterior choroidal artery also run in the velum interpositum.
Hazards include callosomarginal and pericallosal arteries; fornix; internal cerebral veins.

**Telovelar Approach to the Fourth Ventricle**

Perform careful lateral retraction of the tonsils.
Visualize and avoid the PICA.
Open the tela choroidea and, for more superior lesions, the translucent part of the inferior medullary velum.
Visualize the cerebellar peduncle during this process.
Understand the anatomical location of cranial nerve nuclei and tracts in relation to the floor of the fourth ventricle. If the lesion has breached the pial surface, this is the most appropriate entry zone into the brainstem. The presentation of the lesion with respect to the pia should be assessed preoperatively: for example, a T1 weighted MRI allows the most accurate assessment of a brainstem cavernous malformation.
Hazards include vermis; PICA; inferior cerebellar peduncle; structures in the floor of the fourth ventricle.
References

Single Best Answers

1. You are performing a pterional craniotomy to clip an anterior communicating artery aneurysm. You decide to follow the vascular anatomy from proximal to distal. During this procedure you open the chiasmatic and carotid cisterns. Which one of the following structures will NOT be visible?
   A. Anterior choroidal artery
   B. Anterior communicating artery
   C. Internal carotid artery
   D. Posterior communicating artery
   E. Optic nerve

   **Answer:** A.

2. You are undertaking surgery on a lesion located within the anterior part of the third ventricle. The ventricles are modestly enlarged. Which one of the following approaches is most suitable to enable resection and minimize postoperative deficit?
   A. Subtemporal approach to the temporal horn with opening of the choroidal fissure
   B. Transcallosal approach with entry into the third ventricle via the taenia choroidea
   C. Transcallosal approach with interforniceal approach into the third ventricle
   D. Transcallosal approach with unilateral division of the column of the fornix
   E. Transcortical approach via the superior parietal lobule on the non-dominant side

   **Answer:** B.
3. Which one of the following is a commissural fibre?
   A. Uncinate fasciculus
   B. Occipitofrontal fasciculus
   C. Corpus callosum
   D. Superior longitudinal fasciculus
   E. Cingulum

   **Answer: C.**

4. You are exposing the floor of the fourth ventricle by the telovelar approach. Which one of the following vessels do you expect to find as you open the tela choroidea and the inferior medullary velum?
   A. Anterior inferior cerebellar artery
   B. Vertebral artery
   C. Superior cerebellar artery
   D. Posterior inferior cerebellar artery
   E. Superior vermian vein

   **Answer: D.**

5. When entering the lateral ventricle, which one of the following strategies is most effective for confirming lateralization?
   A. Identification of the anterior choroidal artery
   B. Identification of the foramen of Monro
   C. Relation of the anterior septal vein to the choroid plexus
   D. Relation of the thalamostriate vein to the choroid plexus
   E. Visualization of the column of the fornix

   **Answer: D.**
Clinical Cases

1. A 60-year-old patient presented with a history of getting muddled and being vague. On examination she had a mental test score of 25/30. There was no evidence of papilloedema, cranial nerve deficit or limb deficit. An MRI scan showed a large intraventricular tumour with calcification (Fig. 20.9).

**FIG. 20.9** An MRI scan showed a large intraventricular tumour with calcification.

**A. What is the most likely diagnosis?**
Calcification commonly occurs in central neurocytomas. Intraventricular meningiomas can calcify; however, they are usually located in the trigone rather than in the anterior body. Colloid cysts are usually located in the third ventricle at the foramen of Monro. Choroid plexus tumours are very rare in this age group.

**B. What surgical approach would you adopt?**
This case is suitable for a transcallosal approach; a transcortical approach could be adopted as an alternative. The risk of postoperative seizures is
probably higher with a transcortical approach.

2. A 45-year-old male presented with an abrupt onset of moderate headache, dysarthria, impaired balance and diplopia. Examination revealed brainstem signs, including facial numbness, facial weakness, nystagmus, a sixth cranial nerve palsy, weak cough and cerebellar signs, including ataxia, past-pointing and dysdiadochokinesia. A similar constellation of symptoms occurred 2 years previously; the patient made a good recovery after this earlier episode. An MRI scan showed a lesion in the pons (Fig. 20.10).

![Fig. 20.10](image.png)

**A.** What is the most likely diagnosis?  
Cavernous haemangioma of the pons.
B. What operative approach would you adopt?
A midline suboccipital craniotomy or craniectomy; a telovelar approach to provide access to the floor of the fourth ventricle. Removal of the lesion is performed where the lesion breaches the pial surface of the floor of the fourth ventricle. If a brainstem incision is required, safe areas exist lateral to the midline above and below the facial colliculus.
With the increase in the application of endoscopic endonasal surgery to the skull base, it is feasible to access midline lesions in the rostrocaudal axis extending from the cribriform plate to the inferior clivus and the foramen magnum.

The principles of standard sellar approaches both endonasally and via the use of a microscope have been extensively described in the literature. In this chapter, sellar anatomy will be covered with the emphasis on introducing the anatomical principles underlying approaches to the suprasellar region. In order to provide a comprehensive open microsurgical view of this region, pertinent anatomy for performing a transbasal subfrontal approach and anterior clinoidectomy will also be covered. The primary aim is to enable familiarization with the anatomical principles underlying these approaches.
Endoscopic endonasal approaches

Endoscopic transplanum transtuberculum approach

Indication

Variations of the endoscopic transplanum transtuberculum approach are used to access pituitary tumours with suprasellar extension, tuberculum sellae or planum meningiomas, and craniopharyngiomas.

Patient positioning

The patient is positioned supine with a Mayfield head holder being used to maintain a neutral position, or with slight head rotation towards the surgeon.

Critical anatomy and operative steps

Osseous anatomy

Understanding the anatomy of the sphenoid bone is crucial for these approaches. In Fig. 21.1, moving from caudal to rostral, note the location of the sella, tuberculum, chiasmatic sulcus and limbus sphenoidale. The medial optico-carotid recess (MOCR) corresponds to the lateral aspect of the tuberculum,\(^2\) and the lateral optico-carotid recess (LOCR) represents the base of the optic strut. The chiasmatic sulcus is defined as the region from the tuberculum to the limbus sphenoidale that extends between the optic canals.\(^3\) The planum sphenoidale is defined as the region more distal to the limbus. The anterior root of the lesser wing of the sphenoid forms the roof of the optic canal (OC) while the posterior root or the optic strut forms the floor of the OC.
FIG. 21.1 Anatomy of the sphenoid bone as relevant to endonasal sellar and suprasellar approaches. The anterior root (Ant. Root) forms the roof of the optic canal (OC), while the optic strut (Op. Str.) forms the floor. The chiasmatic sulcus (Ch. Sul.) is the area between the tuberculum (Tuber.) and the limbus sphenoidale. Relevant to anterior clinoidectomy, the blue arrow represents the direction of drilling (from lateral to medial) of the anterior clinoid process (ACP) to disconnect it from the anterior root.

Operative approach

Extradural bony drilling

An endoscopic endonasal approach to the sella and tuberculum sellae region involves a wide bilateral sphenoidotomy, posterior ethmoidectomy and posterior septectomy (Fig. 21.2). The intrasphenoidal septations are thinned down using a drill. It should be noted that these septations can lead the operator off the midline to the paraclival or clinoidal internal carotid artery (ICA). Bone overlying the sella and the chiasmatic sulcus is egg-shelled using a coarse diamond 4 mm burr (Fig. 21.3). The thinned-down bone overlying the chiasmatic sulcus is gently dissected off while maintaining dural integrity. A thickened dural fold (limbus dura) overlies the limbus sphenoidale. The tuberculum strut is then carefully thinned down prior to its subsequent removal (see Fig. 21.3). The MOCR at the lateral end of this strut corresponds to the transition between the paraclinoidal and supraclinoidal
segments of the ICA (Fig. 21.4). Understanding these segments from an endonasal perspective is critical for operating safely in this region. The parasellar ICA relevant to this approach is a combination of the cavernous and paraclinoidal segments. The proximal dural ring (located at the level of the middle clinoid) marks the transition between the anterior genu of the cavernous ICA and the clinoidal segment (see Fig. 21.4). From caudal to rostral, the relevant anatomical relationships to note at this stage are the sella, diaphragm, superior intercavernous sinus, tuberculum, chiasmatic sulcus, limbus dura, and finally the dura of the planum. The next step represents further removal of bone to expose the planum dura (see Fig. 21.4). The bone overlying the OC along its medial aspect and the roof can be seen. In a standard transplanum transtuberculum approach, the limbus sphenoidale is drilled, along with further removal of the medial aspect of the anterior root of the lesser wing of the sphenoid that forms the roof of the OC (right side, see Fig. 21.4). This will usually mark the end of the bony drilling involved in such an exposure.
FIG. 21.3 Bone overlying the sella and the chiasmatic sulcus (Ch. Sul.) has been drilled, leaving the tuberculum strut (Tuberc.) intact. From caudal to rostral, note the location of the clival recess (CR); sella; super intercavernous sinus (SIS); tuberculum; chiasmatic sulcus (Ch. Sul).
Anatomy of the optic canal and its decompression for removal of tumours

Intraoperatively, it becomes progressively difficult to drill the superolateral aspects of the OC that are formed by the lateral part of the anterior root of the lesser wing of the sphenoid. A more extensive unroofing or decompression of the osseous OC (left side, see Fig. 21.4) can be carried out: this may be required, for example, when a meningioma invades the OC. Our previous published work demonstrated that such a decompression of the OC allows exposure of both the preforaminal and the intracanalicular segments of the optic nerve after cutting the dura, which facilitates tumour removal from the osseous OC. The true osseous OC with the intracanalicular segment of the ON has a circumferential bony covering. Accordingly, its boundaries are, medially, the body of the sphenoid bone; and inferiorly, the optic strut and the adjacent part of the body of the sphenoid bone; superiorly, the roof is
formed by the anterior root of the lesser wing of the sphenoid bone. Endonasally, the osseous OC approximates to the anteroposterior length of the LOCR (see Fig. 21.4). The preforaminal segment of the OC is posterior to the osseous canal (or LOCR) and is covered by the falciform ligament.

Dural opening and intradural exposure

The endonasal dural incision can be done in different ways, depending upon the pattern of invasion or potential involvement of the OC. A suggested schema which exposes both the infrachiasmatic suprasellar space, as well as cisternal, preforaminal and foraminal segments of the optic nerve (Fig. 21.5), was presented in our 2015 study. The incision starts in the upper part of the sella and continues superiorly across the superior intercavernous sinus, tuberculum dura and the chiasmatic sulcus before turning laterally across the limbus and planum dura. The dural flap is then reflected laterally to identify the origin of the ophthalmic artery. To increase the mobility, two further diaphragmatic cuts are made, with the first directed posteriorly toward the infundibulum and the second performed laterally toward the distal dural ring (or the MOCR), while being cautious about the carotid and ophthalmic arteries. This may suffice for accessing a tumour around the cisternal or preforaminal segments of the ON. The intracanalicular dura around the OC may be opened along its superior aspect from a medial to lateral direction to access a tumour. Structures visualized in the suprasellar infrachiasmatic space (after opening the dura overlying the chiasmatic sulcus, Fig. 21.6) include the superior hypophysial arteries coming off the medial aspect of the supraclinoidal ICA and supplying the undersurface of the chiasma and pituitary stalk. These should be preserved in operative approaches directed toward this region. Dura in the planum region is opened to expose the suprachiasmatic region and gyrus rectus, including the anterior cerebral artery and its branches, and the anterior communicating artery. After resection of tumours, a vascularized nasoseptal flap can be used to cover the defect.
FIG. 21.5  A potential way of opening the dura. The optic nerve (ON), traced to the chiasma, can be seen. Key: Clin. Car, clinoidal carotid artery.
FIG. 21.6 Opening of the dura over the chiasmatic sulcus and the planum exposes the structures as shown. The superior hypophyseal artery (SHA) coming off the supraclinoidal carotid artery supplies the undersurface of the chiasma and the pituitary stalk. Key: ACOM, anterior communicating artery; ON, optic nerve.

**Tips and Anatomical Hazards**

A good understanding of the relevant endonasal anatomy is essential to operate safely in this region. An understanding of the segments of the ICA in relation to endonasal landmarks, as highlighted in this chapter, is essential in order to avoid carotid injury. Careful drilling with constant irrigation is paramount in order to reduce the risk of optic nerve damage when performing optic canal decompression. Apart from potential injury to the ICA, the location of the ophthalmic artery should be kept in mind, particularly when cutting the diaphragm laterally towards the distal dural ring. A medially looping ophthalmic artery can be injured.
Perforators coming off the supraclinoidal ICA (superior hypophysial artery) and supplying the undersurface of the chiasma should be protected.
Early branches of the anterior cerebral arteries, such as the fronto-orbital arteries, may loop inferiorly and be attached to the tumour and dural surfaces.
Open microsurgical approaches
Subfrontal transbasal approach

Indication
There are many variations of the traditional midline subfrontal transcranial approach. A variety of techniques for performing a bifrontal craniotomy with or without orbital osteotomies have been described. Variations of this approach have been used to resect anterior cranial fossa meningiomas (olfactory groove, planum or tuberculum) or to access the region around the lamina terminalis, the retrosellar space and the interpeduncular cistern, in order to remove lesions such as retrochiasmatic craniopharyngiomas. In the following sections, a more contemporary ‘subfrontal transbasal approach’ utilizing the anatomy of the anterior skull base is discussed. This approach obviates the need for performing a separate orbital osteotomy and allows adequate rostrocaudal visualization from the top of the third ventricle superiorly to the interpeduncular cistern inferiorly.

Patient positioning
The head is placed in three-pin fixation and elevated 15–20° to allow venous return. The neck is extended in order to allow the frontal lobe to fall away from the anterior cranial fossa. Use of a lumbar drain may be considered.

Critical anatomy and operative steps

Incision
A bicoronal incision is made extending from one zygoma to the other (no more than 1 cm anterior to the tragus). By staying below the galea aponeurotica during the dissection, a separate vascularized pericranial flap is raised. In order to protect the frontal branch of the facial nerve, an interfascial dissection is carried out, raising the superficial layer of the deep temporal fascia with the fat pad on each side. The pericranium is raised, revealing the underlying osseous anatomy including the orbital rim and the nasion (Fig. 21.7). As the scalp is mobilized anteriorly, the nasofrontal suture should be visualized: the supraorbital nerve and artery should be protected near the supraorbital rim (see Fig. 21.7).
Craniotomy

Possible sites for placing the burr-holes are demonstrated in Fig. 21.8. The craniotomy incorporates the anterior wall of the frontal sinus. The key is to stay low with the inferior margin of the osteotomy, which is carried through the anterior wall of the frontal sinus, starting at the nasofrontal suture and extending laterally over both orbital rims. The craniotomy therefore follows the contour of the anterior skull base in the coronal plane and allows the bone flap to be as low as possible (Fig. 21.9)\(^4\); the need to perform a separate supraorbital osteotomy is eliminated. The mucosa is then removed in addition to the posterior table, which cranializes the sinus. Nasofrontal ducts (Fig. 21.10) are packed prior to the extradural exposure of the anterior cranial fossa or opening of the dura. In this anatomical example, the dura is elevated to demonstrate the cribriform plate and the posterior ethmoidal artery, which lies at the junction of the cribiform plate and the planum sphenoidale. Depending on the target lesion and goals of surgery, an extradural approach can be carried out by transecting both olfactory sulci and removing the crista galli, thus finally accessing the planum sphenoidale, limbus and chiasmatic sulcus. This extradural technique provides early devascularization of meningiomas and facilitates the removal of involved and hyperostotic skull base bone, while minimizing manipulation of intradural neurovascular structures. In selected cases, it is even possible to open the sphenoid sinus,
decompress both optic canals and perform a transclival approach.

**FIG. 21.8** A potential way of placing the burr-holes is demonstrated; other variations exist.

**FIG. 21.9** Completion of the bifrontal craniotomy. The inferior limb of the craniotomy follows the contour of the anterior skull base; frontal mucosa has been exenterated and the sinus cranialized. Nasofrontal ducts are seen bilaterally.
Dural opening and intradural exposure

Dural opening is based on the superior sagittal sinus (SSS), which can be ligated using two 2/0 silk sutures, followed by division of the falx and subsequent dissection of the olfactory tract from the basal frontal lobe. The retraction can be placed just on the right frontal lobe (Figs 21.11, 21.12) as the olfactory tract is followed back to the optic nerve and the surrounding cisterns, which are then opened to facilitate further brain relaxation. Further exposure and trajectory (for example, subfrontal versus interhemispheric) will depend on the pathology being addressed. It is important to appreciate that this trajectory can allow opening of the lamina terminalis and exposure of the anteroinferior part of the third ventricle (see Fig. 21.12) in order to remove tumours like a retrochiasmatic craniopharyngioma. Depending on the operative goals, the surgeon can now dissect towards the top of the third ventricle down to the interpeduncular cistern. At closure, the pericranial flap can be laid across the anterior cranial fossa and the cranialized frontal sinus. The pericranium can also be stitched to the frontobasal dura with multiple sutures.
FIG. 21.11 An intradural view. Olfactory tracts (Olf. Tr.) have been preserved on both sides. Usually, a right-sided frontal lobe elevation is sufficient. Bilateral anterior cerebral arteries (A2) can be seen in the anterior interhemispheric fissure. Key: ICA, internal carotid artery; St, pituitary stalk.

FIG. 21.12 The lamina terminalis has been opened to expose the anterior and inferior aspect of the third ventricle. Key: A2, segment of the anterior cerebral artery; St, pituitary stalk.
Tips and Anatomical Hazards

Extension of the head during positioning makes it easier to attain a subfrontal trajectory. Different methods are employed to cross the midline during the craniotomy. Being aware of the location of the SSS and adequately developing a plane extradurally prior to the craniotomy are important to minimize the risk of the injury.

Sinonasal mucosa should be adequately exenterated and the sinus cranialized during the procedure to prevent the future risk of infection or mucocele. Depending on the indication for this approach, caution should be exercised to prevent injury to the midline perforators arising from the anterior communicating artery (ACOM). Similarly, during removal of a tumour like a craniopharyngioma from the third ventricle, a plane should be well defined between the tumour capsule and the ependyma of the third ventricle.

Reconstruction of the skull base typically requires a pericranial flap plus fat grafts to fill up dead space.

Anterior clinoidectomy: pterional or orbitozygomatic craniotomy and anterior clinoidectomy

Indication

Skull-base and cerebrovascular neurosurgeons should aim to become proficient in this procedure, which can be performed intra- or extradurally. The indications include clipping of paraclinoidal or para-ophthalmic aneurysms; resection of medial sphenoid wing or clinoidal meningiomas; and optic canal decompression. In this section the extradural anterior clinoidectomy and related technique for accessing the lateral cavernous sinus will be described.

Positioning

The patient is positioned in the classic pterional position with three-pin
fixation. Depending on the surgeon's preference and the indication, the head can be rotated 15–30° with the malar eminence being kept uppermost in the field (this is facilitated with mild head extension).

**Critical anatomy and operative steps**

**Osseous anatomy**

The anterior clinoid process (ACP, see Fig. 21.1) is a triangular-shaped bone that overlies the proximal part of the intradural supraclinoidal ICA. It projects from the posteromedial border of the lesser wing of the sphenoid and has three attachments that are pertinent to clinoidectomy. Laterally, the ACP is continuous with the lesser wing of the sphenoid. Medially, it is connected to the sphenoid bone by an anterior root running between the limbus sphenoidale and the ACP, and a posterior root/optic strut. In order to remove the ACP, these three connections must be disrupted. Several ligaments and dural folds, including the anterior petroclinoidal and interclinoidal ligaments and the falciform fold, are attached to the ACP. The posterior surface of the optic strut is intimately related to the clinoidal segment of the ICA (bounded by the proximal and distal dural rings). Cranial nerves III, IV, VI and V₁ (Video 21.1) are located below the proximal ring and just below the optic strut as they leave the lateral wall of the cavernous sinus to enter the medial aspect of the superior orbital fissure. The ACP forms the lateral border of the OC and, as such, any drilling in this area risks injuring the optic nerve; it should be undertaken with copious irrigation. The presence of an osseous ring (between either the anterior and the middle clinoid or the anterior and the posterior clinoid) should be checked using preoperative imaging; a total extradural clinoidectomy in the presence of an osseous ring would risk injury to the ICA and should be avoided.

**Operative steps**

An anterior clinoidectomy is performed after a conventional pterional or orbitozygomatic (OZ) craniotomy has been completed. The steps involved in an anterior clinoidectomy are described and illustrated using images from cadaveric dissection⁵: in Figs 21.13–21.19, a pterional craniotomy has been completed on one side and a two-piece OZ craniotomy has been performed on the other side.
FIG. 21.13  A left-sided pterional craniotomy has been performed.

FIG. 21.14  After drilling of the lateral aspect of the sphenoid ridge, the meningo-orbital band (MOB), containing the meningo-orbital artery and marking the lateral end of the superior orbital fissure, is seen. Key: Fron, frontal dura; Temp, temporal dura.
FIG. 21.15  After division of the meningo-orbital band, temporal dura (Temp.) is peeled back to expose the inner cavernous membrane (CM.) and the full extent of the anterior clinoid process. The lesser wing of the sphenoid is drilled down further. Lateral to medial drilling along the base of the anterior clinoid process is carried out to disconnect it from the anterior root (see Fig. 21.1). Key: Fron, frontal lobe dura.

FIG. 21.16  In addition to drilling the optic strut, the anterior clinoid process is hollowed out. A little remnant of the anterior clinoid (*) is seen in addition to the clinoidal carotid artery. Key: CM, inner cavernous membrane; Fron, frontal lobe dura; ON, optic nerve; Temp, temporal lobe dura.
FIG. 21.17  The remaining portion of the anterior clinoid process has been removed. Key: Car, internal carotid artery; Fron, frontal lobe dura; ON, optic nerve; Temp, temporal lobe dura.

FIG. 21.18  Another example after completion of an orbitozygomatic craniotomy: the location of the optic strut (*) can be appreciated anterior to the clinoidal segment of the carotid artery. This segment of the carotid is in the roof of the cavernous sinus and is bounded by the proximal and distal dural rings. Key: Fron, frontal lobe dura; ON, optic nerve; Temp, temporal lobe dura.
A conventional pterional craniotomy is completed by drilling the sphenoid ridge flat until the lateral end of the superior orbital fissure, marked by the meningo-orbital band, is visualized. At this stage, this band can be coagulated and divided for up to 5 mm. The aim is to establish a plane between the dura propria (middle fossa dura) and the membrane overlying the cavernous sinus. This manoeuvre will allow proper exposure of the more medial aspects of the lesser wing of the sphenoid and the ACP. Using a subfrontal trajectory, the location of the intracranial roof of the OC is confirmed. This step can be carried out earlier if necessary. In order to disconnect the ACP, the following manoeuvres are required (see Figs 21.14–21.17): the lesser wing of the sphenoid is fully drilled down in order to unroof the superior orbital fissure; the base of the ACP is drilled from a lateral to medial direction to disconnect it from the anterior root using a 2 mm diamond burr; the connection with the optic strut is drilled out by advancing from the lateral to the inferior aspect of the optic canal with extreme caution; dense cortical bone is then centrally hollowed out. A circumferential plane should be established around the hollowed-out ACP. The remaining part of the ACP attached to the ligaments (anterior petroclinoidal and interclinoidal) is gently delivered using fine rongeurs (see Fig. 21.17). Any bleeding at this stage from the roof of the cavernous sinus can be controlled with Gelfoam. The clinoidectomy exposes the clinoidal ICA and intradurally exposes the proximal part of the supraclinoidal ICA (see Figs 21.17, 21.19). The dura is opened in a curvilinear fashion that is extended
on to the falciform ligament and distal ring if required (see Fig. 21.19). The distal ring can be cautiously approached with the bleeding from pericavernous complex controlled with thrombin.

The Dolenc technique and its variations involve division of the meningo-orbital band and subsequent sharp dissection to find the right plane between the dura propria and the membrane covering the lateral wall of the cavernous sinus. The anatomy of the cavernous sinus is demonstrated in Fig. 21.20; the accompanying caption provides further detail.

**FIG. 21.20** An anatomical view of the neurovascular structures in the cavernous sinus in the right parasellar location. Note the posterior bend/genu of the internal carotid artery (Car.) in Parkinson’s triangle (space between trochlear and ophthalmic divisions of the trigeminal nerve). Key: III, oculomotor nerve; IV, trochlear nerve; V, ophthalmic division of trigeminal nerve; VI, abducens nerve; ON, optic nerve; Temp, temporal lobe.

### Tips and Anatomical Hazards

Preoperatively, a fine-cut CT scan should be obtained to define the osseous anatomy and to check for the presence of an osseous carotico-clinoidal ring around the ICA. If an osseous ring is present, the clinoidectomy may need to be completed extra- and intradurally. Division of the meningo-orbital band is imperative for adequate
exposure of the ACP.
Copious irrigation should be used throughout to prevent thermal injury to surrounding critical neurovascular structures.
The intimate relationship between the clinoidal ICA, the optic nerve and several other cranial nerves (in particular, the oculomotor nerve) to the optic strut should be kept in mind throughout the clinoidectomy. The oculomotor nerve is vulnerable at the lateral and inferior aspects of the ACP.
Any breach of the sphenoid or ethmoid sinus should be covered with wax to prevent potential leak of cerebrospinal fluid. Preoperative CT will provide information on the extent of pneumatization of the ACP.
References


Single Best Answers

1. Which one of the following structures does the medial optico-carotid recess represent?
   A. Lateral aspect of the tuberculum
   B. Medial aspect of the tuberculum
   C. Lateral aspect of the limbus sphenoidale

   **Answer: A.**

2. Which one of the following anatomical spaces is visualized after opening of the dura over the chiasmatic sulcus?
   A. Suprasellar infrachiasmatic space
   B. Interpeduncular cistern
   C. Pre-pontine cistern

   **Answer: A.**

3. Other than the optic nerve, which one of the following cranial nerves is susceptible to injury during an anterior clinoidectomy?
   A. Maxillary division of the trigeminal nerve
   B. Mandibular division of the trigeminal nerve
   C. Oculomotor nerve

   **Answer: C.**
Clinical Cases

1. A 41-year-old female presented with a history of a known tuberculum sella meningioma that was discovered incidentally 6 years ago. Over the last two years, she has suffered with headaches and more recently developed subjective visual issues. The lesion had demonstrated growth on the surveillance MRI. MRI (Fig. 21.21) showed the presence of a suprasellar lesion with compression of the optic chiasm and involvement of the left preforaminal/cisternal segment of the optic nerve. The patient underwent endoscopic endonasal transsphenoidal transtuberculum transplanum approach for resection of this lesion. The reconstruction was carried out in a multi-layered fashion using a dural substitute and nasoseptal flap. The patient had no deficit postoperatively, with the postoperative MRI demonstrating complete resection of the tuberculum sella meningioma. Pathology was consistent with WHO grade 1 meningioma.

2. A 44-year-old right-handed female presented with a history of altered mental status and speech disturbance of uncertain duration. Neurological examination revealed profound expressive and receptive
speech disturbance. MRI (Fig. 21.22) revealed the presence of a left-sided anterior skull base lesion with significant mass effect and compression of the frontal lobe with the origin centred on the anterior clinoid. The lesion was consistent with a clinoidal meningioma. There was hyperostosis of the anterior skull base (Fig. 21.23) and multiple vascular flow voids were noted indicating the vascularity of the lesion. The patient underwent orbitozygomatic craniotomy (two-piece) and extradural anterior clinoidectomy (see Fig. 21.23) after division of the meningo-orbital band and completion of the Dolenc approach. This allowed early decompression of the optic nerve and devascularization of the tumour including those derived from the ethmoidal and the middle meningeal arteries. The hypervascular tumour was subsequently completely resected. The patient's speech improved significantly 48 hours following the surgical resection in terms of fluency and the extent of dysphasia. Pathology was consistent with WHO grade 1 meningioma.

**FIG. 21.22** Axial T1 weighted MRI (A) shows a contrast-enhancing lesion centred on the anterior clinoid consistent with clinoidal meningioma. Coronal T1 weighted MRI (B) shows the rostral extent of the lesion and compression of the frontal lobe and its extension along the temporal side.
FIG. 21.23 Preoperative CT (A) demonstrates the hyperostosis of the anterior clinoid, lesser wing of the sphenoid overlying the superior orbital fissure and the orbital roof. Postoperative CT (B) demonstrates complete unroofing of the superior orbital fissure and anterior clinoidectomy allowing decompression of the orbital apex and the optic nerve.
Cerebellopontine angle

David Bennett, William AS Taylor

Core Procedures

• Microvascular decompression of the trigeminal nerve
• Microvascular decompression of the facial nerve
• Microvascular decompression of the glossopharyngeal nerve
• Retrosigmoid approach to vestibular schwannomas and other cerebellopontine angle tumours

Surgical access to the cerebellopontine angle (CPA) requires a detailed knowledge of surface anatomy to define the boundaries of safe surgical access, and an understanding of the variation of anatomy within the three neurovascular complexes that traverse the CPA.
Surgical surface anatomy

The relationship between the cranial sutures and venous sinuses can be used in surgical planning.\textsuperscript{1} Surface relationships have been described to identify the junction of the transverse and sigmoid sinuses.\textsuperscript{1–3} A line is drawn from the root of the zygoma to the inion: this line defines the transverse sinus. A vertical line drawn from the mastoid groove to meet this line identifies the point overlying the junction between the transverse and sigmoid sinuses, as the sigmoid sinus then curves caudally (\textbf{Fig. 22.1}). A burr-hole placed just inferior and posterior to this point should expose the sinus junction safely while minimizing the risk of damage to the sinuses. The asterion corresponds to the meeting point of the lambdoid (occipitoparietal), occipitomastoid and parietomastoid sutures (Ch. 14). This craniometric point has often been used to identify the junction of the transverse and sigmoid sinuses, which is the key to this approach. However, this point may be difficult to distinguish in some adults and has a variable relationship to the sinuses.\textsuperscript{2}

\textbf{FIG. 22.1} Surface landmarks for the junction between the transverse and sigmoid sinuses (*). Abbreviations: I, inion; MG, mastoid groove; Z, zygoma.
Clinical anatomy

The standard position in which patients are placed for access to the CPA is the lateral decubitus position, with the head secured with three-point fixation, although some surgeons use supine variations. In this position, the neck is flexed and rotated approximately 10° away from the affected side. For decompression of the trigeminal nerve, the vertex is kept parallel with the floor; for an approach to the facial or lower cranial nerves, the vertex is tilted down 10–15° to improve exposure of the proximal aspect of the facial nerve. The shoulder is taped down and out of the way but care should be taken not to apply excessive force to avoid stretching and damaging the brachial plexus. These manoeuvres allow optimum positioning for surgical access.

The above landmarks are identified and a curved incision, with the concave side facing the ear, is made, one-third above and two-thirds below the junction of the transverse and sigmoid sinuses. There has been a recent trend to perform a craniotomy rather than a craniectomy to expose the dura of the posterior fossa. This is due to a perceived difference in the rate of postoperative cerebrospinal fluid (CSF) leak and morbidity; however, there may be an increased risk of damage to the sinuses. With either technique, it is essential to identify the junction of the transverse and sigmoid sinuses to allow adequate surgical exposure. However, a large exposure is not required and a 2 cm craniotomy is typically sufficient. Bleeding may be encountered from the mastoid emissary vein. It is important to note that this is a poor landmark for the sigmoid sinus due to its variable location and course. Care should be taken to wax any bleeding thoroughly from the bone, and particularly from the mastoid air cells, should they be entered. An incision is made in the dura mater and extended. The dura adjacent to the junction of the sigmoid and transverse sinuses must be clearly identified.

CSF should be drained to reduce the pressure in the posterior fossa and relax the cerebellum to help minimize retraction injury. This is best achieved by opening the arachnoid mater caudally under the microscope with the aid of gentle retraction to enter the cisterna magna. Time spent draining CSF at this juncture will be rewarded with much-improved exposure. A lumbar drain is not necessary. Opening of the cerebellopontine and cerebellomedullary cisterns enables identification of neurovascular structures.

Once CSF drainage has been undertaken, the superolateral angle of the posterior fossa can now be entered. It is essential for the angle between the
tentorium and the dura overlying the petrous temporal bone to be visualized (Fig. 22.2). A retractor is first placed horizontally over the cortical surface to identify the junction before gradually being positioned more vertically with the aid of the microscope to achieve deeper exposure. Bridging veins may be present and care should be taken. Placing a retractor at the angle or more superiorly, and slowly moving more laterally rather than directly retracting laterally reduces the risk of injury to the facial and vestibulocochlear nerve complex, which is very susceptible to retraction injury.

![The dural angle of the tentorium (T) and petrous temporal bone with crossing superior petrosal veins (SPV). Other abbreviations: C, cerebellum; PT, dura overlying the petrous temporal bone; SS, sigmoid sinus; TN, trigeminal nerve; TS, transverse sinus. (Courtesy, The Rhoton Collection; http://rhoton.ineurodb.org)](image)

The superior petrosal venous complex is usually encountered (see Fig. 22.2). This is the main draining vein of the anterolateral posterior fossa structures. Care should be taken not to place this vein under tension, as avulsion from the superior petrosal sinus may result. It may be necessary to sacrifice this vein to gain adequate exposure, particularly of the trigeminal nerve and the superior cerebellar artery. Venous infarction is a rare occurrence. Once adequate retraction has been achieved, the facial and vestibulocochlear nerves are usually seen first, with the trigeminal nerve located anteriorly and rostrally.

It is important to recognize the relationships of the cranial nerves to the arteries in the cerebellopontine region. These will be considered in three
neurovascular complexes. The superior neurovascular complex is related to the superior cerebellar artery (SCA) and the trigeminal nerve. The middle neurovascular complex is related to the anterior inferior cerebellar artery (AICA) and the facial and vestibulocochlear nerves. The inferior neurovascular complex is related to the posterior inferior cerebellar artery (PICA) and the glossopharyngeal, vagus, spinal accessory and hypoglossal nerves.

Each is associated with a separate neurovascular compression syndrome, which can be treated by microvascular decompression. The most common of these is trigeminal neuralgia, followed by hemifacial spasm and glossopharyngeal neuralgia.

**Superior neurovascular complex**

The relevant structures associated with the superior neurovascular complex are the SCA, pons, oculomotor, trochlear and trigeminal nerves, and superior petrosal veins. The oculomotor and trochlear nerves pass superiorly to the SCA and the trigeminal nerve passes inferiorly as the SCA passes around the midbrain to the cerebellomesencephalic fissure, where it runs on the superior cerebellar peduncle to supply the tentorial surface of the cerebellum finally.

Surgical procedures that directly involve the superior neurovascular complex include microvascular decompression of the trigeminal nerve for trigeminal neuralgia.

The oculomotor nerve originates from the anterior aspect of the midbrain. It passes anteriorly, below the posterior cerebral artery and above the SCA, to enter the cavernous sinus, where it lies in the lateral wall. The trochlear nerve is the only cranial nerve to arise from the posterior aspect of the midbrain. It advances anteriorly and inferiorly before passing into the lateral wall of the cavernous sinus adjacent to the posterior clinoid process, where it runs with the oculomotor nerve.

The trigeminal nerve emerges from the brainstem about halfway between the upper and lower borders of the lateral pons, just inferior and medial to the ala of the cerebellum, and runs obliquely upwards towards the petrous apex to enter Meckel's cave. The trigeminal root entry zone is the first 1 cm of the nerve after it has emerged from the lateral pons and it is this area that can be most commonly compressed by the SCA, causing trigeminal neuralgia\(^8\) (Fig. 22.3). It is important to note that the motor component of the
trigeminal nerve courses medial to the sensory root, crosses under the Gasserian ganglion and exits through the foramen ovale. The SCA forms a close relationship to the nerve and care should be taken to avoid injury.
FIG. 22.3  Intraoperative photographs showing microvascular decompression of the trigeminal nerve (TN). A, The neurovascular conflict between the superior cerebellar
The main trunk of the SCA passes above the trigeminal nerve, frequently dividing into rostral and caudal branches. It is these branches that can loop caudally and encounter the trigeminal nerve, usually on its superior or superomedial aspect.\cite{3,9,10} There may be several branches involved, and identifying each branch and ensuring its separation from the trigeminal nerve is essential for successful treatment (see Fig. 22.3). Rarely, the AICA may compress the trigeminal nerve if it loops superiorly before passing inferiorly to travel with the facial and vestibulocochlear nerves. It is also possible, but rare, for more than one artery to be involved.

There is debate as to the relevance of venous compression of the trigeminal nerve as a cause of trigeminal neuralgia.\cite{11} The superior petrosal veins can be formed from the union of several veins and the anatomy is very variable. Several tributaries may lie adjacent to or in contact with the trigeminal nerve, the most common being the veins draining the lateral cerebellar hemisphere, middle cerebellar peduncle and cerebellopontine fissure, and the transverse pontine and pontotrigeminal veins. The transverse pontine veins are the most frequent veins to compress the trigeminal nerve\cite{11}: they usually converge to form a single trunk before entering the superior petrosal sinus. This is also variable, and compression of the trigeminal nerve from a leash of veins in this region can occur.

**Middle neurovascular complex**

The relevant structures associated with the middle neurovascular complex are the AICA, pons, middle cerebellar peduncle, petrosal surface of the cerebellum, cerebellopontine fissure, and the abducens, facial and vestibulocochlear nerves. The AICA arises from the basilar artery at the level of the pons and passes around the pons near the lateral end of the pontomedullary sulcus. It travels near the abducens, facial and vestibulocochlear nerves to reach the surface of the middle cerebellar peduncle. It then passes along the cerebellopontine fissure and supplies the petrosal surface of the cerebellum, where it terminates.

Surgical procedures that will directly involve the middle neurovascular complex include microvascular decompression of the facial nerve for
hemifacial spasm, and excision of vestibular schwannomas and other cerebellopontine angle tumours.

The abducens nerve arises from the pons at the pontomedullary junction medial to the facial nerve. It passes superiorly and anteriorly to run in Dorello's canal to enter the cavernous sinus. Several landmarks help guide the surgeon in localizing the origin of the facial nerve on the brainstem. These include the pontomedullary sulcus, from which it arises at the lateral margin; the choroid plexus of the foramen of Luschka; and the flocculus, which lies just below (Fig. 22.4). The junction of the glossopharyngeal, vagus and spinal accessory nerves with the medulla can be used. A line is drawn along the origin of these nerves and projected superiorly; the facial nerve will enter the brainstem 2–3 mm above, at the intersection with the lateral end of the pontomedullary sulcus. The facial nerve runs medial to the vestibulocochlear nerve and may be concealed from the surgeon during the retrosigmoid approach to the cerebellopontine angle.

![Figure 22.4](http://rhoton.ineurodb.org)

**FIG. 22.4** The middle neurovascular complex showing the location of the facial (VII) and vestibulocochlear (VIII) nerves and their relationship with the anterior inferior cerebellar artery (AICA). Other abbreviations: CP, choroid plexus; F, flocculus; IAC, partial removal of bone exposing the internal auditory canal. (Courtesy, The Rhoton Collection; [http://rhoton.ineurodb.org](http://rhoton.ineurodb.org))

The vestibulocochlear nerve arises from the brainstem caudally and lateral to the facial nerve. Both nerves traverse to the porus acusticus and enter the
internal auditory canal (IAC; internal auditory meatus, IAM) (see Fig. 22.4). There are five nerves at the IAC: the cochlear and the superior and inferior vestibular nerves, which are branches of the vestibulocochlear nerve, and the facial nerve accompanied by the nervus intermedius (nerve of Wrisberg). The transverse crest divides the IAC into superior and inferior compartments. Within the inferior compartment are the cochlear nerve and inferior vestibular nerves, with the cochlear nerve lying anteriorly. The facial nerve and nervus intermedius and the superior vestibular nerve lie within the superior compartment, with the facial nerve anterior and separated from the superior vestibular nerve by a vertical crest of bone known as Bill's bar.

The most common place for the facial nerve to be displaced by a vestibular schwannoma is anteriorly and superiorly, which reflects the normal anatomical relationship of these nerves at the IAC. Displacement by other tumours, such as meningiomas and epidermoid cysts, is determined by their origin and growth pattern, so identifying the location of these nerves in such cases can be challenging.

In most cases, the AICA travels below the facial and vestibulocochlear nerves; however, it may occasionally pass above or between these nerves (see Fig. 22.4). If this loop abuts the facial nerve at the brainstem, this may result in hemifacial spasm. In some cases, the PICA may loop superiorly under the facial and vestibulocochlear nerves before passing inferiorly. The subarcuate, labyrinthine, recurrent perforating and internal auditory arteries arise from the AICA near the facial and vestibulocochlear nerves. The subarcuate artery may need to be sacrificed if entering the IAC but it ends blindly in bone. Care should be taken to preserve other branches. It is possible for the AICA to loop through the porus acusticus into the IAC and therefore care should be taken when opening the IAC via any approach.

The veins in the middle neurovascular complex have a close relationship to the facial and vestibulocochlear nerves. The veins of the middle cerebral peduncle and pontomedullary sulcus, the lateral medullary vein, and the veins of the cerebellopontine and cerebellomedullary fissures all pass near the lateral recess of the fourth ventricle and the origin of the facial and vestibulocochlear nerves on the brainstem.

Inferior neurovascular complex

The relevant structures associated with the inferior neurovascular complex are the PICA, medulla, inferior cerebellar peduncle, cerebellomedullary
fissure, suboccipital surface of the cerebellum, and the glossopharyngeal, vagus, spinal accessory and hypoglossal nerves. The PICA originates at the level of the medulla, then travels in proximity to the glossopharyngeal, vagus, spinal accessory and hypoglossal nerves to the surface of the inferior cerebellar peduncle. It then passes along the cerebellomedullary fissure to supply the suboccipital surface of the cerebellum, where it terminates.

Surgical procedures that directly involve the inferior neurovascular complex include microvascular decompression of the glossopharyngeal nerve for glossopharyngeal neuralgia and, less commonly now, surgical clipping of PICA aneurysms.

The glossopharyngeal, vagus, spinal accessory and hypoglossal nerves arise from the medulla at the level of the olive (Fig. 22.5). The glossopharyngeal, vagus and spinal accessory nerves arise as a series of rootlets in the postolivary sulcus. The glossopharyngeal and vagus nerves exit along the posterior edge of the superior third of the olive. The spinal accessory nerve rootlets exit along the posterior edge of the inferior two-thirds of the olive, the lower medulla and the upper cervical cord segments. They exit the cranium through the jugular foramen along with the glossopharyngeal and vagus nerves. The spinal accessory nerve is often the most useful to aid localization. This is due to it being identifiable by its many rootlets, which are often more clearly visualized passing to the jugular foramen. The hypoglossal nerve arises as a series of rootlets in the preolivary sulcus, exiting along the anterior two-thirds of the anterior olive before passing anteriorly to the hypoglossal canal.
The foramen of Luschka is situated at the lateral margin of the pontomedullary sulcus. This can be identified by an area of choroid plexus that lies just rostral to the junction of the glossopharyngeal and vagus nerves with the brainstem, and immediately inferior to the junction of the facial and vestibulocochlear nerves with the brainstem. The flocculus is another useful structure to help localize this region. It projects into the cerebellopontine angle from the foramen of Luschka and lateral recess, just posterior to where the facial and vestibulocochlear nerves join the pontomedullary sulcus.

The PICA has a very variable and complex relationship with the nerves of the inferior neurovascular complex. It passes around or between the rootlets of the hypoglossal nerve and passes dorsally somewhere between the...
rootlets of the glossopharyngeal, vagus or spinal accessory nerves. It may make larger loops superiorly or inferiorly, or pass in several loops. The vertebral artery usually passes anterior to the nerves in the inferior neurovascular complex. If the vertebral artery is tortuous, it may cause pressure on nerves passing close to it and the PICA. The origins of both the glossopharyngeal and the vagus nerves on the brainstem have been found to be compressed by the PICA or the vertebral artery in cases of glossopharyngeal neuralgia. Occasionally, both arteries have been implicated.

The inferior petrosal veins are often intermixed with the rootlets of the vagus and spinal accessory nerves. Care should be taken not to stretch these veins and risk causing venous bleeding in this region, as the use of cottonoids and bipolar cautery risks damaging nerve rootlets.

### Tips and Anatomical Hazards

Ensure that the craniotomy and dural opening identify the junction of the transverse and sigmoid sinuses.
Release CSF from the cisterna magna early after dural opening.
Release CSF from the CPA and cerebellomedullary cisterns to facilitate exposure of neurovascular structures.
Identify the angle between the tentorium and the dura overlying the petrous temporal bone.
Remember that the choroid plexus of the foramen of Luschka and the flocculus can aid localization of both the facial and glossopharyngeal nerves.
The asterion may not be easily visible and is therefore not a reliable landmark in the elderly.
The mastoid emissary vein is not a reliable landmark for the sigmoid sinus due to its variable location and course.
There may be a small vein in the region of the cisterna magna that may be injured if the cerebellum is excessively retracted or the arachnoid is blindly incised.
Retraction injury to the facial–vestibulocochlear complex should be avoided.
Other diagnoses should be considered prior to surgical intervention for
neurovascular compression syndromes, such as tumours or multiple sclerosis.
References


Single Best Answers

1. Which one of the following is the most reliable landmark in a surgical approach to the trigeminal nerve for locating the junction of the transverse and sigmoid sinuses?

A. A line that is a vertical extension of the mastoid groove meeting a line between the root of the zygoma and the inion
B. A point halfway between the inion and the root of the zygoma
C. A point one-third of the distance between the tip of the mastoid process and the inion
D. The asterion
E. The mastoid emissary vein

**Answer: A.** There are several variations in anatomy, particularly in adults, as regards the location of the asterion and the mastoid emissary vein. The asterion is sometimes difficult to identify; however, it can overlie the transverse–sigmoid sinus junction and can be a useful confirmation if it corresponds to the surface landmark located using the root of the zygoma, the inion and the mastoid groove.

2. Which one of the following is the most accurate anatomical description of the location of the facial nerve on the brainstem?

A. It arises at the medial margin of the pontomedullary sulcus
B. It lies below the choroid plexus of the foramen of Luschka
C. It lies just above the flocculus
D. It lies lateral to the vestibulocochlear nerve
E. It sits on a line formed by the glossopharyngeal, vagus and hypoglossal nerves

**Answer: C.** The facial nerve arises at the lateral margin of the pontomedullary sulcus, above the choroid plexus at the foramen
of Luschka. It is on a line formed by the glossopharyngeal, vagus and spinal accessory nerves rather than the hypoglossal nerve, which lies more anteriorly. It lies medial to the vestibulocochlear nerve. In vestibular schwannoma surgery, when anatomy in this region is inevitably distorted, visualization of the choroid plexus can help identify the facial and vestibulocochlear nerve origin; when a facial nerve monitor or stimulator is being used, the nerve can be identified anterior and medial to the tumour and vestibulocochlear nerve.

3. Which one of the following vascular structures is most likely to be the cause of trigeminal neuralgia?

A. Anterior inferior cerebellar artery
B. Posterior inferior cerebellar artery
C. Superior cerebellar artery
D. Superior petrosal venous complex
E. Transverse pontine vein

**Answer:** C. The superior cerebellar artery has the closest anatomical relationship to the trigeminal nerve and is the vessel most commonly responsible for trigeminal neuralgia. Less frequently, a superior loop of the anterior inferior cerebellar artery can compress the nerve and cause symptoms. Trigeminal neuralgia has been described secondary to a posterior inferior cerebellar artery arising from a congenitally persistent trigeminal artery. Venous structures can be anatomically close and appear to compress the nerve, with the transverse pontine vein being most consistent in its relationship to the nerve and the superior petrosal venous complex being more variable; it is uncertain, however, whether they can cause neuralgia, which is more consistently thought to be secondary to arterial compression.

4. Which one of the following is the most accurate description of the location of the facial nerve in the internal auditory canal
(meatus)?
A. Above the falciform crest and directly above the inferior vestibular nerve
B. Anterior to Bill's bar and above the falciform crest
C. Below Bill's bar and anterior to the inferior vestibular nerve
D. Below the falciform crest and anterior to Bill's bar
E. Posterior to the nervus intermedius and anterior to Bill's bar

**Answer: B.** The internal auditory canal (meatus) is a circular structure that has bony anatomical features dividing it into three sections. The falciform crest divides it into superior and inferior halves, and Bill's bar divides the upper half into an anterior and posterior compartment. In the posterior compartment is the superior vestibular nerve and directly below this is the inferior vestibular nerve. Also in the inferior half, anterior to the inferior vestibular nerve, is the cochlear nerve. In the anterior superior compartment, the facial nerve lies anterior and superior to the nervus intermedius. This relationship is important to bear in mind when approaching the internal auditory canal in acoustic neuroma surgery because the facial nerve is often stretched and attenuated, and is on the far side of the tumour from the surgical approach.
Clinical Case

1. A 63-year-old male presents with a 1-year history of intractable hemifacial spasm. He has previously had stereotactic radiotherapy for an acoustic neuroma and serial enhanced images of his posterior fossa are shown in Fig. 22.6. A decision is made to drain the cyst and perform a subtotal resection of the tumour.

A. Describe how you would position this patient and plan your approach, referring to anatomical structures.

The patient would be positioned in either a lateral or a park bench position; though it is less commonly used now, the sitting position could also be employed. The incision would be planned to overlie the junction of the transverse and sigmoid sinuses with the incision one-third above and two-thirds below this point. The surface landmarks for this would be a point on a line from the inion to the root of the zygoma, which is traversed by a line that is a vertical extension of the mastoid groove.

B. Where would you make the craniotomy?

The optimum position would be 1–2 cm below the sigmoid–transverse junction to approach the facial–vestibulocochlear complex. A burr-hole could
therefore be made below the sinus junction to avoid risk of direct injury, and a small craniotomy then made with a high-speed drill to gain access to the dura.

C. Once the dura has been opened, how would you gain access to the tumour and identify the relevant cranial nerves?

In a case like this, the posterior fossa pressure is likely to be high and the key early manoeuvre is to release cerebrospinal fluid. This is best done by gently introducing a retractor over the cerebellar surface in an inferior and lateral trajectory towards the cerebellar tonsils and cisterna magna. Sometimes the cerebrospinal fluid is released by traction alone, but often the arachnoid needs to be opened using a microdissector or sharp hook. Once this is done, the spinal accessory nerve is a reliable landmark. On superior dissection, the tumour can then be identified; in this case, it is likely to be cystic. The tumour surface can be checked with the facial nerve stimulator, but the facial nerve is likely to be on the deep aspect of the tumour since it arises from the internal auditory canal in the anterior superior quadrant and remains anterior to the vestibular nerve in its course. The tumour can then be entered and cyst fluid released. A plane between the brain and tumour capsule can be developed with dissection anteriorly to identify the choroid plexus at the foramen of Luschka, facilitating identification of the facial–vestibulocochlear nerve complex. Once the facial nerve is identified and confirmed with the stimulator, it can be followed with microdissection accompanied by progressive tumour resection. Later in the procedure, the trigeminal nerve often becomes visible in the superior aspect of the surgical field.
Core Procedures

- Far-lateral approach and transcondylar extension
- Endoscopic endonasal approach to the inferior clivus and foramen magnum
Surgical surface anatomy

The C1 transverse process can often be palpated adjacent to the mastoid process; it acts as a reliable landmark for C1 and the location of the vertebral artery during muscular dissection.
Clinical anatomy

Multiple approaches are directed at the foramen magnum (FM) and inferior clivus from both ventral and dorsal directions.\textsuperscript{1–4} An appreciation of locoregional osseous, muscular and neurovascular anatomy is instrumental in performing these approaches safely. Among posteriorly directed approaches, a simple midline posterior suboccipital approach to the foramen magnum has been well described and is commonly used for FM decompression, e.g. for Chiari malformation. The surgically relevant anatomy for performing a far lateral craniotomy and its transcondylar extension, as well as the anatomical principles surrounding a ventral endoscopic endonasal approach to the anterior FM, are discussed here. Other approaches to this region are outside the scope of this chapter.
Surgical approaches and considerations

Far-lateral approach: basic and transcondylar extension

**Indications**
In its basic form, the far-lateral approach includes a suboccipital craniotomy and C1 hemi- or complete laminectomy without removal of parts of the occipital condyle, thereby providing access to lesions located along the posterior aspect of the FM, e.g. a meningioma. This approach can then be tailored to perform either a transcondylar exposure, in which removal of the posterior part of the occipital condyle improves access to the lower clivus and the area anterior to the medulla oblongata, or a supracondylar transtubercular exposure, involving drilling of the hypoglossal canal followed by the jugular tubercle. The latter exposure provides improved access to the anterior aspect of the brainstem and visualization of the origin of the posterior inferior cerebellar artery (PICA) from the vertebral artery (e.g. as may be necessary for clipping a PICA aneurysm). A third variation is a paracondylar exposure (without drilling of the occipital condyle), which provides access to the posterior part of the jugular foramen and can be combined with a transmastoid approach.

**Patient positioning**
A modified park bench or three-quarter prone position can be used.

**Key operative steps and anatomical details**

**Skin incision**
An inverted U-shaped or horseshoe incision may be made (Fig. 23.1). Both the medial and the lateral limb can be extended inferiorly in order to perform the cervical laminectomy (C1,2) and to visualize the C1 transverse process (including its muscle attachments). The inion marks the midline; the transverse–sigmoid junction should be marked out using landmarks including the mastoid tip, the auricle (pinna) and the zygomatic arch. The superior extent of the incision should extend above the inion. Important palpable landmarks include the mastoid tip, inion and C1 transverse process.
Osseous anatomy

The extent of bony removal during a basic far-lateral craniotomy (solid line on Fig. 23.2) varies according to the access required. The jugular process of the occipital bone (the site of attachment of rectus capitis lateralis) is drilled in the ‘paracondylar’ approach to access the jugular bulb and the jugular foramen (elliptical area). The portion of the occipital condyle drilled in a ‘transcondylar’ approach without risking occipitocervical instability or breaching the hypoglossal canal is also shown (dashed line, as an extension of the solid craniotomy line). The probe on Fig. 23.3 demonstrates the anterolateral direction of the hypoglossal canal. While the posterior third of the condyle is being drilled, the lateral aspect of the intracranial end of the hypoglossal canal will be reached, followed by drilling of the posterolateral aspect of the condyle without breaching the canal. Other surrounding structures of note are also shown on the figures, including the stylomastoid foramen, styloid process and carotid canal. The jugular tubercle is a bony prominence above the hypoglossal canal; it constitutes a shelf on which the
lower cranial nerves sit on their way from the brainstem to the jugular foramen. The jugular tubercle is drilled in the ‘supracondylar transtubercular’ approach, subsequent to drilling of the hypoglossal canal, and will not be discussed in detail here. The inferior petrosal sinus drains into the anterior compartment of the jugular foramen, with the sigmoid sinus draining into its posterior part and the lower cranial nerves lying in between.

FIG. 23.2 The solid line represents the extent of bony removal during a basic far-lateral craniotomy. The elliptical area represents the jugular process of the occipital bone (the site of attachment of rectus capitis lateralis) drilled in the ‘paracondylar’ approach to access the jugular bulb and the jugular foramen. The dashed extension of the solid line represents the portion of the occipital condyle (OC) drilled in a transcondylar approach. The stylomastoid foramen is indicated by a solid arrow; the styloid process is indicated by a dashed arrow. Other abbreviations: CC, carotid canal; DG, digastic groove; JF, jugular foramen; Mas tip, tip of mastoid process.
FIG. 23.3 The probe demonstrates the anterolateral direction of the hypoglossal canal. Note the relationship to surrounding structures, including the stylomastoid foramen (solid arrow), styloid process (dashed arrow) and carotid canal (CC). Other abbreviations: DG, digastric groove; JF, jugular foramen, Lacerum, foramen lacerum; Mas tip, mastoid; OC, occipital condyle.

**Muscle stage**

Intraoperative exposure of the individual muscle layers is not necessary. Usually, the superficial muscles can be detached together from the superior nuchal line in order to demonstrate the suboccipital triangle (Fig. 23.4). The extracranial muscles can be described in three layers, with the most superficial layer involving trapezius, splenius capitis and sternocleidomastoid. The second layer of muscles comprises semispinalis capitis and longissimus capitis. The occipital artery may lie superficial or deep to longissimus capitis. Reflection of the second layer of muscles demonstrates the suboccipital triangle (see Fig. 23.4), defined by superior oblique, inferior oblique (with attachments to the transverse process of C1) and rectus capitis posterior major, with the posterior atlanto-occipital membrane making up its floor. Key contents of the triangle include the vertebral artery ($V_3$ segment, defined as running from the foramen transversarium of C2 to the dural entry of the artery), the C1 dorsal nerve root inferior to the artery, and the vertebral venous plexus encasing these structures. The muscular branch of the vertebral artery and the vertebral venous plexus are susceptible to injury in the suboccipital triangle. Superior
oblique is reflected laterally, while preserving the attachment of rectus capitis lateralis to C1 in order to expose the venous plexus further. Rectus capitis posterior minor is usually seen deep to rectus capitis posterior major and dissected off inferomedially. The venous plexus is then controlled. Inferior retraction of inferior oblique (Fig. 23.5) demonstrates the vertebral artery running along the J-groove in the posterior arch of the atlas and passing medial to the atlanto-occipital joint prior to piercing the dura. It is noteworthy that the occipital condyle is lateral to the anterior half of the FM. The posterior meningeal artery typically arises extradurally from the suboccipital part of the vertebral artery and enters the cranium through the FM.

*FIG. 23.4* The suboccipital triangle (dashed line). A muscular branch of the vertebral artery is seen to emerge from the triangle. Abbreviations: IO, inferior oblique; OA, occipital artery; Rec Cap Post Maj, rectus capitis posterior major; SO, superior oblique.
Craniotomy and extradural drilling

The asterion, inion, occipital condyle and atlanto-occipital joint are identified and the posterior atlas defined by laterally reflecting superior oblique. The suboccipital craniotomy for a standard far-lateral approach can extend up to the asterion and laterally to the edge of the sigmoid sinus (Fig. 23.6). The posterior condylar vein, connecting the vertebral venous plexus and the sigmoid sinus, is another landmark for completion of the basic far-lateral exposure, which should also include either partial or total removal of the posterior arch of C1 (not demonstrated in Fig. 23.6). In order to demonstrate the locoregional anatomy further, the hypoglossal canal is exposed above the posterior part of the condyle, along with the dural entry point of the vertebral artery medial to the atlanto-occipital joint (dashed line in Fig. 23.7): the joint line is preserved. Initial drilling of bone within and above the posterior third of the condyle exposes the cancellous bone, which then gives way to the cortical bone surrounding the hypoglossal canal, containing the venous plexus, hypoglossal nerve and meningeal branch of the ascending pharyngeal artery. This step can be performed as part of the supracondylar transtubercular approach, prior to drilling the jugular tubercle, which is
superior and anterior to the hypoglossal canal. The tubercle can then be removed extradurally in order to enhance visualization of the area anterior to the lower cranial nerves, including the medulla, the origin of the PICA and the pontomedullary junction. Drilling of the tubercle should be undertaken with caution, to avoid directly injuring or causing thermal injury to the lower cranial nerves that course above. Rectus capitis lateralis, attached to the jugular process of the occipital bone, is an important landmark for the paracondylar exposure. The relationship between the lateral mass of C1, the condyle, the hypoglossal canal and the drilled jugular tubercle can be appreciated in Fig. 23.8.

FIG. 23.6 A suboccipital craniotomy for a standard far-lateral approach. The posterior condylar (emissary) vein (PCV) is a landmark for completion of this approach. Other abbreviations: C1L, C1 lateral mass; OC, occipital condyle; SS, sigmoid sinus; T-S junc, transverse–sigmoid junction; VA, vertebral artery.
FIG. 23.7  Exposure of the hypoglossal canal (HC) above the drilled condyle, together with the dural entry point of the vertebral artery (VA) medial to the atlanto-occipital joint (dashed line). Other abbreviations: C1L, C1 lateral mass.

FIG. 23.8  The supracondylar transtubercular approach: endoscopic view. The hypoglossal canal (HC) is seen and the drilled jugular tubercle (JT) visualized above the canal. The drilled part of the occipital condyle (OC) is also seen. Other abbreviations: C1L, C1 lateral mass; Rec Cap Lat, rectus capitis lateralis.
Opening of the dura and intradural anatomy

The dura may be opened in a J-shape from the transverse–sigmoid junction, extending inferomedially towards the FM, posterior to the dural entry point of the vertebral artery (while leaving a cuff of dura around the vertebral artery). The cervical dura is opened linearly in a paramedian fashion down to the lamina of C2. Bleeding may occur from a large circular sinus around the FM. The regional anatomy in the cerebellopontine angle is demonstrated in an endoscopic intradural view after completion of the far-lateral supracondylar transtubercular exposure (Fig. 23.9): the widened exposure in the area anterior to the lower cranial nerves can be appreciated, and the PICA can be seen coursing through the rootlets of the hypoglossal and accessory nerves.

**FIG. 23.9** An intra- and extradural endoscopic view. After drilling of the jugular tubercle, the anatomy of the cerebellopontine angle, including exposure across the lower cranial nerves, can be seen. Abbreviations: FL, flocculus; HC, hypoglossal canal; OC, occipital condyle; PICA, posterior inferior cerebellar artery; VA, vertebral artery; VII, facial nerve; VIII, vestibulocochlear nerve; IX, glossohypoglossal nerve; X, vagus nerve; XI, accessory nerve; XII, hypoglossal nerve.

Key anatomical knowledge

In the far-lateral approach, perhaps more so than in other neurosurgical approaches, there must be an understanding of the anatomy of the muscular stage of the dissection. At this stage, the following are important:
• location of the occipital artery between the first and the second layers of the superficial muscles and its relationship to longissimus capitis, particularly if its preservation is needed for a cerebrovascular bypass procedure
• identification of the suboccipital triangle, with its boundaries and contents, including the vertebral artery and its muscular branch
• reflection of the muscles in the correct orientation (if utilizing the approach described here) while avoiding formation of a significant muscle bulk hindering the operative exposure
• an appreciation of the muscles attached to the transverse process of C1.

Dependent on the pathology and its location, a decision is made regarding the type of far-lateral approach and the extent of bony removal required. The following are then important:

• outlining and identifying the asterion, inion, mastoid tip, transverse process of C1, posterior arch of the atlas, occipital condyle and the atlanto-occipital joint prior to performing the craniotomy
• an understanding of the orientation of the hypoglossal canal and its relationship to the jugular tubercle and occipital condyle for both the transcondylar and supracondylar transtubercular exposures.
Most operative exposures require a basic far-lateral approach with potential extension to a transcondylar exposure to permit adequate lateral reflection of the dura. While the dura is being opened, the location of the vertebral artery medial to the atlanto-occipital joint and, in general, the course of its V1 segment in relation to the foramen transversarium and the posterior arch of C1 should be kept in mind. Levator scapulae acts as a further guide for the vertebral artery, which lies medial to its upper attachment.

**Ventral endoscopic endonasal approach**

The transoral route has previously been described for approaching the FM ventrally. Increasingly, the endoscopic endonasal approach for FM lesions is used, providing a direct route, and minimizing the need for neurovascular manipulation to approach lesions in the region of the FM and inferior clivus, e.g. meningiomas and chordomas. The key anatomical principles are presented here to aid understanding.

**Key operative steps and anatomical details**

Endonasally, the FM region is approached rostrocaudally. The initial important step includes flattening of the midline maxillary crest overlying the hard palate, followed by removal of fascial and muscle layers to expose the inferior clivus. This provides a bony exposure inferior to the floor of the sphenoid sinus and superior to the anterior arch of C1 (Figs 23.10 and 23.11). Superolaterally, the exposure extends to the lower aspect of the foramen lacerum, while the inferolateral exposure includes the occipital condyles and atlanto-occipital joints bilaterally. The inferior part of the clivus is then drilled endonasally to expose the tectorial membrane and the clival dura. At this stage the endonasal corridor can be widened laterally by performing a medial condylectomy analogous to performing a posteromedially directed condylectomy in the far-lateral transcondylar approach (Fig. 23.12). The cortical bone of the hypoglossal canal divides the lateral bony exposure into the condylar and jugular tubercular compartments, located inferiorly and superiorly to the canal, respectively (see Fig. 23.12). Further manoeuvres to increase the exposure rostrocaudally include drilling the superior aspect of the anterior arch of C1 and the odontoid tip. The dural opening at this level will typically expose the premedullary cistern, the V₄ segment of the vertebral artery, the anterior spinal artery and the PICA, which travels
posteromedially through the rootlets of the hypoglossal nerve toward the cerebellomedullary fissure. The hypoglossal nerve, originating from the preolivary sulcus, lies posterior to the vertebral artery, while the C1 rootlets are anterior. These relationships are important to bear in mind for safe navigation around these regions.

**FIG. 23.10** Ventral endoscopic endonasal anatomy of the inferior clivus (Inf. Cliv.). The base of the sphenoid sinus (Sph. Sin.) is seen. The anterior vertebral group of muscles (longus capitis and rectus capitis anterior) and the median pharyngeal raphe are attached to the bony inferior third of the clivus. Other abbreviations: ET, Eustachian tube.
FIG. 23.11  Ventral endoscopic endonasal anatomy. The bony inferior clivus (Inf. Cliv.) is seen together with the anterior arch of C1 and the top of the odontoid peg (Od. Peg).

FIG. 23.12  Ventral endoscopic endonasal anatomy (intra- and extradural view) after dural opening and completion of ventral medial condylectomy. Note the relationship of C1 rootlets and the hypoglossal nerve (XI) to the vertebral artery (VA). Other abbreviations: ASA, anterior spinal artery; BA, basilar artery; OC, occipital condyle; HC, hypoglossal canal; IPS, inferior petrosal sinus.
Tips and Anatomical Hazards

Identification of the suboccipital triangle, correct reflection of the muscles and exposure of the hemilamina in a medial to lateral direction until the transverse process of C1 is palpated will all help minimize the risk of injury to the vertebral artery. Since the patient is placed in a park bench position or one of its variations, there is a risk of disorientation with respect to the ‘true’ midline, which should be checked by using the inion and by identifying the spinal midline during dissection. The muscular branch of the vertebral artery can cause significant bleeding, if injured.

In a transcondylar approach, the posterior third of the condyle can be removed without breaching the hypoglossal canal. Excessive condylar resection may breach the hypoglossal canal and lead to occipitocervical instability, necessitating occipitocervical fusion. Extradural drilling of the jugular tubercle in a supracondylar transtubercular approach (not commonly utilized) should be done with caution, due to the risk of injury to the lower cranial nerves.
References


Single Best Answers

1. Which of the following are the names of the critical vessel contained within the suboccipital triangle and the muscles forming this triangle?
   A. Vertebral artery/Superior oblique, inferior oblique and rectus capitis lateralis major
   B. Occipital artery/Superior oblique, inferior oblique and rectus capitis lateralis minor
   C. Occipital artery/Sternocleidomastoid, splenius capitis and trapezius

   **Answer: A.** Vertebral artery is the key vascular structure in the suboccipital triangle, which is prone to injury during approaches like far-lateral directed to this region. The suboccipital triangle also contains the vertebral venous plexus and the muscular branch coming off the vertebral artery. Rarely the posterior inferior cerebellar artery can arise extradurally from the vertebral artery.

2. Which one of the following describes the relationship of the dural entry point of the vertebral artery in relation to the occipital condyle–C1 joint?
   A. Medial
   B. Lateral
   C. Superior
   D. Inferior

   **Answer: A.** See Figs 23.5 and 23.7, which demonstrate this important relationship.

3. Which one of the following describes the relationship of vertebral artery to the lower cranial nerves?
A. Anterior
B. Posterior

**Answer: A.**

4. In a ventral endoscopic exposure, which one of the following describes the relationship of the C1 rootlets and the hypoglossal nerve to the vertebral artery?

A. C1 (anterior) and hypoglossal nerve (posterior)
B. C1 (posterior) and hypoglossal nerve (anterior)

**Answer: A.**
Clinical Case

1. A 36-year-old right-handed female patient presented with a history of worsening neck pain. Imaging had revealed the presence of a lesion consistent with foramen magnum meningioma. On surveillance MRI this demonstrated growth and led to medullary compression (Fig. 23.13). She underwent a far lateral craniectomy and C1 hemilaminectomy using a modified oblique incision. Postoperatively she woke up neurologically intact, however in the setting of hypotension and potential vasospasm developed significant left-sided hemiparesis. This responded to medically induced hypertension such that her neurological examination two weeks post resection of the lesion had improved to grade 4 in the left lower limb with the exception of grade 2 strength in dorsiflexion. The pathology was consistent with WHO grade 1 meningioma.

**FIG. 23.13** Preoperative sagittal T1 weighted MR (A) with contrast shows the presence of a contrast-enhancing lesion with a dural tail consistent with a foramen magnum meningioma. The lesion is causing compression of the medulla and the craniocervical junction. Postoperative corresponding sagittal T1 weighted MR (B) with contrast shows resection of the foramen magnum meningioma achieved via a far lateral craniectomy and C1 hemilaminectomy.
An understanding of the three-dimensional anatomy of the ventricular system of the brain is critical to the safe and effective practice of neurosurgery. An appreciation of the embryological development aids in comprehension of their neural and vascular relationships, and a sound three-dimensional grip on these relationships underpins the surgical approaches to lesions in the ventricles themselves. This chapter summarizes those relationships and the relevant surgical approaches.

Management of hydrocephalus, one of the most common and pervasive disorders dealt with in neurosurgical practice (whether it is a ‘primary’ congenital problem or secondary to a neoplastic, infective, traumatic or cerebrovascular cause), requires familiarity with both the anatomical configuration and the physiological functioning of these cerebrospinal fluid (CSF)-filled spaces. In addition, many surgical approaches to intracranial lesions (such as tumours or vascular malformations) utilize the ventricular cavities to afford access and to reduce the amount of cerebral tissue that is transgressed. Recent advances in equipment and expertise in neuroendoscopy mean that neurosurgeons frequently enter the ventricular system with endoscopic instruments and therefore need to be familiar with intraventricular landmarks to orientate themselves and carry out procedures.
Clinical anatomy

General considerations of ventricular anatomy

The ventricles are interconnected fluid-filled cavities within the brain. They are lined with ependyma, an epithelium consisting of specialized glial cells connected by tight intercellular junctions and with ciliated and non-ciliated regions. The ependymal layer forms the brain–CSF barrier; the cilia beat in a polarized manner to facilitate the flow of CSF through the ventricles. Macroscopically ependyma has a distinctive shiny white appearance: its intraoperative recognition can be of great help to the neurosurgeon. In health, the ventricular system contains CSF and choroid plexus. In neurosurgical disease, it may also contain haemorrhage, pus or tumour, all of which can distort the normal anatomy and result in localized CSF entrapment or generalized hydrocephalus. CSF is an acellular, colourless fluid that circulates both internally and externally in relation to the brain and spinal cord. Many functions have been postulated for CSF. Physical roles include acting as a ‘shock absorber’ and in modulating changes in intracranial pressure during physiological activities such as straining and coughing. Biochemical roles include transport of brain metabolites and involvement in acid–base balance. The choroid plexus is a frond-like villous structure in the lateral, third and fourth ventricles (choroid is from Ancient Greek, meaning ‘membrane surrounding the fetus’). Traditionally, it has been thought of as the point of production of CSF, while absorption occurs at the arachnoid villi. However, more recent conceptions of CSF circulation and physiology are that CSF absorption and resorption, in addition to the ‘classical’ model, also occur throughout the central nervous system (CNS) in a complex manner. Resection, or more commonly cauterization, of the choroid plexus can reduce CSF production significantly and has recently had something of a resurgence in neurosurgical practice, reflecting increasing evidence that it can be an effective treatment for hydrocephalus in selected cases when combined with endoscopic third ventriculostomy.

Embryologically, the CNS may be described as a tubular structure around an ependyma-lined lumen that, in some areas of the developing brain, undergoes significant dilation to form the ventricular cavities. Each ventricle is associated with a different vesicle of the developing brain: the lateral with the telencephalon (the developing cerebral hemispheres); the third with the diencephalon; and the fourth with the rhombencephalon (pons, medulla
oblongata and cerebellum) (Fig. 24.1). This embryological concept underpins understanding of the anatomical relationships of the ventricles to their surrounding neural structures in the mature brain.5

The lateral ventricles drain into the third ventricle via the paired foramina of Monro; the third ventricle drains into the fourth via the cerebral aqueduct (of Sylvius; embryologically, the lumen of the mesencephalon); and the fourth ventricle drains into the subarachnoid space and cisterns via the foramina of Magendie and Luschka, and into the central canal of the spinal cord via the obex. These interconnecting foramina and aqueducts are of much smaller calibre than the ventricular cavities and are frequently the location of obstruction caused by neurosurgical pathologies, either intraluminal blockage due to haemorrhage or infective debris, or extrinsic compression due to neoplasia.
Lateral ventricles

The paired lateral ventricles are often described as ‘C’-shaped cavities curving around the thalamus and basal ganglia, in the centre of each cerebral hemisphere. By convention, they are divided into five regions: body, atrium (sometimes called the trigone) and three horns named according to the lobe of the cerebral hemisphere into which they extend (frontal, temporal and occipital) (Fig. 24.2). All of these regions have defined medial and lateral walls, a floor and a roof; the frontal and temporal horns also have defined anterior walls.\(^5\)–\(^7\)

![Fig. 24.2 The ventricular system. A, An anterior view. B, A left lateral view. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 18.1.)](image)

**Frontal horn**

The frontal (anterior) horn is defined as that portion of the lateral ventricle anterior to the foramen of Monro and is continuous posteriorly with the body of the lateral ventricle. In coronal cross-section the frontal horn has the vague shape of a right-angled triangle, with its acute angles pointing laterally and inferiorly (Fig. 24.3). Its medial wall is the septum pellucidum, a double-layered membrane named for its translucent appearance, which separates the two lateral ventricles through the greater part of their anterior-posterior length. Its lateral wall is formed of the head of the caudate nucleus, while the
overarching genu of the corpus callosum forms its roof and anterior wall. Its slit-like floor is formed by the rostrum of the corpus callosum. There is no choroid plexus within the frontal horn: if no choroid can be seen on entering the ventricle with a neuroendoscope, it suggests that the instrument is pointed anteriorly into the frontal horn.

**FIG. 24.3** The frontal horn of the left lateral ventricle: a T1-weighted coronal MRI image. Abbreviations: CC, corpus callosum (body); HoC, head of caudate nucleus; R, rostrum of corpus callosum; SP, septum pellucidum.

**Body**

The body of the lateral ventricle lies predominantly in the parietal lobe. It is continuous anteriorly with the frontal horn and posteriorly with the atrium, and extends from the foramen of Monro anteriorly to the limit of the septum pellucidum posteriorly (at which point the fornix fuses with the corpus callosum). Its lateral wall consists of the caudate nucleus. The caudothalamic groove (striothalamic sulcus) contains the stria terminalis and thalamostriate vein; it lies inferiorly, dividing the caudate from the thalamus, which forms the floor. The medial wall is formed in its upper portion by the continuation of the septum pellucidum and in its lower portion by the body of the fornix. Its roof is formed by the body of the corpus callosum (Fig. 24.4). The body contains choroid plexus: identifying the plexus can aid the neurosurgeon
intraoperatively because following it anteriorly will reliably lead to the foramen of Monro.

**Atrium (trigone)**

The atrium (trigone) of the lateral ventricle has three communications: anterosuperiorly (above the thalamus) into the body, anteroinferiorly (below the thalamus) into the temporal horn, and posteriorly into the occipital horn. The medial wall of the atrium is made of two structures: superiorly the bulb of the corpus callosum and inferiorly the calcar avis (which overlies the calcarine sulcus). Its lateral wall consists of the caudate nucleus anteriorly and the tapetum of the corpus callosum posteriorly. The roof is formed by the corpus callosum (body, splenium and tapetum). The floor is the collateral trigone, which overlies the collateral sulcus (**Fig. 24.5**). The atrium usually contains the most voluminous choroid plexus in the brain, referred to as the choroid glomus (glomus choroidea). This may contain benign, incidental choroid cysts, and often becomes calcified with age, which can aid identification on computed tomography.
Temporal horn

The temporal horn, sometimes called the inferior horn, is the anteroinferior continuation of the atrium under the pulvinar of the thalamus into the temporal lobe. It forms a blind-ending sac terminating anteriorly about 2.5 cm from the temporal pole and bounded by a wall formed of the amygdaloid nucleus (Fig. 24.6). It is bounded medially by the choroidal fissure and laterally by the tapetum, which also forms the lateral component of the roof of the temporal horn. The medial roof consists of the inferior thalamus, caudate tail and intervening caudothalamic groove. The floor is made up of the hippocampus medially and the collateral eminence (overlying the collateral sulcus) laterally. The temporal horn contains choroid plexus, which, along with the pearly white appearance of the ependyma, can aid intraoperative identification.
Occipital horn

The occipital (posterior) horn is a small, variably sized continuation of the atrium posteriorly into the occipital lobe, the anterior border of which also defines the anterior border of the horn itself. It has a roughly triangular shape (Fig. 24.7). Its medial wall is the bulb of the corpus callosum (superiorly) and the calcar avis; its lateral wall is the tapetum; its roof is also formed by the tapetum as it courses superiorly; and its floor is the collateral trigone.
Third ventricle

The third ventricle is a complex space that has important relationships with surrounding neural, glandular, venous and arterial structures. These relationships, along with its deep location within the diencephalon, make surgical approaches to this space particularly challenging. In the normal, undilated state, the third ventricle is a rather narrow, cleft-like midline structure that communicates with the lateral ventricles superiorly via the foramina of Monro and with the fourth ventricle inferiorly via the cerebral aqueduct. It has a floor, roof and lateral, anterior and posterior walls (Fig. 24.8).
Floor

The floor of the third ventricle is bounded anteriorly by the optic chiasma and posteriorly by the opening of the cerebral aqueduct in the mesencephalon. From anterior to posterior, it is composed of a number of important structures: namely, the optic chiasma, infundibulum, tuber cinereum, mamillary bodies, posterior perforated substance and mesencephalon. It exhibits several recesses associated with these structures, including the chiasmal recess into the angle formed by the attachment of the chiasma to the anterior wall, and the infundibular recess into the infundibulum. Bulging or rounding out of these recesses is an early indicator of hydrocephalus: as this disease progresses, the whole floor (which is rather thin) can become depressed inferiorly\(^8\) (Fig. 24.9).
FIG. 24.9 A T1-weighted sagittal MRI scan showing distension of the third ventricle in hydrocephalus. Note the dilation and rounding of the recesses, which have acute angles in the healthy state.

Surgically, the region of the floor between the hypothalamus and the tuber cinereum is important because it is a thin, almost avascular, membrane that can be perforated to achieve a third ventriculostomy; this is an important treatment for hydrocephalus caused by obstruction at the level of the cerebral aqueduct. Identification of this region and an understanding of the relationship to surrounding structures are critical to safe operation and are explained in a separate section later in this chapter.

**Roof**

The roof curves in a convex manner from the foramina of Monro back to the suprapineal recess, which forms the posterior boundary. The most superior layer of the roof is formed by the fornix; the tela choroidea and associated blood vessels form the inferior layers. The tela choroidea are two thin layers of pia mater, sandwiching the medial posterior choroidal arteries and the internal cerebral veins in a space called the velum interpositum. The septum pellucidum attaches to the upper, fornical, layer.

**Anterior wall**

The anterior wall is defined by the foramen of Monro superiorly, where it borders the roof, and the optic chiasma inferiorly, where it meets the floor.
From the foramen of Monro down, the anterior wall is composed of the anterior commissure, lamina terminalis, optic recess and, at its lowest point, the chiasma. The lamina terminalis is a thin, mostly avascular, membrane devoid of neural tissue; it is therefore often used as a point to form a third ventriculostomy for the relief of hydrocephalus, and more commonly in open cranial approaches such as clipping of an anterior circulation aneurysm.\textsuperscript{9,10}

**Posterior wall**

The posterior wall begins superiorly at the suprapineal recess and courses inferiorly to meet the mesencephalic opening of the cerebral aqueduct inferiorly. From superior to inferior, it is formed by the suprapineal recess, commissure of the habenula, body of the pineal and its associated recess, posterior commissure and the mesencephalic opening of the aqueduct. Like the recesses found in the floor of the third ventricle, the suprapineal and pineal recesses have a high compliance and their distension occurs early in hydrocephalus.\textsuperscript{8}

**Lateral walls**

The lateral walls of the third ventricle are entirely composed of diencephalic neural tissue: namely, the thalamus and hypothalamus. The superior section of the lateral wall is formed by the anterior part of the ovoid thalamus, while the inferior section consists of the hypothalamus. The hypothalamic sulcus is an inconstant and shallow sulcus dividing the two diencephalic structures and running diagonally from the foramen of Monro anterosuperiorly to the opening of the aqueduct posteroinferiorly. The massa intermedia (interthalamic adhesion) is a band of grey matter that projects between the thalami. Its normal size varies: it may be absent in up to 25% of individuals\textsuperscript{6} and may be duplicated.\textsuperscript{11} The presence of a large massa intermedia, which is often seen in children with open neural tube defects, can obstruct endoscopic surgery in the third ventricle and requires assessment on preoperative imaging\textsuperscript{12} (Fig. 24.10).
Fourth ventricle

The aqueduct of Sylvius is a narrow tubular structure running through the midbrain to open into the fourth ventricle, which is the most inferior ventricle of the brain. The fourth ventricle is an unpaired midline structure found between the dorsal aspect of the brainstem and the cerebellum. It has a vaguely pyramidal shape, often described as ‘tent-like’, and consists of a floor, roof and paired lateral recesses (Fig. 24.11). The floor is diamond-shaped: hence its common name of the rhomboid fossa (Fig. 24.12). All four ‘points’ or tips of the diamond communicate with other CSF spaces. The superior tip of the diamond is formed by the opening of the aqueduct; the inferior tip is sited at the obex (the opening of the central canal of the spinal cord); and the lateral ‘tips’ extend into the lateral recesses and then, via the paired foramina of Luschka, into the basal CSF cisterns. The diamond is divided into two lateral halves by the median sulcus. On each side, the sulcus limitans is lateral to the median sulcus, and paired rounded bands (medial eminences) run between the median sulcus and the sulcus limitans. The
The upper part of the medial eminence contains the facial colliculus, an elevation raised by the facial nerve as it arches backwards around the nucleus of the abducens nerve. The lower part has a ‘pen-nib’ appearance consisting of three triangles: the hypoglossal triangle (overlying the nucleus of the hypoglossal nerve), vagal triangle (overlying the dorsal vagal nucleus) and area postrema. The vestibular area overlying the vestibular nuclei is lateral to the medial eminence. The striae medullares, containing cochlear fibres, run transversely across the caudal–cranial midpoint of the diamond. Injury to any of these structures – for example, during surgery for a posterior fossa tumour – can lead to cranial neuropathies with significant clinical sequelae.

**FIG. 24.11** The third and fourth ventricles, sagittal hemisection of the brain. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 18.10.)
The roof of the fourth ventricle begins as a narrow sheet in the region of the opening of the aqueduct and extends laterally and posteriorly to its widest point at the lateral recesses, before narrowing again down to a point at the obex. The cranial half of the roof is made up of the superior cerebellar peduncles and their interconnecting superior medullary velum, a thin neural sheet. The caudal half consists of the ependymal (and non-neural) inferior medullary velum with a layer of tela choroidea. The absence of any neural tissue in the lower half of the roof forms the basis for the telovelar approach to the fourth ventricle (described below). An opening in this part of the roof communicates with the cisterna magna and is called the foramen of Magendie: this is one of the routes by which CSF exits the fourth ventricle (the other routes being via the foramen of Luschka and the obex).
Surgical approaches and considerations

Lateral ventricle

The lateral ventricle is a large structure with segments within each of the lobes of the cerebrum; consequently, the surgical approach will depend on the location of a lesion.

Ventricular catheter insertion

One of the most basic and essential skills of a neurosurgeon is cannulation of the lateral ventricle, most commonly to relieve acute or chronic hydrocephalus, but also to monitor intracranial pressure, to sample CSF or to inject intrathecal agents. An understanding of both the surface landmarks and the three-dimensional anatomy of the ventricular system is essential to achieve safe and accurate cannulation. Increasingly, neurosurgeons use technology such as computerized image guidance and ultrasound but these remain adjuncts to, not replacements for, good anatomical knowledge.

A large number of eponymous ‘points’ for ventricular access have been described. The most commonly used remains the so-called ‘Kocher’s point’. The entry point (the position of the burr-hole) is 1–2 cm anterior to the coronal suture in the right mid-pupillary line. The catheter tip trajectory is aimed at a point where an imaginary sagittal line from the ipsilateral medial canthus intersects an imaginary coronal line from the ipsilateral tragus of the ear (Fig. 24.13). A catheter thus passed should end at the ipsilateral foramen of Monro at a depth of 5–7 cm from the surface. This point and trajectory avoid eloquent cortical and important vascular structures, and are commonly used for emergency external ventricular drainage and intracranial pressure recording. Other commonly used points of entry include the ‘Frazier’, or occipital burr-hole, and the parietal burr-hole used for posterior shunt insertion.
Anterior transcallosal approach

The anterior transcallosal approach is suitable for tumours located in the anterior portion of the lateral ventricle: that is, the frontal horn and body.\textsuperscript{6,15,16} It can also be used to access the third ventricle (see below). The main advantage of the transcallosal approach is avoidance of incising the
cerebral cortex, reducing the risk of postoperative seizures or cortical deficit.\textsuperscript{17} It also has the advantage of being feasible in the setting of normal-sized or even small ventricles and allows access to both lateral ventricles. Potential disadvantages include potential injury to falcine ‘bridging’ veins during the approach and a relatively narrow working corridor, which makes access to tumours that extend laterally into the ventricle difficult.\textsuperscript{15} Disconnection-type syndromes are extremely rare in anterior callosotomy.

The patient is positioned supine, without rotation of the neck, and the head elevated. Most commonly, a ‘box’ scalp flap is fashioned, although bicoronal and curvilinear incisions can be used. Image guidance is often useful to plan the trajectory accurately and to help avoid bridging veins. A free bone flap is turned, crossing the midline but biased to the preferred (usually the right for midline lesions) side, with two-thirds anterior and one-third posterior to the coronal suture. The dura is opened in a ‘C’ fashion, based on the sagittal sinus medially, taking care not to incise the sinus or bridging veins. As in all intracranial approaches, it is wise to spend some time allowing CSF egress to allow the brain to ‘relax’ after dural opening. The ipsilateral hemisphere is gently retracted laterally to allow progress inferiorly along the falx. Bridging veins between the sinus and hemisphere may be encountered and efforts should be made to preserve these if possible, although one may occasionally be ligated and divided if impeding the approach. Some arachnoid is usually encountered and is gently dissected until the pericallosal arteries (branches of the anterior cerebral arteries) are visualized. A plane is fashioned between the paired arteries and the shiny white corpus callosum is divided in the midline – an opening of 20 mm is usually sufficient – until the ventricle is entered. If the foramen of Monro is not immediately identified, it can be located by tracing the choroid plexus and thalamostriate vein anteriorly because they converge at the foramen. Absence of choroid plexus on opening the ventricle suggests that the frontal horn has been entered and the foramen will be visualized by angling the trajectory posteriorly (\textbf{Fig. 24.14}).
The anterior transcortical approach allows approach to lesions with lateral extension that would be inaccessible using the transcallosal approach. The disadvantage, as mentioned above, is disruption of the frontal cortex with the concurrent risk of seizure or even neurological deficit. The transcortical approach is much easier in a patient with dilated ventricles (such as obstructive hydrocephalus) because it reduces the amount of brain dissection necessary. The patient is again positioned in the supine position, this time with the head rotated slightly away from the side of the approach (selection of laterality being based on the greatest lateral extension of the tumour). Image guidance is useful to plan the exact location of the scalp incision, bone flap and trajectory of approach. Intraoperative ultrasound is also useful to locate the ventricle after bone flap removal in order to optimize the trajectory and reduce the white matter dissection needed to reach the ependymal layer. These adjuncts will allow tailoring of the exact approach to each lesion, but in general a scalp incision and bone flap are fashioned to
allow access over the region of the middle frontal gyrus, this being a relatively safe and non-eloquent area to perform corticotomy. The corticotomy is made and the ventricle is opened; a Dandy brain cannula or ventricular catheter is often used to identify the correct trajectory (by obtaining CSF) and then a channel is gradually widened around the tract to allow access. Once the ependymal lining is visualized, the same intraventricular landmarks as described for the transcallosal approach above can be used to orientate the surgeon. If access to the contralateral ventricle is required, the septum pellucidum can be opened. Because the ventricle is widely opened in this approach, the possibility of postoperative CSF leak is high, and care must be taken to achieve watertight dural closure, good bone fixation and meticulous scalp closure to avoid this potentially serious complication.

**Approaches to the atrium**

Approaches to the atrium of the lateral ventricle present particular challenges because of its close relationships with eloquent cortex and tracts (such the optic radiation) and vascular anatomy, particularly the deep venous system of the brain and the choroidal arteries. Described angles of approach include lateral, posterior and anterior.

Lateral approaches can be divided into transtemporal and subtemporal routes. The transtemporal approach requires a temporal scalp flap, based around the auricle (pinna), with a posterior temporal free bone flap taken to the floor of the middle fossa. A corticotomy is made in the posterior middle or inferior temporal gyrus to allow access to the temporal horn and atrium. While this approach allows access to lesions extending from the atrium into the temporal horn, it carries a risk of injury to the optic radiations. In addition, this approach is unsuitable for lesions in the dominant hemisphere because of the potential of injury to speech areas. The subtemporal route has the potential advantage of avoiding the optic radiations and speech areas. The scalp and bone opening is similar to the transtemporal approach, but then the temporal lobe is gently retracted superiorly to allow a corticotomy in the inferior surface of the lobe: for example, into the collateral sulcus. A potential risk of this route is retraction injury to the temporal lobe: care must be taken to minimize the amount of retraction used, and to avoid injury or obstruction of bridging and cortical veins.

Posterior routes to the atrium can be subdivided into posterior transcallosal, posterior transcortical and occipital approaches. The posterior
transcallosal approach involves positioning the patient in the prone position, with the head slightly rotated to bring the parietal eminence most superior. A ‘box’ or curvilinear scalp flap is raised to permit a parieto-occipital craniotomy. The dura is opened in a ‘C’ fashion, based medially on the sagittal sinus. Dissection proceeds by dividing the arachnoid along the falx until the distal branches of the anterior cerebral arteries are visualized. The next step is identification of the internal cerebral veins, pineal gland and pearly white splenium of the corpus callosum. The posterior part of the body of the corpus callosum is opened in the midline to allow access to the atrium. This approach is suited to lesions in the superior part of the atrium or those that arise from, or extend into, the splenium. One potential advantage of this route is the absence of a corticotomy, which means that the risk of seizure and neurological deficit is reduced. Conversely, posterior callosotomy can cause disconnection syndromes, such as alexia without agraphia.

The posterior transcortical approach begins with positioning the patient either supine (with rotation of the head) or lateral, to present the parietal boss most superiorly. Image guidance is useful in planning the scalp incision and parietal free bone flap. After durotomy, the surface of the parietal lobe is exposed. Corticotomy is made behind the postcentral sulcus on the superior parietal lobule, taking care to avoid the junction of the parietal and temporal lobes in order to reduce potential injury to speech or vision. The risks can be further reduced using advanced imaging techniques or awake craniotomy to ‘map’ eloquent areas pre- or intraoperatively and so define a ‘safe zone’ for cortical entry. The posterior transcortical route is preferred for exposing those lesions within the posterior part of the body and the atrium of the lateral ventricle, and also allows access to the glomus of the choroid plexus. Like the anterior transcortical approach, it is facilitated by dilated ventricles. Pineal region lesions are not well exposed by this route. With an appropriate corticotomy, one potential advantage of approaching from a superior entry point is avoidance of the visual and speech areas. However, a significant disadvantage is that the arterial supply of lesions (derived from the deeply located choroidal vessels) is encountered last because these vessels are deep to the approach. This is particularly relevant in approaching vascular tumours commonly encountered in this region, such as a choroid plexus papilloma. Endovascular techniques may be employed preoperatively to embolize the pedicle and reduce intraoperative blood loss.

The occipital approach is used for those atrial lesions that extend into the pineal region or medial occipital lobe. The patient is positioned prone. The
head may be rotated (30° or so) to bring the side of the approach most dependent, allowing gravity to help with the retraction of the ipsilateral occipital lobe. An occipital ‘box’ flap and craniotomy is fashioned, with exposure of the edge or all of the posterior part of the superior sagittal sinus, to allow a durotomy flap based medially on the sinus. The occipital lobe is gently retracted and a corticotomy is made anterior to the parieto-occipital sulcus to allow access to the medial wall of the atrium behind the choroidal fissure. This approach has the advantage of potentially wide access to the atrium and early identification of the choroidal vessels. Conversely, retraction injury to the occipital lobe can cause significant visual morbidity.

The atrium of the lateral ventricle can be approached anteriorly via the Sylvian fissure. The patient is positioned for a temporal craniotomy (supine, head rotated with the malar eminence superior) and a temporal ‘question mark’ scalp flap is raised. A free bone flap and durotomy are fashioned to provide wide exposure of the Sylvian fissure and the frontal, temporal and parietal lobes. The fissure is then opened and the surgeon proceeds posteriorly, being careful to preserve the vascular structures therein. The transverse gyrus of Heschl is identified on the superior aspect of the temporal lobe: tracing this gyrus medially identifies the posterior insula, which affords entry to the atrium if divided longitudinally. This approach can offer wide exposure, particularly for small lesions situated in the atrium, but risks damaging visual and auditory projections.

**Third ventricle**

Its deep location and exquisite vascular and neural relationships make approaches to the third ventricle among the most challenging in neurosurgery. A good understanding of the three-dimensional anatomy is key to safe microsurgery in this area. Increasingly, surgical technology, such as image guidance, intraoperative scanning, robotics and neuroendoscopy, is helping neurosurgeons achieve safer and more effective surgeries in this critical anatomical location.

**Subfrontal trans-lamina terminalis approach**

The subfrontal trans-lamina terminalis approach utilizes the thin nature of the lamina terminalis to expose lesions such as craniopharyngiomas in the anteroinferior portion of the third ventricle. The patient is positioned supine, with the face pointing directly upwards. A biconoral scalp flap is
fashioned to expose the frontal bones. Craniotomy may be bifrontal or unifrontal, depending on the size and laterality of the lesion, but aims to expose at least the edge of the superior sagittal sinus to allow adequate dural reflection. Care must be taken either to avoid the frontal air sinus or to plan for its cranialization or obliteration to prevent CSF fistula formation. Usually, the dura can be opened on one side, based on the edge of the sinus. For large lesions, the dura can be opened bilaterally and the anterior end of the sinus ligated, divided and lifted to allow a wide corridor of access. This is an interhemispheric approach, with gradual retraction of the medial frontal lobe combined with arachnoid dissection. The trajectory is directed between the rostrum of the corpus callosum superiorly and the anterior communicating artery complex inferiorly; the lamina terminalis is encountered between these landmarks and can be opened longitudinally in the midline to expose the third ventricle.

**Transcallosoal interforniceal approach**

The transcallosoal interforniceal approach to the third ventricle proceeds in an identical fashion to the transcallosoal approach to the lateral ventricle described previously, up until the callosotomy. To continue safely into the third (rather than the lateral) ventricle, it is now best to stay strictly in the midline, with the aim of remaining between the two leaves of the septum pellucidum, separating and protecting both fornices. The trajectory should aim between the two foramina of Monro: the roof of the third ventricle can be safely opened over 15–20 mm at this point because the choroid plexus of the third ventricle and the internal cerebral veins are positioned more posteriorly in the roof. This route allows good access to lesions of the anterior floor such as hypothalamic hamartomas.

**Transcallosoal transchoroidal fissure approach**

The transcallosoal transchoroidal approach may be superior to the interforniceal approach for those lesions situated more posteriorly within the third ventricle (but still anterior to the aqueduct: that is, not pineal region lesions), especially those supplied by the posterior choroidal arteries. There is some evidence that the working corridor exposed is greater than that obtained with the interforniceal approach; however, there is a greater risk of fornical and deep venous injury.

Again, the initial steps of this operation are identical to the transcallosoal
approach described previously. Following callosotomy, the lateral ventricle is entered on the ipsilateral side. The choroidal fissure is dissected from the posterior aspect of the foramen of Monro towards the glomus and opened to 10–15 mm in length. The fornix is pushed to the contralateral side and the tela choroidea of the roof of the third ventricle is opened to allow access to the third ventricle. The taenia fornicis is opened (as opposed to the taenia thalami), reflecting the lower risk to deep veins and the thalamic perforators.\textsuperscript{6,24}

**Infratentorial supracerebellar approach**

Lesions in the hindmost part of the third ventricle, posterior to the aqueduct, are considered pineal region lesions and a separate chapter of this book (Ch. 28) is dedicated to their anatomy and approach. Anterior approaches, as described above, are almost never indicated for pineal lesions because of inadequate exposure and risks to vascular and neural structures.

In brief, the infratentorial supracerebellar approach is a posterior route utilizing the space between the underside of the tentorium and the superior aspect of the cerebellum to reach the pineal gland and associated structures. It can be performed with the patient positioned prone but many surgeons prefer the sitting position, as gravity will add gentle inferior retraction of the cerebellum. A suboccipital craniotomy or craniectomy is fashioned, with a standard posterior fossa ‘Y’-shaped durotomy with the upper leaflet based on the transverse sinuses above. The approach proceeds over the upper surface of the cerebellum, with dissection of the arachnoid to expose the pineal gland. Occasionally, cerebellar veins need to be divided to allow access, although care must be taken not to injure the deep venous system. This approach allows good access to the posterior part of the third ventricle (\textbf{Fig. 24.15}). A full description is located in \textit{Chapter 28}. 
Endoscopic approaches

Advances in neuroendoscopy, such as flexible and angled scopes and endoscopic ultrasonic aspirators, have resulted in increased use of this technology for surgery around the third ventricle. As well as third ventriculostomy for CSF diversion in hydrocephalus, it is now feasible to biopsy and even resect intraventricular lesions using endoscopes.

Endoscopic third ventriculostomy (ETV) is a workhorse neurosurgical procedure for hydrocephalus.\textsuperscript{25,26} It has the potential advantage of avoiding the lifelong need for implanted hardware, with the associated complications, of a ventriculoperitoneal shunt. The patient is positioned supine with the head slightly flexed. As with most intracranial procedures, image guidance can be useful to plan the trajectory. A linear or miniflap incision is placed in the right frontal region to allow a burr-hole placed on the coronal suture in the mid-pupillary line (that is, slightly posterior to the classic ‘Kocher's point’). A dural incision is made and the pial surface coagulated and opened. The endoscope may be advanced directly, although many surgeons prefer a ‘peel-away’ catheter to act as a sheath so that the endoscope can be inserted and removed multiple times from the ventricle without causing injury. The trajectory is aimed at a point where an imaginary sagittal line from the ipsilateral medial canthus intersects an imaginary coronal line from the
ipsilateral tragus (image guidance or intraoperative ultrasound may be used). Once CSF is encountered, the ‘peel away’ is opened and secured, and the endoscope (either rigid or flexible) is then passed into the ventricle. The first step is identification of the landmarks of the lateral ventricle. The tip of the endoscope is then advanced into the foramen of Monro, taking care not to injure the columns of the fornix, and the landmarks of the floor of the third ventricle are identified (Fig. 24.16). If an ETV is required, the thin floor between the tuber cinereum and the mammillary bodies is penetrated and the stoma is enlarged until good CSF flow is visualized. With a flexible scope, the anterior and posterior portions of the third ventricle can be visualized.
FIG. 24.16  Endoscopic anatomy: the lateral ventricle and third ventricular floor. A, The view on entering the lateral ventricle. The foramen of Monro (FOM) is bounded anteriorly by the fornix and care must be taken not to injure this structure. The thalamostriate vein (TS vein) lies on the floor of the ventricle. The choroid plexus can be seen medially entering the foramen. B, On passing through the foramen, the translucent third ventricular floor can be identified between the infundibular recess (In. Rec.) of the pituitary anteriorly and the paired mammillary bodies (MB) posteriorly. The deep red of the basilar artery (BA) can be seen in the posterior section of the floor and must be avoided when fashioning a ventriculostomy across the floor.

Fourth ventricle

Tumours in the fourth ventricle are common neurosurgical problems,
especially in paediatric practice. The traditional approach is to split the vermis in the midline, a route that allows excellent access to the superior part of the fourth ventricle, but at the cost of possible cerebellar mutism and a restricted view of the lateral recesses. More recently, interest has grown in the telovelar approach, which has the advantage of avoiding any division of neural tissue by utilizing natural clefts in the anatomy of the cerebellum. It has the advantage of better exposure of the lateral recesses and foramina of Luschka, and fewer cerebellar complications such as mutism and ataxia. However, tumours with a deep rostral attachment may be more difficult to access in this approach.

**Transvermian approach**

In the transvermian approach, the patient is positioned either prone or sitting. The sitting position has the potential advantage of better visualization and blood/CSF drainage, and anaesthetic complications such as venous air embolism are rare. However, fear of these complications has meant that the prone position is now more commonly used in mainstream neurosurgical practice.

In either position, the head is slightly flexed to ‘open up’ the region of the foramen magnum. A midline incision from inion to the spinous process of C2 is made, and the suboccipital muscles are mobilized in a subperiosteal fashion to expose the occiput, atlanto-occipital membrane, and posterior arch of C1. Burr-holes are placed to allow a suboccipital craniotomy (which is preferred to craniectomy, at least in paediatric practice, due to a better postoperative complication profile). The posterior arch of C1 is also often removed to allow better exposure of the cerebellar tonsils and lower part of the medulla. The dura is then opened in a ‘Y’-shaped fashion, with the superior leaflet based on the transverse sinuses superiorly (Fig. 24.17). The cisterna magna is now opened, and patient CSF egress is permitted to ‘relax’ the brain to allow easier dissection.
FIG. 24.17 The initial approach to the fourth ventricle. A, A straight skin incision is made between the inion of the occiput and the spinous process of C2 (axis). Muscle is stripped from the occiput and C1, and retractors are inserted. B, A suboccipital craniotomy is fashioned, from just below the transverse sinuses to the foramen magnum. A C1 laminectomy is often performed to afford access to the lower part of the posterior fossa. C, A 'Y'-shaped durotomy is incised. In children there is often a rich venous supply, including a midline occipital sinus, and care must be taken to achieve haemostasis during this stage. D, The dural flaps are retracted to allow visualization of the cerebellar tonsils, uvula and hemispheres. The cisterna magna is opened and CSF is patiently drained to allow brain relaxation before continuing.

The vermis is now divided longitudinally in the midline. In general, the shortest possible incision should be used to access the lesion safely. In a
tumour case, the vermis is often stretched and thinned by the expanding lesion, enabling access through the most attenuated section. The most superior limit of the incision should be the superior medullary velum to avoid injury to the decussating fibre tracts it contains.\textsuperscript{34} Surgical dissection of the lesion proceeds with the aim of early identification of the floor of the fourth ventricle and the critical structures therein (see above). Care must be taken not to injure the dentate nuclei during retraction: injury to these structures is thought to cause cerebellar mutism.\textsuperscript{35,36} Avoidance of aggressive lateral retraction protects these structures but limits the lateral exposure possible with this approach.

**Telovelar approach**

The telovelar approach reflects advances in understanding of the microsurgical anatomy of the cerebellum and uses natural, anatomical clefts to reach the fourth ventricular cavity without incising neural tissue.\textsuperscript{27} The initial approach, up to and including opening of the cisterna magna, is identical to that described above for the transvermian approach. The tonsil of the cerebellum is now gently retracted laterally and dissection proceeds in the cleft between the tonsil and the uvula. By developing this plane, and further retracting the tonsil laterally and the uvula medially, the tela choroidea and inferior medullar velum (IMV) are exposed. In large tumours, these are often very thinned and may be opened unnoticed during dissection. If not, the tela is bilaterally incised, beginning at the foramen of Magendie and proceeding superiorly to the point where the tela meets the IMV. The IMV itself is then opened, exposing the ipsilateral lateral recess, providing access to the entire floor of the fourth ventricle. The dissection can further proceed between the tonsil and medulla oblongata through the tela, providing additional access to the full length of the lateral recess and the foramen of Luschka (**Fig. 24.18**). Again, early identification of the floor is critical to safe dissection of the intraventricular lesion.
FIG. 24.18 The telovelar approach to the fourth ventricle. The cerebellar tonsil is gradually retracted laterally, allowing a plane to be developed between it and the uvula of the cerebellar vermis. The membranes that are encountered and opened, the inferior medullary velum and tela choroidea, do not contain neural tissue and it has therefore been hypothesized that this is a less morbid procedure than the traditional vermian split. Key: PICA, posterior inferior cerebellar artery.

**Tips and Anatomical Hazards**

There is no choroid plexus within the frontal horn of the lateral ventricle. If no choroid can be seen on entering the ventricle with a neuroendoscope, it suggests that the instrument is pointed anteriorly into the frontal horn.

Identifying the choroid plexus in the body of the lateral ventricle can aid the neurosurgeon intraoperatively because following it anteriorly will reliably lead to the foramen of Monro.

Calcification of the choroid glomus with age can aid identification on computed tomography.

The transtemporal approach to the atrium of the lateral ventricle carries
a risk of injury to the optic radiations and is unsuitable for lesions in the
dominant hemisphere because of the potential for injury to speech
areas.
Bulging or rounding out of the chiasmal or infundibular recesses of the
third ventricle is an early indicator of hydrocephalus.
The absence of any neural tissue in the lower half of the roof of the
fourth ventricle forms the basis for the telovelar approach to the
fourth ventricle.
Injury to any of the structures in the floor of the fourth ventricle – for
example, during surgery for a posterior fossa tumour – can lead to
cranial neuropathies with significant clinical sequelae.
In all intracranial approaches, it is wise to spend some time allowing
CSF egress to permit the brain to ‘relax’ after dural opening.
Retraction injury to the occipital lobe can cause significant visual
morbidity.
Injury to the dentate nuclei during a transvermian approach is thought
to cause cerebellar mutism.
References


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Single Best Answers

1. Which one of the following embryological vesicles is associated with the third ventricle?
   A. Telencephalon
   B. Diencephalon
   C. Mesencephalon
   D. Myelencephalon
   E. Metencephalon

   **Answer: B.** The diencephalic structures, the paired thalami and hypothalamus, surround the slit-like third ventricle in the developed brain.

2. Which one of the following neurosurgical approaches is most likely to cause postoperative epilepsy?
   A. Transcallosal
   B. Transcortical
   C. Infratentorial supracerebellar
   D. Transvermian
   E. Telovelar

   **Answer: B.** The transcortical approach transgresses cerebral cortical tissue, causing a gliotic scar to form, which can act as an epileptogenic focus. All patients undergoing this surgery must be warned of this risk as part of the preoperative consent process; some surgeons will use prophylactic anticonvulsant drugs in the perioperative period. The other four approaches either use ‘natural’ corridors via CSF spaces or transgress cerebellar cortex, injury to which is not a cause of epilepsy.

3. Which one of the following describes the optimal position on the
right mid-pupillary line for the burr-hole used for a standard endoscopic third ventriculostomy?
A. 1 cm above the orbital rim
B. 3 cm anterior to the coronal suture
C. 2 cm anterior to the coronal suture
D. On the coronal suture
E. 1 cm posterior to the coronal suture

Answer: D. Endoscopic third ventriculostomy requires a trajectory that allows safe traversal of the foramen of Monro, without injury to the columns of the fornix or the deep veins, in order to visualize the thin floor of the third ventricle in the region of the tuber cinereum. In a ‘standard’ case of obstructive hydrocephalus, a burr-hole positioned on the coronal suture in the right mid-pupillary line permits this trajectory. This is posterior to the standard ‘Kocher's point’ (2 cm anterior to the suture), which is used for cannulation of the ventricle. For cases with unusual anatomy – for example, due to distortion of the ventricle by a tumour – image guidance may be used to select the optimum trajectory and entry point.

4. Which one of the following reasons explains why generous CSF egress is encouraged after opening the cisterna magna during an approach for a posterior fossa tumour?
A. To obtain CSF for microbiological analysis
B. To drain CSF, which potentially contains malignant cells
C. To decompress the cystic part of the tumour
D. To relax the brain and reduce the need for retraction
E. To allow better visualization of the tumour and associated critical structures
Answer: D. One of the basic principles of intracranial surgery is to use the minimal amount of retraction on the brain because retraction can lead to cerebral oedema, venous insufficiency and even infarction if used injudiciously or for extended periods. Therefore, neurosurgeons will patiently drain CSF on opening the cisterna magna to allow the brain to ‘relax’ (by decreasing total intracranial volume) and so reducing the need for retraction.

5. The telovelar approach may be preferred to the transvermian approach because there is a reduced risk of cerebellar mutism. Injury to which one of the following structures is this complication thought to be related to?

A. Superior cerebellar peduncles
B. Fastigium
C. Dentate nuclei
D. Olivary nuclei
E. Superior medullary velum

Answer: C. Cerebellar mutism, or posterior fossa syndrome, is a feared complication of surgery for tumours of the fourth ventricle, especially in children, who appear to be particularly prone to this condition. There is often a delayed onset (usually 24–48 hours) after surgery. Cerebellar mutism is characterized by mutism, cranial nerve dysfunction and psychomotor depression; there is no specific treatment and it may take many months to resolve. The dentate nucleus, the largest deep cerebellar nucleus, has multiple connections with the thalamus, olive and red nucleus, and it is the disruption of these pathways that is thought to be the neural substrate of the clinical phenomenon. Bilateral dentate injury, such as that seen after transvermian surgery with aggressive retraction of the cerebellar hemispheres, appears to be a particular risk factor.
Clinical Case

1. A 56-year-old female collapses at home following a sudden-onset severe headache. CT scanning reveals extensive subarachnoid haemorrhage with intraventricular clot and acute hydrocephalus. She requires insertion of an external ventricular drain (EVD) to control the hydrocephalus.

A. Define your landmarks for the incision and burr-hole.  

The patient should be positioned supine, with the head resting on an adjustable head frame. Most surgeons will use a small degree of ‘head up’, with the head positioned above the level of the heart. The right side is preferred, as it is non-dominant in the vast majority of the population. The right mid-pupillary line and the coronal suture, which is usually easily palpable as a horizontal prominence under the scalp, are noted; a skin marker pen is used to indicate a point 2 cm in front of the suture on the mid-pupillary line (Kocher’s point). This will be the entry point for the EVD. Following appropriate skin preparation and sterile draping, a 5 cm linear incision is made with the marked point at its centre. A periosteal elevator is used to expose the bone. The coronal suture can be directly visualized at this point to confirm the location. A high-speed drill is then used to fashion a burr-hole on Kocher’s point.

B. What trajectory and depth should be used for cannulation of the ventricle?  

The trajectory is aimed at a point where an imaginary sagittal line from the ipsilateral medial canthus intersects an imaginary coronal line from the ipsilateral tragus. The aim is for the tip of the catheter to sit adjacent to the ipsilateral foramen of Monro in the frontal horn of the lateral ventricle. This is usually around 5 cm from the cortical surface and can be confirmed by perusing the preoperative CT scan (coronal images).

C. Following successful EVD insertion and stabilization on the intensive care unit, the source of the haemorrhage is found to be a ruptured anterior communicating artery aneurysm. The patient is taken back to theatre for pterional craniotomy and clip ligation of the aneurysm. What intraoperative manoeuvre may help reduce the risk of long-term hydrocephalus?  

Opening of the lamina terminalis of the third ventricle, which can be performed during surgery for anterior circulation aneurysms, creates a CSF
pathway from the ventricles into the basal cisterns, which can effectively treat obstructive hydrocephalus. However, there is often a communicating component to post-haemorrhagic hydrocephalus and, while there is some published evidence that this manoeuvre may reduce the long-term need for a permanent CSF shunt, it may not always be successful in preventing this complication of subarachnoid haemorrhage.
Cerebral hemispheres and white matter tracts

Sandip S Panesar, Kumar Abhinav, Juan C Fernandez-Miranda

Core procedures

- Treatment of medically refractory epilepsy.

This chapter will address the key surgically relevant cortical and white matter anatomy of the brain and some of the principles underlying resection of limbic/paralimbic gliomas and removal of tumours in the eloquent cortex.
Clinical anatomy

Osseous anatomy and landmarks

Sutures
The cranial vault (calvaria) encloses the meninges and central nervous tissue. It consists of single frontal and occipital bones and bilateral parietal bones. The greater wings of the sphenoid bone and the squamous parts of the temporal bones enclose it laterally. These bones articulate at a series of fibrous sutures. The coronal suture separates the squamous frontal bone from each parietal bone across the midline. The sagittal (interparietal) suture begins at the bregma (the meeting point between the frontal and two parietal bones) and continues in the midline perpendicular to the coronal suture. It terminates at the lambda, which is the most apical point of the occipital bone. The lambdoid suture runs laterally and inferiorly from the lambda to form an approximately equilateral triangle between the parietal and occipital bones. At its most lateral and inferior aspect, the coronal suture terminates in a region known as the pterion. Here it meets the apex of the sphenofrontal suture, which separates the frontal bone from the greater wing of sphenoid, at an oblique angle. The sphenofrontal suture continues posteriorly as the sphenoparietal suture, separating the superior plateau of the greater sphenoid wing from the inferior edge of the parietal bone. The sphenoparietal suture terminates abruptly at the point where the sphenoid, parietal and temporal bones meet. From this point, the posterior edge of the greater sphenoid wing and anterior edge of the temporal bone are separated by the sphenosquamous suture. The parietal bone and the superior edge of the temporal bone are separated by the squamosal suture, which assumes an arc-like trajectory across the lateral aspect of the skull. Towards its posterior edge, the squamous suture plateaus and continues posteriorly to meet the obliquely travelling lambdoid suture. This plateau is the parietomastoid suture, which separates the parietal bone from the mastoid portion of the temporal bone. The asterion is defined as the junction of the parietomastoid, occipitomastoid and lambdoid sutures.

Bony landmarks
The nasion is the midline bony depression inferior to the glabella, demarcating the junction of the frontal and bilateral nasal bones. The external occipital protuberance or inion is found in the sagittal plane
posteriorly: surgically, it is a landmark for the torcular Herophili or confluence of the superior sagittal, straight, occipital and transverse venous sinuses. Several landmarks may be located using the nasion and inion as geographical landmarks together with imaginary lines. Kocher's point is a parasagittal landmark, 11 cm posterior and 2–3 cm lateral to the nasion, used as a guide for catheter placement into the frontal horn. Frazier's point, used for catheter placement into the posterior aspect of the lateral ventricle, is found 6–7 cm above and 3–4 cm lateral to the inion. Keen's point is located 3 cm superior and 3 cm posterior to the top of the pinna and is used for catheter placement into the lateral aspect of the lateral ventricle, as commonly undertaken during paediatric ventriculoperitoneal shunt placement.

Cortical anatomy

The cerebral hemispheres are separated in the midline by the sagittal or interhemispheric fissure, running from the frontal pole to the occipital pole. Viewed laterally, the central sulcus separates the frontal and parietal lobes. It runs perpendicularly on either side of the interhemispheric fissure and passes obliquely, coronally and anteriorly before terminating inferiorly at the Sylvian (lateral) fissure. The primary motor cortex lies immediately anterior to the central sulcus; the primary sensory cortex lies immediately posterior to it. The Sylvian fissure separates the opercula of the temporal lobe (inferiorly) from the frontal opercula (anteriorly) and the parietal opercula (posteriorly). It travels posteriorly and superiorly, and terminates approximately one-third of the way along the horizontal length of the parietal lobe. Broca's area is part of the frontal opercula, located within the inferior frontal gyrus, lying above the Sylvian fissure. Wernicke's area is part of the temporal opercula, found immediately behind and below the posterior termination of the Sylvian fissure at the superior temporal gyrus; traditionally, this area is thought to be involved in enabling speech comprehension. The insula is a deep infolding of cortex lying within the Sylvian fissure and is typically obscured from view unless the Sylvian fissure is ‘opened’.

Cortical and subcortical anatomy of the insula

The insula resembles a cortical shield that covers the external capsule of white matter and protects the deeply located basal ganglia. The insular cortex is involved in visceral sensation, regulation of sympathetic cardiovascular
tone, pain processing and motor planning, among other somatosensory functions. Insular gliomas represent a technical challenge for the neurosurgeon due to difficult-to-reach anatomy, relations of highly eloquent cortex and a complex vascular supply.\textsuperscript{1,2} The insular cortex, when exposed, is divided by the oblique insular central sulcus and bounded by the anterior, superior and inferior peri-insular sulci at its anterior, superior and inferior walls, respectively. Anterior to the central sulcus there are three oblique gyri: the anterior, middle and posterior short insular gyri (Fig. 25.1A). Posterior to the central sulcus are the anterior and posterior long gyri. The most anteroinferior polar extremity of the insula is the limen insulae, containing the temporal stem (uncinate and inferior fronto-occipital fasciculi) (Fig. 25.1B). Deep to the central insula are the extreme capsule, claustrum, external capsule and lentiform nucleus. Posteriorly, geniculate motor fibres within the internal capsule run deep to the posterosuperior extremity of the circular sulcus.
FIG. 25.1  

A. Removal of para-insular structures reveals the insular gyrus lying within the Sylvian fissure. Obliquely bisecting the insular surface is the central insular sulcus (white perforated line). Gyral convolutions lying anterior to the central sulcus are the anterior (ASG), middle (MSG) and posterior (PSG) short gyri. These converge inferiorly to form the limen insulae (LI). Lying posterior to the central sulcus are the anterior (ALG) and posterior (PLG) long gyri. 

B. Lying deep to the insular cortex are critical white matter structures that may be damaged during surgery. The temporal stem consists of association white matter of the uncinate fasciculus (UF; anterior) and inferior fronto-occipital fasciculus (IFOF, posterior); the claustrum (Claust.) lies deep to the dorsal insular aspect.

Vascular supply of the insula

The insular cortex is supplied by perforators given off the M₂ and M₃ segments of the middle cerebral artery. Collateral perforators given off by the prefrontal artery, originating from the superior trunk of M2, supply the anterior short insular gyrus. Perforators from the precentral artery, again originating from the superior trunk, supply the middle short insular gyrus.
M2 subsequently continues posterosuperiorly along the lateral insular surface as the superior trunk, which branches into the central, anterior parietal, posterior parietal, angular and temporo-occipital arteries. These branches give off perforators supplying the posterior insular gyri. The inferior edge of the insula is supplied by either the temporal branch or the inferior trunk of the middle cerebral artery, which bifurcates into the middle and posterior temporal arteries that give off perforators supplying the cortex.

**Surgical resection of insular tumours**

The M1 segment gives off lenticulostriate perforators prior to its bifurcation into M2 branches. The lenticulostriate perforators represent the medial limit of resection for insular gliomas. Identification of vascular structures is critical during insular surgery because inadvertent damage may produce ischaemic deficits. Surgery involves careful Sylvian fissure dissection and retraction of the temporal and frontal lobes to expose the insular surface. An alternative approach has been developed to avoid Sylvian fissure opening and dissection of middle cerebral artery branches, involving the use of intraoperative cortical mapping to identify eloquent cortex. Non-dominant insular tumours can be removed under general anaesthesia, with mapping of facial somatic responses. Dominant hemispheric tumours must be removed using awake craniotomy, with concurrent speech mapping to ensure language preservation. Once language and motor cortical regions are localized, safe cortical ‘windows’ are created to access the insular region in a subpial fashion, preserving the pia–arachnoid layering overlying middle cerebral artery branches. With these factors taken into consideration, insular tumours, particularly low-grade gliomas once thought to be inoperable, can be safely removed with significant improvement in oncosurgical outcomes.

**Frontal lobe**

The frontal lobe is divided by the precentral sulcus, which runs anterior and parallel to the deep central sulcus and defines the anterior limit of the precentral/motor gyrus. The superior frontal sulcus begins anteriorly, perpendicular to the precentral sulcus, and demarcates the lateral limit of the superior frontal gyrus, which runs adjacent to the interhemispheric fissure. The middle frontal gyrus lies inferior to the superior frontal sulcus and travels parallel to the superior frontal gyrus. The ventral limit of the middle frontal gyrus is demarcated by the inferior frontal sulcus running parallel to the superior frontal sulcus. The most ventral and lateral aspect of the frontal
lobe is the inferior frontal gyrus. It is further divided by an ‘M’-shaped sulcal
arrangement, from dorsal–ventral and posterior–anterior, into the pars
opercularis, pars triangularis and pars orbitalis. The former two contribute to
Broca's area, traditionally associated with the expressive aspect of speech.

**Parietal lobe**

The anterior limit of the parietal lobe is bounded by the central sulcus, with
the postcentral gyrus lying immediately behind and running parallel to it.
The inferior third of the parietal lobe is bounded by the Sylvian sulcus. An
‘H’-shaped sulcal system further divides the part of the parietal lobe
posterior to postcentral gyrus. The anterior and vertical limb of the ‘H’ is
formed by the postcentral sulcus, the horizontal limb by the intraparietal
sulcus, and the posterior–vertical limb by the parieto-occipital arcus. The
superior and inferior parietal lobules lie immediately behind the postcentral
gyrus, separated dorsoventrally by the intraparietal sulcus. The inferior
parietal lobule contains two important parieto-temporal gyri: the
supramarginal (anterior) and angular (posterior) gyri.

**Occipital lobe**

The parieto-occipital arcus demarcates the anterior and dorsal boundaries of
the occipital lobe; the ventral boundary is approximately delineated by the
terminations of the horizontally travelling superior and inferior temporal
sulci. Two opposing sulci divide the occipital lobe into an approximate wedge
shape. The transverse occipital sulcus runs dorsoventrally and
posteroanteriorly, where it is met by the lateral occipital sulcus running
posteroanteriorly. The demarcation of the occipital lobe is more distinct when
viewed from a medial perspective. The cuneus is the region between the
parieto-occipital sulcus and the calcarine fissure. The lingual gyrus lies
ventral or inferior to the calcarine sulcus.

**Temporal lobe**

The temporal lobe lies ventral to the frontal and parietal lobes and anterior
to the occipital lobe. On its lateral surface, it is bounded dorsally by the
Sylvian fissure and posteriorly by the preoccipital notch. The temporal pole is
the most anterior portion of the temporal lobe. Beginning posterior to the
temporal pole, the superior temporal sulcus runs anteroposteriorly,
demarcating the superior temporal gyrus. The middle temporal gyrus is
inferior to the superior temporal sulcus. The middle temporal sulcus divides the middle from the inferior temporal gyrus. The latter forms the inferior limit of the hemisphere and is continuous with the occipital pole posteriorly. The collateral sulcus anteriorly forms the lateral boundary of the parahippocampal gyrus, separating it from the occiptotemporal or fusiform gyrus. The occipitotemporal sulcus demarcates the fusiform gyrus medially from the inferior temporal gyrus laterally. The latter is the most inferior cortical gyrus.

**Cortical anatomy**

The medial aspect of the temporal lobe represents the most anatomically complex cortical surface [(Fig. 25.2)](#)\(^3–5\) To simplify its anatomy, it can be divided into three segments: anterior, middle and posterior. The anterior segment begins at the upward turning of the rhinal sulcus, at the posterior limit of the temporal pole, and terminates at an imaginary vertical line representing the posterior limit of the uncus. The middle segment continues from the posterior uncus to another imaginary vertical line at the level of the quadrigeminal plate. The posterior segment continues from the quadrigeminal plate to the calcarine point, which is the junction of the parieto-occipital and calcarine sulci. The uncus lies posterior to the temporal pole and consists of anterior and posterior segments. The anterior uncus contains the amygdala, which is covered by the semilunar gyrus along the superior aspect of the anterior segment. The semianular sulcus separates the semilunar gyrus from the ambient gyrus, which lies medially and anteriorly to the semilunar gyrus. The ambient gyrus thus occupies the anterior and inferior segments of the anterior uncus. The posterior uncus possesses superior and inferior portions. The inferior part is occupied by the entorhinal area, which extends to the inferoanterior portion of the uncus, effectively forming its inferior limit. The entorhinal area is limited by the rhinal sulcus anteriorly and the collateral sulcus laterally. The superior part is formed by the hippocampal head and contains the fornical fimbriae at its posterior limit. It possesses three small gyri: from anterior to posterior, these are the uncinate gyrus, the band of Giacomini and the intralimbic gyrus. The middle segment of the medial temporal surface contains the parahippocampal gyrus (inferiorly), dentate gyrus (middle) and fimbria (superiorly). The hippocampal sulcus separates the parahippocampal and dentate gyri. This arrangement is achieved via lateral then medial infolding of the parahippocampal gyrus, more commonly visualized as a coronal ‘S’-shaped
cross-section. Forming the bottom curve of the ‘S’ is the entorhinal area, which transforms successively into the parasubiculum, presubiculum, subiculum, CA1, CA2 and CA3, terminating at CA4. CA3 and CA4 are found within the intralimbic gyrus: the ‘S’ becomes less well defined posteriorly. The posterior medial–temporal region is the posterior continuation of the parahippocampal gyrus which meets the anterior limit of the calcarine sulcus, bifurcating into the isthmus of the cingulum superomedially and the lingual gyrus inferolaterally. Cingulate fibres pass from the cingulum to the parahippocampal gyrus via the isthmus. The fimbria, located superiorly, passes within this region by looping over the thalamic pulvinar. The hippocampal tail continues posteriorly and passes underneath the callosal splenium.

**FIG. 25.2** A, An anterior view of a coronal transection of the temporal lobe and
brainstem structures. Medially, the mammillary bodies (MB), oculomotor nerve (CN III) and cerebral peduncle (CP) are visible. Cerebellar peduncular fibres have been removed to expose the vertically oriented corticospinal tracts (CST) at the level of the pons. Medial temporal lobe structures are visible lateral to the peduncles. Most ventrolateral is the fusiform gyrus (Fus.), separated from the medially lying parahippocampal gyrus (PhG; containing the entorhinal cortex) by the collateral sulcus (CS). Dorsal and medial to the PhG lies the subiculum (Su.), which is the first infolding of the hippocampal formation. The dentate gyrus (DG) forms the ventral surface of the hippocampus (Hipp.) (containing CA 1–4), while the fimbria forms the dorsolateral surface of the hippocampal formation. The choroid plexus (Ch.) lies within the temporal horn of the lateral ventricle (LV) and forms the lateral border of the hippocampal formation. B, A basal view of a hemisphere illustrating temporal lobe structures. The inferior temporal and fusiform cortices have been removed to expose the inferior aspect of the inferior longitudinal fasciculus (ILF; bounded by yellow perforated lines). The parahippocampal gyrus (entorhinal cortex) has also been removed from the medial temporal region to expose the underlying hippocampus (Hipp.). Also visible is a section of choroid plexus (Ch.) towards the posterior aspect of the hippocampus, where it continues with the isthmus of the cingulum (Ist.). The fimbria (Fim.) is a medial continuation of hippocampal tissue and separates it from the thalamic pulvinar (Pul.). Anterior to the pulvinar lie two important nuclei: the medial (MGN) and lateral (LGN) geniculate nuclei, from which the acoustic and optic radiations, respectively, originate. The temporal pole (TP) is the most ventral and anterior extremity of the temporal lobe and lies lateral to the uncus (Unc.).

Subcortical temporal white matter structures

Aside from the complex surface anatomy of the medial temporal lobe, several critical white matter structures pass subcortically. The optic radiation (geniculocalcarine tract), carrying information from the contralateral visual field, lies within the anterior temporal lobe. Traced from their origin in the lateral geniculate nucleus, the fibres in the optic radiation pass through the retrolentiform part of the internal capsule and spread out into three main bundles: an anterior bundle (Meyer's loop); a central bundle; and a posterior bundle (Baum's loop). As the anterior bundle fans out along its course medial to the medial wall of the temporal horn of the lateral ventricle, it turns over the roof of the downward-curving temporal horn; its fibres ultimately terminate on neurones along the anteroinferior bank of the calcarine sulcus. The central bundle travels more laterally, initially along the roof of the temporal horn of the lateral ventricle. It turns posteriorly to run along the occipital horn of the lateral ventricle, lying superior to the anterior bundle and deep to the superior gyrus of the temporal lobe; its fibres terminate on neurones in the posterior calcarine sulcus. The posterior bundle is relatively superior to both the anterior and the central bundles, running dorsally and posteriorly, separated from the lateral wall and roof of the
occipital horn of the lateral ventricle by the tapetum; its fibres terminate on neurones in the superior bank of the calcarine sulcus. Disruption of these white matter tracts may result in partial or total visual deficits: for example, damage to Meyer's loop may cause upper contralateral quadrantanopia.

The anterior temporal stem, passing within the ventral external capsule may also be damaged by medial temporal lobe surgery. Susceptible tracts include the uncinate fasciculus, the hook of which lies deep to the limen insulae, and the inferior fronto-occipital fasciculus, which passes dorsal and lateral to the uncinate fasciculus within the ventral external capsule.

**Vascular supply of the medial temporal lobe**

The medial and inferior temporal lobes are principally supplied by the posterior cerebral artery. The uncus and choroid plexus of the temporal horn are supplied by the anterior choroidal artery. The posterior cerebral artery, as it passes laterally around the cerebral peduncle, bifurcates into anterior (P2a) and posterior (P2p) segments approximately at the level of the middle segment of the medial temporal surface. The anterior segment continues behind the uncus and cerebral peduncle (crural cistern). The posterior segment passes between the parahippocampal gyrus and the midbrain (ambient cistern). The P2a segment supplies the anterior aspect of the medial temporal surface via the anterior hippocampal–parahippocampal artery and numerous other small perforators. The P2p segment displays variable branching. It becomes the P3 and P4 segments approximately at the posterior surface of the medial temporal lobe. The posteroinferior temporal, posterior hippocampal, splenial, calcarine and parieto-occipital arteries supply the posterior segment of the medial temporal lobe.

**Surgical approaches to the medial temporal lobe**

Surgery of the medial temporal lobe is a gold standard for treatment of medically refractory epilepsy. Surgery may involve removal of the anteromedial temporal lobe or selective amygdalohippocampectomy via either transcortical or trans-sylvian routes. Of potential concern during surgery within this region is the potential for damage to the nearby structures, including Meyer's loop, optic radiations and other white matter pathways, and vascular structures.3

The medial temporal lobe can be approached laterally, via an anteromedial temporal lobectomy or a transcortical amygdalohippocampectomy. A detailed
description of these approaches is beyond the scope of this chapter. Trans-sylvian approaches include the trans-sylvian selective amygdalohippocampectomy. Inferior routes also exist. Anteromedial temporal lobectomy may cause postoperative functional deficits, as a consequence of removal of cortical structures (which could be relevant for verbal memory on the dominant side) and carries the potential risk of iatrogenic damage to Meyer's loop and long association tracts. The frontal extent of Meyer's loop is approximately 3 cm posterior to the temporal pole. On the lateral aspect of the temporal lobe, the inferior longitudinal and inferior fronto-occipital fasciculi may be damaged during lateral approaches such as a transcortical amygdalohippocampectomy. Trans-sylvian approaches involve exposure of the uncus and insula via splitting of the Sylvian fissure. The route is primarily through the inferior limiting sulcus of the insula, just posterior to the limen insulae. The anterior temporal stem is thus partially breached, and damage to the uncinate fasciculus and inferior fronto-occipital fasciculus may occur.

**Cingulate gyrus**

The cingulate gyrus is a part of the limbic lobe and is visible only from the medial aspect. It is a curved gyrus travelling above the corpus callosum. It begins anteriorly and inferiorly below the rostrum of the corpus callosum, travels posteriorly around the genu and body of the corpus callosum, and terminates underneath the splenium at the isthmus. Laterally and within the temporal lobe, the posterior limit of the white matter of the cingulate gyrus (cingulum) is continuous with the parahippocampal gyrus, and together they form the limbic lobe. The cingulate sulcus separates the cingulate gyrus from the medial superior frontal gyrus and paracentral lobule. It terminates posterior to the paracentral lobule as the marginal sulcus (ascending ramus of the cingulate sulcus), separating the former from the precuneus. The precuneus, part of the parietal lobe, is continuous with the superior parietal lobule and is limited posteriorly by the parieto-occipital sulcus.

**White matter anatomy**

The cerebral white matter lies immediately beneath the cortical grey. White matter pathways can be classified as U-fibre, association, limbic, projection and commissural systems. These systems are of variable length and angular orientation. Prior to the introduction of diffusion magnetic resonance tractography, postmortem white matter dissection was the primary method of
visualizing human white matter architecture. Tractography permits in vivo visualization of white matter architecture in health and disease.

**U-fibre system**
The cortico-cortical U-fibres are the shortest and most superficial white matter pathways and are so named because they connect adjacent gyri. Due to their short course and abundance across the hemispheric surface, their anatomy is poorly described in humans. They are thought to facilitate integration of multimodal cortical functions.

**Association system**
Association fibres subserve multimodal associative integration, and consist of a heterogeneous group of white matter tracts interconnecting distant gyri within the same hemisphere.

**Arcuate fasciculus and superior longitudinal fasciculus**
The arcuate fasciculus ([Fig. 25.3](#)) is an arc-shaped tract that interconnects lateral frontal and temporal regions. From its dorsal terminations at the lateral aspect of the three temporal gyri, the fibres form a compact stem that arcs dorsally and anteriorly around the posterior end of the Sylvian fissure, without connecting with the parietal gyri, and terminates within the pars opercularis and triangularis, ventral premotor cortex and posterior middle frontal gyrus. The contemporary description of the arcuate fasciculus segments it into a volumetrically and connectively leftward-lateralized (higher volume of the tract on the left side), dorsal–ventral arrangement.
FIG. 25.3  A, White matter dissection of a left hemisphere. Overlying cortex and U-fibres have been removed to expose the arcuate fasciculus (AF) and superior longitudinal fasciculus (SLF), the most superficial large white matter pathways. The anterior temporal lobe has also been dissected to reveal the anterior (temporal) segment of the inferior longitudinal fasciculus (ILF) (most ventral) and the middle longitudinal fasciculus (MdLF). B, The corresponding tractographic image for Fig.
The superior longitudinal fasciculus is a frontoparietal tract that travels dorsally and superficially to the arcuate fasciculus, interconnecting the caudal middle frontal and ventral precentral gyri and pars opercularis with the supramarginal and angular gyri of the parietal lobe. As with the arcuate fasciculus, contemporary descriptions of the superior longitudinal fasciculus separate it into dorsal and ventral subcomponents. It differs from the former, however, in that it is the only volumetrically and connectively rightward-lateralized system. Together, the arcuate and superior longitudinal fasciculi provide the neural substrate of the dorsal component for a dual-stream language model. The dorsal component is thought to subserve the mapping of auditory stimuli on to their corresponding motor representations and is essential for speech production (see Fig. 25.3A and B).

**Inferior and middle longitudinal fasciculi**

The inferior longitudinal fasciculus (see Fig. 25.3) lies within the inferior aspect of the temporal lobe, deep to the temporal termination of the arcuate tract. It originates from the ventrolateral aspects of the anterior temporal cortex and travels posteriorly along the inferior surface of the temporal lobe to terminate within the occipital lobe. Its existence as a robust, unique fascicle has been called into question. The middle longitudinal fasciculus is superior to the inferior longitudinal fasciculus. It originates from the superior temporal gyri, and travels obliquely from the superolateral temporal surface to terminations within the superior parietal and rostral occipital cortices: it is thought to subserve auditory–spatial orientation (see Fig. 25.3C and D).
Uncinate and inferior fronto-occipital fasciculus

The inferior fronto-occipital fasciculus (see Fig. 25.3) originates from the dorsolateral (i.e. superior and middle frontal), ventrolateral (i.e. pars orbitalis) and ventromedial (i.e. frontal polar) regions of the frontal gyri. Its fibres narrow into a compact stem as they traverse the ventral external capsule, passing into the occipital lobe, superficial to the sagittal stratum. The inferior fronto-occipital fasciculus is the longest of the association tracts and its anatomical description has been subject to considerable debate about the extent of its anterior origins and posterior terminations and its subdivisions. It lies within the same anatomical plane as the claustro-cortical fibre system, a fan-shaped projection of fibres forming the dorsal external capsular white matter. The uncinate fasciculus, a short, hook-shaped tract originating from the orbitofrontal and ventrolateral frontal region, shares frontal origins with the inferior fronto-occipital fasciculus. Its fibres narrow into a compact stem as it passes into the ventral external capsule with the inferior fronto-occipital stem. Here, the uncinate fasciculus hooks away, travelling ventromedially and then anteriorly to the temporal pole. Historically, the uncinate was thought to be a conduit between the association and limbic systems via amygdalar connectivity but recent tractography studies have disputed this. The inferior fronto-occipital, uncinate and inferior longitudinal fasciculi (see Fig. 25.3E and F) are thought to contribute to the neural substrate for the ventral or semantic component of the dual-stream language model.6

Recently described short association tracts

At the frontal extremity, the frontal aslant tract originates dorsally from the superior frontal gyrus (supplementary motor area) and travels perpendicular and anterior to the frontal components of the arcuate and superior longitudinal fasciculi. It terminates at various points along the inferior frontal gyrus, including the ventrolateral frontal cortex, and it has been functionally related to the initiation of speech. Previous descriptions of the arcuate fasciculus include a vertical component connecting Wernicke’s (superior temporal) and Geschwind’s (inferior parietal) areas. This is now thought to be a distinct, independent fascicle, the temporo-parietal aslant tract, which interconnects the inferior parietal lobule with middle and inferior temporal gyri, and which may have a role in speech integration.

At the occipital extremity, the vertical occipital fasciculus originates from the fusiform and inferior temporal gyri, travels posteriorly superiorly and
superficially to the inferior longitudinal and inferior fronto-occipital fasciculi, and terminates within the superior and middle occipital gyri: it is thought to subserve visual integration.

**Limbic system**

The limbic system (Fig. 25.4) is an extended neural network concerned with emotional and motivational activity, also subserving memory and learning. It consists of a series of grey matter nuclei inter connected by white matter. The classic Papez circuit connects the hippocampus with the mammillary bodies via the fornix. On each side, the fornix (see Fig. 25.4) originates from the hippocampus as fimbria, which become the crus of the fornix. The two fornical crura pass upward and forward beneath the corpus callosum, joined by crossing fibres (the commissure of the fornix or hippocampal commissure). The crura merge to form the body of the fornix as they travel forward, lying ventral to the septum pellucidum of the lateral ventricles. The body splits anteroposteriorly and lateral–medially, approximately at the anterior commissure, into pre- and postcommissural bundles. Precommissural fibres arise mainly from the pyramidal cell layer of the hippocampus and end in the septal and accumbens nuclei. Postcommissural fibres originate in the subiculum of the hippocampus and pass to the mammillary nucleus of the hypothalamus. The mamillothalamic tract travels to the anterior thalamic nuclei. A series of short projections radiate from the thalamus to the cingulum among other adjacent cortical gyri. The cingulum is the largest limbic component and consists of a heterogeneous population of white matter fibres of variable length. As the cingulum travels posteriorly around the corpus callosum, it gives off projections to various frontal, parietal and temporal areas and the precuneus. The cingulum terminates within the medial–temporal parahippocampal cortex (see Fig. 25.4A and B).
FIG. 25.4  A, A sagittal hemisection at the level of the third ventricle. The fornix has been exposed throughout its entirety from its origins at the mammillary body (MB), anterior pillar (AP), body (Bo.) and crus (Cr.). The anterior commissure (AC) can be visualized. Other abbreviation: CC, corpus callosum. B, The corresponding tractographic image for Fig. 25.4A. The fornix (For.) and anterior commissure (AC) are visualized in relation to each other. C, The lentiform and caudate nuclei have been removed to expose the thalamus (Thal.) and the optic radiations (OR), which originate from the lateral geniculate body. Meyer's loop (ML) passes over the temporal horn of the lateral ventricle before travelling posteriorly as the optic radiations. D, The corresponding tractographic image for Fig. 25.4C. Note the relations of the deep grey matter nuclei: putamen (Put.), caudate (Caud.) and thalamus (Thal.) The optic radiations (OR) are the deepest component of the sagittal stratum.

**Projection system**

Projection fibres include the primary motor (see Fig. 25.3) and sensory tracts and optic (see Fig. 25.4), acoustic and cerebellar projections. This text is confined to the cerebral portions of these tracts.

**Primary motor and sensory tracts**

The final segment of the sensory pathway consists of thalamocortical sensory projections, which ascend from the ventroposterior thalamic nuclei via the internal capsule. During their ascent, they rotate posteriorly before terminating in the postcentral primary sensory cortex, which is somatotopically arranged in the classic homuncular pattern. This rotation is thought to occur to accommodate the spatial differences in somatotopic representation between the thalamic nuclei and sensory cortex.

Corticospinal fibres (see Fig. 25.3E and F) originate from widespread regions of the cerebral cortex, including the primary motor cortex of the
The fibres descend through the genu of the internal capsule and the cerebral peduncle, and subsequently decussate within the medullary pyramids. The majority then cross to the contralateral side in the motor decussation in the medullary pyramids and continue caudally as the lateral corticospinal tract in the spinal cord. Corticonuclear (corticobulbar) projections descend lateral and posterior to the corticospinal projections within the corona radiata, through the genu and cerebral peduncle, and terminate in brainstem nuclei such as the red nucleus, reticular nuclei, olivary nuclei and cranial nerve nuclei. The internal capsule also contains the geniculate motor fibres, which descend from the motor nuclei of the precentral gyrus in a somatotopic arrangement that is preserved throughout the tract course.

**Optic and acoustic radiations**

The optic (see Fig. 25.4C and D) and acoustic radiations are sensory conduits between ventral–thalamic nuclei and their associated functional cortices. The optic radiations continue from the lateral geniculate nucleus, carrying visual information from the ipsilateral temporal field and contralateral nasal field. The fibres fan out as they pass anteriorly within the temporal lobe, curving acutely around the rostral contour of the anterior horn of the lateral ventricle and forming the so-called Meyer's loop. These fibres travel posteriorly within the sagittal stratum, following the lateral contour of the lateral ventricle. The tapetum is a thin sheet of commissural fibres from the splenium of the corpus callosum that separates the lateral ventricular wall from the optic radiations. The radiations pass from the temporal lobe into the medial aspect of the occipital lobe to terminate on the dorsal and ventral surfaces of the calcarine sulcus. The auditory radiations originate medial to the optic radiations, from the medial geniculate nucleus. Their course is more convoluted, passing initially underneath the optic radiations before turning upwards and curving around the inferior insular sulcus before terminating within the first transverse temporal or Heschl's gyrus.

**Corticocerebellar and corticopontine tracts**

The cerebral cortex is the largest single source of fibres that project to the pontine nuclei. The fibres traverse the cerebral peduncle, those from the frontal lobe occupying the medial part of the peduncle; corticonuclear and corticospinal fibres occupying its central part; and fibres from the parietal,
occipital and temporal lobes occupying its lateral part. The mediolateral sequence of fibres in the cerebral peduncle is approximately maintained at their termination within the pontine nuclei. Prefrontopontine fibres and the frontal eye fields project medially and rostrally; motor and premotor projections terminate centrally and caudally; and parietal, occipital and temporal fibres terminate in the lateral pontine nuclei. Motor and premotor projections are somatotopically organized: the face is represented rostrally and the hindlimb caudally in the nuclei. The pontocerebellar projection is almost completely crossed. Fibres from the pontine nuclei access the cerebellum via the middle cerebellar peduncle and terminate throughout the entire cerebellar cortex. The superior cerebellar peduncle contains all of the efferent fibres from the dentate, emboliform and globose nuclei, and a small fascicle from the fastigial nucleus. Its fibres ascend ipsilaterally via the periventricular pons and are destined to synapse in the contralateral red nucleus and ventrolateral thalamic nuclei (the dentatorubrothalamic tract).

Commissural system
Commissural fibres run between the cerebral hemispheres and consist primarily of the anterior commissure and the corpus callosum. The anterior commissure passes transversely between the hemispheres and possesses a ‘handlebar’ shape. Centrally, the body of the anterior commissure travels within the anterior wall of the third ventricle, branching into anterior and posterior crura as it travels laterally within each hemisphere. On each side, the anterior crus terminates within the olfactory bulb, anterior perforated substance and anterior olfactory nucleus; the posterior crus terminates within the hippocampus and amygdala. The corpus callosum is a dense collection of white matter connecting the hemispheres across the midline. Traditional anatomical subdivisions (from anterior to posterior) include the rostrum (anteroinferior), the genu, forming the anterior ‘pole’ of the sagittal profile of the corpus callosum, the body, and the splenium or ‘tail’. The corpus callosum is continuous with the lamina terminalis anteroinferiorly.
Principles underlying surgery in eloquent cortex and subcortical white matter

The three methods primarily employed in elucidating anatomy and minimizing damage during tumour resection are preoperative tractography, preoperative functional neuroimaging and intraoperative electrical stimulation.

Tractography, functional magnetic resonance imaging and magnetoencephalography

Preoperative tractography is most useful in cases of space-occupying lesions and can identify displacement or infiltration of critical white matter tracts by tumours. With knowledge of white matter tract functionality, observed preoperative clinical deficits can be correlated with structural abnormalities involving white matter. Intraoperative MRI is becoming commonplace and efforts to integrate tractography with intraoperative MRI are under way.

Functional neuroimaging also allows preoperative identification of eloquent cortex. Techniques include functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG). fMRI utilizes the principle of blood oxygen level contrast to identify metabolically active areas involved in particular tasks undertaken whilst the patient is within the scanner. Essentially, this technique of blood oxygenation level dependent (BOLD) imaging relies on the fact that deoxygenated haemoglobin is paramagnetic whereas oxygenated haemoglobin is not.

MEG employs sensitive magnetometers to detect magnetic fields produced by electrical currents occurring within brain areas during activity. Though MEG requires structural information provided by computed tomography or MRI, it is a non-MRI modality. Both fMRI and MEG produce a cortical ‘map’ of functional activity related to particular tasks or faculties. All three techniques are presurgical; fMRI and MEG provide functional cortical information whereas tractography provides white matter structural information. Efforts have been made to combine these modalities and functional cortical mapping (MEG or fMRI) is routinely combined with tractography and intraoperative electrocortical stimulation to optimize anatomico-functional correlation of grey and white matter during surgery.
Intraoperative cortical stimulation

Intraoperative cortical stimulation involves passing a small, constant current via a probe placed on a neural structure and waiting to observe a sensorimotor effect. It may be conducted with the patient awake, using local anaesthetic, or under general anaesthesia when only motor function is to be evaluated. A low-frequency pulse train, of 50 Hz (Europe) or 60 Hz (North America) is utilized; the pulse form may be monophasic or biphasic. Bipolar probes are considered more accurate than monopolar probes because current passes only between the opposing electrodes rather than propagating peripherally from the single source, which increases the chance of a false effect. Once the electrical signal is applied, its effect can be measured either by directly observing the patient’s reaction or, in the case of motor response evaluation, via peripherally placed electrodes (electromyography). The latter method allows for documentation and analysis of reaction. Likewise, a strip of electrodes may be placed on spatially distant cortex to monitor induction of seizure activity. Procedurally, stimulation should start at suspected motor cortex, beginning at a low-intensity signal and increasing stepwise by approximately 1 mA until movement is observed. This signal strength should subsequently be used for further stimulation. Each area should be stimulated at least three times, for a duration of 1–2 msec. The probe should then be moved to adjacent exposed areas within 5 mm of its previous location. An area should not be repeatedly stimulated: a small marker may be placed to indicate an area where a positive reaction has been elicited, both for documentation and for subsequent avoidance.

Once motor mapping has been completed, and depending on whether the patient is awake or under general anaesthesia, other faculties can be assessed. For awake patients, cognitive and language tasks may be assessed by an allied health professional during surgery; ideally, this should be a neuropsychologist who has previously evaluated the patient. For these tasks, stimulation should begin prior to the task so that deficits may be classified as present or absent; a longer stimulus duration (3–4 seconds) is usually required. For subcortical stimulation, white matter tracts may be mapped by using a combination of anatomical knowledge and the geographical relationship of the tract in question to the overlying cortex. A higher current is usually required for subcortical mapping; 2 mA current increments are recommended.
**Tips and Anatomical Hazards**

All preoperative adjuncts, including tractography, should be interpreted against a sound neuroanatomical background. Posterosuperior aspects of resection in insular gliomas risk injury to the internal capsule and potential motor deficit. The most laterally placed lenticulostriate branches coming off the $M_1$ (or $M_2$) guide the medial limit of resection of insular gliomas.
References

1. What one of the following best describes the relationship of the superior longitudinal fasciculus (SLF) to the arcuate fasciculus (AF) and which areas are connected by the SLF and AF?
   A. Superficial; frontotemporal (SLF), frontoparietal (AF)
   B. Deep; frontotemporal (SLF), frontoparietal (AF)
   C. Superficial; frontotemporal (AF), frontoparietal (SLF)
   
   **Answer: C.**

2. From lateral to medial, in what order are the extreme capsule, claustrum, external capsule and lentiform nucleus encountered when viewed in an axial cross-section’?
   A. Extreme capsule, claustrum, external capsule and lentiform nucleus
   B. Extreme capsule, external capsule, claustrum and lentiform nucleus
   C. Extreme capsule, lentiform nucleus, external capsule and claustrum
   
   **Answer: A.**

3. Which one of the following fibre systems separates the optic radiation from the lateral ventricular wall?
   A. Superior longitudinal fasciculus
   B. Inferior fronto-occipital fasciculus
   C. Tapetum
   
   **Answer: C.**

4. During resection of an insular tumour, resection of which one of the following margins exposes the patient to the highest risk of a
postoperative motor deficit?
A. Anteroinferior
B. Posteromedial
C. Posterosuperior

Answer: C.
Clinical cases

1. A 26-year-old male presented to the accident and emergency department after experiencing new onset of generalized tonic–clonic seizures. Subsequent contrast MRI of his head demonstrated a large, non-enhancing, 7 cm diameter mass involving the medial left frontal lobe, with inferior extension into the lateral ventricle. Neuroimaging of the tumour was compatible with a low-grade glioma originating from the left supplementary motor area that had invaded the adjacent left cingulum and corpus callosum. He underwent an awake left frontal craniotomy and microsurgical tumour resection. Resection was limited posteriorly by the motor cortex and corticospinal tract, which were accurately identified with intraoperative electrical cortical and subcortical mapping techniques. It was also limited deep, posteriorly and laterally by the arcuate tract, similarly identified using subcortical mapping, and this caused naming difficulties. A small portion of residual tumour was left in these areas to protect motor and speech functions, achieving a resection of more than 95%. Postoperatively, the patient was found to have mild expressive dysphasia and severe right-sided weakness requiring discharge to an inpatient rehabilitation facility; this was compatible with a supplementary motor syndrome, given the absence of stroke or corticospinal tract injury. Two weeks postoperatively, he was found to have regained most of his strength with near-complete resolution of his naming difficulties. He had a completely normal neurological and neuropsychological examination at his 3-month postoperative visit. Pathology demonstrated a diffuse World Health Organization (WHO) grade II glioma.

A. Fig. 25.5A is an axial T2 FLAIR image of the patient. What does it show?
FIG. 25.5  A, An axial T2 FLAIR image of the patient described in Clinical case 1. A large hyperintense lesion with cystic areas representing a large left frontoparietal tumour is seen with significant mass effect. B, A sagittal T1 FLAIR image of the same patient: further mass effect is apparent and the tumour is compressing the corpus callosum and lateral ventricle. C, A sagittal view demonstrating a left hemispheric tumour (pink) displacing the frontal aslant tract (light blue), cingulum
A large hyperintense lesion with cystic areas representing a large left frontoparietal tumour with significant mass effect.

**B. Fig. 25.5B** is a sagittal T1 FLAIR image of the same patient. What does it show?

Further mass effect is apparent; the tumour is compressing the corpus callosum and lateral ventricle.

**C. Fig. 25.5C** is a sagittal view demonstrating a left hemispheric tumour (pink) displacing the frontal aslant tract (light blue), corticospinal tract (purple), arcuate fasciculus (red) and superior longitudinal fasciculus (orange) and **Fig. 25.5D** is an axial view demonstrating both hemispheres. Tumour is apparent in the left hemisphere with associated displacement of the tracts. Is the orientation of the tracts in the right hemisphere normal?

Yes, the orientation of the tracts that can be seen in the right hemisphere is normal.

**Fig. 25.5E** shows a posterior para-axial view of both hemispheres, with the tumour shaded out (black area in the middle). Extreme displacement of the left cingulate bundle is noted, which is shifted across the midline by mass effect. **Fig. 25.5F** shows a postoperative sagittal view of the left hemisphere showing reconstitution of the tracts to their normal anatomical locations following removal of the space-occupying lesion.

2. A 41-year-old female presented to the neurosurgical clinic after experiencing long-standing headaches of increasing severity associated with left upper-extremity incoordination and weakness. She also experienced a range of non-specific symptoms, including fatigue, nausea, dysphagia, lower-extremity swelling, excessive thirst, dizziness and depressed mood.

A T2 MRI sequence demonstrated that the hyperintense mass within the right insula extended into the right temporal pole and fronto-orbital opercula, suspicious for a low-grade glioma. The lesion had been followed with imaging studies for 2 years, showing evidence of
tumour expansion. The patient underwent an image-guided right frontotemporal craniotomy, with microsurgical resection of the tumour. As the tumour extended into the anterior temporal lobe, a right anteromedial temporal lobectomy was performed, followed by Sylvian fissure opening for accessing the superior and posterior aspects of the tumour. A complete tumour resection was achieved, with no surgical complications. Pathology demonstrated a WHO grade II gemistocytic astrocytoma.

A. **Fig. 25.6A** is a coronal T2 FLAIR image of the patient. What does it show?
FIG. 25.6  **A**, A coronal T2 FLAIR image of the patient in Clinical case 2. A hyperintense lesion representative of an infiltrative glioma is visible in the right insular region.  **B**, An axial T2 FLAIR image. A hyperintense lesion representative of an infiltrative glioma is visible within the right insular region.  **C**, A sagittal view demonstrating the right hemispheric insular tumour (pink) which is infiltrating the ventral external capsular tracts (inferior fronto-occipital (green) and uncinate (blue)), and displacing the inferior longitudinal fasciculus (yellow) and claustroro-cortical fibres (pale khaki) (see Fig. 25.1B for a comparison).  **D**, A postoperative sagittal view demonstrating the missing central, ventral external capsular portion of the inferior fronto-occipital fasciculus with intact frontal and posterior continuations.

A hyperintense lesion suggesting an infiltrative glioma in the right insular region.

**B. Fig. 25.6B** is an axial T2 FLAIR image of the same patient. What does it show?

The tumour extends into the right temporal pole and fronto-orbital opercula.

**C. Fig. 25.6C** is a sagittal view demonstrating the right hemispheric insular
tumour (pink) which is infiltrating the ventral external capsular tracts (inferior fronto-occipital (green) and uncinate (blue)), and displacing the inferior longitudinal fasciculus (yellow) and claustr-o-cortical fibres (pale khaki) (see Fig. 25.1B for a comparison). **Fig. 25.6D** is a postoperative sagittal view. What does it demonstrate?

The central, ventral external capsular portion of the inferior fronto-occipital fasciculus is missing but the frontal and posterior continuations are intact.

3. A 52-year-old male experienced a generalized tonic–clonic seizure requiring emergency intubation. Contrast MRI demonstrated a left hippocampal mass that extended across all three segments of the medial temporal lobe.

A. **Fig. 25.7A** is an axial T1 image of the patient. What does it show?

A space-occupying lesion core surrounded by vasogenic oedema in the left mesial temporal region.
FIG. 25.7  A, An axial T1 image of the patient described in Clinical case 3. In the left mesial temporal region, a space-occupying lesion core is surrounded by vasogenic oedema. B, A coronal T2 FLAIR shows a hyperintense lesion representative of a tumour compressing brainstem structures. C, A pre-operative sagittal view of a left medial temporal lobe tumour (pink) displacing the arcuate (red), inferior fronto-occipital (green) and uncinate (blue) fasciculi. D, A postoperative sagittal view of the
B. **Fig. 25.7B** is a coronal T2 FLAIR image of the patient. **What does it show?**

A hyperintense lesion representative of a tumour compressing brainstem structures.

Preoperative neuropsychological testing revealed generally intact verbal, visuospatial, language, attention and memory tasks, with a notable weakness in verbal recognition. A two-stage operation was planned. First, a left-sided image-guided fronto-temporal craniotomy was performed. A microsurgical trans-sylvian approach via the inferior insular sulcus was employed to remove the anterior and middle portions of his left hippocampal tumour. Prior to discharge, examination was notable for mild receptive dysphasia and right upper quadrantanopia. Pathology revealed WHO grade II astrocytoma. Eight weeks later, he underwent a supracerebellar transtentorial approach in a sitting position to remove the posterior portion of the hippocampal tumour; complete tumour resection was achieved. At the 6-month follow-up he had no neuropsychological deficits and no further seizures, but did have a persistent right superior quadrantanopia.

4. **Fig. 25.7C** is a preoperative sagittal view of a left medial temporal lobe tumour (pink) displacing the arcuate (red), inferior fronto-occipital (green) and uncinate (blue) fasciculi. **Fig. 25.7D** is a postoperative sagittal view of the same patient.

A. **What does it show?**

Reconstitution of arcuate (red), inferior fronto-occipital (green) and uncinate (blue) fasciculi to their correct orientation.
Core procedures

- Open approaches to the anterior circulation
- Open approaches to the posterior circulation
- Endovascular approaches to the anterior and posterior circulation

Many vascular lesions (such as aneurysms) are approached via an endovascular route. Open surgery is more frequently performed for tumour resection, epilepsy and microvascular decompression of the trigeminal nerve rather than for aneurysm clipping.
Embryology

Embryological variants of cerebral vascular anatomy are commonly encountered and appear to be associated with an increased incidence of vascular pathology, probably as a result of increased flow. Variants include a persistent fetal posterior communicating artery supplying the posterior cerebral artery, occurring in approximately 20% of the population,\(^1\) and much rarer persistent primitive communications between the carotid and basilar circulation in the form of a trigeminal artery,\(^2\) an otic artery,\(^3\) a hypoglossal artery\(^4\) or a proatlantal intersegmental artery.\(^3\) Embryological variants of the anterior cerebral artery include a solitary azygos A\(_2\) segment.\(^5\)
Surgical surface anatomy

The pterional approach is most frequently used to access the anterior circulation. This is performed via a curvilinear incision from the pretragal region to the upper forehead behind the hairline. The pretragal access enables visualization of the superior aspect of the zygomatic arch, permitting the inclusion of the lower temporal bone in the craniotomy flap. This provides good visualization of the Sylvian fissure. Superiorly, the scalp flap must be retracted to enable visualization of the readily palpable frontozygomatic process.

For posterior fossa approaches, the occipital protuberance indicates the level of the confluence of the venous sinuses. A posterior extension of the level of the zygomatic arch provides a marker for the level of the transverse sinus. The spinous process of the second cervical vertebra is readily palpable. Landmarks for lateral approaches to the foramen magnum are considered in Chapter 23. The lateral mass of the first cervical vertebra is usually palpable in this approach.
Clinical anatomy

Arterial supply

The cranial compartment is supplied by paired internal carotid arteries (ICA) feeding the anterior circulation and paired vertebral arteries (VA) supplying the posterior circulation. Considerable individual variability in the circulation exists and there are many well-described anatomical variants. The anterior and posterior circulations both contribute to the circulus arteriosus (circle of Willis), lying in the basal cisterns and giving rise to the anterior, middle and posterior cerebral arteries (Figs 26.1 and 26.2).

FIG. 26.1 Arteries of the base of the brain. The left temporal pole has been removed to show the middle cerebral artery. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 19.2.)
Anterior circulation

Extradural internal carotid artery (segments C1–C3)
The ICA is a terminal branch of the common carotid artery (CCA), which
arises from the aortic arch on the left and the brachiocephalic trunk on the right. The ICA, described using the Gibo/Rhoton classification, is divided into four main parts: C1–C4, which are referenced to enable accurate locations of pathological lesions. The C1 (cervical) segment arises at the bifurcation of the CCA at the level of the third cervical vertebra, giving rise to the carotid sinus soon after its origin. The artery ascends within the anterior triangle of the neck, passing deep to the parotid gland, hypoglossal nerve, digastic muscle and structures attached to the styloid process, and posterior to the pharyngeal branch of the vagus nerve and the glossopharyngeal nerve; these structures are all at risk during exposure of the vessel in the neck. It then enters the carotid canal within the petrous temporal bone, where it is referred to as the C2 (petrous) segment. It ascends for a short distance, separated by a thin film of lamellar bone from the tympanic cavity (middle ear) and the cochlea posteriorly, and then turns anteromedially toward the non-patent foramen lacerum. As the artery enters the horizontal portion of the canal, it lies caudal to the floor of the trigeminal ganglion (Gasserian ganglion, Meckel's cave). This is often deficient, in which case the artery is separated from the trigeminal ganglion by a thin fibrous membrane. The C2 segment gives rise to the Vidian artery (artery of the pterygoid canal) and the carotico tympanic artery. As it crosses under the petrolingual ligament, the C2 segment enters the cavernous sinus, which envelops the C3 (cavernous) segment. It ascends towards the posterior clinoid process, before turning in an anterior direction within the sinus. The C3 segment gives rise to the meningohypophysial trunk, the inferolateral trunk and the medial trunk. The meningohypophysial trunk further divides into the tentorial artery of Bernasconi and Cassinari, which supplies the tentorium; the inferior hypophysial artery, which supplies the neurohypophysis; and the dorsal meningeal artery, which supplies part of the clivus and the abducens nerve.

The ICA next ascends at the level of the anterior clinoid process, passing medial to it and through the proximal and distal dural rings. The transitional stage between the proximal and distal rings, referred to as the clinoidal segment in the modified Fischer/Bouthillier classification, is clinically relevant because aneurysms arising here are not intradural and do not give rise to subarachnoid haemorrhage. As the artery passes through the distal ring it becomes intradural and is referred to as the C4 (supraclinoid) segment.

**Intradural internal carotid artery (segment C4)**
The carotid cistern contains the C4 (supraclinoid) segment of the ICA. This cistern lies immediately inferior to the anterior perforated substance, which is delineated anteriorly by the medial and lateral olfactory striae arising from the olfactory tract; this serves as a useful surgical landmark. As the vessel emerges from the distal dural ring, it projects posteriorly, coursing in a parallel trajectory to the C3 segment, to produce a loop referred to as the carotid siphon. The supraclinoid segment is further subdivided into three parts: ophthalmic, communicating and choroidal, based on the origin of its major branches.

The ophthalmic segment extends from the origin of the supraclinoid ICA to the origin of the posterior communicating artery (PComm); it gives off the ophthalmic artery, just distal to the distal dural ring, usually from the medial third of the superior surface of the ICA, and the superior hypophysial artery. The ophthalmic artery follows the inferior surface of the optic nerve into the optic canal and orbit. Variants can arise from the clinoidal or cavernous segments and, rarely, from the external carotid artery. Perforating arteries from this segment supply the pituitary stalk, optic chiasma/tract and the preمامillary portion of the third ventricle. The communicating segment extends from the origin of the PComm artery to the origin of the anterior choroidal artery. The PComm artery usually arises on the posteromedial aspect of C4 and courses posteromedially to the posterior cerebral artery. If the fetal variant persists, the artery often takes a course lateral to the oculomotor nerve, supplying the posterior cerebral artery. This segment often does not give rise to perforators (60%); when present, perforators have the same distribution as those in the ophthalmic segment and may perforate the anterior and posterior perforated substances. The choroidal segment runs from the origin of the anterior choroidal artery to the terminal bifurcation of the ICA. The anterior choroidal artery usually arises from the posterolateral aspect of the ICA and runs posteromedially, crossing inferior to the optic tract from lateral to medial, to reach the lateral aspect of the cerebral peduncles. At the lateral geniculate nucleus, it turns laterally and then continues superior to the uncus to enter the choroidal fissure. This is the most common site of origin of perforators from the ICA, typically from the posterior aspect of the vessel; they supply the anterior perforated substance, optic tract and uncus. Anterior perforated substance perforators supply both limbs and genu of the internal capsule, the basal ganglia and the anterior portion of the thalamus. Apart from direct perforators arising from the ICA, contributions also arise from the anterior choroidal, middle cerebral and
anterior cerebral vessels.

**Middle cerebral artery**

The middle cerebral artery (MCA) is the largest of the terminal divisions of the ICA and lies in the Sylvian fissure. It consists of four principal segments, M1–M4, which are described in relation to the adjacent anatomical structures. Knowledge of this anatomy is required when clipping MCA aneurysms and undertaking resection of tumours in the insula.

The M1 (sphenoidal) segment extends from the ICA bifurcation to the limen insulae, the most anterior aspect of the insular cortex. M1 runs laterally, about 9 mm posterior to the sphenoidal wing, inferior to the anterior perforated substance, and gives off several lateral lenticulostriate arteries and temporal polar branches. The lenticulostriate vessels penetrate the anterior perforated substance to supply the anterior limb, genu and posterior limb of the internal capsule; they need to be preserved in aneurysm surgery and represent the medial extent of insular tumour resection. The M1 segment usually bifurcates proximal to the limen; the bifurcation can be equal or asymmetric. A temporal branch often arises from the M1 prior to its bifurcation. At the limen, the two trunks of the MCA are referred to as the M2 (insular) segments. They course over the insular surface, giving rise to anterior and posterior cortical branches. On reaching the circular sulcus, the arteries enter the M3 (opercular) segment, where branches are closely adherent to the frontoparietal and temporal operculae. The M3 vessels emerge at the surface of the Sylvian fissure, where they become the M4 (cortical) segments. Arteries projecting to the frontoparietal cortex exhibit two 180° bends, at the circular sulcus and at the cortical surface of the operculum; these are visible on anteroposterior angiographic projections. The largest M4 vessels supply the temporo-occipital and angular regions, and make effective targets for extracranial–intracranial (EC–IC) bypass (Fig. 26.3).
Anterior cerebral artery

The anterior cerebral artery (ACA) arises from the supraclinoid ICA bifurcation in the carotid cistern. Using Fischer's classification scheme, the ACA is divided into five segments.\(^{10}\) The A1 (precommunicating) segment projects anteromedially towards the lamina terminalis cistern, lying above the optic nerve/chiasma and inferior to the medial olfactory striae. Short A1 segments are closely opposed to the optic apparatus, whereas longer vessels tend to be tortuous. Hypoplasia of this segment is common and is associated with the development of anterior communicating artery (AComm) aneurysms. Medial lenticulostriate perforating arteries arise from the proximal half of A1 and course posterosuperiorly towards the anterior perforated substance, supplying the optic apparatus, anterior segment of the globus pallidus and the genu, and, less frequently, the posterior limb of the internal capsule. The paired ACAs converge in the interhemispheric fissure, where they are connected by the AComm, just superior to the optic chiasma in the majority of cases. Embryologically, the AComm arises from the coalescence of a vascular plexus, which can give rise to duplications or
triplications. The calibre of the AComm is related to the difference in diameters between the paired A1 segments. Perforators from the AComm arise from its posteroinferior aspect and supply the infundibulum, optic chiasma, anterior perforated substance, subcallosal area and preoptic nucleus of the hypothalamus. Rarely, a solitary median (azygos) ACA circulation persists. Distal to the AComm, the ACA continues as the pericallosal artery. The A2 (infracallosal) segment extends from this point to the junction between the rostrum and genu of the corpus callosum. The orbitofrontal and frontopolar arteries typically arise from this segment. The orbitofrontal artery is the first cortical branch of the ACA and supplies the gyrus rectus, olfactory tract and medial aspect of the orbitofrontal cortex. The frontopolar artery passes anteriorly in the interhemispheric fissure to supply medial and some lateral aspects of the frontal lobe. Perforators from this segment pass posteriorly to supply the optic chiasma, lamina terminalis, anterior forebrain, anterior commissure, columns of the fornix, septum pellucidum and the anteroinferior part of the striatum.

The recurrent artery of Heubner almost always arises from the proximal A2. The vessel backtracks along the anterior aspect of the ACA towards the anterior perforated substance, where it supplies the head of the caudate nucleus, the putamen and parts of the anterior limb of the internal capsule. En route, it passes superior to the terminal carotid to accompany the MCA in the medial aspect of the Sylvian fissure. The artery is vulnerable to injury during aneurysm surgery. The callosomarginal branch of the A2 extends from its origin in the region of the genu to run along the cingulate sulcus. Some authors define only the segment of the ACA distal to the origin of the callosomarginal artery as the pericallosal artery; however, the simplified approach described here, proposed by Rhoton, does away with the confusion associated with the variability in the site of origin and occasional absence of the callosomarginal artery. The A3 (precalscalos) segment extends to a sharp bend on the superior surface of the genu, continuing over the corpus callosum as the A4 (supracallosal) segment and subsequently as the A5 (postcallosal) segment after a virtual plane arising at the coronal suture (Fig. 26.4).
Vertebrobasilar circulation

Vertebral artery (segments V1–V4)

The vertebral artery arises as the first branch of the subclavian artery\(^{12}\) (Chs 19, 31). The V1 (preforaminal, extraosseous) segment passes posteromedially through the triangle bordered by longus colli medially, scalenus anterior laterally and the subclavian artery inferiorly, towards the foramen transversarium of the sixth cervical vertebra. It lies posterior to the carotid artery and anterior to the transverse process of the seventh cervical vertebra and the inferior cervical ganglion. The V2 (foraminal) segment ascends through the foramina transversaria of the sixth to the second cervical vertebrae. As the artery emerges from the laterally projecting foramen of the second cervical vertebra, it becomes the V3 (extradural, extraspinal) segment. This continues vertically through the foramen transversarium of the first cervical vertebra (atlas), lateral to the superior articular process, where it turns posteriorly along the lateral aspect of the superior articular process. It turns medially through a groove on the posterior arch of the atlas and then
turns anteriorly to pierce the atlanto-occipital membrane and enter the vertebral canal. The posterior aspect of the V3 segment must be avoided in posterior fossa approaches. The V4 (intradural) segment continues in an anterosuperior course to meet its contralateral counterpart at the pontomedullary junction, forming the basilar artery. V4 lies anterior to the hypoglossal root and the roots of the first cervical spinal nerve, and inferior to the first dentate ligament.

The vertebral artery gives off an anterior spinal artery and paired posterior spinal arteries. The anterior spinal artery courses inferiorly on the anterior surface of the spinal cord, adjacent to the ventral median fissure. Although the vessel arises intracranially, this contribution to the vessel is rarely dominant: the cervical cord is mainly supplied via segmental radiculomedullary branches of the V2 segment, which anastomose with the anterior spinal artery. The posterior (or lateral) spinal artery arises from the extra- or intradural vertebral artery. Once within the subarachnoid space, the vessel courses posterior to the dentate ligament and close to the rootlets of the spinal accessory nerve. It eventually bifurcates into ascending and descending branches. Rarely, the posterior spinal artery may arise from the posterior inferior cerebellar artery.

**Basilar artery**
The basilar artery arises at the convergence of the paired vertebral arteries at the pontomedullary junction. It travels superiorly, in a median/paramedian plane, posterior to the clivus and anterior to the pons, and terminates near the pontomesencephalic junction. Medial perforators arise from the posterior aspect of the artery and enter the pons; circumflex perforators circumscribe the pons prior to terminating within it. Named branches of the basilar artery include the anterior inferior cerebellar artery, the superior cerebellar artery and the posterior cerebral artery. The artery to the internal auditory canal usually arises from the anterior inferior cerebellar artery but occasionally comes off as a direct branch of the basilar artery.

**Posterior inferior cerebellar artery**
The posterior inferior cerebellar artery (PICA) has the most tortuous, complex and variable path of all the posterior fossa vessels. Typically, it arises as the largest branch of the intradural segment of the vertebral artery (V4), adjacent to the inferior olivary nucleus, but it may arise anywhere from the
vertebrobasilar junction to the extradural vertebral artery.\textsuperscript{13} It has five segments: anterior, lateral and posterior medullary, supratonsillar and cortical.\textsuperscript{14} The anterior medullary segment starts at the origin at the vessel, anterior to the medulla, and extends posteriorly, closely related to the hypoglossal rootlets, to reach the most prominent part of the inferior olivary nucleus. This segment might be absent if the vessel arises lateral to the medulla. The PICA then continues posteriorly as the lateral medullary segment, which is closely related to the rootlets of cranial nerves IX, X and XI. On passing posterior to these rootlets, the posterior medullary (tonsillomedullary) segment begins. It circumscribes the medulla, lying posterior to it before continuing posteriorly between the medulla and the tonsil to reach the medial aspect of the inferior pole of the cerebellar tonsil. Here it often forms a caudal loop that may reach the foramen magnum. It then courses superiorly, reaching the midpoint of the medial surface of the tonsil, where the telovelar (supratonsillar) segment begins. The artery continues superomedially until it reaches the central part of the inferior medullary velum, where it turns inferiorly and medially between the vermis and the tonsil, giving rise to a rostral loop, also known as the choroidal point or cranial loop. Branches distal to this point no longer supply the brainstem. The cortical segment radiates over the posteroinferior aspect of the cerebellum. The PICA often bifurcates in the region of the termination of the telovelar segment into a primary lateral trunk and a smaller medial trunk (\textbf{Fig. 26.5}).
Anterior inferior cerebellar artery

The anterior inferior cerebellar artery (AICA) arises from the lower half of the basilar artery, most often as a common trunk with rostral and caudal bifurcations, usually at a point proximal to the facial/vestibulocochlear nerve complex in the cerebellopontine angle. The AICA is divided into four segments: anterior and lateral pontine, flocculopeduncular and cortical. The anterior pontine segment lies in the prepontine cistern and is often related to the abducens nerve at its origin in the pontomesencephalic sulcus. The lateral pontine segment begins at the anterolateral aspect of the pons and courses towards the cerebellopontine angle, where it becomes intimately related to the facial and vestibulocochlear nerves. Here it is also related to the lateral recess and the foramina of Luschka, as well as the internal auditory canal, which further divides the vessel into premeatal, meatal and postmeatal parts. The lateral pontine segment produces a number of branches, including the labyrinthine artery, recurrent perforating arteries and the subarcuate artery. The flocculopeduncular segment begins when the lateral pontine segment passes superior or inferior to the flocculus to reach
the middle cerebellar peduncle. Distally, this continues as the cortical segment, which predominantly supplies the petrosal surface of the cerebellar hemisphere.

**Superior cerebellar artery**

The superior cerebellar artery (SCA) is the most constant of the cerebellar arteries, arising as a common trunk from the basilar artery apex anterior to the midbrain and inferior to the origin of the posterior cerebral artery. It lies inferior to the oculomotor nerve and bifurcates into rostral and caudal branches. The SCA is divided into four segments: anterior and lateral pontomesencephalic, cerebellomesencephalic and cortical.\(^{15}\) The anterior pontomesencephalic segment extends from the origin of the vessel, posterior to the dorsum sellae, to the anterolateral margin of the brainstem. It lies inferior to the oculomotor nerve, although the vessel can occasionally arise from the posterior cerebral artery and run superior to the nerve. This segment and, usually, the proximal portion of the second segment are supratentorial. The lateral pontomesencephalic (ambient) segment loops caudally to lie lateral to the pons; the caudal loop often reaches the root entry zone of the trigeminal nerve, where the vessel enters the cerebellomesencephalic fissure and becomes the cerebellomesencephalic (quadrigeminal) segment. A common trunk, when present, often bifurcates closest to the point of maximal caudal descent. The trochlear nerve, posterior cerebral artery and basal vein lie superior to this segment. As the vessel emerges on to the tentorial surface of the cerebellum, the cortical segment starts.

**Posterior cerebral artery**

The terminal bifurcation of the basilar artery in the interpeduncular cistern gives rise to the posterior cerebral arteries. The posterior cerebral artery (PCA) is divided into four segments: P1–P4.\(^{16}\) The P1 (precommunicating) segment arises from the basilar artery and gives off thalamoperforating arteries, which pass into the posterior perforating substance and supply a number of deep-seated nuclei, including the thalamus, subthalamus, substantia nigra, red nucleus, oculomotor nerve nucleus and the posterior limb of the internal capsule. Other branches also supply the cerebral peduncles and mesencephalic tegmentum and tectum. Embryologically, the PCA arises from the supraclinoid ICA as a continuation of what becomes the
PComm artery. Before birth, the supply is taken over by the basilar artery in 80% of hemispheres. However, a fetal distribution persists in 20% of hemispheres, in which case the P1 segment has a smaller calibre than the PComm artery.

The P2 (postcommunicating) segment runs from the junction of the PComm artery to the posterior edge of the mesencephalon, lying in the crural and ambient cisterns. The P2A (anterior) subsegment courses superior and medial to the tentorial edge and the trochlear nerve, circumscribing the cerebral peduncle and running in the interpeduncular and crural cisterns. Throughout its course, it lies inferior to the optic tract, basal vein and anterior choroidal artery, medial to the uncus. It gives rise to perforators to the crus cerebri. The P2P (posterior) subsegment continues into the ambient cistern, ending at the posterior aspect of the midbrain. The P2 segment gives rise to a number of inferior temporal arteries as well as two posterior choroidal arteries. The medial choroidal artery arises from the P2A segment, passing above the pineal gland to enter the velum interpositum and the roof of the third ventricle, supplying the choroid plexus through to the lateral ventricles. The P2P gives rise to the lateral choroidal artery which, together with the anterior choroidal artery, enters the atrium of the lateral ventricle through the choroidal fissure.

The P3 (quadrigeminal) segment begins in the quadrigeminal cistern under the pulvinar of the thalamus and ends at the anterior limit of the calcarine sulcus. In the majority of cases, the artery divides into the calcarine and parieto-occipital arteries prior to reaching the calcarine sulcus. The P4 (cortical) segment refers to the cortical branches of the PCA (Fig. 26.6).
Venous drainage

Knowledge of venous anatomy is key when undertaking any craniotomy procedure, particularly for pathology located near the venous sinuses. Venous anatomy is crucial to the safe conduct of intraventricular operations. Venous anatomy is also relevant when considering the spread of intracranial infection.

Intracranial venous anatomy is complex and variable, possessing frequent anastomotic connections; it can be a major hindrance in approaching deep-seated pathology. Notwithstanding this connectivity, injury can lead to severe morbidity. Knowledge of the venous structures is extremely important in providing helpful intraoperative landmarks, particularly in the ventricles. The anatomy of this system can be described in two major divisions: a superficial and a deep group.\textsuperscript{17}

**Superficial group**

The superficial group can be subdivided into superior and inferior groups,
which collectively drain the cortical surfaces of the hemispheres and consist of a combination of veins in the pia–arachnoid layers and in the dural venous sinuses between the periosteal and meningeal layers of dura mater.

**Superior group**
The superior group is illustrated in **Fig. 26.7**.

![Diagram](image)

**FIG. 26.7** The cerebral venous system, showing the principal superficial and deep veins of the brain and their relationship to the dural venous sinuses, viewed from the left side. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 19.11.)

The superior sagittal sinus is the largest of the dural venous sinuses. It runs from the foramen caecum, just anterior to the crista galli on the anterior cranial fossa floor, along the attachment of the falx cerebri to the cranial vault, to the confluence of the sinuses, where the falx cerebri and tentorium cerebelli meet. Blood then drains into the transverse sinus through a venous confluence (torcular Herophili), with the flow predominantly directed towards the right transverse sinus. Bridging veins connecting cortical veins to the sinus are least common in the frontal region anterior to a vertical plane from the genu of the corpus callosum. It is therefore considered generally safe to occlude the sinus at a point anterior to the coronal suture, without a significant risk of venous infarction. These bridging veins are often found to
be adherent to the lateral wall of the sinus prior to joining it, with longer adherent sections in the more posterior vessels. The sinus also possesses intradural venous spaces (lacunae) lateral to it, which extend laterally over the convexity. The largest lacunae are usually located in the posterior frontal and parietal regions, occasionally extending up to 3 cm from the midline. Cortical veins do not typically drain into these lacunae but course inferior to them to reach the sinus, and therefore they are usually safe to occlude. Projections of arachnoid cells, referred to as arachnoid granulations, are often present within the lacunae and are thought to play a role in cerebrospinal fluid haemostasis. The superior sagittal sinus drains cortical veins derived from the superior aspects of the frontal, parietal and occipital lobes.

The inferior sagittal sinus drains the deep medial aspect of the cortex, primarily pertaining to the limbic lobe. It starts superior to the genu of the corpus callosum, running posteriorly in the free edge of the falx, to terminate in the straight sinus posteriorly. Runoff from the inferior sagittal sinus continues into the straight sinus.

The straight sinus arises from the confluence of the inferior sagittal sinus and the great vein of Galen at the midpoint of the free edge of the tentorium cerebelli. It continues posteriorly towards the internal occipital protuberance and drains through the torcular Herophili/confluence of the sinuses, predominantly into the left transverse sinus.

The transverse sinus arises where the tentorium attaches to the cranial vault at the internal occipital protuberance. From here, it follows the tentorial attachment laterally, to continue as the sigmoid sinus as it joins the superior petrosal sinus behind the petrous ridge. The calibre of the paired transverse sinuses is often asymmetrical; the right one typically drains the superior sagittal sinus and is usually the larger. Partial or complete agenesis of one transverse sinus occurs in approximately 20% of cases.

The sigmoid sinus starts at the junction of the transverse and superior petrosal sinuses, and runs in a sinusoidal groove on the posterior aspect of the mastoid until it reaches the posterolateral aspect of the jugular foramen (pars vascularis), where it drains into the jugular bulb and then into the internal jugular vein. The right jugular bulb is usually larger than the left and the jugular bulb can rise above the level of the internal acoustic canal to become ‘high-riding’: these are important variations to be aware of during surgery.

Veins draining the lateral and basal aspect of the temporal and occipital
lobes tend to descend, draining either into tentorial sinuses or directly into the transverse and superior petrosal sinuses. The tentorial sinuses are asymmetrical vascular channels within the tentorium that drain medially into the straight sinus and laterally into the transverse sinuses.

**Inferior group**

The inferior group is illustrated in Fig. 26.7.

The cavernous sinuses are interconnected, paired sinuses on either side of the sella turcica. The ophthalmic veins and sphenoparietal sinuses drain into the anterior aspect of the cavernous sinuses. Venous drainage continues through the posterior aspect via superior and inferior petrosal sinuses and a basilar sinus. The superior petrosal sinus runs along the tentorial attachment to the petrous ridge into the junction between the transverse and sigmoid sinuses. *En route*, it is closely related to the posterior root of the trigeminal nerve and receives a number of bridging veins arising from the cerebellum and brainstem, referred to as the superior petrosal veins of Dandy: these are often visualized and may limit access in retrosigmoid approaches. The inferior petrosal sinus runs in the corresponding inferior petrosal sulcus between the petrous temporal bone and the clival part of the occipital bone, to join the sigmoid sinus at the jugular foramen and contribute to the formation of the internal jugular vein.

The cortex adjacent to the Sylvian fissure drains towards the superficial Sylvian vein, which courses along the fissure. It drains predominantly towards the sphenoparietal sinus (sinus of Breschet), which is situated just inferior to the sphenoid ridge. In its distal course above the pterion, it is accompanied by the anterior branch of the middle meningeal artery, and as it courses proximally, it drains into the anterior aspect of the cavernous sinus. In view of the temporal direction of the venous drainage, a superficial Sylvian split is usually performed on the frontal aspect of the Sylvian vein to preserve its drainage. When this sinus is poorly developed, the superficial Sylvian vein can occasionally drain directly into the cavernous sinus or, less commonly, into sphenobasal and sphenopetrosal sinuses.

Anastomoses between cortical veins and sinuses are frequent and variable. Three veins, the superior and inferior anastomotic veins and the superficial Sylvian vein, are large and relatively constant. The superior anastomotic vein (vein of Trolard) is defined as the largest cortical vein connecting the aforementioned superficial Sylvian vein to the superior sagittal sinus and typically runs across or adjacent to the central lobe. Conversely, the inferior
anastomotic vein (vein of Labbé) is the largest vessel that bridges between the superficial Sylvian vein and the transverse sinus. The vessel often arises at the midpoint of the Sylvian vein and courses over the temporal lobe towards the anterior aspect of the ipsilateral transverse sinus. Asymmetry in the calibre of these vessels between contralateral hemispheres is common.

Deep group
The deep group consists of veins that start in the ventricles and cisterns and that eventually coalesce into the basal veins (of Rosenthal), the internal cerebral vein and the great vein (of Galen), and drain primarily into the straight sinus (Fig. 26.8).

![Diagram](image)

**FIG. 26.8** The internal (deep) cerebral veins, viewed from above after removal of the central portion of the corpus callosum. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 19.13.)

Intraventricular group
Detailed intraventricular venous anatomy is reviewed in Chapter 24. Subependymal veins course on both medial and lateral ventricular surfaces and coalesce into prominent named veins prior to their termination either anteriorly into the internal cerebral vein or posteriorly through the choroidal fissure into the basal vein and great vein.

In the frontal horn of the lateral ventricle, the anterior septal vein on the medial wall and the anterior caudate vein on the lateral wall course towards the foramen of Monro. The former terminates in the internal cerebral vein, whereas the latter drains into the thalamostriate vein (TSV). The TSV arises from multiple branches that coalesce on the striothalamic sulcus of the lateral ventricular wall, courses anteromedially towards the foramen of Monro, where it turns acutely posteriorly to enter the velum interpositum, and drains into the internal cerebral vein. The TSV is a very important intraoperative landmark for intraventricular surgery. Other vessels that converge on the foramen of Monro, situated in the body of the ventricle, include the posterior septal veins and the thalamocaudate vein. In the atrium, occipital and temporal horns, multiple small veins drain into either the internal cerebral vein or the basal vein, or their tributaries.

The paired internal cerebral veins course in the roof of the third ventricle, finding their origin at the foramen of Monro and running posteriorly in the velum interpositum. They then pass superior to the pineal gland to exit the third ventricle and enter the quadrigeminal cistern. The two veins unite either superior or posterior to the pineal gland, inferior to the splenium, to form the great vein of Galen.

**Cisternal group**

The cisternal group of veins drain a wide territory at the base of the brain, divided into the anterior, middle and posterior incisural regions. The anterior incisura is located anterior to the brainstem, the middle incisura lies lateral to the brainstem, and the posterior incisura lies posterior to the brainstem.

The paired basal veins (of Rosenthal) start in the anterior incisural region, just inferior to the anterior perforating substance, by the convergence of the deep Sylvian and anterior cerebral veins. At this point, a number of other veins draining the walls of the subcallosal, chiasmatic, carotid, interpeduncular and Sylvian cisterns converge to drain into the basal veins. They then course posteriorly between midbrain and temporal lobe, to enter the middle and posterior incisural regions, and terminate by converging with the internal cerebral or great vein in the quadrigeminal cistern.
In the posterior incisural region, the basal, internal cerebral and great veins, and a number of tributaries, all converge, forming a complex venous network. The tributaries in this region include posteroinferior ventricular veins and cisternal veins that drain the thalamus, midbrain and medial aspect of the occipital lobe.

**Infratentorial venous system**

Three main groups of veins (superior, anterior and posterior) drain structures in the posterior fossa. The superior group drains the superior part of the cerebellar hemispheres, vermis and mesencephalon into the great vein. Tributaries include the precentral cerebellar vein (vein of the cerebellomesencephalic fissure), superior vermian vein and posterior mesencephalic vein (peduncular vein). The anterior group drains the brainstem and the anterior aspect of the cerebellum into the superior and inferior petrosal sinuses. Tributaries of note include the petrosal veins (of Dandy) and the anterior and lateral pontomesencephalic veins. The posterior group drains the posterior aspect of the cerebellum into the tentorially based sinuses, including the straight, tentorial and transverse sinuses. The inferior vermian vein is a major vessel of the group.

**Tips and Anatomical Hazards**

Key points of vulnerability when undertaking surgery in the region of the AComm include damage to the recurrent artery of Heubner. This risk can be minimized by undertaking subpial dissection during exposure of the anatomy (usually an aneurysm).

Preservation of the lenticulostriate perforators is vital during surgery of the insula or during dissection of the MCA.

In the posterior fossa, the close apposition of vessels to the cranial nerves mandates careful tissue handling to avoid postoperative lower cranial nerve palsy.

The basilar artery perforators are sacrosanct and there is a high risk of brainstem infarction if injury occurs.

The posterior cerebral artery needs to be carefully noted during the resection of medial temporal lobe tumours that extend to the medial edge of the tentorium cerebelli.
Preoperative venography is advisable prior to resection of parasagittal meningiomas. This will enable a judgement to be made concerning the extent of sinus occlusion. Surgery in the vicinity of the great vein of Galen is hazardous due to the risk of causing venous infarction. Tumours in this area often develop an arachnoidal capsule that helps the surgeon stay within appropriate tissue planes.
References

11. Perlmutter D, Rhoton AL Jr. Microsurgical anatomy of the


Single Best Answers

1. Which one of the following pairs of sinuses meet at the jugular foramen to give rise to the internal jugular vein?
   A. Superior and inferior petrosal sinuses
   B. Cavernous and sigmoid sinuses
   C. Inferior sagittal and straight sinuses
   D. Inferior petrosal and sigmoid sinuses
   E. Superior petrosal and sigmoid sinuses

   **Answer: D.** The jugular foramen can be divided into three compartments: an anterior compartment containing the inferior petrosal sinus; an intermediate compartment containing cranial nerves IX, X and XI; and a posterior compartment containing the sigmoid sinus and minor meningeal arterial vessels. The inferior petrosal sinus drains into the sigmoid sinus to form the internal jugular vein.

2. Which one of the following segments of the internal carotid artery gives rise to a vessel that supplies the tentorial artery (of Bernasconi and Cassinari)?
   A. Cervical
   B. Petrous
   C. Cavernous
   D. Supraclinoid
   E. None of the above

   **Answer: C.** The cavernous segment of the internal carotid artery gives rise to the meningohypophysial trunk, inferolateral trunk and medial trunk. The meningohypophysial trunk further divides into the tentorial artery of Bernasconi and Cassinari, which supplies the tentorium; the inferior hypophysial artery, which
supplies the neurohypophysis; and the dorsal meningeal artery, which supplies part of the clivus and the abducens nerve.

3. From which one of the following vessels does the recurrent artery of Heubner most commonly arise?
A. M1 segment of the middle cerebral artery
B. P2 segment of the posterior cerebral artery
C. A1 segment of the anterior cerebral artery
D. A2 segment of anterior cerebral artery
E. Superior cerebellar artery

**Answer: D.** The recurrent artery of Heubner typically arises from the proximal component of the A2 segment of the anterior cerebral artery, just distal to the anterior communicating artery. From here, it doubles back sharply to run along the A1 segment towards the anterior perforated substance. Less commonly, it can arise from the distal A1 segment.

4. During exposure of the vertebral artery, which one of the following muscles lies dorsal to the suboccipital triangle?
A. Superior oblique
B. Semispinalis capitis
C. Inferior oblique
D. Rectus capitis posterior major
E. All of the above

**Answer: B.** The suboccipital triangle is bounded by superior oblique (obliquus capitis superior), inferior oblique (obliquus capitis inferior) and rectus capitis posterior major. This triangle contains the V3 segment of the vertebral artery, the dorsal ramus of C1 and a venous plexus. Semispinalis capitis lies dorsal to the triangle.
5. Into which one of the following vessels do the basal veins of Rosenthal most commonly drain?

A. Internal cerebral vein  
B. Sigmoid sinus  
C. Straight sinus  
D. Cavernous sinus  
E. Vein of Galen

**Answer:** E. The basal veins of Rosenthal are paired paramedian veins that arise adjacent to the anterior perforated substance, course posteriorly and usually terminate in the great vein of Galen.
Clinical cases

1. A 50-year-old female with a background of hypertension and smoking was admitted to hospital with a sudden-onset, worst ever headache. This was associated with nausea and vomiting, photophobia and neck stiffness. On examination, her Glasgow Coma Scale score was 14 (E4, V4, M6) with no focal neurological deficits. A CT of the head revealed subarachnoid haemorrhage, predominantly within the basal cisterns and left Sylvian fissure.

A. Which aneurysm does this pattern of blood distribution suggest?
The asymmetrical involvement of the Sylvian fissure, through which the middle cerebral artery travels, is suggestive of a middle cerebral artery aneurysm (Table 26.1).

**TABLE 26.1**

<table>
<thead>
<tr>
<th>Location of heaviest blood load</th>
<th>Likely aneurysm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sylvian fissure</td>
<td>Middle cerebral artery</td>
</tr>
<tr>
<td>Interhemispheric fissure</td>
<td>Anterior communicating artery</td>
</tr>
<tr>
<td></td>
<td>Anterior cerebral artery</td>
</tr>
<tr>
<td>Basal cisterns</td>
<td>Posterior communicating artery</td>
</tr>
<tr>
<td></td>
<td>Basilar artery</td>
</tr>
<tr>
<td></td>
<td>Superior cerebellar artery</td>
</tr>
<tr>
<td>Third ventricle</td>
<td>Anterior communicating artery (through lamina terminalis)</td>
</tr>
<tr>
<td></td>
<td>Basilar artery</td>
</tr>
<tr>
<td>Fourth ventricle</td>
<td>Posterior inferior cerebellar artery</td>
</tr>
<tr>
<td>Perimesencephalic</td>
<td>Posterior circulation aneurysms</td>
</tr>
<tr>
<td></td>
<td>Non-aneurysmal</td>
</tr>
</tbody>
</table>

B. A CT angiogram (Fig. 26.9) was performed as a first-line angiographic investigation to confirm the source of the haemorrhage. Identify the labelled structures.
FIG. 26.9 A three-dimensional reconstruction of a CT angiogram performed for the patient in Clinical case 1, revealing vascular anatomy of the circle of Willis and pathology. (Kindly provided by Dr William Adams, Consultant Neuroradiologist, Derriford Hospital, Plymouth, UK.)

A, anterior cerebral artery – A2 (right); B, anterior cerebral artery – A1 (right); C, supraclinoid internal carotid artery (right); D, posterior cerebral artery – P2 (right); E, basilar artery; F, anterior inferior cerebellar artery (right); G, vertebral artery – intradural, V4 (right); H, middle cerebral artery bifurcation aneurysm (left); I, middle cerebral artery – M2 (left); J, middle cerebral artery – M1 (left).

C. The left middle cerebral artery aneurysm arising at the bifurcation of the parent vessel was not amenable to endovascular treatment. Surgical clipping was performed. After a pterional craniotomy, a proximal-to-distal dissection of the anterior circulation affords early identification of the M1 segment of the middle cerebral artery and proximal control. Which cistern contains the supraclinoid internal cerebral artery?

The carotid cistern, together with the suprachiasmatic cistern and cistern of the lamina terminalis, lies anterior to Liliequist's membrane. It continues laterally into the Sylvian fissure/cistern.

D. What anatomical landmarks are helpful in identifying this artery?

The olfactory nerve, which runs posteriorly in the olfactory sulcus, divides into the medial and lateral olfactory striae. These delineate the anterior perforated substance, which forms the roof of the carotid cistern.

E. The optic nerve and chiasma lie immediately medial to the supraclinoid
internal carotid artery. Name the segments of the supraclinoid internal carotid artery.

Ophthalmic segment, communicating segment and choroidal segment (from proximal to distal).

F. What important vessels arise from the terminal portion of the internal carotid artery and proximal middle cerebral artery, manipulation of which should be avoided during operative clipping?

The lenticulostriate arteries, a collection of small perforating vessels that supply the basal ganglia and the external and internal capsules. In view of their eloquent territory, trauma to these vessels may present with a hemiplegia.

G. An incidental aneurysm was also identified in the cavernous segment of the left internal carotid artery. Could this aneurysm be contributing to the patient’s subarachnoid haemorrhage, and if so, why?

No. Aneurysms within the cavernous segment of the internal carotid artery are anatomically isolated from the subarachnoid space by the dural rings. Therefore, rupture of these aneurysms cannot give rise to subarachnoid haemorrhage.

2. A 48-year-old gentleman presents with new double vision associated with limitation of movements in his left eye and severe left-sided periorbital pain. Examination reveals a dilated left pupil, ptosis and an eye directed laterally and inferiorly.

A. What aneurysms can produce a third cranial nerve palsy and why?

Posterior communicating artery aneurysms are classically associated with painful third cranial nerve palsies. The third cranial nerve exits the anterior aspect of the midbrain within the interpeduncular fossa. As it courses anteriorly towards the posterior aspect of the cavernous sinus, it lies between the posterior cerebral artery and the superior cerebellar artery. In its course, the nerve runs next to the point where the posterior communicating artery arises from the internal carotid artery: this is the point of origin for most posterior communicating artery aneurysms. Given its anatomical course, other aneurysms arising from the superior cerebellar artery, basilar artery bifurcation (basilar tip) and cavernous internal carotid artery can also give rise to a third cranial nerve palsy.

3. A 60-year-old lady is diagnosed with subarachnoid haemorrhage and
undergoes a digital subtraction angiogram. This reveals an anterior communicating artery aneurysm that is amenable to endovascular coiling. The procedure was uneventful. However, 3 days after the procedure, the patient develops a new left hemiparesis, which predominantly affects the lower limb, as well as apraxia and cognitive changes.

A. Ischaemia of which vessel could have caused this weakness?
Delayed ischaemic neurological deficits can be secondary to vasospasm or embolic events arising from complications of endovascular coiling. The anterior cerebral artery supplies the medial and superolateral aspect of the frontal lobe and, to a variable extent, the parietal lobe. This territory involves, among other things, part of the primary motor cortex that is associated with primarily lower limb and pelvic movement. Involvement of the supplementary motor area can give rise to apraxia and speech disturbances. Sensory symptoms corresponding to the territory affected by the weakness can arise due to the involvement of the posterior aspect of the paracentral lobule and anterior superolateral parietal lobe.

B. Five years after the coiling, MR angiogram follow-up reveals a recurrence of the aneurysm at the neck of the vessel that could not be secured with coils. An elective clipping was performed through a right-sided pterional approach. The patient developed an immediate postoperative left-sided hemiplegia. An early CT of the head was unremarkable and a CT angiogram confirmed patency of the major intracranial vessels. What could explain the postoperative neurological deficit?

Inadvertent injury to the lenticuloistriate arteries, recurrent artery of Heubner and anterior choroidal artery can all lead to significant neurological deficits. The former two supply the head of the caudate, putamen, globus pallidus and anterior limb of the internal capsule. Therefore, injury is typically associated with hemiparesis predominantly affecting the face and arm, hemisensory disturbances and, in the case of a dominant hemispheric infarct, expressive dysphasia. The anterior choroidal artery supplies the posterior limb of the internal capsule, thalamus and optic radiations, leading to a hemiplegia, hemisensory loss and a homonymous hemianopia.
Basal ganglia and thalamus

Erlick A Pereira, Rahul S Shah

**Core Procedures**

- Stereotactic deep-brain stimulation electrode implantation (subthalamic nucleus, globus pallidus pars interna, Vim), radiofrequency lesioning (e.g. pallidotomy), biopsy or radiosurgery
- Management of any lesion (e.g. tumour, arteriovenous malformation, haematoma) partly or wholly involving the basal ganglia or thalamus
Surface anatomy for frame-based stereotaxy

Stereotaxy makes use of a three-dimensional coordinate system relative to a fixed frame of reference on the body to target deep lesions with high precision. Stereotactic brain surgery is commonly performed using a frame-based method (e.g. Leksell, Cosman–Roberts–Wells), although frameless alternatives are available. The stereotactic frame sits on a base ring, which must be applied to the patient's skull immediately preoperatively (Fig. 27.1) using four skull-pins screwed under local anaesthesia with sedation in the sitting position. The base ring should be placed parallel to a line extending from the lateral canthus to the tragus or the zygomatic arch to approximate the plane of the anterior commissure–posterior commissure (AC–PC) line. This aligns the stereotactic CT to the preoperative MRI, which is normally aligned from nasion to occiput. Once the equipment is attached, high-resolution head CT is commonly performed and fused with the preoperative MRI in specific computer software to generate appropriate stereotactic coordinates, such that the trajectory avoids sulci that contain vessels, visible cortical vessels, eloquent cortex, and a transventricular route. Such software can also incorporate standardized stereotactic brain atlases to aid planning (e.g. Schaltenbrand et al\textsuperscript{1}).

### Tips and Anatomical Hazards

For stereotactic targeting of deep structures, acquire a preoperative high-quality MRI (under general anaesthesia, if required), to be fused with intraoperative head CT (taken once the base ring has been attached to the skull) in the target planning software.

Fit the stereotactic base ring parallel to the orbitomeatal line and symmetrically, to aid image fusion.

Ensure multiple checks of coordinates and frame setting are performed by multiple surgeons.

Check coordinate accuracy first, using a phantom target if available.

Avoid or minimize loss of cerebrospinal fluid on dural puncture, to reduce brain shift.

Do not choose an entry route where cortical vessels are visible on susceptibility-weighted imaging MRI and avoid sulcal entry.

Do not choose a transventricular route because this often results in more medial targeting and increased bleeding risk with ependymal
violation.
Gross anatomy of the basal ganglia and thalamus

The basal ganglia are thought to be critical for adaptive behaviours (including goal-directed action selection, habit formation and motor control). The thalamus is the ‘gateway to the cortex’, and thalamocortical neurones are the only route by which basal ganglia output, cerebellar output and ascending sensory information (except olfaction) can reach the cortex. Historically, the basal ganglia included the corpus striatum (striatum, globus pallidus and internal capsule), claustrum and amygdala, but modern scientific and clinical usage is restricted to the following telencephalic and diencephalic structures: striatum (split into the caudate and putamen by the internal capsule), globus pallidus (pars interna and pars externa), subthalamic nucleus and substantia nigra (pars compacta and pars reticulata). With growing knowledge about the functional connectivity of each of these deep nuclei and the ability to identify them individually on modern MRI scans (Fig. 27.2), older terminology derived from gross pathological appearances, such as ‘lentiform nucleus’ (putamen and globus pallidus) and ‘corpus striatum’ (‘striped body’: caudate, putamen and globus pallidus), is becoming less common.
FIG. 27.2  MRI appearances of the basal ganglia and thalamus. A, B, 3T T2 axial and coronal MR images showing the relative positions of the red nucleus (RN), substantia nigra (SN) and subthalamic nucleus (STN). The bright white dots are deep brain stimulation electrodes in bilateral STN. C, Coronal fast grey matter acquisition T1 inversion recovery (FGATIR) 3T MRI demonstrating the basal ganglia, internal capsule and thalamus. Abbreviations: C, caudate nucleus; GPe, globus pallidus pars externa; GPi, globus pallidus pars interna; i.c., internal capsule; o.t., optic tract; Pu, putamen; Th, thalamus; Zi, zona incerta. (Courtesy of Erlick Pereira.)

The striatum is considered to be the principal ‘input’ structure of the basal ganglia since it receives the majority of afferents from other parts of the brain – predominantly from the cortex but also midbrain dopaminergic neurones and intralaminar/ventral thalamus (Table 27.1). It is divided into dorsal (caudate nucleus and putamen) and ventral (nucleus accumbens and
olfactory tubercle) parts, which regulate sensorimotor control/learning and reward-related behaviours, respectively. The caudate nucleus is a C-shaped structure that is closely associated with the lateral wall of the lateral ventricle via its large head (anterior pole), tapering body and tail terminating at the amygdala in the temporal lobe (Fig. 27.3A). Anteriorly and inferolaterally, it is separated from the putamen (which has the same structure and function) and from the globus pallidus by the anterior limb of the internal capsule (Fig. 27.3B). Medially, the caudate is separated from the thalamus by the sulcus terminalis, where the striae terminalis (fibres from the amygdala to the thalamus/hypothalamus), striae medullaris (hypothalamus/anterior thalamus to habenula) and thalamostriate vein reside (Fig. 27.3C). Medially, the putamen is separated from the globus pallidus by an external medullary lamina and laterally it is separated from the claustrum by the external capsule. Within the globus pallidus, the internal medullary lamina divides pars externa (GPe) from pars interna (GPi). The GPi lies in the medial aspect of the ‘lentiform nucleus’, immediately lateral to the genu of the internal capsule and above the optic tract; it sends efferent inhibitory projections to the thalamus via the ansa lenticularis and lenticular fasciculus (Fig. 27.3D). The subthalamic nucleus (STN) is separated from the thalamus by the zona incerta and fields of Forel superiorly; the substantia nigra (‘black substance’) lies anteroinferolaterally, the red nucleus posteromedially and the internal capsule laterally. The substantia nigra has a pars compacta (SNc), formed by dopaminergic neurones (containing neuromelanin) that project to the caudate–putamen, and a less dense pars reticulata (SNr), containing GABAergic (GABA, gamma-aminobutyric acid) projection neurones that project to the thalamus, pedunculopontine nucleus and superior colliculus.
### Table 27.1
Major connections of the basal ganglia structures

<table>
<thead>
<tr>
<th>Basal ganglia nucleus</th>
<th>Input(s)</th>
<th>Major output(s)</th>
<th>Clinical notes</th>
</tr>
</thead>
</table>
| Dorsal striatum       | Cortex, Thalamus, SNc (dopaminergic)  | Inhibitory to GPi/SNr (direct pathway) | Caudate atrophy in Huntington's disease  
Loss of nigrostriatal input in Parkinson’s disease |
|                       |                                       | Inhibitory to GPe (indirect pathway)  |                                                                                  |
|                       |                                       |                                      |                                                                                  |
| Ventral striatum      | Cortex, Ventral tegmental area (dopaminergic) | Ventral pallidum | Mesolimbic dopamine release here underlies the locomotor effects of psychostimulant drugs  
Nucleus accumbens has been targeted for addiction and anorexia nervosa |
|                       |                                       |                                      |                                                                                  |
| Globus pallidus pars externa (GPe) | Striatum (indirect pathway medium spiny neurones) | Inhibitory to STN | Loss of striatal (indirect pathway) input in Huntington's chorea |
|                       |                                       |                                      |                                                                                  |
| Subthalamic nucleus (STN) | GPe, Cortex (hyperdirect pathway) | Excitatory to GPi/SNr | Stroke classically causes hemiballism  
Bilateral STN deep-brain stimulation for Parkinson’s disease |
| Globus pallidus pars interna (GPI) | Striatum (direct pathway) STN (indirect or hyperdirect) GPe (indirect) | Inhibitory to thalamus and pedunculopontine nucleus | Unilateral or bilateral deep-brain stimulation for focal or generalized dystonia, Parkinson's disease (especially if levodopa-induced dyskinesia) |
| Substantia nigra pars reticulata (SNr) | Striatum (direct pathway) STN (indirect or hyperdirect) GPe (indirect) | Inhibitory to thalamus, pedunculopontine nucleus and superior colliculus | Small motor role in primates compared to GPi but uniquely targets superior colliculus. May explain gaze palsy in Parkinson’s disease |
| Substantia nigra pars compacta (SNc) | Striatum, Pedunculopontine nucleus Amygdala | Dopaminergic input to dorsal striatum | Loss of SNc dopaminergic neurones projecting to dorsal striatum in Parkinson’s disease |
FIG. 27.3 Anatomical relationships of the basal ganglia and thalamus. A, The location of the basal ganglia and thalamic structures within the cerebral hemispheres. B, A transverse (axial) section at the level of the genu of the corpus callosum.
The thalamus is a 4 cm egg-shaped mass with a long axis at 30° to the midline. Anteriorly, it is separated from the head of the caudate nucleus by the genu of the internal capsule. Medially, it forms the lateral wall of the third ventricle. It is almost always connected to the contralateral thalamus by the interthalamic adhesion (which can impede a third ventriculostomy). Superiorly, from medial to lateral, it is covered by tela choroidea, forms the floor of the lateral ventricle, and is separated from the body of the caudate nucleus by the stria medullaris, stria terminalis and thalamostriate vein (see Fig. 27.3C). Laterally, it is separated from the lentiform nucleus (globus pallidus and putamen) by the genu and posterior limb of the internal capsule. Inferiorly, it is separated from the subthalamic nucleus by the fields of Forel and zona incerta (together these structures form the ‘subthalamus’ or ‘ventral thalamus’). Posteriorly, the thalamus forms the anterior wall of the atrium of the lateral ventricle. All known connections between thalamus and cerebral cortex are reciprocal, two-way radiations (thalamocortical and corticothalamic), running in the internal capsule and corona radiata. The medial and anterior thalamic nuclei produce the anterior thalamic peduncle (radiation), which runs towards the anterior and inferior frontal cortical areas. Axons of the superior thalamic peduncle run vertically to connect the thalamus with posterior frontal and parietal cortical areas. The inferior thalamic peduncle courses towards the temporal lobe cortex and includes the auditory radiation. The posterior thalamic peduncle and the optic radiation run backwards to the occipital and inferior parietal cortex. The important connections between basal ganglia, thalamus and cortex are summarized in Table 27.2.

### Table 27.2

**White matter structures connecting the basal ganglia, thalamus and cortex**

<table>
<thead>
<tr>
<th>White matter</th>
<th>Description</th>
<th>Blood supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior limb of internal capsule</td>
<td>Anterior thalamic radiation to cingulate and prefrontal cortex  Frontopontine fibres</td>
<td>Superior half: lenticulostriate arteries (MCA)</td>
</tr>
<tr>
<td>(ALIC)</td>
<td>Inferior half: recurrent artery of Heubner (ACA)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Genu of internal capsule</td>
<td>Corticobulbar tract (face)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frontopontine fibres</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part of superior thalamic radiation</td>
<td></td>
</tr>
<tr>
<td>Posterior limb of internal capsule (PLIC)</td>
<td>Posterior thalamic radiation (including optic radiation from lateral geniculate nucleus)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Superior half: lenticulostriate arteries (MCA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior one-third: sensory thalamocortical fibres (face, arm, leg, trunk)</td>
<td></td>
</tr>
<tr>
<td>Retrolenticular internal capsule</td>
<td>Superior half: lenticulostriate arteries (MCA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inferior half: anterior choroidal artery (ICA)</td>
<td></td>
</tr>
<tr>
<td>Sublenticular internal capsule</td>
<td>Anterior choroidal artery (ICA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inferior thalamic radiation (including auditory radiation)</td>
<td></td>
</tr>
<tr>
<td>Subthalamic fasciculus</td>
<td>Anterior choroidal artery (ICA) and P1 PCA perforators</td>
<td></td>
</tr>
<tr>
<td>Lenticular fasciculus</td>
<td>Pallidosubthalamic (GPe–STN) and subthalamopallidal (STN–GPi) fibres</td>
<td></td>
</tr>
<tr>
<td>Ansa lenticularis</td>
<td>Pallidothalamic fibres (GPi–VA/VL) coursing above the STN and via Forel field H2 to reach prerubral field H</td>
<td></td>
</tr>
<tr>
<td>Thalamic fasciculus (Forel's tegmental field H1)</td>
<td>Pallidothalamic fibres (GPi–VA/VL) coursing below the STN to reach prerubral field H</td>
<td></td>
</tr>
<tr>
<td>Forel's tegmental field H2</td>
<td>Contains pallidothalamic, cerebellothalamic (dentatothermalamic) and rubrothalamic fibres</td>
<td></td>
</tr>
<tr>
<td>Prerubral field (Forel's H field)</td>
<td>The part of the lenticular fasciculus arching over the dorsal border of the STN under the zona incerta</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large zone of grey and white matter anterior (rostral) to the red nucleus. This is where the pallidothalamic fibres in the ansa lenticularis and lenticular fasciculus join before merging with dentatothermalamic fibres to form the thalamic fasciculus</td>
<td></td>
</tr>
</tbody>
</table>

Other abbreviations: ACA, anterior cerebral artery; GPe, globus pallidus pars externa; GPi, globus pallidus pars interna; H, Haubenfeld (hooded field), forming a cap over the anterior limb of the internal capsule in the tegmentum; ICA, internal carotid artery; MCA, middle cerebral artery; PCA, posterior cerebral artery; STN, subthalamic nucleus; VA, ventral anterior; VL, ventral lateral.
Functional and clinical anatomy of the basal ganglia

The clinical relevance of the basal ganglia to motor function was established by key observations in the early twentieth century (see Jahanshahi et al for review\(^2\)), although it is also important to be aware of the cognitive and limbic corticostriatal thalamocortical loops and their dysfunction in drug addiction, obsessive–compulsive disorder and Tourette's syndrome. The direct/indirect pathway model of basal ganglia function is still used to understand normal and abnormal basal ganglia function (Fig. 27.4). It is based on the idea that movement occurs when there is an increase in thalamocortical neurone firing and subsequent excitation of motor cortex. However, since basal ganglia output to the thalamus (i.e. from GPi and SNr) is tonic and inhibitory (GABAergic), basal ganglia output must decrease for thalamic firing (and thus motor cortex activity) to increase. This can be achieved by altering the balance in the activity of two parallel pathways within the basal ganglia. In the direct pathway (which facilitates movement), dopamine D1-receptors expressing GABAergic (inhibitory) striatal neurones project on to inhibitory GPi/SNr neurones. Activation of this pathway results in reduced GPi/SNr tonic inhibition of the thalamus. In the indirect pathway (which inhibits movement), dopamine D2-receptors expressing GABAergic (inhibitory) striatal neurones project on to inhibitory GPe neurones, which project on to excitatory STN neurones projecting on to inhibitory GPi/SNr neurones. Activation of this pathway results in STN excitation of GPi/SNr tonic inhibition of the thalamus. Dopamine release in the striatum causes greater activity in the direct pathway than in the indirect pathway activity, allowing voluntary movement (see Fig. 27.4). However, too little dopamine can inhibit movement (e.g. bradykinesia and rigidity in Parkinson's disease) and too much can result in involuntary movements (e.g. dyskinesia). In Huntington's disease, choreiform movements may be the result of unopposed direct pathway activity due to early selective loss of indirect pathway D2 striatal projection neurones. A hyperdirect pathway from the cortex to the STN (i.e. bypassing the striatum) and then on to GPi/SNr is now also thought to be important for suppressing erroneous movements. Its location in both the indirect and the hyperdirect pathways may explain why infarctions involving the STN can result in hemiballismus.
The blood supply to the basal ganglia is summarized in Table 27.3, along with the clinical syndromes associated with their occlusion. Isolated infarcts of basal ganglia structures are rare, but the most common associations\(^3\) are: the caudate (abulia); the lentiform nucleus (dystonia; bilateral lesions associated with Parkinsonism or dystonia–Parkinsonism) and the STN (hemiballism).
Table 27.3

Blood supply to the basal ganglia

<table>
<thead>
<tr>
<th>Blood supply</th>
<th>Basal ganglia structures supplied</th>
<th>Other structures supplied</th>
<th>Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior cerebral artery perforators</td>
<td>Anteromedial caudate head, anterior putamen</td>
<td>Inferior half of the anterior limb of the internal capsule</td>
<td>If unilateral, cause contralateral arm and face weakness, dysarthria, hemichorea If bilateral, can cause akinetic mutism</td>
</tr>
<tr>
<td>(distal medial striate artery, i.e. recurrent artery of Heubner)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle cerebral artery perforators</td>
<td>Posterior caudate, putamen and globus pallidus pars externa</td>
<td>Superior half of the anterior limb of the internal capsule, genu of the internal capsule, and superior part of the posterior limb of the internal capsule</td>
<td>Lacunar infarcts in internal capsule can cause pure motor or pure sensory stroke</td>
</tr>
<tr>
<td>(lateral lenticulostriate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior choroidal artery (ICA)</td>
<td>Globus pallidus pars interna, tail of the caudate</td>
<td>Caudal posterior limb of the internal capsule, and mesial temporal lobe</td>
<td>Hemiplegia, hemianaesthesia and contralateral hemianopia</td>
</tr>
<tr>
<td>P1 posterior cerebral artery perforators</td>
<td>Subthalamic nucleus and substantia nigra</td>
<td>Midbrain structures (e.g. red nucleus, oculomotor nucleus)</td>
<td>Rare in isolation Weber’s and Benedikt’s syndromes do not classically involve the subthalamus but show ipsilateral oculomotor palsy, crossed hemiataxia/chorea or contralateral hemiparesis</td>
</tr>
</tbody>
</table>

Abbreviations: ICA, internal carotid artery.
Functional and clinical anatomy of the thalamus

The thalamus is a diencephalic structure containing excitatory glutamatergic neurones that project almost exclusively to the cortex (thalamocortical fibres). It is thought to be involved in a wide range of brain functions, including consciousness, sleep, memory and sensorimotor activity. Thalamic nuclei are termed ‘first-order’ relays if they receive subcortical glutamatergic input (e.g. peripheral sensory input, cerebellar input) and project directly to relevant cortical areas; they are termed ‘higher-order’ relays if they predominantly receive glutamatergic input from one cortical area and relay this back to another cortical area. Thalamic nuclei receiving inhibitory GABAergic basal ganglia input (ventral anterior/ventral lateral thalamus, intralaminar, mediodorsal nuclei) do not fit neatly into this classification scheme but are generally thought of as higher-order nuclei. *Terminologia Anatomica* currently lists over forty thalamic grey matter nuclei but other classification systems are also used (see ‘Tips and Anatomical Hazards’ below and Table 27.4). The thalamus does not officially include structures in the epithalamus (habenula), subthalamus (subthalamic nucleus, zona incerta and fields of Forel) or hypothalamus. The most medial wall of the thalamus is formed by the median nuclei, while the rest of the thalamus is divided into an anterior, a medial and a large lateral mass by a vertical, Y-shaped sheet of white matter – the internal medullary lamina (Fig. 27.5) – within which lie the intralaminar nuclei. Unlike the basal ganglia structures, thalamic nuclei do not have reciprocal projections with each other: the reticular thalamus is the only thalamic nucleus that projects to other thalamic nuclei, does not project to the cortex, and consists entirely of GABAergic inhibitory neurones. The most clinically relevant thalamic nuclei and their connections are summarized in Table 27.4.
Table 27.4
Major connections of clinically relevant thalamic nuclei

<table>
<thead>
<tr>
<th>Thalamic nuclear group</th>
<th>Specific nucleus (Anglo-American terminology)*</th>
<th>Equivalent nuclei (Hassler terminology (1959))²</th>
<th>Subcortical input</th>
<th>Output</th>
<th>Indication for deep-brain stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Anterodorsal</td>
<td>A.d.</td>
<td>Mammillary bodies</td>
<td>Cingulate cortex</td>
<td>Epilepsy</td>
</tr>
<tr>
<td>Medial</td>
<td>Medial dorsal (MD)</td>
<td>M.fi.</td>
<td>Amygdala</td>
<td>Prefrontal cortex</td>
<td>Inferior thalamic peduncle for obsessive–compulsive disorder/depression</td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral anterior (VA)</td>
<td>L.p.o. (ant)</td>
<td>SNr</td>
<td>Supplementary motor area</td>
<td>Striatum</td>
</tr>
<tr>
<td></td>
<td>V.o.a.</td>
<td></td>
<td>GPi (medial)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral medial (VM)</td>
<td>V.o.m.</td>
<td>Basal ganglia input</td>
<td>Striata</td>
<td>Tremor Dystonia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>entry zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral lateral, anterior (VLa)</td>
<td>V.o.a.</td>
<td>GPi (lateral)</td>
<td>Supplementary motor area</td>
<td>Striata</td>
</tr>
<tr>
<td></td>
<td>V.o.p. (ant)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral lateral, posterior (VLp)</td>
<td>V.o.p. (post)</td>
<td>Deep cerebellar nuclei (contralateral)</td>
<td>Primary motor cortex</td>
<td>Tremor Dystonia</td>
</tr>
<tr>
<td></td>
<td>V.o.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V.i.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral posterolateral (VPL)</td>
<td>V.c.e.</td>
<td>Spinothalamic tract</td>
<td>Somatosensory cortex</td>
<td>Pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medial lemniscus</td>
<td>Insula</td>
<td></td>
</tr>
<tr>
<td>Ventral</td>
<td>Ventral posteromedial (VPM)</td>
<td>V.c.i.</td>
<td>Trigeminothalamic tract</td>
<td>Somatosensory cortex</td>
<td>Pain (facial)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medial lemniscus</td>
<td>Insula</td>
<td></td>
</tr>
<tr>
<td>Intralaminar</td>
<td>Anterior:</td>
<td></td>
<td>GPi</td>
<td>Motor cortex</td>
<td>Tourette's syndrome, minimally conscious state, pain, epilepsy</td>
</tr>
<tr>
<td></td>
<td>Central medial</td>
<td></td>
<td>Deep cerebellar nuclei (contralateral)</td>
<td>Striatum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paracentral</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Central lateral</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior:</td>
<td></td>
<td>GPi</td>
<td>Motor cortex</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centromedian (CM)</td>
<td></td>
<td>Deep cerebellar nuclei (contralateral)</td>
<td>Striatum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parafascicular (Pf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Other abbreviations: GPi, globus pallidus pars interna; SNr, substantia nigra pars reticulata.
Accurately defining the clinical neurology of thalamic disorders is limited by the fact that thalamic nuclei are small and lack their own discrete blood supply (Table 27.5), so highly specific ischaemic lesions from which to draw conclusions about function are rare (but do occur). In addition, other common lesions that may affect the thalamus (e.g. tumour, haemorrhage) usually involve the adjacent internal capsule and basal ganglia structures too. However, there are three well-recognized patterns.
Table 27.5

Blood supply to the thalamus

<table>
<thead>
<tr>
<th>Blood vessel</th>
<th>Thalamic territory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuberothalamic (polar) branch of the posterior communicating artery</td>
<td>Anterior nuclei, VA, rostral VL, rostral MD, reticular thalamus, mamillothalamic tract, ventral internal medullary lamina and ventral amygdalofugal pathway</td>
</tr>
<tr>
<td>Inferolateral (thalamogeniculate) arteries from the P2 posterior cerebral artery</td>
<td>Motor part of VL, sensory nuclei (VPL, VPM), medial geniculate, pulvinar, lateral dorsal</td>
</tr>
<tr>
<td>Posterior choroidal arteries from the P2 posterior cerebral artery</td>
<td>Medial branches (medial geniculate nucleus, pulvinar, posterior CM/CL) Lateral branches (lateral geniculate nucleus, lateral dorsal, lateral posterior, inferolateral pulvinar)</td>
</tr>
<tr>
<td>Paramedian thalamoperforators from the P1 posterior cerebral artery (may be supplied bilaterally by a single artery of Percheron)</td>
<td>MD, intralaminar (CM, Pf, CL), posteromedial VL, ventromedial pulvinar</td>
</tr>
</tbody>
</table>

Abbreviations: CL, central lateral; CM, central medial; MD, medial dorsal; Pf, parafascicular; VA, ventral anterior; VL, ventral lateral; VPL, ventral posterolateral; VPM, ventral posteromedial.

In posterolateral thalamic syndromes, pure sensory stroke can be caused by a lacunar infarct in the ventral posterolateral or ventral posteroomedial nucleus, and gives rise to contralateral hemianesthesia affecting all somatic modalities equally (light touch, conscious proprioception, two-point discrimination, vibration, pain and temperature), unlike lesions of the internal capsule or cortex that impair somatic sensory function, which typically affect different modalities to varying extents and often leave pain sensation intact. Thalamic pain (Dejerine–Roussy) syndrome may occur after a delayed period of recovery from damage to ventral posterolateral and ventral posteroomedial nuclei. It is characterized by severe and intractable hyperalgesia or causalgia in the previously hemianesthetic region. If the lateral geniculate body is affected, there is a contralateral homonymous hemianopia.

Paramedian thalamic syndromes are characterized by disorders of consciousness or behaviour. If an artery of Percheron is present, occlusion can cause bilateral paramedian thalamus infarction, resulting in altered mental status, vertical gaze palsy (involvement of traversing medial longitudinal fasciculus fibres) and memory impairment.

Anterolateral thalamic syndromes involve damage to the ventral anterior and ventral lateral nuclei, which can cause movement disorders resembling cerebellar damage (ataxia and intention tremor) and/or basal ganglia damage (choreoathetoid movements); these disorders are contralateral.
Basal ganglia and thalamic targets in functional neurosurgery

The three commonly used targets in deep-brain stimulation for movement disorders are the STN, GPi and Vim (Fig. 27.6).\textsuperscript{5,6} STN deep-brain stimulation is performed bilaterally for Parkinson's disease for desired symptomatic improvement and levodopa dose reduction, whereas stimulation of the GPi and Vim may be performed unilaterally or bilaterally, depending on the indication. Unilateral radiofrequency lesioning may sometimes also be performed in the GPi and Vim (they are only rarely performed in the STN due to the risk of hemiballism). Visible targets (e.g. STN or GPi visible on MRI) in the brain can be described in terms of their distance from the zero reference point in x, y and z directions when the head is fixed into a stereotactic frame (or frameless system). For invisible targets (e.g. Vim), targeting is based either on their known distance from deep brain landmarks such as the mid-commissural point or on use of stereotactic atlases. Accuracy of targeting may also be supplemented through the use of intraoperative microelectrode or deep-brain stimulation macroelectrode recordings identifying the characteristic neural activity of the target brain region. General risks of stereotactic surgery include haemorrhage, failed targeting, lead fracture and infection. Potential adverse effects of stimulation vary depending on the planned target and direction of current spread. The average classical coordinates for lead placement are given in Table 27.6.
Table 27.6
Established coordinates for deep-brain stimulation targets in movement disorder surgery

<table>
<thead>
<tr>
<th>Target</th>
<th>Lateral to AC–PC</th>
<th>Vertically below AC–PC line</th>
<th>Relative to mid-commissural point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subthalamic nucleus</td>
<td>11 mm</td>
<td>4–6 mm</td>
<td>2–4 mm posterior</td>
</tr>
<tr>
<td>Globus pallidus pars interna</td>
<td>20 mm</td>
<td>4–8 mm</td>
<td>2 mm anterior</td>
</tr>
<tr>
<td>Ventral intermediate nucleus of the thalamus, Vim</td>
<td>11–13 mm</td>
<td>0 mm</td>
<td>4 mm posterior</td>
</tr>
</tbody>
</table>

Abbreviations: AC–PC, anterior commissure–posterior commissure line.

Passage of an STN electrode may produce a microsubthalamotomy effect
(tremor disappearance) but only increasing stimulation will improve bradykinesia and rigidity. Poor placement of the electrode may result in dysarthria or tonic facial contractions (corticobulbar capsular effects), or contralateral muscle contractions (corticospinal) if too lateral. Paraesthesias occurring at low thresholds suggest that the electrode should be moved anterolaterally. Inadvertent placement of the stimulating electrode in the substantia nigra may cause loss of rigidity/dyskinesia but worsening of akinesia/loss of the levodopa effect. If the electrode is placed superior to the STN, either in the zona incerta or thalamus, a reduction in tremor may be elicited but akinesia persists. Posterior electrode placement may produce sweating, mydriasis and dysaesthesias. Placement of the stimulating electrode medial to the STN (red nucleus, hypothalamus) may cause diplopia, eye deviation and mydriasis.

Deep-brain stimulation of the GPi for dystonia is usually performed under general anaesthesia, whereas it can be performed awake in Parkinsonian patients; during the procedure, the patient is assessed for loss of tremor, rigidity and dyskinesia. Contralateral limb rigidity or muscular contraction, or dysarthria and facial contractions (capsular responses), suggests that the position is too medial. Contralateral visual phosphenes (flashing lights) suggest that the electrode is too deep and close to the optic tract.

Initial passage of a Vim electrode often produces a microthalamotomy effect (with loss of tremor), but if this is not seen, low-frequency stimulation usually drives the tremor while higher-frequency stimulation ameliorates it. Poor placement of electrode may result in capsular responses (too lateral), dysaesthesias (too posterior; sensory thalamus) or increased muscle tone (too anterior in Voa).

**Tips and Anatomical Hazards**

Classically, thalamic neurones have been grouped into nuclei based on cytoarchitectonic borders with Nissl staining, but this has resulted in multiple different classification schemes being proposed over the last century and their variable adoption during the early days of movement disorder surgery. Defining the borders of thalamic nuclei in this way does not accurately parcellate the thalamus into groups of neurones with anatomically
similar input and outputs likely to have a similar function.
References


Single Best Answers

1. Which one of the following structures contains cerebellothalamic fibres?
   A. Ansa lenticularis
   B. Thalamic fasciculus (Forel's field H1)
   C. Lenticular fasciculus
   D. Prerubral field H
   E. Forel's field H2

   **Answer: B.**

2. Which one of the following deep-brain stimulation targets allows levodopa dose reduction in idiopathic Parkinson's disease?
   A. Anterior thalamus
   B. Globus pallidus pars interna
   C. Vim thalamus
   D. Inferior thalamic pedicle
   E. Subthalamic nucleus

   **Answer: E.**

3. During deep-brain stimulation surgery for dystonic Parkinson's disease, a patient describes contralateral visual phosphenes. Where should the electrode tip be repositioned?
   A. A more anterior site
   B. A more posterior site
   C. A more medial site
   D. A more lateral site
   E. A more superficial site
   F. A deeper site
Answer: E.
Clinical case

A 64-year-old male presented with a seven-year history of Parkinson’s disease. Medications included Madopar qds, Rotigotine, cocodamol and losartan. His problems included motor fluctuations with dyskinesia, tremor, slowness of movement (bradykinesia), poor sleep and back pain. Postural stability was good and he had no problems with swallowing or blood pressure, mood, impulsivity or dementia. After the neurologist’s assessment, the patient received an L-dopa challenge test with a 50% improvement in his UPDRS part III score. Psychological assessment revealed good cognition and no contraindications. After an MRI brain scan, multi-disciplinary team meeting and joint clinic, the patient was offered deep brain stimulation surgery.

Bilateral subthalamic nucleus deep brain stimulation electrodes were inserted under general anaesthesia and connected to a rechargeable pulse generator. After a few weeks the patient had derived considerable benefit in movement and sleep from his stimulation and was able to reduce his dopamine medications.
Brainstem and pineal region

Kristian Aquilina, Matthew A Kirkman, Julia Sharma

**Core Procedures**

**Brainstem**

- Midline suboccipital craniotomy to the cerebellum and fourth ventricle
- Retrosigmoid craniotomy to the lateral cerebellum and cerebellopontine angle
- Far lateral approach to the ventral brainstem
- Cranio-orbitozygomatic approach to the upper brainstem

**Pineal Gland**

- Supracerebellar infratentorial approach
- Occipital interhemispheric transtentorial approach
- Posterior transcallosal approach

Surgical approaches to the brainstem and pineal region are complex. The pineal gland is closely related to the confluence of veins draining most deep cerebral structures. The brainstem runs through the supra- and infratentorial spaces and contains major motor and sensory tracts, as well as autonomic and cranial nerve nuclei. This chapter provides an overview of the anatomical principles and approaches to lesions involving these structures.
Brainstem

Surgical anatomy and approaches to the brainstem

The most common approaches to the brainstem involve access to lesions within the fourth ventricle, a frequent location for brain tumours, particularly in children. The role of surgery in some brainstem tumours, such as diffuse intrinsic pontine glioma, remains small. However, with a better understanding of the pathology of brainstem tumours, as well as developments in MRI, image-guided surgery and microsurgery, good long-term results have been achieved after resection of focal gliomas and adjuvant therapy.\textsuperscript{1–3} There is a significant literature on resection of brainstem cavernomas.\textsuperscript{4} Advanced MR techniques have been integrated with fibre dissection cadaveric studies, leading to more precise anatomical definition within the brainstem, as well as the delineation of safe entry zones for lesions that do not present to the pial or ependymal surfaces.\textsuperscript{5–10} The clinical use of diffusion tractography allows selection of the optimal approach and increases surgical safety.\textsuperscript{1}

Fourth ventricle

The fourth ventricle is a rhomboid structure, located within the posterior fossa and bounded anteriorly by the brainstem, posteriorly by the cerebellum and laterally by the cerebellar peduncles (Ch. 24). It communicates with the third ventricle through the cerebral aqueduct at its rostral apex; it also opens to the cisterns of the posterior fossa caudally through the foramen of Magendie and laterally, at its broadest point, to the cerebellopontine angles through the foramina of Luschka (Fig. 28.1).
The floor of the fourth ventricle is constituted by the dorsum of the brainstem and is highly eloquent. The rostral two-thirds are posterior to the pons and the caudal third is posterior to the medulla. A median sulcus runs from the aqueduct to the obex at its caudal tip, anterior to the foramen of Magendie, which divides the floor into two equal halves. The level of the foramina of Luschka corresponds to the junction between the pons and medulla. The sulcus limitans runs parallel to the median sulcus; it delineates a medial section adjacent to the midline at the median sulcus from a lateral section overlying the vestibular nuclei known as the vestibular area. The medial section is elevated above the rest of the floor and is called the median eminence. This is wider rostrally than caudally. In its rostral region it is highly prominent; it overlies the ascending part of the facial nerve as it crosses over the nucleus of the abducens nerve. More caudally, in turn, it overlies the hypoglossal nucleus, the vagal nucleus and the area postrema; the latter lies just rostral to the obex. The vestibular nuclei lie deep to the
vestibular area and extend into the lateral recesses. The cochlear nuclei form a prominence within the most lateral part of the vestibular area. The striae medullaris form a useful landmark, extending medially from the region of the foramina of Luschka to disappear into the median eminence.

The roof of the fourth ventricle is pyramidal, with its apex at the fastigium. In its upper half, the roof consists of the superior medullary velum, a thin layer of white matter across the midline, connecting the deep surface of the superior cerebellar peduncle on each side. The top of the cerebellar vermis, the lingula, sits on the dorsal surface of this part of the roof. The inferior medullary velum contributes to the roof of the lower fourth ventricle in the midline and is continuous with the superior medullary velum at the fastigium. At its inferior margin it is attached to the tela choroidea at the telovelar junction. The tela carries the choroid plexus on its ventricular surface; it extends from the nodule of the vermis laterally into the lower half of the lateral recess. However, in its inferior extent, the tela is attached to the inferior cerebellar peduncles as they border the lower fourth ventricle towards the obex. Gaps in the tela form the foramen of Magendie and the foramina of Luschka.

The foramina of Luschka connect the fourth ventricle with the cerebellopontine angles. The paired foramina arise caudal to the cerebellar peduncles, with the inferior peduncle forming their rostral wall. The flocculus extends from the lateral part of the tela choroidea, emerging at the superior aspect of the recess. It is a useful landmark at surgery in this region. The foramen has important relationships to cranial nerves in the region. The vestibulocochlear nerve crosses its floor, whereas the facial nerve arises superior to it and the glossopharyngeal and the vagus nerves arise ventral to it.

The cerebellar tonsils are the lowest part of the cerebellar hemispheric surface and their anatomy is relevant to the telovelar approach. The tonsillar peduncles are white matter bundles that connect the cerebellar hemispheres to the tonsils along their superolateral borders. Below the peduncles, the tonsils, on their lateral surfaces, are adjacent to the biventral lobules of the cerebellum. The cerebellomedullary fissure separates the tonsils dorsally from the medulla oblongata ventrally. The ventral surface of the superior poles of the tonsils overlies the lower roof of the fourth ventricle, which at this level consists of the inferior medullary velum and the tela choroidea. The tonsils form a barrier to the opening of the lower fourth ventricular cavity; separating the two tonsils surgically allows access to the ventricle.
The dentate nucleus, the largest of the deep cerebellar nuclei, is located just rostral to the superior pole of the tonsil, within the cerebellar white matter in the superior part of the lateral recess, near the inferior medullary velum.\textsuperscript{11} It receives afferents from the premotor and supplementary motor areas, as well as the spinocerebellar tract.\textsuperscript{12} The most caudal component of the vermis, seen between the tonsils, is the uvula. The component just cranial to this is the pyramid, which is attached to the medial cerebellar hemisphere on both sides. This point of attachment is the medial part of the dentate nucleus.\textsuperscript{12} It is also useful to remember that the facial colliculus and the nucleus of the abducens nerve within the floor of the fourth ventricle are at the same level as the dentate nucleus.\textsuperscript{12} The dentatothalamic tract, running within the superior cerebellar peduncle, is the main efferent tract of the dentate nucleus. The fibres of the superior cerebellar peduncle ascend medial to the middle cerebellar peduncle, forming the lateral walls of the upper fourth ventricle.

Tumours in or arising from the brainstem often distort the nuclei within the floor of the fourth ventricle, underlining the importance of intraoperative monitoring and mapping during surgical resection.\textsuperscript{13} Cranial nerve nuclei may be displaced and compressed ventrally by a tumour and become evident only on mapping once the resection is under way. This is typical for the lower cranial nerve nuclei with medullary brainstem tumours; pontine tumours displace the facial nerve nucleus around the edge of the tumour.\textsuperscript{14} The posterior fossa syndrome (PFS), characterized by mutism, ataxia and emotional lability, occurs in up to 25\% of surgical resections of tumours within the fourth ventricle.\textsuperscript{15,16} Risk factors include age under 5 years, large tumours and medulloblastoma.\textsuperscript{16} Although initially described as transient, deficits in speech and mobility often persist. Studies correlating clinical PFS with tractography have identified injury to the dentatorubrothalamic tract as central to the aetiology of the condition.\textsuperscript{17} Hypertrophy of the inferior olivary nucleus is an associated change on long-term surveillance imaging.\textsuperscript{18} Although the precise aetiology remains unclear, a diaschisis syndrome involving acute reduction of input from the dentate nucleus to the thalamo-cortical motor system has been postulated.\textsuperscript{19}

Traditionally, the transvermian approach has been used to access lesions within the fourth ventricle. Injury to the vermis, particularly the lower vermis, has been associated with PFS and ataxia.\textsuperscript{15} Arguably by preserving the vermis, the telovelar approach is less likely to lead to PFS; however, this is
unclear from the current literature.\textsuperscript{20,21} This approach involves dissection of the tela choroidea and the inferior medullary velum, hence exposing the entire length of the fourth ventricle up to the aqueduct through the cerebellomedullary fissure. Dissection begins in the plane between the medial tonsil and the lateral surface of the uvula (\textbf{Fig. 28.2}). Upward and lateral retraction of the tonsil exposes the tela choroidea and the inferior medullary velum. The posterior inferior cerebellar artery is protected and the tela is incised. This incision is extended superiorly through the inferior medullary velum. Large fourth ventricular tumours stretch both the tela and the velum, and facilitate this step. This approach also allows early definition, and protection, of the fourth ventricular floor and cerebellar peduncles, as well as early identification of arterial supply to the tumour from the posterior inferior cerebellar artery with the potential to minimize blood loss in small children. It also facilitates access to the lateral recesses of the fourth ventricle. The telovelar approach may reduce the need for permanent cerebrospinal fluid (CSF) diversion after posterior fossa surgery; this is probably related to the wide opening between the cisterna magna and the foramen of Magendie.\textsuperscript{22}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig28_2.png}
\caption{The telovelar approach. \textbf{A}, Dissection between the uvula medially and the tonsil laterally. \textbf{B}, Intraoperative photograph, taken during the initial dissection of the telovelar approach for a fourth ventricular tumour, demonstrating the cerebellar tonsils (T), vermis (V), uvula (U) and posterior inferior cerebellar artery (white arrow).}
\end{figure}

Although the telovelar approach is appropriate for most lesions within the
fourth ventricular cavity, tumour location within the rostral third of the fourth ventricle has been associated with a lower rate of complete surgical resection. A study using image guidance to compare access using transvermian and telovelar approaches demonstrated that exposure of the lateral recesses and foramina of Luschka was more complete with the telovelar approach, whereas the rostral half of the fourth ventricle was more easily accessed through a transvermian approach.

**Cerebellopontine angle**

The cerebellopontine angle (CPA) contains the fourth to eleventh cranial nerves, which run in three neurovascular bundles. These are the superior cerebellar artery (SCA) and the trigeminal nerve; the anterior inferior cerebellar artery (AICA) and the facial–acoustic bundle; and the posterior inferior cerebellar artery (PICA) and the lower cranial nerves. The retrosigmoid approach is the principal surgical corridor to these areas. Clinically, the most common indications for these procedures are trigeminal neuralgia related to neurovascular conflict in the upper complex and vestibular schwannomas related to the middle complex. Other pathology such as posterior fossa ependymomas in children, typically involves all three levels of the CPA.

Retrosigmoid craniotomy is typically carried out with the patient in the park bench position, although a supine position can be used with the head fully rotated, flexed and angulated away from the side of the pathology to enhance exposure. Image guidance is useful in order to map out the venous sinuses accurately prior to surgery. The key to the procedure is definition of the transverse sigmoid junction, which is located at the asterion and lies along a line extending occipitally from the zygoma; this is approximately at a point one-third down the auricle (pinna) of the ear. Through a curved incision behind the ear, crossing the site of the transverse sinus and extending caudally to a point 2 cm behind the mastoid process, a burr-hole is drilled at or just below the junction of the transverse and sigmoid sinuses. An emissary vein consistently lies inferior to this point. The burr-hole is then extended to a craniotomy. It is crucial to drain CSF from the cisterna magna prior to mobilization of the cerebellar hemisphere to reduce the degree of retraction required. Intraoperative monitoring is useful to identify the cranial nerves early, particularly if they are expected to be embedded within a large tumour. Monitoring can also warn against excessive cerebellar retraction and
reduce the risk of stretch injury to the cranial nerves, most evident in preventing deafness during neurovascular decompression of the facial nerve for hemifacial spasm.25

Approaches to the midbrain

The anterior surface of the midbrain and cerebral peduncles is approached through the orbitozygomatic route. This involves the removal of the orbital rim and roof, as well as the zygomatic process of the frontal bone and the frontal process of the zygoma, in addition to a standard pterional craniotomy. Inclusion of the orbital rim in the craniotomy allows a low trajectory with minimal frontal lobe retraction. The proximal Sylvian fissure is opened and the middle cerebral artery is followed towards the carotid bifurcation. The third nerve is identified and the oculomotor triangle is followed towards the interpeduncular fossa and cerebral peduncle.

The interpeduncular cistern contains the origins of both oculomotor nerves, as well as several perforating vessels arising from the posterior cerebral, basilar, posterior medial choroidal and superior cerebellar arteries. Dissection in this region is best avoided. The relatively safe entry zone in this region of the brainstem is located on the cerebral peduncle, between the oculomotor nerve and the corticospinal tract in the lateral part of the peduncle (Fig. 28.3A).7,8 Tumours in this region are often exophytic; dissection is limited to an area medial to the pyramidal fibres, parallel to the oculomotor nerve.10
FIG. 28.3 Brainstem entry zones. **A**, Ventral aspect of the brainstem and corresponding axial images illustrating the anterior mesencephalic and lateral medullary safe entry zones. **B**, Dorsal aspect of the brainstem, showing the lateral mesencephalic and posterior median sulcus entry points. The latter is just caudal to the obex.

The lateral surface of the midbrain is approached through the subtemporal route. Dissection of the arachnoid at the middle and anterior parts of the incisural space exposes the brainstem, with the P2 segment of the posterior
cerebral artery running horizontally across it. Division of the tentorium lateral to the fourth nerve should bring the superolateral pons and the pontomesencephalic junction into the operative field. The relevant entry zone in this region is the lateral mesencephalic sulcus, extending from the medial geniculate body to the pontomesencephalic junction (Fig. 28.3B). Potential complications include injury to the vein of Labbé and oculomotor morbidity related to the third and fourth nerves.

**Approaches to the pons**

The epitrigeminal region is a relatively safe entry zone into the pons. This is situated on the anterolateral surface of the pons in front of the trigeminal root and lateral to the corticospinal tract. It is best approached through the Kawase (anterior petrosectomy) route, which involves drilling the petrous bone anterior to the internal auditory canal, medial to the greater (superficial) petrosal nerve and posterior to the mandibular division of the trigeminal nerve. The posterior surface of the pons is approached through the fourth ventricle. The floor of the fourth ventricle is very eloquent and its critical structures may be displaced by lesions in this area. The use of intraoperative neurophysiological mapping is an important adjunct in these procedures. The safe entry zones within the floor of the fourth ventricle include the supracollicular area, situated above the facial colliculus and bordered medially by the median longitudinal fasciculus, medial to the median sulcus, and laterally by the superior cerebellar peduncle. The infracollicular region is bordered superiorly by the facial colliculus, medially by the medial longitudinal fasciculus and inferiorly by the striae medullaris.

**Approaches to the medulla oblongata**

The medulla is the lowermost part of the brainstem and is usually approached through the telovelar, transvermian or retrosigmoid routes. Relatively safe entry zones to the medulla include the inferior cerebellar peduncle approach, known as the lateral medullary zone (see Fig. 28.3A). This is situated inferior to the cochlear nuclei and posterior to the origins of the glossopharyngeal and vagus nerves. It can be reached through a telovelar or retrosigmoid approach. Another safe zone is through the posterior median sulcus at the obex (see Fig. 28.3B). This is easily accessible through a midline suboccipital approach and represents the superior extension of the
midline approach to the spinal cord. Access is restricted laterally by the gracile nuclei.\textsuperscript{7} Morbidity rates related to these approaches include hypopnea and respiratory failure, as well as vocal cord paresis.\textsuperscript{10}

Lesions situated ventral to the brainstem or cervicomedullary junction are approached through the far lateral route. Through a hockey stick incision, the suboccipital triangle, which contains the vertebral artery, is exposed. The vertebral artery is identified above the posterior arch of C1; the ipsilateral half of the posterior arch of C1 is then removed.\textsuperscript{28} The size and position of the suboccipital craniotomy depends on the location and extent of the lesion. The key difference with this approach is that more bone lateral to the foramen magnum is removed. This may extend to involve the posterior – or, on occasion, the entire – condyle. For brainstem tumours, it is not often necessary to resect any part of the posterior condyle nor to transpose the vertebral artery laterally.\textsuperscript{7,10} Division of the dentate ligament at the point of dural entry of the vertebral artery allows sufficient access to the anterolateral brainstem in most cases.\textsuperscript{10}

Ventral extra-axial lesions should then be visible, and dissection and resection proceed through the corridors between the cranial nerves. Intra-axial lesions are more challenging but can be accessed anterior or posterior to the olive. The anterolateral sulcus runs along the anterior margin of the olive, between the origins of the hypoglossal and the C1 rootlets. This is very close to the decussation of the pyramidal tract.\textsuperscript{10} The posterior olivary sulcus is located between the olive and the inferior cerebellar peduncle, and affords a small space to allow resection of an intrinsic lesion.\textsuperscript{8,10}
Pineal gland

The anatomy of the pineal gland and surrounding region is complex and several surgical approaches have evolved to biopsy or resect tumours in this location. The pathology of lesions in this region is diverse and includes germ cell tumours, pineal parenchymal tumours, glial tumours, and a range of other lesions that includes cysts and vascular malformations. Pineal lesions often occlude CSF flow and cause hydrocephalus; definition of the pathology and management of associated hydrocephalus are important steps in the overall management of pineal lesions. Empirical radiotherapy, once used as the primary method to discriminate the more common radiosensitive germ cell tumours from radioresistant lesions, is no longer acceptable in clinical practice. In addition, pineal cysts, present in up to 4% of otherwise normal cranial MRI scans, under 2 cm in diameter, with an enhancing rim representing compressed pineal tissue, need to be excluded radiologically before any surgery is considered.29

Hydrocephalus secondary to pineal lesions is now usually managed by endoscopic third ventriculostomy (Ch. 24); a biopsy of a posterior third ventricular or pineal region lesion can be considered at the same time. The presence of elevated levels of α-fetoprotein (AFP) or β-human chorionic gonadotrophin (beta-HCG) in the serum or CSF implies that a pineal lesion is a malignant germ cell tumour, obviating the need for biopsy or resective surgery. The absence of tumour markers in serum and CSF mandates a biopsy, with consideration to subsequent surgical resection, depending on the pathology.

Alternatives to endoscopic biopsy include stereotactic biopsy or open biopsy. The latter provides a larger specimen, which is particularly valuable, given the heterogeneous and often mixed nature of pineal tumours. Trajectory planning for stereotactic biopsies needs to ensure avoidance of the deep veins. This technique, using a frontal paramedian or lateral temporoparietal approach, has been shown to be safe in a large series of patients.30

Surgical anatomy of the pineal region

The pineal gland is an extra-axial structure, and a surgical plane is normally present between a pineal lesion and surrounding structures.31 Infiltration of the thalamus or brainstem limits the resectability of a pineal tumour.
The pineal gland is supported by a stalk, arising from the posterior wall of the third ventricle. From within the third ventricle, the posterior wall is composed of, superiorly to inferiorly, the tela choroidea in the roof, suprapineal recess, habenular commissure, pineal body, posterior commissure and aqueduct. The pineal recess projects posteriorly into the pineal gland. From its posterior surface, the pineal gland is situated within the quadrigeminal cistern. It is covered superiorly by the splenium of the corpus callosum, laterally by the thalami, and inferiorly by the quadrigeminal plate and cerebellar vermis.

Together with the quadrigeminal plate, the pineal gland constitutes the anterior wall of the quadrigeminal cistern. More laterally, the anterior wall of the cistern is formed by the pulvinar of the thalamus. The quadrigeminal plate is the posterior surface of the midbrain and presents the superior and inferior colliculi at this surface, separated from the dorsal surface of the cerebellar vermis by the cerebellomesencephalic fissure. In infratentorial approaches to large pineal lesions, it is important to remember that the trochlear nerve arises from below the inferior colliculi and turns laterally around the midbrain, below the pulvinar, into the ambient cisterns.

The roof of the quadrigeminal cistern contains the great veins, incorporated within thick arachnoid tissue. The roof is continuous anteriorly with the velum interpositum and roof of the third ventricle, and the veins contained within it are continuous with the internal cerebral veins. The superior surface of this arachnoid tissue is in contact with the inferior surface of the splenium.

The vein of Galen is formed in the quadrigeminal cistern by the confluence of the two internal cerebral veins as their downward posterior curve turns upwards, passing through the velum interpositum, and the basal veins of Rosenthal, which course through the ambient cisterns (see Fig. 26.7). The internal cerebral veins are formed by the confluence of the anterior septal and thalamostriate veins within the lateral wall and roof of the third ventricle, just inside the foramen of Monro. They course posteriorly within the two leaves of the tela choroidea in the roof of the third ventricle, near the midline, diverging laterally as they pass over the superior surface of the pineal gland and uniting underneath the splenium. The basal veins of Rosenthal course anteriorly in the crural cistern and posteriorly in the ambient cistern. They pass superomedial to the uncus of the temporal lobe and turn laterally around the cerebral peduncle, joining the vein of Galen in the quadrigeminal cistern.
The calibre of the basal veins is almost the same as that of the internal cerebral veins. The vein of Galen, 4–15 mm long, joins the inferior sagittal sinus to form the straight sinus at the falcotentorial junction or tentorial apex. The neurological consequences of injury to the deep veins have been poorly reported. Although extensive venous tributaries and improved collateral flow suggest that sacrifice of one of the internal cerebral veins is safe, infarction and haemorrhage within deep structures, including the basal ganglia, have been reported.

Surgical approaches to the pineal region

Surgical approaches to the pineal region may be supratentorial (such as the occipital interhemispheric transtentorial and the posterior transcallosal) or infratentorial (such as the supracerebellar infratentorial). The relationship of the pineal tumour to the venous structures in the region to a large part determines the surgical approach. The more common anatomical arrangement is for the large veins to be displaced superiorly and dorsally. The lesion is then amenable to the supracerebellar infratentorial approach. Ventral and inferior displacement of the veins is less common; this arrangement is more conducive to the occipital interhemispheric transtentorial approach. Supratentorial approaches are more suitable for large tumours with supratentorial and lateral extensions into the atrium and lateral ventricles.

Supracerebellar infratentorial approach

The supracerebellar infratentorial approach, first described in 1971, is ideal for pineal region tumours that are predominantly in the midline and that displace the venous structures superiorly. In this approach, the venous system does not limit access to the tumour. The sitting position, with the head flexed to bring the tentorium parallel to the floor, augments the benefits of this procedure: it encourages the cerebellum and the tumour to drop into the craniotomy, and facilitates drainage of CSF and blood from the operative field (Fig. 28.4). It also facilitates safe dissection of the tumour from the veins, which are encountered towards the end of the tumour resection. The risks of the sitting position relate to air embolism, anaesthesia, haemostasis, pneumocephalus and subdural haemorrhage secondary to cortical collapse. Patients must not be hypovolaemic when placed in the
sitting position. A drop in end-tidal carbon dioxide partial pressure detects air embolism. Preoperative echocardiography to exclude a patent foramen ovale or other right to left cardiac shunts reduces the risks associated with air embolism. Doppler ultrasonography, positioned on the anterior chest wall, and a central venous line allow early detection and management of intravenous air. Haemostasis is particularly important in the context of the low or negative venous pressure in the operative field and should be confirmed on Valsalva manœuvre at the end of the resection. Alternatively, the three-quarter prone or full prone positions may be used for this approach.
FIG. 28.4  The supracerebellar infratentorial approach to the pineal region. **A**, The relationships between the venous structures and the pineal and posterior surface of the midbrain. **B and C**, Intraoperative photographs, with the patient in the sitting position, showing the descent of the cerebellum (C) and the opening of the supracerebellar corridor below the tentorium (T). The venous structures (V) are located within the arachnoid tissue posterior to the pineal tumour (PT) in B. In C, the tumour has been resected and the cavity of the third ventricle is seen (arrows), with the thalami evident on both sides (asterisk).

It is not necessary to expose the transverse sinuses and the craniotomy can be fashioned just below them; collapse and low flow within these sinuses increase the risk of perioperative venous thrombosis. For large tumours, the
craniotomy extends to include the foramen magnum, allowing optimal settling of the cerebellar hemispheres with minimal retraction. Dural opening is ‘Y’-shaped and based on the transverse sinus, allowing full superior retraction of the dura. Drainage of CSF from the cisterna magna achieves a similar effect with a smaller craniotomy. It should not be necessary to retract the cerebellar vermis inferiorly. Veins and arachnoid adhesions arising from the superior cerebellar surface, including the precentral cerebellar vein, can be divided. In most cases, the tumour is then visible below the thickened arachnoid of the quadrigeminal cistern, which contains the great veins. This is sharply incised. The vein of Galen and the internal cerebral veins are visible above the tumour; the basal veins extend laterally and inferiorly, and the superior vermian vein is posterior to the tumour.32

The highest point of the vermis, the culmen, tends to obscure the lower dorsal surface of the tumour and the quadrigeminal plate; a slight lateral shift of the viewing angle is usually sufficient to correct this. With mild retraction of the lateral cerebellar hemisphere, this approach can also be used to expose the ipsilateral cerebellomesencephalic fissure and the posterior part of the ambient cistern.37 Division of the tentorial edge at the notch increases exposure superiorly if necessary. Care must be taken to avoid injury to the trochlear nerves, which run lateral to the free edge of the tentorium in the posterior and middle incisural spaces.37 The most difficult part of the dissection often relates to the interface between the tumour and the brainstem. Gentle upward retraction of the tumour, or its emptied capsule, and blunt dissection under direct vision, is safe and effective.31

Uschold et al describe an endoscopically assisted modification of this procedure.38 In this technique, using the sitting position, a small burr-hole, up to 2.5 cm in diameter, was positioned just below and lateral to the torcular Herophili. Cerebellar relaxation was most often achieved with mannitol and lumbar drainage. The endoscope was advanced along the inferior tentorial surface; a variety of endoscope viewing angles, including 0, 30 and 45°, were used. Micro-instruments were advanced outside the endoscope. Tentorial veins were divided along the surgical corridor to facilitate endoscope and instrument movement in the supracerebellar space. Once the deep venous complex at the vein of Galen was visualized, the endoscope was directed inferiorly towards the pathology. Sharp dissection was used to define and resect the lesion in piecemeal fashion. Only 1 out of 9 cases required conversion to an open microsurgical procedure; in the unsuccessful case, this was due to failure to obtain sufficient cerebellar retraction. Limitations to
this approach include large lesions with bilateral infiltration into neural structures and veins, high vascularity, and lesions extending above the tentorium.

The authors also argue that in the case of incompletely resected tumours or pineal cysts, fenestration between the pineal recess and the quadrigeminal cistern, or posterior third ventriculostomy, is equivalent to the standard stoma in the floor of the third ventricle in terms of relieving obstructive hydrocephalus.\(^\text{38}\)

**Occipital interhemispheric transtentorial approach**

The occipital interhemispheric transtentorial approach is preferred for pineal lesions situated above the vein of Galen or centred at the tentorial edge; tumours involving the pulvinar and the medial occipital lobe are also approached effectively by this route (\textbf{Fig. 28.5A}).\(^\text{32,37}\) It provides excellent views of the anterior part of the tentorial surface of the cerebellum and its vertical exposure extends from the splenium down the length of the brainstem.\(^\text{39}\) It has also been advocated for large supracerebellar tumours arising from the superior medullary velum in children, such as atypical teratoid rhabdoid tumours.\(^\text{40}\) This procedure is performed in the three-quarters prone or park bench position, with the head elevated and rotated towards the floor and the side of entry in a dependent position. In this way, the exposed occipital lobe is allowed to fall laterally under gravity, minimizing the need for active retraction.
FIG. 28.5  A, The occipital interhemispheric transtentorial approach to a pineal tumour. B, The posterior interhemispheric approach, shown here prior to the splenial callosotomy, which would allow further superior exposure of the pineal lesion.
The craniotomy exposes the lateral posterior sagittal sinus and the superior margin of the transverse sinus at the torcular. The durotomy is based on the transverse sinus; fortunately, there are no bridging veins along the posterior 5 cm of the medial occipital lobe. Administration of intravenous mannitol, or aspiration of CSF through an external drain or ventricular access device, facilitates mobilization of the occipital lobe without the need for retraction; even minor retraction may cause hemianopia in this procedure.

The tentorium and straight sinus are visualized. The tentorium is incised 1 cm lateral and parallel to the straight sinus; the incision is extended into the posterior incisural space. The lateral tentorial leaf can be retracted laterally using a suture. This exposes the pineal tumour and, depending on the extent of displacement by tumour, the tough arachnoid tissue containing the deep veins. The tumour is typically removed in piecemeal fashion between the vein of Galen, the straight sinus and the laterally placed basal veins. The tentorial division allows access into the space above the cerebellum, as well as into the cerebellomesencephalic fissure. The splenium forms the superior extent of the exposure. It is often stretched by a large tumour but only rarely requires division to facilitate access into the superior part of the posterior third ventricle. The lateral extent of the exposure is defined by the thalami. Dissection from the thalami and quadrigeminal plate can be performed under direct vision.

In comparison with the supracerebellar infratentorial approach, the occipital transtentorial approach allows better visualization of the ipsilateral cerebellomesencephalic fissure, the posterior part of the ambient cistern and the lateral surface of the cerebral peduncle. However, the lateral half of the contralateral quadrigeminal cistern is more difficult to access. Visual field deficit, usually transient, is an important complication specific to this procedure. A recent study has used diffusion tractography to identify the termination areas of the various components of the optic radiation and recommends that retraction of the occipital lobe should be limited to its inferior surface. Retraction of the occipital pole is likely to compromise central (foveal) vision.

**Posterior transcallosal approach**

Pineal tumours extending upwards through the splenium or lying within the atrium of the lateral ventricle, and therefore above the level of the vein of Galen, may be managed through the posterior transcallosal approach (Fig. 28.5B). Through a parieto-occipital scalp flap, the posterior interhemispheric
corridor is developed towards the splenium. Division of bridging veins posterior to the central sulcus should be avoided. The splenium is divided in the midline; additional division of the hippocampal commissure leads to entry into one of the lateral ventricles. In most cases, incision of the splenium alone allows visualization of the tumour, with the roof of the third ventricle situated anteriorly. The internal cerebral veins may be involved within the tumour. Every effort should be made to preserve these veins.\textsuperscript{32}

**Tips and Anatomical Hazards**

- The facial colliculus and the nucleus of the abducens nerve within the floor of the fourth ventricle are at the same level as the dentate nucleus.
- Tumours in or arising from the brainstem often distort the nuclei within the floor of the fourth ventricle; intraoperative monitoring and mapping during surgical resection are important.
- Defining the transverse sigmoid junction is the key to retrosigmoid craniotomy. It is located at the asterion and lies along a line extending occipitally from the zygoma, at a point approximately one-third down the auricle (pinna) of the ear.
- The telovelar approach allows a more complete exposure of the lateral recesses and foramina of Luschka.
- It is crucial to drain CSF from the cisterna magna prior to mobilization of the cerebellar hemisphere to reduce the degree of retraction required.
- Dissection in the interpeduncular cistern is best avoided.
- The relationship of a pineal tumour to the venous structures in the pineal region plays a significant part in determining the surgical approach.
- Retraction of the occipital pole is likely to compromise central (foveal) vision.
20. Kellogg JX, Piatt JH. Resection of fourth ventricle tumors without splitting the vermis: the cerebellomedullary fissure


31. Sonabend AM, Bowden S, Bruce JN. Microsurgical resection


Single Best Answers

1. Which one of the following statements about the fourth ventricle is correct?
   A. The rostral one-third is posterior to the pons and the caudal two-thirds are posterior to the medulla oblongata
   B. The vestibular area is lateral to the sulcus limitans and extends to the lateral recess
   C. The striae medullaris course medially from the lateral recess across the middle cerebellar peduncle
   D. The facial colliculus overlies the ascending section of the root of the facial nerve and is situated lateral to the sulcus limitans
   E. The vagal triangle in the caudal floor overlies the nucleus accumbens

Answer: B. The rostral two-thirds of the fourth ventricle are posterior to the pons. The striae medullaris course across the inferior cerebellar peduncle. The facial colliculus is situated medial to the sulcus limitans, on the median eminence. The vagal triangle overlies the dorsal nucleus of the vagus.

2. Which one of the following statements about the cerebellopontine angle is correct?
   A. The posterior inferior cerebellar artery is intimately related to the superior vestibular nerve
   B. Retrosigmoid craniotomy to expose the cerebellopontine angle is often carried out in the sitting position
   C. The superior cerebellar artery is typically manipulated and displaced from the trigeminal nerve during surgery for trigeminal neuralgia
   D. The fourth cranial nerve is an important anatomical landmark during surgery in this region
E. The motor root of the trigeminal nerve courses across the rostral cerebellopontine angle on its way to the foramen rotundum

**Answer: C.** The posterior inferior cerebellar artery is intimately related to the lower cranial nerves. Retrosigmoid craniotomy is most often carried out in the park bench position. The fourth cranial nerve is situated in the ambient cistern. The motor root of the trigeminal nerve courses through the foramen ovale.

3. Which one of the following statements about the cerebral venous system is correct?

A. The velum interpositum contains the internal cerebral veins and is attached superiorly to the hippocampal commissure

B. The internal cerebral veins are formed by the confluence of the anterior septal vein and the thalamostriate vein anterior to the foramen of Monro

C. The internal cerebral veins join the basal veins of Rosenthal at the falcotentorial junction and the straight sinus

D. The superior vermian vein must be preserved during the supracerebellar infratentorial approach

E. Numerous bridging veins at the occipital pole present a significant challenge in the occipital transtentorial approach

**Answer: A.** The internal cerebral veins are formed at the posterior margin of the foramen of Monro. They join the basal veins of Rosenthal in the quadrigeminal cistern, to form the vein of Galen, which subsequently drains into the straight sinus at the falcotentorial junction. The superior vermian vein is divided to allow cerebellar descent during the supracerebellar infratentorial approach. The medial surface of the posterior occipital lobe is usually devoid of bridging veins.
4. Which one of the following statements about approaches to the brainstem is correct?

A. In the Kawase approach to access the epitrigeminal entry zone, injury to the greater (superficial) petrosal nerve is associated with minimal clinical consequence
B. The lateral medullary safe entry zone traverses the middle cerebellar peduncle
C. Temporary paresis of the oculomotor nerve is common after use of the anterior mesencephalic entry zone
D. The telovelar approach offers a limited exposure of the fourth ventricular floor
E. The flocculus is a reliable landmark during surgery around the foramen of Magendie

**Answer: C.** The greater (superficial) petrosal nerve carries the preganglionic parasympathetic secretomotor nerves destined for the lacrimal gland via the pterygopalatine ganglion and injury causes a dry eye. The lateral medullary entry zone traverses the inferior cerebellar peduncle. The telovelar approach offers an excellent exposure of most of the fourth ventricular floor. The flocculus is a reliable landmark during surgery around the foramen of Luschka.
1. An 8-year-old girl presented with a 6-week history of progressive headache, ataxia and vomiting. Her MRI scan on presentation is shown in Fig. 28.6A, B. The lesion involves the pineal gland and right posterior thalamus. There is patchy enhancement and signal shortening on unenhanced T1-weighted scans suggestive of recent haemorrhage. The tumour did not restrict on diffusion-weighted sequences. There was associated obstructive hydrocephalus.
FIG. 28.6  A, B, Preoperative post-gadolinium sagittal (A) and FLAIR coronal (B) MR images, demonstrating the heterogeneous haemorrhagic pineal region tumour involving the right posterior thalamus, with associated obstructive hydrocephalus. C, D, Postoperative sagittal post-gadolinium (C) and FLAIR coronal (D) MR scans showing complete resection of the lesion through the supracerebellar infratentorial approach.

The patient underwent an endoscopic third ventriculostomy and biopsy of the lesion within the posterior third ventricle. The biopsy was suggestive of pilocytic astrocytoma. This led to an improvement in her clinical condition. One week later she underwent resection of the tumour through an infratentorial supracerebellar approach. The tumour was heterogeneous,
partly solid and partly cystic, with areas of haemorrhage. A postoperative scan confirmed gross total resection of the tumour (Fig. 28.6C, D). Histology was confirmed as a pilocytic astrocytoma. The child was discharged on the fifth postoperative day and her ataxia continued to improve. On review 3 months postoperatively, she was asymptomatic, and her surveillance MRI scan at 9 months remains clear.

2. A 5 year-old boy presented with a 2-week history of headache and vomiting. Examination at the time of hospital admission revealed drowsiness and papilloedema. An MRI scan (Fig. 28.7A, B) showed an enhancing irregular pineal region tumour and obstructive hydrocephalus. He underwent emergency endoscopic third ventriculostomy and endoscopic biopsy of the tumour. Pathology was reported as a mature teratoma. Serum and CSF tumour markers (AFP and β-HCG) were negative.
The lesion was resected through an occipital interhemispheric transtentorial approach 10 days later. The teratoma was adherent to the surrounding structures, particularly the tectal plate, and the child demonstrated Parinaud's syndrome for 3 days postoperatively. MRI scans (Fig. 28.7C, D) confirmed gross total resection. He was discharged on the seventh postoperative day with no neurological deficit.
Spinal cord

Erlick A Pereira, Aswin Chari

Core Procedures

- Myelotomy for intramedullary tumour
- Dorsal root entry zone lesioning for pain
- Selective dorsal rhizotomy for spasticity
- Cordotomy for pain
- Syringoperitoneal/syringopleural shunting

The spinal cord lies within the upper two-thirds of the vertebral canal (spinal canal), which is formed by the vertebral bodies anteriorly, their pedicles and facet joints laterally and their laminae posteriorly. Although a discussion of the osseous anatomy of the spine is outside the remit of this chapter (Section 4), it is a prerequisite for understanding the surgical anatomy of the spinal cord itself.

In general terms, the spinal cord receives afferent input from, and controls the functions of, the trunk and limbs. It begins at the upper border of the C1 vertebral body where it is continuous with the inferior border of the medulla oblongata; the spinal cord is therefore also known as the medulla spinalis. The cord ends at the conus medullaris, on average at the level of the middle third of the body of the L1 vertebra in adults; it may end as high as the middle third of the body of the T11 vertebra or as low as the middle third of the body of the L3 vertebra. Since the spinal cord is shorter than the vertebral column, the more caudal spinal roots descend for varying distances around and beyond the cord to reach their corresponding foramina. In so doing, they form a divergent sheaf of spinal nerve roots, the cauda equina, which is gathered around the filum terminale in the spinal theca, mostly distal to the apex of the cord.
Embryology

The central nervous system (CNS) forms through primary, junctional and secondary neurulation. Primary neurulation begins at stage 9 (25–27 days post fertilization) and is completed during stage 12 (30–32 days post fertilization). In this process the neural plate (a pseudostratified epithelium) forms a neural groove in the midline, where the cells of the hinge plate become wedge-shaped. The lateral edges of the neural plate elevate so that they approach each other dorsally and fuse bidirectionally, forming a neural tube. Fusion starts at the level of somites 1 and 2 (adjacent to the developing rhombencephalon) and proceeds rostrally to form the brain and caudally to the level of somite 31 (equivalent to the future second sacral vertebra), forming part of the spinal cord. Secondary neurulation begins at stage 12 and ends about stage 17 (39–41 days post fertilization) by a different process, in the absence of a neural plate. Cells in the caudal midline (caudal eminence) undergo mesenchymal/epithelial transition and produce a cellular cylinder which fuses seamlessly with the caudal end of the neural tube. Further elongation of this portion of the caudal neural tube involves cavitation of caudal eminence cells. The formation of the portion of the neural tube between primary and secondary neurulation is termed junctional neurulation.\(^1\)

Differential gene expression in three axes determines the final structure of the spinal cord – rostrocaudal, ventrodorsal and radial – are noted. Regarding the rostrocaudal axis, early brain regions are identified before rostral neuropore closure and homeotic (Hox) genes are involved in rhombencephalic and neural crest cell patterning. There is no evidence for intrinsic segmentation in the developing spinal cord; the position of motor and sensory spinal nerve roots is dependent on informational cues from adjacent somites. Regarding the ventrodorsal axis, the notochord, invaginating at the end of the primitive streak, and the floor plate of the neural tube control ventrodorsal differentiation. The caudal eminence gives rise to the most caudal part of the notochord. The proximity of the notochord ventrally induces formation of a basal plate (predominantly motor neurones) and an alar plate (predominantly sensory neurones), separated by the sulcus limitans. Regarding the radial axis, the neural tube shows radial patterning throughout development. Closest to the central canal of the spinal cord (equivalent to the ventricles in the brain), the ventricular zone is the site of cell division. Progeny migrate ventriculofugally (radially) along radial glial
cells, which extend from the ‘ventricle’ to the outer pial surface. An
outermost layer containing only cytoplasmic processes of cells (marginal
zone) forms as proliferation continues, followed by an inner, intermediate
zone (mantle zone), containing motor and sensory neuroblasts and
glioblasts.

Initially, the cord is the same length as the canal, extending to the last
coccygeal vertebrae. From the second trimester, the vertebral column grows
more rapidly than the spinal cord and the position of the conus medullaris
lies at progressively higher levels. By week 25 it has ascended nine vertebral
segments and is level with the L3 vertebra. By week 40 (full term) it lies
between L1 and L3. The typical adult cord ends around the inferior border of
the body of the L1 vertebra. This developmental ascent results in a mismatch
between spinal cord segments and vertebral level. The lower motor and
sensory nerve roots lengthen as the conus medullaris ascends and pass
caudally as the cauda equina. A thin filum terminale remains attached to S2.

Clinically, disorders of spinal cord development result in the spectrum of
spinal dysraphism disorders, including spina bifida occulta (absence of
spinous process/lamina), meningocele (cystic dilation of meninges but
normal neural tissue) and myelomeningocele (cystic dilation of meninges
and abnormal neural tissue), which result from incomplete caudal closure of
the neural tube (Fig. 29.1). Other disorders include tethered cord (resulting
in a characteristic low-lying conus medullaris) and the spinal cord
malformations diastematomyelia (a segment of two hemicords in two dural
sheaths) and diplomyelia (a segment of two hemicords within a single dural
sheath).
**FIG. 29.1** Radiographic representations of some of the disorders of cord development. **A**, A sagittal T2 weighted MRI showing spina bifida occulta and a tethered cord. **B**, A sagittal T1 weighted MRI showing a meningocele cavity without neural elements (arrow). **C**, A sagittal T2 weighted MRI showing a myelomeningocele cavity with neural elements extending into the cavity (arrows). **D**, An axial T2 weighted MRI showing diastematomyelia at the upper thoracic level.
Surgical surface anatomy

Pre- and intraoperative localization of spinal levels is established via either plain X-ray image intensifier or intraoperative guidance systems utilizing X-ray or CT. However, it is useful to be aware of the palpable surface landmarks that correspond with various vertebral levels (Table 29.1).

**Table 29.1**

**Surface landmarks and their corresponding vertebral levels**

<table>
<thead>
<tr>
<th>Anterior Approach to Cervical Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1–2: Angle of mandible</td>
</tr>
<tr>
<td>C3–4: Hyoid bone</td>
</tr>
<tr>
<td>C4–5: Thyroid cartilage</td>
</tr>
<tr>
<td>C5–6: Cricothyroid membrane</td>
</tr>
<tr>
<td>C6–7: Cricoid cartilage</td>
</tr>
<tr>
<td>Posterior Approach to Thoracolumbar Spine</td>
</tr>
<tr>
<td>T2–3: Scapular spine</td>
</tr>
<tr>
<td>T6: Inferior scapular pole</td>
</tr>
<tr>
<td>L4–5: Intercristal line between the iliac crests</td>
</tr>
</tbody>
</table>
Clinical anatomy

Cross-sectional anatomy

Fissures and sulci extend along most of the external surface of the spinal cord. In transverse section, the spinal cord is incompletely divided into right and left halves by an anterior (ventral) median fissure and a posterior (dorsal) median sulcus and septum; they are joined by a commissural band of nervous tissue that contains a central canal. The anterior median fissure is lined by pia. There are also paired postero-intermediate sulci (between the gracile and cuneate fasciculi) and posterolateral sulci (lateral to the dorsal columns) where the dorsal roots enter the cord. The posterior median and posterolateral sulci are both relevant for surgical access.

The spinal cord consists of an outer layer of white matter and an inner core of grey matter; their relative sizes and configuration vary according to level (Fig. 29.2). The amount of grey matter reflects the number of neuronal cell bodies present and is proportionately largest in the cervical (C3–T2) and lumbar (L1–S3) enlargements, which contain the neurones that innervate the limbs. The absolute amount of white matter is greatest at cervical levels and decreases progressively at lower levels because descending tracts shed fibres as they descend and ascending tracts accumulate fibres as they ascend.
FIG. 29.2 Transverse sections through the spinal cord at representative levels (approximately ×5). Note the differences in the amount of grey and white matter at the different levels. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed.)
The spinal grey matter is often described as being ‘butterfly-shaped’ or resembling the letter ‘H’ in transverse section. The cord consists of four linked cellular masses: the right and left dorsal horns, which project dorsolaterally, and the right and left ventral horns, which project ventrolaterally towards the surface. The grey matter that immediately surrounds the central canal and unites the two sides forms the dorsal and ventral grey commissures. The dorsal horn is the site of termination of the primary afferent fibres that enter the cord via the dorsal roots of the segmental spinal nerves. The tip of the dorsal horn is separated from the dorsolateral surface of the cord by a thin fasciculus or tract (of Lissauer), in which primary afferent fibres ascend and descend for a short distance before terminating in the subjacent grey matter. The ventral horn contains efferent neurones, whose axons leave the spinal cord in the ventral roots. A small intermediate, or lateral, horn is present at thoracic and upper lumbar levels and contains the cell bodies of preganglionic sympathetic neurones.

Spinal grey matter is a complex mixture of neuronal cell bodies, their processes and synaptic connections, neuroglia and blood vessels. Neurones in the grey matter are multipolar. They vary in size and features, such as the length and the arrangement of their axons and dendrites, and they may be intrasegmental (i.e. contained within a single segment) or intersegmental (i.e. their ramifications spread through several segments). On the basis of cytoarchitecture, spinal grey matter may be divided into 10 zones, known as Rexed's laminae, which are numbered sequentially from dorsal to ventral and defined on the basis of neuronal size, shape, cytological features and density (Fig. 29.3). Some of these laminae are equated with cell groupings of particular functional types. Laminae I–IV correspond to the dorsal part of the dorsal horn, and are the main sites of termination of cutaneous primary afferent terminals and their collaterals. Many complex polysynaptic reflex paths (ipsilateral, contralateral, intrasegmental and intersegmental) start from this region, as also do many long ascending tract fibres, which pass to higher levels. Lamina II consists of densely packed small neurones and corresponds approximately to the substantia gelatinosa. Laminae V and VI lie at the base of the dorsal horn and receive most of the terminals of proprioceptive primary afferents, profuse corticospinal projections from the motor and sensory cortex, and input from subcortical levels, suggesting their involvement in the regulation of movement. Lamina VII occupies the region
just ventral to lamina VI and extends across the spinal grey matter on each side. The region is known as the intermediate zone and includes the lateral horn within the thoracic cord. Lamina VII contains three important nuclear groups: the posterior thoracic nucleus (nucleus thoracicus posterior, Clarke's column), which extends throughout the thoracic and upper lumbar segments and gives rise to the dorsal spinocerebellar tract; the intermediolateral nucleus, which is located between T1 and L2, and gives rise to the preganglionic sympathetic fibres; and the intermedio-medial nucleus, which extends the full length of the cord and may be involved in the control of visceral motor neurones. White matter tracts are bundles of axons (tracts) that project to or from specific areas of the brain and can be classified into sensory (ascending), motor (descending), autonomic and intersegmental tracts. Some major tracts are topographically organized; others are more diffuse in their distribution (Table 29.2 and Fig. 29.4).

<table>
<thead>
<tr>
<th>Descending tracts</th>
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<tbody>
<tr>
<td>Lateral corticospinal tract</td>
<td>Corticospinal (pyramidal tract) fibres originate from widespread regions of the cerebral cortex, including the primary motor cortex of the frontal lobe where the opposite half of the body is represented in a detailed somatotopic fashion. The fibres descend throughout the length of the brainstem. The majority then cross to the contralateral side in the motor decussation of the pyramids in the medulla. Thereafter, they continue caudally as the lateral corticospinal tract of the spinal cord, which terminates in association with interneurones and motor neurones of the spinal grey matter. The principal function of the corticonuclear and corticospinal tracts is the control of fine, fractionated movements, particularly of those parts of the body where delicate muscular control is required. These tracts are particularly important in speech (corticonuclear tract) and movements of the hands (corticospinal tract).</td>
</tr>
<tr>
<td>Anterior corticospinal tract</td>
<td>Control of axial musculature. Uncrossed fibres decussate at the level at which they terminate in the spinal cord.</td>
</tr>
<tr>
<td>Rubrospinal tract</td>
<td>Thought to be involved in the control of movement velocity. Originates in red nucleus (connections with cerebellum and primary motor cortex) and decussates in brainstem. Rubrospinal fibres cross in the ventral tegmental decussation and descend in the lateral funiculus of the cord, where they lie ventral to, and intermingled with, fibres of the lateral corticospinal tract. The origin, localization, termination and functions of rubrospinal connections are poorly defined in humans.</td>
</tr>
<tr>
<td>Reticulospinal tracts (medial and lateral)</td>
<td>Involved in the integration of sensory input in guiding motor output. Fibres descend ipsilaterally from the pontine and medullary reticular formation to the spinal cord. The course and location of the reticulospinal tracts are poorly defined in humans because the fibres tend to be scattered throughout the ventral and lateral columns rather than forming well defined tracts.</td>
</tr>
<tr>
<td>Vestibulospinal tracts (medial and lateral)</td>
<td>Modulate posture and balance. Fibres descend ipsilaterally to the spinal cord from medial and lateral vestibular nuclei. The lateral vestibulospinal tract arises from small and large neurones of the lateral vestibular nucleus (Deiters’ nucleus). It descends ipsilaterally, initially in the periphery of the ventrolateral spinal white matter, but subsequently migrating into the medial part of the ventral funiculus at lower spinal levels. Fibres of this tract are somatotopically organized: fibres projecting to the cervical, thoracic and lumbosacral segments of the cord arise from neurones in the rostroventral, central and dorsocaudal parts, respectively, of the lateral vestibular nucleus. Lateral vestibulospinal fibres end ipsilaterally, mostly in the medial part of the ventral horn. The medial vestibulospinal tract arises mainly from neurones in the medial vestibular nucleus, but some are also located in the inferior and lateral vestibular nuclei. It descends in the medial longitudinal fasciculus into the ventral funiculus of the spinal cord, where it lies close to the midline in the so-called sulcomarginal fasciculus. Unlike the lateral tract, it contains both crossed and uncrossed fibres, and does not extend beyond the mid-thoracic cord level. Fibres of the medial tract project mainly to the cervical cord segments. The vestibular nuclei exert a strong excitatory influence upon the antigravity muscles by way of the medial and lateral vestibulospinal tracts. The antigravity muscles include the epaxial muscles of the vertebral column and the extensor muscles of the lower limbs.</td>
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<table>
<thead>
<tr>
<th>Ascending tracts</th>
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<tbody>
<tr>
<td>Dorsal column-medial</td>
<td>Primary afferent fibres carrying proprioceptive information (from mechanoreceptors such as Pacinian corpuscles and Merkel cells) and fine (discriminative) touch from the torso and peripheral somatosensory inputs are transmitted to the spinal cord via the dorsal columns of the spinal cord and subsequently to the brainstem and thalamus.</td>
</tr>
<tr>
<td>lemniscus</td>
<td>limbs ascend ipsilaterally in the spinal cord as the dorsal columns (fasciculus gracilis and fasciculus cuneatus); they end by synapsing on second-order neurones in the dorsal column nuclei (nucleus gracilis and nucleus cuneatus) of the medulla. Axons of second-order neurones decussate in the medulla and then ascend as the medial lemniscus to the ventral posterior nucleus of the contralateral thalamus, where they synapse on the cell bodies of third-order neurones. Axons of these neurones pass through the internal capsule to reach the cerebral cortex, terminating in the primary somatosensory cortex. A similar homologous projection exists for afferents derived from the head.</td>
</tr>
<tr>
<td>Spinothalamic tracts (lateral and anterior)</td>
<td>Primary afferent fibres carrying pain, temperature and coarse touch/pressure information from the torso and limbs ascend a few levels in Lissauer’s tract and synapse in the dorsal horn near their point of entry into the spinal cord. Homologous fibres from the head terminate in the trigeminal sensory nucleus of the brainstem. The cell bodies of second-order neurones are located in either the dorsal horn or the trigeminal sensory nucleus. Their axons decussate and ascend to the ventral posterior nucleus of the contralateral thalamus as the spinothalamic or the trigeminothalamic tract, respectively; they synapse on the cell bodies of third-order neurones in the thalamus. Axons of these neurones pass through the internal capsule to reach the cerebral cortex, terminating in the postcentral gyrus of the parietal lobe (primary somatosensory cortex).</td>
</tr>
<tr>
<td>Spinocerebellar tracts (dorsal/posterior and ventral/anterior)</td>
<td>The dorsal (posterior) and ventral (anterior) spinocerebellar tracts occupy the periphery of the lateral aspect of the spinal white matter and carry proprioceptive and cutaneous information to the cerebellum for the coordination of movement. The dorsal spinocerebellar tract lies lateral to the lateral corticospinal tract. It begins at about the level of the second or third lumbar segment and enlarges as it ascends. Axons of the tract originate ipsilaterally from the larger neurones of the posterior thoracic nucleus, throughout spinal segments T1–L2. The posterior thoracic nucleus receives input from collaterals of long ascending primary afferents of the dorsal columns and terminals of shorter ascending primary afferents of the dorsal columns. Many of these afferent fibres ascend from segments caudal to L2. In the medulla, the dorsal spinocerebellar tract passes through the restiform body and thence via the inferior cerebellar peduncle to terminate ipsilaterally in the rostral and caudal parts of the cerebellar vermis. The ventral spinocerebellar tract lies immediately ventral to the dorsal tract. Its cells of origin are in the lumbosacral cord and the tract carries information from the lower limb. Most of the axons forming the tract decussate but some remain ipsilateral. The tract begins in the upper lumbar region and ascends through the medulla oblongata to reach the upper pontine level, from where it descends in the dorsal part of the superior cerebellar peduncle to terminate, mainly contralaterally, in the anterior cerebellar vermis.</td>
</tr>
<tr>
<td>Autonomic tracts</td>
<td>Hypothalamo-spinal fibres exist in animals and arise from the paraventricular nucleus and other areas of the hypothalamus. These fibres descend ipsilaterally, mainly in the dorsolateral region of the cord, to be distributed to sympathetic and parasympathetic preganglionic neurones in the intermediolateral columns of the spinal cord. That similar pathways exist in humans may be inferred from ipsilateral sympathetic deficits (e.g. Horner’s syndrome), which follow lesions of the hypothalamus, the lateral tegmental brainstem, or the lateral funiculus of the cord.</td>
</tr>
<tr>
<td>Intersegmental tracts</td>
<td></td>
</tr>
<tr>
<td>Dorsolateral funiculus (Lissauer’s tract)</td>
<td>The tract of Lissauer (dorsolateral tract) lies between the apex of the dorsal horn and the surface of the spinal cord, where it surrounds the incoming dorsal root fibres. It is present throughout the spinal cord and is most developed in the upper cervical regions. The tract consists of fine myelinated and unmyelinated axons, many of which are the branches of axons in the lateral bundles of the dorsal roots. These axons bifurcate into ascending and descending branches as they enter the cord. The branches travel in the tract of Lissauer for one or two segments and give off collaterals that end on and around neurones in the dorsal horn. The tract also contains propriospinal fibres, some being short axons of small substantia gelatina neurones, which re-enter the dorsal horn.</td>
</tr>
<tr>
<td>Fasciculus proprius (lateral and medial)</td>
<td>Propriospinal pathways (fasciculi proprii) consist of the ascending and descending fibres of intrinsic spinal neurones. They contact other neurones within the same segment and/or in more distant segments of the spinal cord and so subserve intrasegmental and intersegmental integration and coordination. The majority of spinal neurones are propriospinal neurones, most of which lie in laminae V–VIII of the spinal cord. Propriospinal fibres are mainly concentrated around the margins of the grey matter but are also dispersed diffusely in the white funiculi. The propriospinal system plays important roles in spinal functions. Descending pathways end on specific subgroups of propriospinal neurones and these, in turn, relay to motor neurones and other spinal neurones. The system mediates all those automatic functions that continue after transection of the spinal cord, e.g. sudomotor and vasomotor activities, and bowel and bladder functions.</td>
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</tbody>
</table>
Meninges

The meninges comprise the dura mater and the leptomeninges (arachnoid and pia mater). Dura mater, the outer meningeal layer, is known as the thecal sac; it terminates at the level of the second sacral vertebra in the adult. Tubular prolongations of the dural sheath extend around the spinal roots into the lateral zones of the vertebral canal and out into the root canals, eventually fusing with the epineurium of the spinal nerves. The intermediate meningeal layer, arachnoid mater, extends a series of highly perforated intermediate sheets which envelop nerve roots and vessels as they cross the
subarachnoid space. The innermost layer is the pia mater, which covers the entire spinal cord surface.

The filum terminale, a filament of connective tissue approximately 20 cm long, descends from the apex of the conus medullaris. Its upper two-thirds, the filum terminale internum, runs within the thecal sac and reaches the caudal border of the second sacral vertebra. Its final third, the filum terminale externum, fuses with the investing dura mater, and then runs outside the thecal sac to fuse with the posterior periosteum of the first coccygeal vertebral segment. The filum terminale internum is continuous with the spinal pia and may have remnants of neural tissue (Co2–3 segments) attached to it.

The epidural space between the theca and the walls of the vertebral canal is clinically important. It is loosely filled with fat, connective tissue containing small arteries and lymphatics, venous plexuses and meningovertebral ligaments that anchor the thecal sac to the osseous vertebral canal. The space is confined cranially by the dural attachment to the periosteal dura of the foramen magnum and caudally by the posterior sacrococcygeal ligament, which is penetrated during a caudal epidural injection. The subarachnoid space, filled with cerebrospinal fluid (CSF), lies between the arachnoid and the pia mater which surrounds the cord parenchyma. The subpial collagenous layer in the spinal subpial ‘space’ is thicker than it is in the cerebral region and is continuous with the collagenous core of the ligamentum denticulatum (denticulate ligament). The latter is a flat, fibrous sheet on either side of the spinal cord between the ventral and dorsal spinal roots. Its medial border is continuous with the subpial connective tissue and its lateral border forms a series of triangular processes, the apices of which are fixed at intervals to the dura mater.

**Vascular supply and drainage**

The spinal cord is supplied by three major longitudinal arteries: a single anterior spinal artery (ASA) that descends along the anterior median fissure and paired posterior spinal arteries (PSAs) (Fig. 29.5). The ASA supplies the anterior half to two-thirds of the cord, including the corticospinal and spinothalamic tracts and the ventral (anterior) horns. The PSAs supply the remainder, including the dorsal columns, dorsal horns and dorsal roots.
The ASA is formed from branches of the vertebral arteries which arise close to the vertebrobasilar junction and join around the level of the foramen magnum. There is additional supply from 6–8 radiculomedullary arteries, usually at the levels of C3, C6, C8, T4/5 and T9–12. The last, usually arising from the left side, is known as the arteria radicularis anterior magna, or artery of Adamkiewicz, and is the main supply from T8 down to the conus medullaris. The mid-thoracic segments therefore constitute a watershed zone, susceptible to ischaemia during hypotension.

The PSAs are less well defined but also formed from either branches of the vertebral or posterior inferior cerebellar arteries, augmented by supply from 10–23 radicular branches of segmental vessels. The arterial supply to the cord is further augmented by radicular arteries that enter via the nerve roots. At the conus, the ASA and PSAs anastomose to form the arcade of Lazorthes (arterial basket of the conus medullaris).

Venous blood drains from the cord parenchyma into the pial plexus, from which longitudinal veins arise. The territory of the PSA is drained by a midline posterior spinal vein and paired posterolateral spinal veins, and that of the ASA is drained by a midline anterior spinal vein and paired anterolateral spinal veins. These in turn drain into epidural and extravertebral venous plexuses. Their valveless connections to the deep pelvic, retroperitoneal and thoracic plexuses (Batson's plexus) are believed to account for the spread of infection and metastatic disease from these locations to the spine.

Spinal nerves

A linear series of dorsal and ventral rootlets emerge at the posterolateral and anterolateral sulci, respectively, of the spinal cord. Adjacent groups of rootlets unite to form dorsal and ventral roots. Dorsal roots carry primary afferent nerve fibres from neuronal cell bodies located in dorsal root ganglia, whereas ventral roots carry efferent fibres from neuronal cell bodies located in the spinal grey matter. The roots merge to form 31 pairs of segmentally arranged spinal nerves. Each nerve exits the vertebral canal via an intervertebral foramen and divides into a large ventral (anterior) ramus.
and a smaller dorsal (posterior) ramus. In general terms, ventral rami innervate the limbs, together with the muscles and skin of the anterior part of the trunk, and dorsal rami innervate the postvertebral muscles and the skin of the back. The nerve fibres within the ventral rami serving the upper and lower limbs are redistributed within brachial and lumbosacral plexuses, respectively. Sinuvertebral nerves are recurrent branches of the ventral rami that re-enter the intervertebral foramina and supply the anterolateral dura, posterior longitudinal ligament and periosteum. Notably, the posteromedial dura is devoid of nervous supply.
The area of skin where sensation is subserved by all the cutaneous sensory
branches of a single spinal nerve is termed a dermatome. There is marked overlap between dermatomes of adjacent spinal nerves, particularly for the segments least affected by development of the limbs, i.e. the second thoracic to the first lumbar segments. A group of anatomically and functionally related skeletal muscles supplied by a single spinal nerve is termed a myotome.

Each dorsal root exhibits a swelling, the dorsal root ganglion, which contains the cell bodies of unipolar sensory neurones that project centrally to the spinal cord and peripherally as sensory nerves. Ventral roots from T1 to L1 contain preganglionic sympathetic fibres (the thoracolumbar outflow); ventral roots from S2 to S4 contain preganglionic parasympathetic fibres (the sacral component of the craniosacral outflow). Preganglionic fibres synapse on postganglionic neurones in ganglia either in the sympathetic chain or in abdominopelvic autonomic plexuses such as the coeliac and hypogastric plexuses.

There are many anatomical variations of the nerve roots that spinal surgeons must be aware of during decompressive procedures (Fig. 29.7).6

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**FIG. 29.7** Variations of nerve root anatomy, as classified by Neidre and McNab 1983. **A**, Type 1: two roots from a common dural sheath. **B**, Type 2: two roots exiting through a single foramen. **C**, Type 3: adjacent roots connected by anastomosis. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 45.6.)
Core procedures

Myelotomy for intramedullary tumour

Intramedullary spinal tumours constitute about 20% of all intradural spinal tumours. The majority are of glial origin (95%), comprising ependymomas (60%) and astrocytomas (30%). Other tumours may include haemangioblastomas and metastases.

Following adequate imaging, multidisciplinary review and patient consent, surgery is usually performed with the aim of resecting the tumour while minimizing additional neurological deficit, which is aided by intraoperative neurophysiological monitoring, including somatosensory and motor evoked potentials (SSEPs and MEPs).

The standard approach is via a midline posterior incision and laminectomy. The dura is opened longitudinally in the midline, where it is relatively avascular and is devoid of nervous supply. The myelotomy is performed along the posterior (dorsal) median sulcus, which is often thinned or splayed by a centrally located tumour (Fig. 29.8). If the tumour is located more laterally, other approaches, such as through the posterolateral sulcus, may be warranted.\(^7\) The tumour is resected using a combination of careful dissection, cautery and an ultrasonic aspirator while regular attention is paid to the intraoperative monitoring to avoid neurological deficit. Following resection, the myelotomy is approximated (some advocate closing it\(^8\)) and the dura is closed in a watertight fashion either by primary suture or by other techniques (e.g. clips). Formal fixation to maintain the stability of the spinal column is seldom undertaken and depends on the extent of the laminectomy and the number of levels involved.
Dorsal root entry zone lesioning for pain

Modern dorsal root entry zone (DREZ) lesioning was first described in the 1970s and was designed to destroy the nociceptive fibres grouped in the lateral bundle of the dorsal rootlet, the excitatory medial part of Lissauer's tract and the deafferented hyperactive neurones of the dorsal horn in patients with refractory pain following spinal cord, cauda equina or brachial plexus injury.\textsuperscript{9,10} Neurophysiological evaluation and careful patient selection are crucial determinants of operative outcomes.

Following a hemilaminectomy and posterolateral durotomy, the DREZ is
identified at the posterolateral sulcus. The lateral part of the DREZ, medial part of Lissauer's tract and apex of the dorsal horn are first stimulated then either cut (Sindou technique) or coagulated (Nashold technique), forming a lesion 3 mm deep. The procedure is performed at the level of the pain and one dermatome above and below. Good results have been reported for segmental, paroxysmal pain$^9$ and may be correlated with lack of evidence of DREZ damage on preoperative MRI scans.$^{10}$ Brachial plexus avulsion pain is a particularly successful indication.

**Selective dorsal rhizotomy for spasticity**

The selective dorsal rhizotomy (SDR) procedure is used mostly for paediatric patients with diplegic cerebral palsy, with the aim of relieving spasticity and improving mobility.$^{11,12}$ The procedure can involve a single-level laminectomy at the level of the conus (identified via ultrasound). The dorsal nerve roots of L2–S2 are isolated and each root is split into 3–5 rootlets. Each rootlet is stimulated in turn using intraoperative electromyography and is deemed pathological if there is a sustained response from multiple muscles to a train of tetanic stimuli. If this is the case, that fascicle is divided such that 60–65% of the most active fascicles are divided (Fig. 29.9). Once bilateral SDRs have been performed, the dura is closed in a watertight fashion.
FIG. 29.9  The selective dorsal rhizotomy procedure. A, The dorsal roots are identified. B, Each root is then split into 3–5 rootlets. C, The rootlets are individually subjected to electromyographical testing. D, If a sustained response from multiple muscles to a train of tetanic stimuli is not achieved, the rootlet is spared. E, Otherwise, the rootlet is divided. F, The procedure continues until each dorsal root between L2 and S2 has been tested. (From T.S. Park, J.M. Johnston, Surgical techniques of selective dorsal rhizotomy for spastic cerebral palsy, Neurosurg. Focus. 21 (2006) e7.)
Cordotomy for cancer pain

Cordotomy is a procedure that involves ablation of the anterolateral spinothalamic tract and can be performed either open or percutaneously for patients with refractory somatic nociceptive cancer-related pain. Currently, the accepted standard is CT-guided percutaneous radiofrequency ablation at the C1–2 level. Using this technique, the adverse effects, including temporary limb weakness, are purported to be rare. The largest series to date from Turkey suggests an excellent response to the procedure in terms of pain and functional outcomes, although its applicability to settings with optimized medical management has been questioned.

Syringoperitoneal/syringopleural shunting

Syringomyelia refers to a cystic dilation within the spinal cord and is associated with numerous other disorders, including Chiari I malformation, trauma, inflammation and neoplasms. When controlling the primary pathology does not result in symptomatic improvement in patients with progressive neurological deficit, syringoperitoneal, syringopleural or syringosubarachnoid shunts may be used to divert fluid. These are achieved via a midline approach, laminectomy and midline durotomy, as previously described, and a midline myelotomy to expose the cavity. The proximal catheter is placed inside the cavity and the distal catheter is tunnelled into the peritoneal or pleural cavities or placed in the subarachnoid space and the dura closed over it. Often used as a last-resort procedure, it has high rates of complications, including neurological deficit secondary to myelotomy, underdrainage or overdrainage, and infection.

Tips and Anatomical Hazards

When approaching intradural intramedullary spinal cord lesions, one must always think about corridors for access, minimizing neurological deficit and minimizing the risk of subsequent cerebrospinal fluid (CSF) leak.

Corridors of access: Intramedullary spinal cord tumours often create their corridors of access due to their expansile nature and this is most commonly via the avascular dorsal median sulcus. Careful splitting
and anchoring of the pia via hitch sutures can greatly aid operative exposure and subsequent dissection of the cord–tumour interface. Minimizing neurological deficit: In addition to meticulous technique, care must be paid at all times to the intraoperative neurophysiological monitoring via motor evoked potentials (MEPs) and somatosensory evoked potentials (SSEPs) for intramedullary tumours. Recordings at each stage of the procedure should be compared to baseline recordings and efficient communication between the surgeon and neurophysiologist is essential. If recordings change, time must be given to see if they recover before deciding on whether to stop or proceed further with caution.

Minimizing CSF leak: CSF leak is not an uncommon complication following intradural surgery and can result in significant morbidity including wound and central nervous system infection. Dural closure is made easier by the resection of tumour mass and closure is achieved via either primary suture or ligature clip systems, although the authors would recommend primary suture. Surgeons may decide, on occasion, to leave either a wound drain or intradural lumbar drain and place the patient on bed rest for a few days to allow the wound to heal prior to mobilization.
References


Single Best Answers

1. At which one of the following vertebral levels is the conus medullaris most commonly located?
   A. T11–12
   B. L1–2
   C. L3–4
   D. L5–S1
   E. S2–3

   **Answer: B.** The conus usually ends at the level of the bodies of the L1 or L2 vertebrae. In the fetus, initially the cord is the same length as the vertebral canal, extending to the last coccygeal vertebra. By full term, the conus usually lies between L1 and L2. A low-lying conus can indicate a tethered cord syndrome, which can present with motor deficits and sphincter disturbance, usually in children.

2. Which one of the following is the correct number of pairs of nerve roots that exit the spinal cord?
   A. 24
   B. 27
   C. 29
   D. 31
   E. 33

   **Answer: D.** There are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal pairs of nerve roots.

3. Which one of the following levels does NOT correspond to the level of a radiculomedullary artery that supplies the anterior spinal artery?
A. C3
B. C6
C. T4–5
D. T9–12
E. L2–3

**Answer: E.** The most inferior radiculomedullary artery is usually at the level of T9–12, called the arteria radicularis anterior magna, or artery of Adamkiewicz and is the main supply from T8 down to the conus medullaris.

4. Which one of the following tracts mediates fine touch and proprioception?
   A. Corticospinal tract
   B. Anterolateral spinothalamic tract
   C. Vestibulospinal tract
   D. Spinocerebellar tract
   E. Dorsal column–medial lemniscus

**Answer: E.** Fine touch and proprioception is mediated by the dorsal columns, which are split into the gracile (below T6) and cuneate (above T6) fasciculi. These uncrossed fibres synapse at the gracile and cuneate nuclei (medulla oblongata), decussate as the fibres of the medial lemniscus and synapse again at the VPL nucleus of the thalamus before ascending to the primary somatosensory cortex.

5. Which one of the following terms is used to refer to the presence of two separate hemicords in two dural sheaths?
   A. Diastematomyelia
   B. Meningocele
   C. Spina bifida occulta
D. Diplomyelia
E. Myelomeningocele

**Answer: A.** This is differentiated from diplomyelia, which is the presence of two hemicords within the same dural sheath. The other three answers are part of the spectrum of dysraphic disorders resulting from varying degrees of incomplete neural tube closure.
Clinical Case

1. A 15-year-old boy presents to his GP. Up until 4 months ago, he was the top cross-country runner in his school but has struggled to even finish his last few races. He is also finding it difficult to use his hands for fine motor tasks such as eating with a knife and fork and tying his shoelaces. An MRI scan has been performed which reveals an expansile mass within the substance of his cervical spinal cord.

A. How could you classify the neurological syndromes associated with spinal cord pathology?
This can be thought of as one of three syndromes:

i. Myelopathy: This is caused by spinal cord pathology/compression, resulting in motor weakness, sensory disturbance and sphincter dysfunction affecting all levels below the level of pathology. ‘Upper motor neurone’ signs are characteristic, such as spastic tone, hyperreflexia and clonus.

ii. Radiculopathy: This is caused by pathology/compression of the nerve roots, resulting in pain, motor weakness and sensory disturbance at the level of pathology. ‘Lower motor neurone’ signs are characteristic, such as hyporeflexia, muscle wasting and fasciculations.

iii. Myeloradiculopathy: A combination of the above syndromes. This is common in degenerative cervical myelopathy where a C5/6 disc prolapse may result in bilateral C6 radiculopathy and myelopathy below the lesion, affecting the distal upper limbs, trunk and lower limbs

B. What other symptoms would you enquire about in the history?
In addition to motor and sensory symptoms, it is also important to ask about bladder, bowel and sexual dysfunction. Spinal cord pathology may result in a ‘spastic’ bladder and bowel dysfunction, with detrusor-sphincter dyssynergia manifesting as incomplete voiding and incontinence and increased colonic and anal sphincter muscle tone manifesting as constipation. Sexual dysfunction is a key determinant of psychological wellbeing and quality of life, especially
for patients with traumatic spinal cord injury. Pain is also a key component. Axial pain (neck or back pain) is often musculoskeletal in origin but may be a sign of dural stretching/irritation. Radicular pain follows dermatomal distributions.

C. What signs would you try to elicit on a neurological examination? Whilst a thorough and complete neurological examination of the cranial nerves and upper and lower limbs must be conducted in all cases of suspected brain or spinal cord pathology, certain myelopathic signs are important objective markers to look for. These include:

- **Hypertonia**: Increased tone can affect the upper and lower limbs. Specifically, you will need to know how to differentiate between the ‘spastic’ tone of upper motor neurone pathology and the ‘rigid’ tone of Parkinsonian syndromes.
- **Hyperreflexia**: Exaggerated deep tendon reflexes are best appreciated through practice of examining numerous normal reflexes. In myelopathic patients, the patellar reflex can be elicited using just the fingers.
- **Hoffman’s sign**: Flexion of the thumb following a manoeuvre that consists first of passive flexion of the patient's middle finger by pressure over the nail bed, followed by sudden release of this pressure.
- **Crossed adductor reflex**: Stimulation of either the adductor tendon (just above the medial femoral condyle) or knee reflex elicits a reflex contraction of the contralateral adductor muscles.
- **Ankle clonus**: Up to 3–4 beats of clonus may be normal in some individuals but anything >5 is considered abnormal.
- **Babinski’s sign**: Reflex dorsiflexion of the great toes and fanning of the other toes by stroking the lateral side of the sole of the foot. The normal response is plantarflexion.

D. What are the nerve roots (and peripheral nerves) associated with each of the deep tendon reflexes?
- **Biceps reflex**: C5–6 (musculocutaneous nerve)
- **Triceps reflex**: C7–8 (radial nerve)
- **Brachioradialis reflex**: C6 (radial nerve)
• Patellar reflex: L3–4 (femoral nerve)
• Achilles’ tendon reflex: S1–2 (tibial nerve)

E. How may spinal cord tumours be anatomically classified?
Spinal cord tumours may be described as extradural, intradural–extramedullary or intradural–intramedullary. The most common types of tumour in each group are shown below:

<table>
<thead>
<tr>
<th>Extradural (55%)</th>
<th>Metastatic tumours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intradural–extramedullary (40%)</td>
<td>Schwannoma</td>
</tr>
<tr>
<td></td>
<td>Neurofibroma</td>
</tr>
<tr>
<td></td>
<td>Meningioma</td>
</tr>
<tr>
<td>Intradural–intramedullary (5%)</td>
<td>Ependymoma</td>
</tr>
<tr>
<td></td>
<td>Astrocytoma</td>
</tr>
<tr>
<td></td>
<td>Oligodendroglioma</td>
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F. Describe the midline approach to an intradural–intramedullary spinal cord tumour in the cervical spine.
A midline skin incision is made overlying the spinous processes at the relevant levels, which are localized using an intraoperative X-ray image intensifier. After going through the subcutaneous fat and the nuchal ligament in the midline, a bilateral subperiosteal dissection is performed to expose the spinous processes and laminae of the vertebrae. Following a laminectomy, which may be performed with a drill or a Kerrison punch, the dura is exposed and opened via a midline durotomy. Once the spinal cord is exposed, a midline myelotomy is usually performed over the posterior median sulcus to expose the tumour.
SECTION 4
Back and Spine

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The patterned anatomy of the spine is not without its drawbacks. While the study of any individual level can enlighten the surgeon about several adjacent, or even all, levels, a blind reliance on repetition and consistency can be disorienting, leading to wrong-level surgery, patient injury or even death. It is essential for surgical exposure of the spine to be done in a responsible manner. Beyond the avoidance of neurological and vascular structures, the biomechanical relationships between bones, joints, ligaments and muscles must be respected; violation of these load-bearing structures may condemn a patient to instability, wound dehiscence and the need for revision surgery. In order to remain oriented and precise when approaching the spine surgically, a surgeon must have a sound understanding of the relevant topographical anatomy. In the absence of a skeletonized exposure of multiple levels, surgeons must always know exactly what is being displayed in the operative field, where their instrument is and what tissues they are handling: these skills have become ever more important with the increased use of minimally invasive approaches.

This chapter contains a general overview of surgically relevant spinal anatomy. Details of the unique anatomy of each level of the spine, and how these details can be leveraged to access the spine safely, are reviewed in the chapters that follow in this section.
Surgical surface anatomy

Surface anatomy plays an important role in achieving adequate surgical exposure of the spine but its limitations must be appreciated. In the setting of revision surgery, previous scars or even palpable hardware may be enough to localize the starting point of the selected approach. When using apparently reliable landmarks, it may be reasonable to confirm localization with fluoroscopic imaging prior to making an incision or widening an established exposure. There are surface landmarks for nearly every cervical vertebra. The prominent spinous processes of C2 and C7 (vertebra prominens) can be palpated about the posterior midline (Fig. 30.1). The hyoid bone approximates the level of C3, the upper border of the thyroid cartilage is used to indicate C4, and the cricothyroid space approximates the C5–C6 disc space. Chassaignac’s tubercle can be palpated on the anterior transverse process of C6. For the thoracic spine, the suprasternal notch and the sternal angle can be used to approximate T2–T3 and T4–T5, respectively.\(^1\) Posteriorly, and with the arms resting at the sides, palpation of the scapular spine and the inferior angle of the scapula may help to localize T3 and T7, respectively. The spine of T7 overlies the level of the body of T8, and is at the level of the T9–T10 spinal cord segment (see Fig. 30.1).
The lumbar spine has several useful surface anatomy landmarks, although individual variations should always be borne in mind. The midline median furrow indicates the insertion of latissimus dorsi on to the supraspinous ligaments between the spinous processes; it runs the entire length of the spine and is deepest in the mid-lumbar spine. The furrow flattens out at the start of the natal cleft, which approximates the S3 vertebral level. Each spinous process, and the intervening interspinous space between two adjacent processes, can be palpated in the midline. Starting in the paramedian plane, the posterior superior iliac spines (PSIS) can be palpated on either side as the most medial aspects of the iliac crests: they usually correspond to approximately the S1 or S2 spinous process. From these points the iliac crests can be palpated along their course on each side.
laterally. At their most superior aspects, the iliac crests constitute an important skeletal landmark (see Fig. 30.1). An imaginary line drawn between them, the intercristal (Tuffier's) line, corresponds to the L4–L5 interspace when studied radiographically but can commonly fall at the L3–L4 interspace by palpation, particularly in females and in patients with higher body mass indices. The greater trochanter of the femur can be palpated over the lateral hip. The imaginary line between this point and the ipsilateral PSIS is often used to indicate a corridor for safe passage of instrumentation within the iliac wing.

Important surface anatomy landmarks for the direct lateral approach to the lumbar spine are the lower ribs, the iliac crests and the greater trochanter of the hip. The lowest two ribs, usually originating from T11 and T12 vertebral levels, are typically ‘false’ or ‘floating’ ribs that do not articulate anteriorly with the sternum. Due to their obliquity, they can often pass over the L1–L2 and L2–L3 disc spaces, respectively, although table angulation can elevate their position. These ribs are flexible and can usually be displaced sufficiently for surgical access during the approach without necessitating rib resection. The greater trochanter of the hip can be palpated and is an important landmark for positioning on the operating table: the patient should be placed on the table in a position such that the greater trochanter lies just distal to the hinge of the table angular breakpoint. These surface landmarks will provide the general region of the incision but lateral radiographs are used to localize to the middle, anterior border and posterior border of the targeted intervertebral disc space prior to incision.

To achieve a successful approach to the anterior lumbar spine, it is critical for the surgical incision to be optimally placed, based on either preoperative fluoroscopic or radiographic imaging with a marker placed on the skin, or on the patient's surface anatomy, according to surgeon preference and experience. Since the original description of the anterior approach to the lumbar spine for the excision of an intervertebral disc and interbody fusion by Paul Harmon in 1963, this approach has been a widely used technique by spine surgeons. It provides maximal access to the intervertebral disc space and can be utilized for tumour resection, debridement of infection and interbody fusion for degenerative processes; in many countries it remains the only available surgical approach for the implantation of a lumbar artificial disc replacement. The retroperitoneal approach is most commonly utilized, usually with the aid of a vascular surgeon. Depending on which spinal level is targeted, either the approach can pass between the common iliac veins and
arteries, or these vessels must be mobilized and transposed for the duration of the procedure. It is important to know that the aorta bifurcates at the level of the L4 vertebral body in approximately 70% of patients, at the L4–L5 disc space level in 12% of patients, and at the L5 vertebral body level in 18% of patients. Access to the L1–L4 levels usually requires a peri-umbilical incision and the surgeon may need to mobilize the abdominal aorta to gain access to the midline spinal structures. The lumbosacral junction (L5–S1 disc space) can usually be accessed via an incision that starts immediately superior to the pubic symphysis, which can be readily palpated regardless of body habitus. If the operation is planned for only the L5–S1 level, then either a vertical (median or paramedian) or transverse (Pfannenstiel) incision can be used within the hypogastric quadrant. A major advantage of a median vertical incision is that it passes through the relatively avascular plane of the linea alba and is muscle-splitting.

The sacral vertebrae are small and difficult to palpate.
Clinical anatomy

Vertebral column

The vertebral column is a curved linkage of individual vertebrae that forms the posterior bony element of several clinically significant junctional or transitional zones, including the prevertebral/retropharyngeal zone of the neck, the thoracic inlet, the diaphragm and the pelvic inlet. It forms the strong, flexible central axis of the body, supporting the full weight of the head and trunk, and transmits even greater forces generated by muscles attached to it directly or indirectly (such as the muscles of the anterolateral abdominal wall). The vertebral (spinal) canal transmits and protects the spinal cord and nerve roots, their coverings and vasculature, and extends from the foramen magnum to the sacral hiatus (see Fig. 31.1). Paired lateral intervertebral foramina transmit mixed spinal nerves, smaller recurrent nerves, and blood and lymphatic vessels. Typical vertebrae articulate via fibrocartilaginous intervertebral discs and paired synovial facet (zygapophyseal) joints, and are linked by ligaments, overlying muscles and fasciae (Ch. 31).

The anterior aspect of the vertebral column is formed by the anterior surfaces of the vertebral bodies and intervertebral discs, and is covered centrally by the anterior longitudinal ligament, which forms a fascial plane with the prevertebral and endothoracic fascia and with the subperitoneal areolar tissue of the posterior abdominal wall. Infection and other pathological processes may spread along this fascial plane. The lateral aspect of the vertebral column is arbitrarily separated from the posterior aspect by articular processes in the cervical and lumbar regions and by transverse processes in the thoracic region. Anteriorly, it is formed by the sides of the vertebral bodies and intervertebral discs. The oval intervertebral foramina, behind the bodies and between the pedicles, permit communication between the lumen of the vertebral canal and the paravertebral soft tissues. Each foramen contains a segmental mixed spinal nerve and its sheaths, from two to four recurrent meningeal (sinuvertebral) nerves, variable numbers of spinal arteries, and plexiform venous connections between the internal and external vertebral venous plexuses (Ch. 31). The foramina are smallest at the cervical and upper thoracic levels, and increase progressively in size in the thoracic and upper lumbar regions. The lumbosacral (L5/S1) intervertebral foramen is the smallest of the lumbar foramina.

The lateral aspects of the vertebral column have important anatomical relations, some of which vary considerably between the two sides. The
posterior aspect of the column is formed by the posterior surfaces of the laminae and spinous processes, their associated ligaments and the facet joints, and is covered by the deep muscles of the back. Depending on the spinal level and degree of lordosis or kyphosis, the space between laminae can range from wide apart to entirely covered. This highlights the care that must be taken when approaching the spine posteriorly. It is important to remain vigilant regarding these anatomical variances to avoid plunging an instrument into the spinal canal through an interlaminar space.

**Structural defects of the posterior bony elements**

Deformity and bony deficiency may occur at several sites within the posterior elements.

The laminae may be wholly or partially absent, or the spinous process alone may be affected, with no abnormalities in the overlying soft tissues (spina bifida occulta). A defect may occur in the bone that joins the superior and inferior articular processes (pars interarticularis): this condition is spondylolysis, and may be developmental or result from acute or fatigue fracture. If such defects are bilateral, the column may become unstable at that level, and forward displacement of that part of the column cranial to the defects may occur: this is spondylolisthesis. Abnormality of the laminar bone or degenerative changes in the facet joints may also lead to similar displacement in the absence of pars defects. The deformity of the vertebral canal resulting from spondylolisthesis may lead to neural compression and subsequent damage. Much more rarely, bony defects may occur elsewhere in the posterior elements, such as in the pedicles.

**Vertebrae: general features**

There are 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (usually fused) and 4 coccygeal vertebrae. A typical vertebra has a ventral body; a vertebral (spinal) canal; a dorsal vertebral (neural) arch; a median dorsal spinous process (spine); paired pedicles, transverse processes and laminae; and paired superior and inferior articular processes (zygapophyses) that arise from the vertebral arch at the pediculolaminar junctions. Typical vertebral bodies are united by fibrocartilaginous intervertebral discs between sheets of hyaline cartilage (vertebral end-plates) and by anterior and posterior longitudinal ligaments (Ch. 31). In life, the vertebral canal contains the spinal cord or cauda equina (depending on level), meninges, epidural and subarachnoid spaces, cerebrospinal fluid (CSF), venous plexuses, spinal arteries,
lymphatics and epidural fat. The clinical anatomy of the epidural space (the space within the canal but lying outside the dura) is described in Chapter 35; the cervical vertebrae (including atypical vertebrae C1, C2 and C7) are described in more detail in Chapter 32; and the lumbar vertebrae, sacrum and coccyx are described in Chapter 34.

Pedicles are short, thick, rounded dorsal projections from the superior part of the body at the junction of its lateral and dorsal surfaces; the concavity formed by the curved superior border of the pedicle is shallower than the inferior one. When vertebrae articulate by the intervertebral disc and facet joints, these adjacent vertebral notches contribute to an intervertebral foramen. The complete perimeter of an intervertebral foramen consists of the notches, the dorsolateral aspects of parts of adjacent vertebral bodies and the intervening disc, and the capsule of the synovial facet joint (Ch. 31). The laminae are directly continuous with the pedicles. They are vertically flattened and curve dorsomedially. Lateral to the spinous processes, vertebral grooves contain the deep dorsal muscles. At cervical and lumbar levels, these grooves are shallow and mainly formed by laminae. In the thoracic region, they are deeper, broader and formed by the laminae and transverse processes. The laminae are broad for the first thoracic vertebra, narrow for the second to seventh, broaden again from the eighth to eleventh, but become narrow thereafter down to the third lumbar vertebra. The spinous process (vertebral spine) projects dorsally and often caudally from the junction of the laminae. Spines vary considerably in size, shape and direction. They lie approximately in the median plane and project posteriorly, although in some individuals a minor deflection of the processes to one side may be seen. The spines act as levers for muscles that control posture and active movements (flexion/extension, lateral flexion and rotation) of the vertebral column.

The paired superior and inferior articular processes (zygapophyses) arise from the vertebral arch at the pediculolaminar junctions. The superior processes project cranially, bearing dorsal facets that may also have a lateral or medial inclination, depending on level. Inferior processes run caudally with articular facets directed ventrally, again with a medial or lateral inclination that depends on vertebral level. Upper lumbar superior articular processes are further apart than inferior ones but the difference is slight in the fourth and negligible in the fifth. In the thoracic and lumbar spine, the ipsilateral superior and inferior articular processes are connected via the pars interarticularis. This segment of bone is easily identifiable by its lack of
muscular attachment. From T12 to L2, the pars can be traced distally into the facet joint line via a straight longitudinal trajectory. From L3 distally, it is localized medial to the facet joint line.

Transverse processes project laterally from the pediculolaminar junctions as levers for muscles and ligaments, particularly those concerned in rotation and lateral flexion. In the cervical region, the transverse processes are anterior to the articular processes, lateral to the pedicles and between the intervertebral foramina. In the thoracic region, they are posterior to the pedicles, considerably behind those of the cervical and lumbar processes, and in the lumbar region, they are anterior to the articular processes but posterior to the intervertebral foramina. There is considerable regional variation in the structure and length of the transverse processes. In the cervical region, the transverse process of the atlas is long and broad, which allows the rotator muscles maximum mechanical advantage. Breadth varies little from the second to the sixth cervical vertebra, but increases in the seventh. In thoracic vertebrae, the first is widest, and breadth decreases to the twelfth, where the transverse elements are usually vestigial. The transverse processes become broader in the upper three lumbar vertebrae and diminish in the fourth. The transverse process of the fifth lumbar vertebra is the most robust; it arises directly from the body and pedicle to allow for force transmission to the pelvis through the iliolumbar ligament.

**Fascia**

The fascial layers of greatest surgical relevance are the thoracolumbar fascia, the deep cervical fascia and the prevertebral, endothoracic, retroperitoneal and posterior parts of the pelvic fasciae (the latter four layers collectively form the continuous prevertebral plane). Other important structures with fascial components are the ligamentum nuchae and the aponeurosis of erector spinae.

The cervical fascial layers are described in Chapter 15. The thoracolumbar (lumbodorsal) fascia covers the deep muscles of the back and the trunk. Above, it passes anterior to serratus posterior superior and is continuous with the superficial lamina of the deep cervical fascia on the back of the neck. In the thoracic region, the thoracolumbar fascia provides a thin fibrous covering for the extensor muscles of the vertebral column and separates them from the muscles connecting the vertebral column to the upper extremity. Medially, it is attached to the spines of the thoracic vertebrae, and
laterally to the angles of the ribs. In the lumbar region, the thoracolumbar fascia is in three layers (Fig. 30.2). The posterior layer is attached to the spines of the lumbar and sacral vertebrae and to the supraspinous ligaments. The middle layer is attached medially to the tips of the lumbar transverse processes and the intertransverse ligaments, below to the iliac crest, and above to the lower border of the twelfth rib and the lumbocostal ligament. The anterior layer covers quadratus lumborum and is attached medially to the anterior surfaces of the lumbar transverse processes behind the lateral part of psoas major; below, it is attached to the iliolumbar ligament and the adjoining part of the iliac crest; above, it forms the lateral arcuate ligament. The posterior and middle layers unite to form a tough raphe at the lateral margin of erector spinae, and at the lateral border of quadratus lumborum they are joined by the anterior layer to form the aponeurotic origin of transversus abdominis. At sacral levels, the posterior layer is attached to the posterior superior iliac spine and posterior iliac crest, and fuses with the underlying erector spinae aponeurosis. Bogduk (2005) describes two laminae in the posterior layer at lumbar levels, relating the varying orientation of the constituent collagen fibres to the biomechanical function of the fascia. The posterior and middle layers of the thoracolumbar fascia and the vertebral column together form an osteofascial compartment that encloses the erector spinae muscle group.

Joints

All vertebrae from C2 to S1 articulate via symphyses between their bodies, synovial joints between their articular processes, and fibrous joints between their laminae, transverse and spinous processes. Typical vertebral bodies are united by anterior and posterior longitudinal ligaments and by fibrocartilaginous intervertebral discs between sheets of hyaline cartilage (vertebral end-plates) (Ch. 31).

Zygapophysial or facet joints are synovial. They are surrounded by a thin fibrous capsule that is replaced by the ligamentum flavum anteriorly in the lumbar spine. Arterial anastomoses occur around the lateral facet joints. The joints are innervated segmentally by medial branches from dorsal primary
rami. Injury to these structures will devascularize or denervate the facet joint and the adjacent muscle.

**Ligaments**

The anterior longitudinal ligament runs from the basilar occipital bone down to the anterior tubercle of C1 and extends distally to the anterior sacrum (see Fig. 31.4). It becomes thinner as it broadens caudally. The ligament adheres to the intervertebral discs, end-plates and margins of the vertebral bodies. Its most superficial fibres extend over three or four vertebrae, its intermediate fibres extend between two or three vertebrae, and the deepest fibres run between adjacent bodies. The posterior longitudinal ligament is the posterior analogue of the anterior longitudinal ligament. It is continuous with the tectorial membrane and also attaches to the intervertebral discs, end-plates and margins of the vertebral bodies. The ligament is broader proximally, becoming denticulated and narrowing in the lower thoracic and lumbar regions. Superficial fibres cover 3–4 vertebrae, while deeper fibres join adjacent vertebrae. The ligamentum flavum connects the laminae of adjacent vertebrae (see Fig. 31.7). Its parallel yellow fibres run from the anterior inferior aspect of the cephalad (superior) lamina to the superior dorsal aspect of the caudal (inferior) lamina. The fibres extend from the joint capsules to the ipsilateral spinolaminar junction, a raphe separating the left and right ligaments, known to consist of multiple layers; its deepest layer is continuous with the anterior capsule of the facet joints in the lumbar spine. Interspinous ligaments connect adjacent spinous processes. They run from the supraspinous ligament down to the level of the ligamentum flavum. The ligaments are thicker further caudally; there is a midline cleft between the left and right components of the lumbar spine. The supraspinous ligament connects the tips of the spinous processes from C7 to L3 or L4. The superficial fibres connect up to four vertebrae, while the deepest fibres connect adjacent vertebrae. Proximally, the ligament is replaced by the ligamentum nuchae. Distal to L4, the ligament is replaced by decussating fibres of latissimus dorsi. Intertransverse ligaments run between adjacent transverse processes, are thickest about the thoracic spine and are replaced by muscle in the cervical spine.

**Muscles**
A detailed description of the posterior paraspinal muscles is beyond the scope of this chapter (see Baron and Tunstall (2016)). Briefly, the musculature of the back is arranged in a series of layers, of which only the deeper are true, intrinsic, back muscles, characterized by their position and by their innervation by branches of the posterior (dorsal) rami of the spinal nerves. Below the neck, they lie deep to the posterior layer of the thoracolumbar fascia. In the lumbar region, where the layers of the thoracolumbar fascia are well defined, they occupy the compartment between its posterior and middle layers. In the context of surgical approach, it is important to be familiar with these structures because they can serve as both landmarks for orientation and boundaries for prevention of injury.

The extrinsic, ‘immigrant’ muscles lie superficial to the intrinsic muscles. The most superficial – trapezius, latissimus dorsi, levator scapulae and the rhomboid muscles – run between the upper limb and the axial skeleton (Fig. 30.3 and Video 30.1). Deep to this layer lie the serratus posterior group, superior and inferior; they are variably developed but usually thin muscles. All the extrinsic muscles are innervated by ventral rami of the spinal nerves; trapezius is innervated by the spinal accessory nerve.
The intrinsic muscles are arranged in layers. The more superficial layers contain the splenius muscles in the neck and upper thorax, and the erector spinae group in the trunk as a whole. The deeper layers include the spinotransverse group, which is itself layered into semispinalis, multifidus
and the rotatores, and the suboccipital muscles. Deepest of all lie the interspinal and intertransverse muscles. The latter group constitute a mixture of dorsal and ventral spinal muscles. The lumbar intertransversarii mediales, thoracic intertransversarii and medial parts of cervical posterior intertransversarii are innervated by dorsal rami, but the others are supplied by ventral rami.

When the posterior cervical spine is approached, an avascular plane can be identified in the midline between the paraspinal muscles. When divided carefully, this can lead exposure directly down on to the spinous processes. Deviation from this course can injure the highly vascularized adjacent muscle, resulting in significant bleeding. In the lumbar spine, the interval between longissimus and multifidus can be located a few centimetres lateral of midline: this interval (the Wiltse interval) can be used to access the posterolateral lumbar spine with minimal muscle damage (Ch. 34).

The anterior approach to the subaxial cervical spine is commonly used in the surgical treatment of conditions such as cervical disc herniation, cervical spondylitic myelopathy and diseases of cervical vertebral bodies. It is guided by multiple muscular planes and muscle fibre trajectories. The medial border of sternocleidomastoid indicates to surgeons how laterally they will need to dissect in order to obtain a deeper exposure using the Smith Robinson approach (Ch. 32). The superior belly of omohyoid can be identified on deeper exposure by its medial (proximal) to lateral (distal) trajectory; it is present over the levels of C4, 5 and 6. The longus colli muscles run vertically along the anterior surface of the cervical spine. The cervical sympathetic trunk (CST) lies posteromedial to the carotid sheath, anterior to the longus muscles, extending longitudinally over longus capitis and longus colli under the prevertebral fascia. It lies approximately 11 mm lateral to the medial border of longus colli, and is at potential risk of injury during extensive anterolateral cervical dissection, or if the longus colli muscles are cut transversely to expose either the transverse foramen or uncovertebral joint. Iatrogenic injury to the CST would cause a Horner's syndrome and care must therefore be taken to minimize trauma to the longus colli muscles during an anterior approach.

With regard to anterior or lateral approaches to the lumbar spine (Fig. 30.4), psoas major can be thought of as analogous to the more proximally located longus colli muscles, in that its dissection must be minimized to avoid iatrogenic injury to the components of the lumbar plexus that lie between the superficial and deep layers of the muscle, becoming more
anterior distally. From above downwards, the iliohypogastric, ilioinguinal, lateral femoral cutaneous and femoral nerves emerge from the lateral border of psoas; the obturator and accessory obturator nerves (when present) and the upper root of the lumbosacral trunk all emerge from the medial border; and the genitofemoral nerve emerges from the anterolateral surface. Medially, psoas is related to the bodies of the lumbar vertebrae and lumbar vessels. Along its anteromedial margin, it is in contact with the sympathetic trunk and aortic lymph nodes, and along the pelvic brim, with the external iliac artery. This margin is covered by the inferior vena cava on the right side, and lies posterior and lateral to the abdominal aorta on the left side. On visual inspection, the thin tendon of psoas minor may be seen anterior to psoas major; it is not always present.
Vascular supply and lymphatic drainage

The skin of the back of the trunk receives its arterial blood supply mainly from musculocutaneous branches of the posterior intercostal, lumbar and lateral sacral arteries, which all accompany the cutaneous branches of their respective dorsal rami. In addition, there is a supply from the dominant
vascular pedicles of the superficial (extrinsic) back muscles. The skin over the scapula is supplied by branches of the suprascapular, dorsal scapular and subscapular arteries. The skin covering the back of the neck is supplied mainly by branches of the occipital and deep cervical arteries, with a contribution from branches of the superficial cervical or transverse cervical arteries to the skin of the lower part of the back of the neck. Veins drain the skin of the back of the neck into tributaries of the occipital and deep cervical veins, and the skin of the back of the trunk into the azygos system via tributaries of the posterior intercostal and lumbar veins.

The true (intrinsic) muscles of the back receive their blood supply from a number of sources: the vertebral artery; deep cervical artery; superficial and deep descending branches of the occipital artery; deep branch of the transverse cervical artery (when present); superior intercostal artery, via dorsal branches of the upper two posterior intercostal arteries; posterior intercostal arteries of the lower nine spaces via dorsal branches; dorsal branches of the subcostal arteries; dorsal branches of the lumbar arteries; dorsal branch of arteria lumbalis ima; and dorsal branches of the lateral sacral arteries. While paraspinal angiosomes have been described by many authors, the arterial supply is universally described as originating ventrally before coursing laterally around the posterior elements. The clinical implications of this are that excessively wide, posterior, subperiosteal exposures devascularize the muscle envelope, contributing to an increased risk of wound dehiscence and infection.

Lymph from the skin of the back of the neck drains into occipital, lateral deep cervical and axillary nodes. Lymph from the skin of the back of the trunk drains into the posterior (subscapular) axillary nodes and to the lateral superficial inguinal nodes.

**Innervation**

The skin of the back of the neck and trunk is innervated by the dorsal (posterior primary) rami of the spinal nerves (Figs 30.5 and 30.6). In the cervical and upper thoracic regions (down to T6), skin is supplied by the medial branches of these rami, while in the lower thoracic, lumbar and sacral regions it is supplied by the lateral branches; the spinal nerves involved include C2–C5, T2–L3, S2–S4 and Co1. Following midline posterior incisions, peri-incisional numbness is common. This gradually decreases with time, as seen with surgery elsewhere in the body. More anteriorly, both incisions and
wound closures require the surgeon to remain cognizant of abdominal wall innervation. Horizontal incisions and large suture bites can transect or strangulate the nerves supplying motor innervation to the abdominal wall, leading to hernias or pseudo-hernias.

**FIG. 30.5** A left posterolateral view of the lumbar spine showing the branches of the lumbar dorsal rami. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 45.10.)
Typical dermatome maps are shown in Fig. 30.6. There is about half a segment of overlap between these cutaneous ‘strips’: those supplied by the dorsal rami do not correspond exactly to those served by ventral rami, differing slightly in both width and position. Maps of dermatome distribution are useful in clinical neurology as a guide to identify the location of pathology in patients with peripheral sensory deficits, but it is important to remember that they are approximations. They are somewhat inconsistently
reported by different authors, reflecting the fact that the maps are composites that have been compiled to a large extent by clinical observations of patients with cranial or spinal nerve pathology, and also that considerable normal individual variation exists.

All the suboccipital muscles are supplied by the dorsal ramus of the first cervical spinal nerve. Erector spinae is innervated by the lateral branches of the dorsal rami of the cervical, thoracic and lumbar spinal nerves. At lumbar levels, lateral branches innervate iliocostalis and intermediate branches innervate longissimus.
References

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Single Best Answers

1. Which one of the following statements about the anterior approach to the lumbar spine is FALSE?
   A. The aorta bifurcates at the L4 vertebral body level in 70% of patients
   B. The lumbosacral junction is typically accessed via an incision immediately superior to the pubic symphysis
   C. A transverse incision should be avoided, as this tends to cause excessive muscle damage
   D. This approach can be used to access the caudal lumbar vertebrae either between or around the common iliac arteries and veins

   Answer: C. A transverse incision of the skin is a common choice for cosmetic reasons. At the muscular layer, the rectus muscles can still be spared by dividing them longitudinally along the linea alba.

2. Which one of the following descriptions could be used correctly with regard to the vertebral foramina?
   A. The lumbosacral intervertebral foramen is the largest of the lumbar foramina
   B. Each foramen contains a spinal nerve, plexiform venous connections and a single spinal artery
   C. The foramina are smallest at the cervical and upper thoracic levels and increase in size in the thoracic and lumbar spine
   D. The sinuvertebral nerve passes external to the vertebral foramen

   Answer: C. The lumbosacral intervertebral foramen is the smallest of the lumbar foramina. Each foramen contains a
segmental mixed spinal nerve, its sheaths, two to four recurrent meningeal (sinuvertebral) nerves, variable numbers of spinal arteries, and plexiform venous connections between the internal and external vertebral venous plexuses.

3. Which one of the following statements about the ligaments of the spine is FALSE?

A. The anterior longitudinal ligament adheres to intervertebral discs, with its most superficial fibres extending across up to four vertebrae
B. The posterior longitudinal ligament becomes broader as it moves caudally into the lumbar spine
C. The ligamentum flavum has multiple layers, the deepest layer known to be continuous with the anterior capsule of the facet joint in the lumbar spine
D. Distal to L4, the supraspinous ligament is replaced by decussating fibres of latissimus dorsi

**Answer: B.** The posterior longitudinal ligament is broader proximally and becomes narrower in the lower thoracic and lumbar regions.

4. Which one of the following features of the anterior approach to the cervical spine does NOT have an analogue in the lateral approach to the lumbar spine?

A. Damage to the anterior, longitudinally running muscle belly should be minimized to avoid nerve injury
B. Identification of the interval for dissection can be guided by palpating the pulse of an adjacent vascular structure
C. Identification or development of a tendinous ridge or cuff can be leveraged to retract muscle effectively away from the disc space of interest
D. Left-sided and right-sided approaches have nearly identical
Answer: D. The anterior approach to the cervical spine and the lateral, ante psoas approach to the lumbar spine share many features. Damage to longus colli can lead to a Horner's syndrome through injury to the cervical sympathetic trunk. Likewise, a quadriceps palsy can be caused by injury to the lumbar plexus when excessive retraction or dissection of the psoas muscle is performed. Both aforementioned muscles can be retracted effectively through development/identification of a cuff or tendinous ridge. The anterior approach to the cervical spine is guided through palpation of the carotid artery pulse, and the aorta can be palpated during the lateral approach to the lumbar spine. However, the lumbar spine is unique in that a left-sided approach is guided by palpation of the aorta, and a right-sided approach puts the surgeon at greater risk of encountering the less palpable and more fragile inferior vena cava.
Intervertebral joints, foramina and ligaments

Eli M Baron

Core Procedures

- Anterior and posterior cervical foraminotomy
- Lumbar microdiscectomy
- Lumbar laminotomy and foraminotomy
- Endoscopic foraminotomy and discectomy
- Transforaminal lumbar interbody fusion (TLIF)

A number of surgical procedures are performed in and around the foramina of the spine, commonly in the cervical or lumbar spine and occasionally in the thoracic spine. They generally consist of decompressive procedures such as a foraminotomy. Different approaches to accomplish a foraminotomy and fusion procedures undertaken through the foramen, such as a transforaminal lumbar interbody fusion (TLIF), are discussed briefly, together with a review of the relevant anatomy. The anatomy of the ligaments, their pathological relationships to clinical entities and their importance in spinal stability are reviewed.
Clinical anatomy

Vertebral canal

The vertebral canal extends from the foramen magnum to the sacral hiatus and follows the vertebral curves (Fig. 31.1). In the cervical and lumbar regions, which exhibit free mobility, it is large and triangular, but in the thoracic region, where movement is less, it is small and circular. These differences are matched by variations in the diameter of the spinal cord and its enlargements. In the lumbar region, the vertebral canal decreases gradually in size between L1 and L5, with a greater relative width in the female.
For clinical purposes, it is useful to consider the vertebral canal as having three zones: a central zone, between the medial margins of the facet joints,
and two lateral zones, beneath the facet joints and entering the intervertebral foramina. Each lateral zone passes into and just beyond the intervertebral foramen, and can be subdivided into subarticular (lateral recess), foraminal and extraforaminal regions. The lateral zone thus described forms the canal of the spinal nerve (the radicular or ‘root’ canal). If the lateral recess is considered to be part of the radicular canal rather than part of the central zone, then the central zone of the canal is a little narrower than the radiological interpedicular distance.

**Spinal stenosis**

Narrowing (stenosis) of the vertebral canal may occur at single or multiple spinal levels, and mainly affects the lumbar and cervical regions.

Stenosis may affect the central canal and the ‘root canals’ either together or separately. There is a developmental form of the condition which mainly affects the central canal, but more commonly the stenosis is degenerative and results from intervertebral disc narrowing and osteoarthritic changes in the facet joints. This latter combination is more likely to narrow the intervertebral foramen and the ‘root canal’, even though the sectional profile of the vertebral canal in affected lumbar vertebrae typically changes from the shape of a bell to that of a trefoil. The lumbosacral intervertebral foramen, which is normally the smallest in the region, is particularly liable to such stenosis. Severe spinal stenosis may compress the spinal cord and compromise its arterial supply. More localized ‘root canal’ stenosis will present with the clinical features of spinal nerve compression but without the tension signs that characterize the stretching of nerve roots over a prolapsed disc. Ischaemia of the nerves and roots may provoke more damage than the actual physical compression of the neural tissue.

Stenosis can also affect the cervical and thoracic spine. If the central canal is affected, this can manifest as myelopathy. Cervical and/or thoracic radiculopathy may result if the neuroforamina are narrowed in size. This is usually due to a combination of superior articular facet tip hypertrophy and disc degeneration (**Fig. 31.2**). If needed, this can be treated surgically via a laminoforaminotomy with mesial facetectomy (see below).
FIG. 31.2  A 68-year-old female presented with right-sided arm pain refractory to conservative measures. **A**, An axial CT myelogram of her cervical spine. **B**, A sagittal image demonstrating right-sided critical foraminal stenosis.
Intervertebral foramina

Intervertebral foramina are the principal routes of entry to and exit from the vertebral canal and are closely related to the main intervertebral articulations. (Minor routes occur between the median, often partly fused, margins of the ligamenta flava.) The same general arrangement applies throughout the vertebral column, between the axis and sacrum, although there are some quantitative and structural regional variations. Because of their construction, contents and susceptibilities to multiple disorders, the intervertebral foramina are loci of great biomechanical, functional and clinical significance.

The boundaries of a generalized intervertebral foramen (Fig. 31.3) are: anteriorly, from above downwards, the posterolateral aspect of the superior vertebral body, the posterolateral aspect of the intervertebral symphysis (including the disc), and a small (variable) posterolateral part of the body of the inferior vertebra; superiorly, the compact bone of the deep arched inferior vertebral notch of the vertebra above; inferiorly, the compact bone of the shallow superior vertebral notch of the vertebra below; and posteriorly, a part of the ventral aspect of the fibrous capsule of the facet synovial joint.

FIG. 31.3 The boundaries of an intervertebral foramen. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 43.25.)

The thoracic and lumbar intervertebral foramina face laterally and their transverse processes are posterior. In addition, the anteroinferior boundaries of the first to tenth thoracic foramina are formed by the articulations of the head of a rib and the capsules of double synovial joints (with the demifacets
on adjacent vertebrae and the intra-articular ligament between the costocapitular ridge and the intervertebral symphysis). Lumbar foramina lie between the two principal lines of vertebral attachment of psoas major. The walls of each foramen are covered throughout by fibrous tissue, which is in turn periosteal (though the presence of a true periosteum lining the vertebral canal is controversial\(^1\)), perichondrial, anular and capsular. The more lateral parts of the foramina may be crossed at a variable level by narrow fibrous bands, the transforaminal ligaments (for detail of these ligaments see Bogduk\(^2\)). The true foramen is the foraminal region of the canal of the spinal nerve (the radicular or ‘root’ canal). A foramen contains a segmental mixed spinal nerve and its sheaths, from two to four recurrent meningeal (sinuvertebral) nerves, variable numbers of spinal arteries, and plexiform venous connections between the internal and external vertebral venous plexuses. These structures, particularly the nerves, may be affected by trauma or one of the many disorders that may involve tissues bordering the foramen. In particular, nerve compression and irritation may be caused by intervertebral disc prolapse, or by bony entrapment as the size of the foramen decreases. This decrease may result from facet joint osteoarthritis, osteophyte formation, disc degeneration and degenerative spondylolisthesis, all of which may lead to lateral or foraminal spinal stenosis.

**Ligaments of the vertebral column**

**Anterior longitudinal ligament**

The anterior longitudinal ligament is a strong band that extends along the anterior surfaces of the vertebral bodies (Fig. 31.4). It is broader caudally and thicker and narrower in thoracic than in cervical and lumbar regions, and is also relatively thicker and narrower opposite vertebral bodies than at the levels of intervertebral symphyses. It extends from the basilar part of the occipital bone to the anterior tubercle of C1 and the anterior surface of the body of C2, then continues caudally to the anterior surface of the upper sacrum. Its longitudinal fibres are strongly adherent to the intervertebral discs, hyaline cartilage end-plates and margins of adjacent vertebral bodies, and are loosely attached at intermediate levels of the bodies, where the ligament fills their anterior concavities, flattening the vertebral profile. At these various levels, ligamentous fibres blend with the subjacent periosteum, perichondrium and periphery of the anulus fibrosus. The anterior longitudinal ligament has several layers. The most superficial fibres are the
longest and extend over three or four vertebrae, the intermediate extend between two or three, and the deepest from one body to the next. Laterally, short fibres connect adjacent vertebrae.

**FIG. 31.4** A median sagittal section through the upper lumbar vertebral column showing discs and ligaments. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)

**Posterior longitudinal ligament**

The posterior longitudinal ligament lies on the posterior surfaces of the vertebral bodies in the vertebral canal (**Fig. 31.5**), attached between the body of C2 and the sacrum, and continuous with the membrana tectoria above. Its smooth, glistening fibres, attached to intervertebral discs, hyaline cartilage end-plates and adjacent margins of vertebral bodies, are separated between attachments by basivertebral veins and the venous channels which drain them into anterior internal vertebral plexuses. At cervical and upper thoracic levels the ligament is broad and of uniform width, but in lower thoracic and lumbar regions it is denticulated, narrow over vertebral bodies and broad over discs. Its superficial fibres bridge three or four vertebrae, while deeper fibres extend between adjacent vertebrae as perivertebral ligaments, which are close to and, in adults, fused with, the anulus fibrosus of the intervertebral disc. The layers of the posterior longitudinal ligament and the relationship of the ligament to associated membranes in the epidural space are fully discussed by Loughenbury et al.¹
Ligamenta flava

The ligamenta flava connect laminae of adjacent vertebrae in the vertebral canal (Fig. 31.6). Their attachments extend from facet joint capsules to the point where laminae fuse to form spines. Here their posterior margins meet and are partially united; the intervals between them admit veins which connect the internal and posterior external vertebral venous plexuses. Their predominant tissue is yellow elastic tissue, whose almost perpendicular fibres descend from the lower anterior surface of one lamina to the posterior surface and upper margin of the lamina below. The anterior surface of the ligaments is covered by a fine, continuous, smooth lining membrane. The ligaments are thin, broad and long in the cervical region, thicker in the
thoracic and thickest at lumbar levels. They arrest separation of the laminae in spinal flexion, preventing abrupt limitation, and also assist restoration to an erect posture after flexion, perhaps protecting discs from injury.

![Image of ligamenta flava and costotransverse ligaments](image)

**FIG. 31.6** The ligamenta flava and costotransverse ligaments, ventral aspect. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)

The morphology and histology of the ligamentum flavum has been studied in the thoracolumbar region. On a macroscopic level, it has two layers, superficial and deep, whose fibres run in opposite directions. On a microscopic level, the ligamentum flavum has predominantly elastic fibres. The superficial layer is innervated by a medial branch from the dorsal root of the corresponding spinal nerve. The deep layer is innervated by sinuvertebral nerves.

**Interspinous ligaments**

Interspinous ligaments connect the facing edges of consecutive spinous processes, and extend ventrally as far as the ligamentum flavum and dorsally to the supraspinous ligament, when this ligament is present (see below). They differ structurally in the thoracic and lumbar levels.

The thoracic interspinous ligaments are narrow and elongated, whereas
those at lumbar levels are thick and quadrilateral, and occur as closely applied pairs, the left and right ligaments being separated by a narrow or potential cleft. In the lumbar ligaments, collagen fibres run obliquely inferiorly and ventrally, and only the deepest fibres are truly ligamentous. The more dorsal fibres are derived from tendons of longissimus thoracis that dip into the interspinous space to gain attachment to the superior edge of the spinous process rather than to its tip.

**Supraspinous ligament**

The supraspinous ligament (see Fig. 31.4) is a strong fibrous cord that connects the tips of spinous process from C7 to L3 or L4. It is regularly deficient.

The most superficial fibres extend over three or four vertebrae, the deeper span two or three, and the deepest connect adjacent spines and are continuous with the interspinous ligament. Most of the ligament is formed by the tendons of muscles with posterior midline attachments, i.e. semispinalis, longissimus, trapezius and latissimus dorsi. Only the most superficial fibres lack any connection with muscle. Below L4 the ligament is replaced by the decussating fibres of latissimus dorsi.

**Intertransverse ligaments**

Intertransverse ligaments run between adjacent transverse processes. At cervical levels they consist of a few irregular fibres which are largely replaced by intertransverse muscles; in the thoracic region, they are cords intimately blended with adjacent muscles; in the lumbar region, they are thin and membranous. For the detailed anatomy of the lumbar intertransverse ligaments, see Bogduk.²
Joints

All vertebrae from C2 to S1 articulate by secondary cartilaginous joints (symphyses) between their bodies, synovial joints between their articular processes, and fibrous joints between their laminae and transverse and spinous processes. In the cervical region, from C3 to C7, joints have been described between the uncinate or neurocentral processes of the inferior vertebral body and the bevelled lateral border of the superior body at each level. These small uncovertebral or neurocentral ‘joints’ are absent at birth, do not contain synovium and are probably clefts in the intervertebral discs.

Intervertebral joints

Joints between vertebral bodies are symphyses. Typical vertebral bodies are united by fibrocartilaginous intervertebral discs between sheets of hyaline cartilage (vertebral end-plates) and by anterior and posterior longitudinal ligaments.

Intervertebral discs

The intervertebral discs are the chief bonds between the adjacent surfaces of vertebral bodies from C2 to the sacrum. Except at the sites of the uncovertebral (neurocentral) joints of Luschka, disc outlines correspond with the adjacent bodies. Their thickness varies in different regions and within individual discs. Each disc consists of an outer lamellated anulus fibrosus and an inner nucleus pulposus (see Fig. 31.4). Discs adhere to their adjacent vertebral end-plates. They are attached to the anterior and posterior longitudinal ligaments, as well as the heads of ribs articulating with adjacent vertebrae in the thoracic spine. The posterolateral disc forms the anterior boundary of the intervertebral foramen. Posteriorly, the disc is exposed to the spinal canal contents. Anteriorly, depending on the level, adjacent structures include the pharynx, oesophagus, sympathetic trunks, hypogastric plexus, aorta and inferior vena cava. In cervical and lumbar regions, the discs are thicker anteriorly, contributing to the anterior convexity of the vertebral column. In the thoracic region, they are nearly uniform and the anterior concavity is largely due to the vertebral bodies. Discs are thinnest in the upper thoracic region and thickest in the lumbar region. They adhere to thin layers of cartilage on the superior and inferior vertebral surfaces, the vertebral end-plates. The latter do not reach the periphery of the vertebral
bodies but are encircled by ring apophyses. The end-plates contain both hyaline cartilage and fibrocartilage. The fibrocartilaginous component lies nearer to the disc and is sometimes considered not to be part of the end-plate itself. The fibrocartilaginous components of the end-plates above and below the nucleus pulposus, together with the innermost lamellae of the anulus fibrosus, form a flattened sphere of collagen that surrounds and encloses the nucleus. The overall proportion of fibrocartilage in the end-plate increases with age. While all discs are attached to the anterior and posterior longitudinal ligaments, discs in the thoracic region are additionally tied laterally, by intra-articular ligaments, to the heads of ribs articulating with adjacent vertebrae. Intervertebral discs form about one-quarter of the length of the postaxial vertebral column; cervical and lumbar regions make a greater contribution than the thoracic and are thus more pliant.

**Anulus fibrosus**

The anulus fibrosus has a narrow outer collagenous zone and a wider inner fibrocartilaginous zone. Its lamellae, which are convex peripherally when seen in vertical section, are incomplete collars. The internal vertical concavity of the lamellae conforms to the surface profile of the nucleus pulposus. In all quadrants of the anulus, about half the lamellae are incomplete; the proportion increases in the posterolateral region. The exact nature of the interlamellar substance remains in some doubt. Posteriorly, lamellae join in a complex manner. Fibres in the rest of each lamella are parallel and run obliquely between vertebrae at about 65° to the vertical (Fig. 31.7). Fibres in successive lamellae cross each other obliquely in opposite directions, thus limiting rotation. The obliquity of fibres in deeper zones varies in different lamellae. Posterior fibres may sometimes be predominantly vertical, which possibly predisposes them to herniation. This standard description of the anulus may not apply at all spinal levels: a cadaveric study indicates that the anulus is usually incomplete posteriorly in adult cervical discs.⁵
FIG. 31.7 The main structural features of an intervertebral disc. For clarity, the number of fibrocartilaginous laminae has been greatly reduced. Note the alternating obliquity of collagen fascicles in adjacent laminae. **A**, A lumbar disc. **B**, The detailed structure of the anulus fibrosus. Key: $\phi = \text{approximately } 65^\circ$. **C**, A cervical disc. (After N. Bogduk, Clinical Anatomy of the Lumbar Spine and Sacrum, third ed., Edinburgh, Churchill Livingstone, 1997.)
The nucleus pulposus is better developed in cervical and lumbar regions and lies between the centre of a disc and its posterior surface. At birth it is large, soft, gelatinous and composed of mucoid material. It contains a few multinucleated notochordal cells and is invaded by cells and collagen fibres from the inner zone of the adjacent anulus fibrosus. Notochordal cells disappear in the first decade and the mucoid material is gradually replaced by fibrocartilage, derived mainly from the anulus fibrosus and the plates of hyaline cartilage adjoining the vertebral bodies. The nucleus pulposus becomes less differentiated from the remainder of the disc as age progresses, and gradually becomes less hydrated and increasingly fibrous. The type II collagen of the nucleus becomes more like the type I of the anulus as its fibril diameter increases. The quantity of aggregated proteoglycans in the nucleus decreases, while the keratan sulphate/chondroitin sulphate ratio increases. As increased cross-linking occurs between collagen and the proteoglycans, the discs lose their water-binding capacity, becoming stiffer and more liable to injury. Contrary to what was previously thought, it has now been shown that lumbar discs do not decrease in overall height as a part of normal ageing. The anulus gradually loses height as its radial bulge increases, but the nucleus retains height and may increase in convexity as it increasingly indents the end-plate. Loss of trunk height with age results from a decrease in vertebral body height. When the disc is not loaded, pressure in the nucleus pulposus is low at all ages. For a review of the structure and function of the human intervertebral disc see Adams et al.

**Prolapsed intervertebral disc**

A prolapsed intervertebral disc most commonly affects the 20–55 year age group, and is most often seen at the L4/5 and lumbosacral levels. It may also affect the cervical discs, particularly at C5/6 and C6/7, but thoracic discs are rarely involved. Acute tearing or chronic degeneration of the posterior lamellae of the anulus fibrosus allows deformation and herniation of the disc contents. The disc most often prolapses just lateral to the posterior longitudinal ligament and can compress one or two spinal nerves unilaterally. Much less commonly, the prolapse is central, in the midline posteriorly. The compression of neural structures may then be bilateral, affecting the cord itself or the whole cauda equina. If the damaged anulus ruptures completely, some of the nuclear tissue may escape into the vertebral and ‘root’ canals. This sequestrated material may migrate within the canals and cause nerve compression at spinal levels distant from that of the disc rupture. The disc
material itself may have an irritative effect on the spinal nerve. When thinking about disc prolapse, it is important to understand that one or both of two spinal nerves and their roots may be affected by a single prolapse, depending on the exact site of the prolapse in the horizontal plane. At the level of each disc and foramen, there are two spinal nerves (and their roots) to consider: these are the exiting nerve and the traversing nerve. The nerve usually affected at lumbar levels is the traversing nerve, which crosses the back of the disc on its way to become the exiting nerve at the level below. Thus, a lumbosacral (i.e. L5/S1) disc prolapse usually compresses the S1 nerve. However, a prolapse may affect the exiting nerve at its own level, particularly if the prolapse is in the extraforaminal zone of the ‘root’ canal, the so-called ‘far lateral’ prolapse. At cervical levels, because the roots and nerve leave the vertebral canal almost horizontally, the prolapse usually affects the exiting nerve. This nerve will still bear the number of the vertebra below the affected disc because cervical nerves exit the canal above the pedicle of their numerically corresponding vertebra. Neurological presentation will include signs and symptoms of spinal nerve damage at the affected level. Sensory changes usually precede motor loss: pain and sensory loss will be dermatomal in distribution. Internal disruption of a lumbar intervertebral disc is more common than disc prolapse and is now an increasingly recognized cause of back pain. Typically, the nucleus is decompressed and the inner lamellae of the anulus appear to collapse into it. For more detail on disc pathology and its consequences, see Adams et al.7

Facet (zygapophysial) joints

Joints between the vertebral articular processes (zygapophyses) are synovial and have long been called zygapophysial joints by anatomists. In current clinical practice they are commonly called ‘facet joints’; Bogduk has pointed out that the term ‘facet joint’ is both incorrect and essentially ambiguous, on the grounds that facets are not restricted to zygapophysial articular processes.2

The fibrous capsule is thin and loose, and attached peripherally to the articular facets of adjacent articular processes. Capsules are longer and looser in the cervical region and the anterior fibrous capsule may be replaced by the ligamentum flavum in the lumbar spine.2

Intracapsular structures
Bogduk describes two types of intra-articular structure in lumbar facet joints: namely, subcapsular fat and ‘meniscoid’ structures. The latter structures may be collagenous, fibro adipose or purely adipose, and project into the crevices between non-congruent articular surfaces. They resemble inclusions seen in the small joints of the hand; their function is conjectural.

**Lumbar articular tropism**

In the lumbar region, asymmetrical orientation of the facet joints occurs in about one-fifth of the population. Such facet tropism does not appear to predispose to degenerative disc disease.
Spinal stability

The vertebral column is remarkable in that it combines mobility, stability and load-bearing capacity and also protects its contained neural structures, irrespective of its position. Much of the stability of the vertebral column depends on dynamic muscular control but there are also bony and ligamentous ‘static’ stabilizers. There is considerable variation between segments of the column in terms of stability and mobility: the most mobile levels are the least stable. The latter are those in which the ratio of intervertebral disc height to vertebral body height is highest. Stability may be compromised by damage to any of these structures.

Trauma may affect any vertebral region. Levels of specialized mobility (e.g. atlanto-axial joint) and the junctions of mobile and relatively fixed regions (e.g. cervicothoracic, thoracolumbar) are particularly vulnerable to severe structural damage, often accompanied by spinal cord and nerve injury. Injuries of the vertebral column may involve purely the soft tissue (ligaments, joint capsules and muscles) or may affect bony structures. Pure ligamentous/capsular injuries leading to instability may be particularly difficult to diagnose in the absence of gross radiological signs. In the cervical spine, subluxation and dislocation of the facet joints commonly occur without bony injury because of the orientation of the articular facets.

Chronic infections of many types (e.g. tuberculosis) may involve the vertebrae and lead to their deformity and collapse, affect their mechanical properties and compromise their neuroprotective function. Acute infections, spreading locally or via the blood stream, may lead to the collection of pus within the vertebral canal, causing spinal cord compression (epidural abscess).

The integrity of the vertebrae may also be affected by malignant disease, most commonly metastatic. Vertebrae have a copious blood supply throughout life, and many of the common cancers (e.g. breast, bronchus) spread via the arterial system. Cancers of the haemopoietic system (e.g. multiple myeloma) also commonly affect the vertebrae. Prostatic carcinoma has a predilection to metastasize to the vertebral column, often using the venous (Batson's plexus) rather than the arterial route. Metastatic deposits may occur within the epidural space, compressing the contents of the dural sac at multiple levels.

Systemic inflammatory diseases may cause both deformity and instability of the vertebral column. Rheumatoid arthritis inflames facet joints and
weakens ligaments, leading to instability, especially in the cervical spine (see below). Ankylosing spondylitis and other seronegative arthritides affect joints and ligamentous attachments (entheses), leading to ectopic ossification of collagenous structures, fusion (ankylosis) of interbody and facet joints, and loss of the normal spinal curvatures. Widespread new bone formation at and around the joints of the column occurs in diffuse idiopathic skeletal hyperostosis. Such conditions would seem to increase stability of the column, at the expense of its mobility and function, but an ankylosed spine is very liable to fracture, with an associated risk of neural damage (Fig. 31.8).
FIG. 31.8  A, A sagittal CT in an 88-year-old female with ankylosing spondylitis and an unstable L1 distraction extension injury (arrow). In this type of fracture, the spine acts almost like a long bone because there are multiple segments that are fused above and below the level of injury. B, C, Lateral and anteroposterior X-rays show stabilization of the fracture with pedicle screws and rods.

Full stability and load-bearing capacity both require intact vertebral bodies and intervertebral discs. Earlier views regarding the relative importance of the disc–body complex and the posterior elements have proved somewhat simplistic. Clinical observation led to the ‘three-column concept’ of spinal stability, in which the column is divided into three longitudinal parts rather than two. The anterior column is formed by the anterior longitudinal ligament, the anterior half of the vertebral body and the anterior anulus fibrosus. The middle column is made up of the posterior longitudinal ligament, the posterior half of the vertebral body and pedicles and the posterior anulus fibrosus. The posterior column consists of the neural arch and facet joints and the posterior ligamentous complex. The more columns that are affected, the worse is the instability: an injury to two columns is usually unstable. A more recent thoracolumbar injury classification and severity (TLICS) score stresses the importance of the posterior ligamentous complex in determining stability of the injured spine in addition to injury morphology and the patient's neurological status.

All ligaments of the column, as well as the facet joint capsules, are
important in the maintenance of stability. The anterior longitudinal ligament is very strong and resists translational displacement (shear) of the vertebrae, as well as extension. All the ligaments of the posterior complex resist flexion and rotation, and their integrity determines the range of movements allowed. These ligaments can support the whole column when the muscles are inactive, e.g. in quiet standing. At the limit of lumbar flexion, the column is supported mainly by the thoracolumbar fascia and by collagenous tissue within the electrically silent muscles of the back.\textsuperscript{10} Movements are both determined and constrained by the shape and orientation of the facet joints, whose articular surfaces stabilize the column primarily by resisting horizontal gliding (shear) movements and axial rotation. In the most mobile regions, the joint surfaces are flatter and more horizontally placed, as will become apparent if a typical cervical facet joint is compared with a typical lumbar joint.

Damage to the ligaments controlling stability of the column may occur in the absence of evident bony pathology. This is particularly prevalent in inflammatory disease of the upper cervical spine, where rheumatoid arthritis may weaken or destroy the ligaments on which atlanto-axial stability depends. The transverse ligament is stronger than the dens, which therefore usually fractures before the ligament ruptures. The alar ligaments are weaker, and combined head flexion and rotation may avulse one or both alar ligaments: rupture of one side results in an increase of about a third in the range of rotation to the opposite side. Pathological softening of the transverse and adjacent ligaments or of the lateral atlanto-axial joints results in atlanto-axial subluxation, which may cause spinal cord injury. Ligamentous damage also may occur in spinal injuries: e.g. in the ligamentous Chance fracture. In this fracture pattern a flexion distraction injury occurs where the spine rotates around a fixed axis such as a lap belt. Chance fractures may also involve the bone, at which point they are classified as bony Chance fractures (Fig. 31.9). Damage may also occur as a result of spinal surgery where ligament removal in addition to bone removal (such as partial facet resection) may result in iatrogenic instability. Developmental laxity of ligaments may also lead to problems with instability, especially if there is an episode of trauma: this combination is probably responsible for atlanto-axial rotational instability. Laxity of cervical spinal ligaments may be a normal variant in children and lead to diagnostic difficulties. In X-rays of the upper cervical spine in children aged less than 8, a deceptive appearance of subluxation (‘pseudosubluxation’) may result from a combination of ligamentous laxity
and facet orientation. This usually occurs between C2 and C3, but may occasionally be seen at C3/4. Clinical and other radiological features should facilitate the correct diagnosis.
A 28-year-old neurologically intact female who had been involved in a motor vehicle collision. A, A sagittal reconstruction CT scan showing a T11 bony Chance fracture. Note the widening of the interspinous distance (arrow). Given the presence of a compression fracture and ligamentous injury, her thoracolumbar injury classification and severity (TLICS) score is 4, signifying operative as opposed to non-operative management. B, A T1 weighted sagittal MRI shows disruption of the ‘black stripe’ (arrow), signifying disruption of the supraspinous ligament. C, A T2 weighted sagittal MRI showing hyperintensity in the T11 vertebral body (arrow), consistent with a fracture.

The elastic deformability of intervertebral discs permits tilting and axial rotation between vertebral bodies and also helps to reduce vertical accelerations of the head. The main shock-absorbing mechanism of the column stems from the spinal curves, which increase and decrease slightly during locomotion against the restraining tension of the trunk muscles. The elastic strain energy in the stretched tendons of the muscle is responsible for shock absorption.

Both body height and spinal stability are subject to a marked diurnal variation. Body height is affected by changes from recumbency to the upright posture. These diurnal variations appear to be due to changes that occur within the cervical, thoracic and lumbar regions of the spine. Investigations using stereophotogrammetry have demonstrated that 40% of diurnal changes occur in the thoracic spine and affect the degree of kyphosis, and a further 40% in the lumbar spine but do not affect the lordosis. The greatest change
in vertebral column length is found in adolescents and young adults. The height loss occurs within 3 hours of rising in the morning, with an overall loss of about 15 mm.

Although the curvatures within the vertebral column contribute to the changes in height, changes within the intervertebral disc contribute both to observed height loss and to variation in stability. MRI investigations reveal a dynamic movement of fluid into and out of an intervertebral disc and adjacent vertebral body over a 24-hour period. Body position affects the movement of fluid. In the early morning, the discs are swollen with water, the intervertebral ligaments and the anulus fibrosus are taut, and the intrinsic bending stiffness and stability of the osteoligamentous spine are relatively high. After several hours of normal activity, the discs lose approximately 20% of their water and height. This change makes the ligaments slack and greatly reduces the bending stiffness of the spine, so that relatively more of the stability of the spine must then be provided by the musculature. The diurnal expulsion of water from intervertebral discs also affects the distribution of compressive loading in the spine. As the day progresses, the hydrostatic pressure in the nucleus pulposus falls and stress concentrations arise in the anulus fibrosus and facet joints.

Certain regions of the vertebral column are further stabilized by additional extraspinal factors. The thoracic spine is stabilized by its position as an integral part of the thoracic cage and by its strong ligamentous linkages with the ribs. The sacrum is effectively a virtually fixed integral element of the bony pelvis.

The contribution to stability conferred by the musculature has been grossly underrated. The whole vertebral column is stabilized by the ‘guy-rope’ or staying effect of the long muscles which attach it to the girdles, the head and the appendicular skeleton. This effect is particularly marked for erector spinae, which controls global posture and movement. The small and deep muscles of the back are best able to resist shear movements between vertebrae because only they have sufficient angulation to the long axis of the vertebral column to do this effectively. The deep muscles can also fine-tune intervertebral movements.

For many spine problems in clinical practice, especially chronic low back pain, enhancing muscle strength, stamina, and coordination with the many other muscle groups that contribute to stability, e.g. pelvic girdle muscles, is the most appropriate and effective therapeutic avenue. Only a minority of cases benefit from surgery. Furthermore, neglecting the musculature may
explain the relatively high failure rates from surgery.

**Ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis**

Ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis (DISH) are two disease entities involving proliferation of the bone in the spine.

The mechanisms by which bone proliferates in these diseases is dissimilar and there is often confusion based on the radiographic appearances of these conditions. Ankylosing spondylitis usually starts in the second or third decade of life and rarely begins after the age of 40. Most early findings are seen within the sacroiliac joints.\(^\text{12}\) Osteoporosis may be a considerable finding with inflammation in ankylosing spondylitis.\(^\text{13}\) In the spine, ankylosing spondylitis involves inflammation of the discovertebral junction. There is subsequent adjacent subchondral osteitis, which is radiologically characterized by a lesion known as a Romanus lesion. This is the destruction of the vertebra and sclerosis confined to the anterior corners of the vertebra. With healing, there is bony remodelling, which results in a squaring of the vertebra. There is also a gradual ossification of the periphery of the anulus fibrosus, resulting in the formation of bony bridges (syndesmophytes), producing what is known as a ‘bamboo spine’. Ankylosing spondylitis is also very frequently associated with thoracic kyphosis and limitation of spinal mobility. The condition is usually painful. Sacroiliac joint erosion is very common in ankylosing spondylitis. DISH occurs particularly in the thoracic spine in patients over 50. Its aetiology is unknown but it is associated with various metabolic conditions, including obesity and insulin-dependent diabetes.\(^\text{12}\) There is typically flowing ossification extending over four contiguous vertebrae; relative preservation of the intervertebral disc height relative to the age; and absence of the sacroiliac joint changes seen with ankylosing spondylitis. The biggest differentiating findings between the two conditions are revealed by examination of the sacroiliac joints. In ankylosing spondylitis, the ligaments and synovial parts of the sacroiliac joints show sclerosis, erosion, joint space narrowing or effusion. In DISH, only the ligamentous portion is obliterated. Syndesmophytes are also seen in ankylosing spondylitis. They differ from the outgrowths seen in DISH, which reflect ossification involving the anterior longitudinal ligament. They have been reported rarely to coexist.

In ankylosing spondylitis, fractures often occur, even with trivial trauma.
Because multilevel bony fusion exists, long lever arms typically develop on the spinal column which act during trauma. Additionally, the ossification of supportive tissues may further predispose to neurological deficit with fracture. Osteoporosis also contributes. DISH may be associated with similar spinal fractures and may have comparable fracture mechanisms to ankylosing spondylitis. Most injuries that occur with DISH and ankylosing spondylitis are extension-type injuries. These injuries are often highly unstable. Historically, they have been treated with immobilization but it is increasingly common to treat them surgically, typically performed posteriorly with long segment fixation, although anterior fixation may also be needed.\textsuperscript{14}
Surgical approaches and considerations

Cervical foraminal disease

Cervical pathology affecting the lateral aspect of the spinal cord or neural foramen can be addressed by posterior or anterior approaches. Posterior cervical foraminotomy was developed by Frykholm\textsuperscript{15} in 1947 and the technique was further refined by Scoville and Whitcomb.\textsuperscript{16}

In the subaxial cervical spine, the lateral portion of the spinal canal is bounded posteriorly by the lateral aspects of the superior and inferior laminae. Ventrally, the ligamentum flavum is attached to two-thirds of the undersurface of the superior lamina but is attached only to the superior edge of the lower lamina. The anterior boundary of each cervical neural foramen, from rostral to caudal, is the posterolateral cortical margin of the superior vertebral body, the intervertebral disc covered by the posterior longitudinal ligament, and a small portion of the posterolateral cortical margin of the inferior body. The posterior boundary of a cervical neural foramen, from rostral to caudal, is 1–2 mm of superior articular facet and the entire ventral surface of the inferior articular facet. The superior and inferior boundaries of the neural foramina are the superior and inferior vertebral pedicles.\textsuperscript{17–19}

The root sleeve is a connective tissue sheath covering the dura and deep to the ligamentum flavum. It also contains the radicular artery. A motor and a sensory root exit the spinal canal within a single dural sleeve, which then divides in the neural foramen into an anterior inferior sleeve containing the motor roots and a posterior superior sleeve containing the sensory roots.\textsuperscript{5} Pathology that commonly affects the neural foramina includes acute disc protrusions, anterior proliferative osteophytes, and a hypertrophied facet impinging on the exiting root. Bony anatomy is often best assessed with a CT scan; an MRI scan and CT myelogram are useful in assessing soft tissue pathology compressing the exiting roots.

Posterior cervical foraminotomy provides a means of readily decompressing the foramen by removing pathology in the posterior portion of the foramen that is compressing the nerve roots. It is also useful for removing soft disc pathology but is less useful as a procedure for removing ventral osteophytes, although it has been used for this purpose. The procedure is performed by removal of the lateral portions of the lamina and the mesial portion of the inferior facet joint, exposing the entire medial aspect of the superior facet joint. The medial half of the superior articular
facet is then drilled under the microscope until it is wafer-thin and microsurgical technique is then used to remove a thin shell of bone covering the exiting nerve root.

In terms of disc pathology, an acutely herniated lateral fragment can be removed by opening the nerve root sheath and working typically within the axilla. If necessary, the superomedial aspect of the inferior pedicle is resected using a drill. In this manner, access to the ventral space is obtained with minimal tension on the root. The nerve root is usually retracted rostrally to remove any underlying fragment but may be retracted inferiorly. Osteophytes can be removed in a similar manner from the ventral canal. Excellent outcomes have been described by numerous authors with this procedure but it contains some risk. Limitations of the procedure are an inability to access bony ventral pathology, although in the hands of a skilled surgeon this is feasible. Posterior cervical foraminotomy has also been performed in a minimally invasive manner, both endoscopically and with minimal access retractor systems. In terms of stability of the facet joint post decompression, an experimental model demonstrated that bilateral resection of more than 50% of the facet joint would lead to failure of the cervical spine bony anatomy in shear.

Anterior cervical approaches were developed later to access the ventral surface of the spinal cord more safely. These were popularized by both Cloward and by Smith and Robinson in the 1950s. As described initially, the approach entailed performing a total discectomy or discectomy and fusion. The functional motion segment was lost with these techniques because, even when a fusion was not performed at surgery, removal of the disc would naturally lead to ankyloses or collapse of the segment. A more modern variant involves artificial disc replacement after this approach. Subsequent anterior cervical decompressive techniques were designed to preserve the disc. In 1968, Verbiest reported on an anterolateral approach to the cervical spine. The approach involved exposure of the vertebral artery and carried with it some risk of vascular injury; it was not popularized. Later, Jho described a microsurgical anterior cervical foraminotomy for radiculopathy. This approach and its subsequent modification have been described by others. The procedure involves accessing the cervical spine in a manner similar to anterior cervical discectomy and fusion. In Jho’s approach, longus colli is excised and the medial portions of the transverse processes are exposed. The ipsilateral uncovertebral joint is then removed.
Drilling proceeds with a high-speed burr between transverse processes, with removal of the medial portion of the uncovertebral joint. A thin rim of cortical bone is left attached to the ligamentous tissue covering the medial portion of the vertebral artery. Drilling continues down to the posterior longitudinal ligament and is carried medially in order to avoid injuring the vertebral artery. Drilling of the base of the uncinate process is done cautiously because the nerve root lies just behind the bone. Using microsurgical technique, Jho described removal of the base of an uncinate process and the lateral uncinate process where the vertebral artery can be identified. Disc material or osteophytes can be removed from the neural foramen. If this method is proceeded with, the uncovertebral joint and pathological osteophytes and disc herniations could all be removed with minimal disruption to the disc. Of note, a variation of this technique does not involve removal of the more lateral aspect of the uncinate process in order to protect the vertebral artery and avoid violation of the foramen transversarium. In general, good results have been reported in relatively small series with this technique. The vertebral artery is at risk when the anterior transverse process at the C7 level of the C6–C7 segment is addressed and authors have cautioned care in approaching and identifying this vessel if the procedure is to be done at the C6–C7 segment. It is recommended that MRI images should be studied because the level at which the vertebral artery enters the foramina transversaria of the cervical vertebrae varies: it may enter at the level of C7 or at C5 (see Fig. 32.4).

Lumbar foraminal disease

Most commonly, pathology being accessed by the surgeon in the lumbar spine consists of disc disease or spinal stenosis. Lumbar stenosis can occur in various locations in the spine. Most frequently, the term is used to refer to lumbar central stenosis, which could be congenital or constitutional, in that it may develop with conditions such as achondroplasia. The term ‘nerve root canal stenosis’, as described by Crock, and the term ‘lateral stenosis’ both refer to isolated narrowing of the semi-tubular structure through which a nerve root runs in the thecal sac into an intervertebral foramen. Additionally, stenosis may be accompanied by spondylolisthesis. In terms of decompressive techniques, laminectomy was historically the standard method of decompression of central spinal stenosis. More recently, laminotomies have been performed, either bilaterally or unilaterally, with
undercutting of the bony neural arch which allows for an excellent central decompression.

In terms of stenosis affecting the lateral recess, this can be readily addressed via either laminectomy or laminoforaminotomy, where an undercutting facetectomy is performed.\textsuperscript{29} In this technique, the medial portion of the inferior facet is resected with a burr and osteotome, followed by removal of the mesial portion of the superior articular facet using fine Kerrison rongeurs. Decompression rarely involves the distal neural foramen. Should it do so, a complete facetectomy with discectomy is sometimes necessary; an interbody fusion technique, such as transforaminal lumbar interbody fusion (TLIF), is quite useful. In the case of lumbar decompression performed where pre-existing instability does not exist, fusion should be a consideration if more than two-thirds of the facet joint is resected in the procedure.\textsuperscript{29}

Various minimally invasive techniques have been described to decompress neural foramina. In terms of actually removing disc material, this may be done from an inside-out approach (from within the disc space) or an outside-in approach. In the inside-out approach, as developed by Gore and Yeung, a cavity is made in the disc for viewing and manipulating endoscopic instruments.\textsuperscript{30} This allows visualization of disc fragments from within the disc and so fragments are extracted from within the disc space. This may permit better visualization of pathology and normal anatomy than techniques that target disc fragments from outside the disc space. Hoogland et al described an outside-in approach for a transforaminal endoscopic technique involving a foraminoplasty, where the neural foramen is enlarged.\textsuperscript{31} Kambin’s triangle is an important anatomical landmark when performing these procedures. It is bordered by the traversing nerve root medially, the exiting nerve root laterally and the adjacent pedicle distally.\textsuperscript{32} A needle is inserted into the disc space using biplanar fluoroscopy. On lateral view, the needle should be at the lower portion of the neural foramen as it enters the disc. On anterior–posterior view, the needle tip should be at the medial interpedicular line. This is followed by placement of a guide wire, and subsequently by dilators and reamers, all under endoscopic visualization. A discectomy can be performed as needed. In general, the use of endoscopic techniques in the lumbar spine is less popular than the use of traditional microsurgical open technique.

TLIF was developed as a modification of posterior lumbar interbody fusion (\textbf{Fig. 31.10}). Instead of the neural elements being retracted, the procedure is
performed through a more lateral corridor.\textsuperscript{33,34} A cut is made across the pars interarticularis in order to expose the superior articular process, which is then removed in its entirety to expose the underlying disc. The resultant working corridor for the TLIF approach is bounded medially by the traversing nerve root and thecal sac, superiorly by the exiting nerve root, and inferiorly by the pedicle of the vertebra below the disc space. Because the exiting nerve root hugs the undersurface of the superior pedicle, there is a safe working zone just above the pedicle of the inferior vertebra. Typically, a unilateral corridor will be used for discectomy. Javernick et al noted that 69\% of a disc could be resected via this corridor.\textsuperscript{35} The advantages of this approach over posterior lumbar interbody fusion include the lack of retraction of neural elements (and hence reduced neurological complications) and the ability to decompress the neuroforamen completely. Disadvantages include a limited ability to restore lordosis because the graft is not anteriorly placed; limited utility in severely collapsed disc spaces, where end-plate damage may occur; and limited utility in the osteoporotic spine, where both end-plate damage and telescoping of the intervertebral spacer may occur.\textsuperscript{36} Anand et al described a cantilever TLIF technique where a C-shaped graft is placed anteriorly, allowing the authors to achieve an average of 7° of increased lordosis.\textsuperscript{37} Additional lordosis can be achieved if this technique is performed in the setting of bilateral osteotomies.\textsuperscript{38}
FIG. 31.10
A 67-year-old male with back and leg pain. He underwent transforaminal lumbar interbody fusion. A, Grade I spondylolisthesis. B, A trial in the disc space after discectomy is completed. C, D, A polyetheretherketone (PEEK) cage has been inserted and rotated into position along the anulus fibrosus. E, At 1 year, there has been a solid fusion of the two vertebral bodies.

Additional posterior lumbar fusion techniques

Fusion, or abolition of the motion segment by joining two vertebral segments, can be achieved in several ways, including posterolateral fusion, interspinous fusion and intervertebral fusion. Historically, posterolateral fusion has been used most, typically with pedicle screw and rod technology. Pedicle screws are widely used in spinal surgery as the most common method for achieving internal fixation (Fig. 31.11). Initially described by Harrington and Tullos, their use was later promoted by Steffee, Roy-Camille, Louis and Dick. Placement of pedicle screws provides a safe, effective method for providing rigid internal fixation and allowing the maintenance or restoration of spinal alignment. These screws also resist loading in all directions. Although the complication rate is low, common complications include inaccurate screw placement, dural tear and screw failure.

Lumbar pedicle screws are typically placed using either a freehand
technique or fluoroscopic or neuronavigational assistance. Freehand technique relies on identification of anatomical landmarks and the experience of the surgeon. Important anatomical landmarks include the pars interarticularis, transverse process, base of the mammillary process and the accessory process. Using an awl or high-speed drill, a hole is made at the junction of the pars interarticularis, mammillary ridge and transverse process, which usually corresponds to the accessory process. In a degenerated spine, the entry point may be further medial along the inferior border of the mammillary process. Some surgeons will use a rongeur to bite off bone and identify cancellous bone because this may assist entry. Effort should be made to medialize pedicle screws as much as is appropriate and possible because triangulated screws have been demonstrated to increase pullout strength.

Posterolateral fusion is achieved by decorticating the posterolateral elements and typically grafting with an onlay of autograft, allograft or other biological materials (see Fig. 31.11). Advantages of posterolateral fusion include lack of violation of the spinal canal; the largest historical experience clinically of fusion using this technique; the ability to stabilize the spine rapidly (especially in the trauma setting); the ability to fuse multiple segments in this manner; and, coupled with osteotomies and facetectomies, the ability to correct deformity. This is the most common technique used in the correction of adolescent idiopathic scoliosis. Disadvantages, especially in the older population, are the lack of a favourable biological environment in which to achieve fusion; the inability to restore foraminal volume in the setting of degenerative conditions or spondylolisthesis; and the inability to restore lordosis in the setting of kyphosis.

Interspinous fusion has been developed as a more minimally invasive technique to perform fusion that does not necessitate the more extensive exposures needed to place pedicle screws. Typically, an interlaminar decompression will be performed in addition to placing an allograft spacer, and the graft is secured with an interspinous process plate. Fusion rates have been typically low (72–84%) but reported outcomes have been good for this short segment procedure.

Various interbody fusion techniques are used to treat lumbosacral spine pathology. Most have been used for degenerative spine conditions and spondylolisthesis, and increasingly they have been employed in the correction of spinal deformity. They include posterior lumbar interbody fusion (PLIF); transforaminal lumbar interbody fusion (TLIF); anterior
lumbar interbody fusion (ALIF); the transpsoas approach for discectomy and fusion; the antepsoas approach for discectomy and fusion; and the trans-sacral approach for interbody fusion. This chapter focuses on posterior approaches to achieve interbody fusion; lateral and anterior techniques are discussed in Chapter 34.

PLIF was the first widely used posterior technique for achieving interbody fusion (Fig. 31.12). Popularized by Cloward and Lin, the technique involves performing a complete laminectomy and insertion of bilateral intervertebral grafts. This is done with nerve root retraction, providing unimpeded access to the disc space. Excellent results have been achieved; the most widely used indications are lytic spondylolisthesis. PLIF is associated with a relatively high complication rate, including durotomy and neural injury, because a laminectomy and thecal sac retraction are typically performed while the disc is accessed; TLIF was developed as a modification of PLIF to avoid dural retraction and neural injury.
The trans-sacral approach for interbody fusion provides an alternative
corridor to achieve interbody fusion at L5–S1 and L4–5 (when L5–S1 is also being fused). Advantages of this approach include avoidance of the neural elements, a posterior corridor and an entirely minimally invasive corridor. This approach has been criticized on the grounds that it may be associated with lack of lordosis and a relatively high rate of delayed pseudarthrosis.

### Tips and Anatomical Hazards

Posterior, lateral and anterior relations of an intervertebral disc are important in planning interventional investigative and therapeutic procedures. The posterolateral surface of the disc forms the anterior boundary of the intervertebral foramen on each side and so is closely related to the spinal nerve and its accompanying vessels. More centrally, the disc is related posteriorly to the dura mater covering the spinal cord and the cauda equina. Anterior relations vary considerably with vertebral level but important ‘at risk’ structures include the pharynx and oesophagus, the descending aorta and the inferior vena cava. Laterally, the parietal pleura in the thorax, and the sympathetic trunk and psoas muscles in the lumbar region, are important relations. Anteriorly, the capsules of the facet joints form the posterior boundaries of the intervertebral foramina. Posteriorly and laterally, the joints are related to the deep muscles of the back, some of whose fibres attach to the capsules. The joints also lie in close relation to the medial branches of the dorsal rami of the spinal nerves and to their accompanying arteries and veins. Damage to the medial branches of the dorsal rami may denervate the deep back muscles. Access to the facet joints and their related nerves may be required in the diagnosis and treatment of spinal pain.
References


32. Lewandrowski KU. “Outside-in” technique, clinical results, and indications with transforaminal lumbar endoscopic


61. Melgar MA, Tobler WD, Ernst RJ, et al. Segmental and global lordosis changes with two-level axial lumbar interbody fusion and posterior instrumentation. *Int. J. Spine*
Single Best Answers

1. A 34-year-old female presents with left arm pain and weakness in her right triceps. MRI findings are as shown in Fig. 31.13. She sees a surgeon, who elects to perform a posterior cervical foraminotomy and discectomy. Which one of the following is LEAST likely to occur as a surgical complication of this procedure?
FIG. 31.13  Images to accompany Single Best Answers, question 1.

A. Residual numbness
B. Durotomy
C. Vertebral artery injury
D. Carotid artery injury
E. Iatrogenic instability

**Answer: D.** Carotid injury is extremely unlikely, given the artery's remote location relative to the surgical field. Common complications of posterior cervical foraminotomy and discectomy include injury to the dura and/or nerve and complications related to aggressive facet resection. While unusual, vertebral artery injury can occur, especially with an errant lateral trajectory of discectomy.

2. Regarding anterior cervical foraminotomy, which one of the following statements is most likely to be FALSE?
A. Allows direct access to osteophyte and compressive pathology
B. Allows the patient to retain the disc without a prosthetic substitute or fusion
C. There is increased muscle pain when compared to a posterior approach
D. The approach is relatively minimally invasive
E. Patients experience relatively few problems with instability following the procedure

**Answer: C.** There is decreased muscle pain associated with this approach. The anterior approach for cervical foraminotomy allows direct access to osteophyte and compressive pathology, while allowing the patient to retain the disc. Relatively few patients have instability following this procedure.

3. Which one of the following is the most likely injury pattern to be seen in the cervical spine of an elderly man with diffuse idiopathic skeletal hyperostosis (DISH) who falls?
A. Flexion compression injury
B. Flexion distraction injury
C. Traumatic disc herniation
D. Distraction extension injury
E. Type I odontoid fracture

**Answer: D.** Both DISH and ankylosing spondylitis are associated with distraction extension injuries with trauma. In this fracture mechanism, the fused segment of the spine actually separates, with the spine acting like a long bone. Flexion compression injuries (or teardrop fractures) are less commonly seen in this group, as are flexion distraction injuries (jumped/perched facet joints). Similar, type I odontoid fractures and traumatic disc herniations are relatively rare in this group of patients after trauma.

4. In terms of lumbar pathology, which one of the following is LEAST likely to be well addressed by laminoforaminotomy with mesial facetectomy with or without discectomy?
A. Lateral recess stenosis
B. Far lateral foraminal stenosis
C. Central stenosis
D. Central disc herniation
E. Posterolateral disc herniation with subligamentous migration

**Answer: B.** Lumbar laminoforaminotomy with mesial facetectomy is a well-accepted procedure where the spinal canal can be readily accessed, along with the proximal neuroforamen for decompression where ligamentum flavum, bone or disc material can be removed. Limitations of this procedure include the inability to access the distal neuroforamen and extraforaminal compartments. The distal foramen is more readily
decompressed by total facetectomy (as in transforaminal lumbar interbody fusion) or, if an endoscopic technique is being used, by foraminoplasty.
1. A 72-year-old female presents with isolated leg pain with walking. She denies back pain. She has tried numerous conservative treatments for her symptoms, including physical therapy, chiropractic and epidural steroid injections. On examination, she is strong throughout her lower extremities. MRI of the lumbar spine is shown in Fig. 31.14.

A. What compartment of the lumbar spine is most narrowed?
In this case, the central canal and lateral recess are critically narrowed at L3–4. The foramen is minimally narrowed, as shown on the sagittal MRI (see Fig. 31.14B).

B. What are the major surgical considerations here?
The patient has a spondylolisthesis at L3–4 and no back pain. The disc is relatively collapsed. Since most of her symptoms are radicular, would she do well with a decompression alone (such as a laminoforaminotomy) or does the
spondylolisthesis alone constitute enough instability to mandate a fusion? This question is still debated.

2. A 57-year-old male with subjective unilateral left upper extremity weakness and pain presents for evaluation; his symptoms have been present for 3 months. He has minimal axial neck pain and slight weakness of the interossei, but other than that, he is strong. Biceps and triceps reflexes are absent on the left side; otherwise he is normo-reflexic. He undergoes plain X-rays, MRI and CT imaging. CT imaging is provided for review (Fig. 31.15).
A. What do the images show?
Fig. 31.15A is a sagittal CT and shows left C5–6, C6–7 and C7–T1. Fig.
31.15B is an axial CT and shows left C6–7 foraminal narrowing.

B. **What further work-up should ensue?**
Most probably, the patient has symptoms related to multilevel cervical foraminal stenosis and he should undergo electromyography/nerve conduction velocity (NCV) testing because he also has findings consistent with a concurrent ulnar neuropathy.

C. **What is the initial treatment of choice in this case?**
Given that many individuals respond to non-operative therapy, patients with cervical foraminal stenosis may benefit initially from treatment with physical therapy and possibly traction therapy.

D. **If non-operative treatment is unsuccessful, what is the most appropriate treatment choice here?**
In the case of multilevel foraminal stenosis, a posterior approach offers a reduced likelihood of complication. Most surgeons who would treat this anteriorly would also perform discectomy and fusion, which would entail additional risk and healing time. Multilevel anterior cervical foraminotomy can also be undertaken, but is less commonly done and may be a more tedious procedure.

E. **The decision is made to perform a multilevel cervical foraminotomy. At operation, the surgeon notes that he/she has resected approximately 80% of the facet joint on the left at C6–7. What is the most likely clinical consequence?**
In this case, the patient has advanced degenerative changes in his discs with disc collapse. He has not had surgery on his right side and therefore it is most likely that his cervical spine will remain stable. He should be observed to see whether he develops any abnormal motion (on flexion/extension) or neck pain. In the immediate postoperative period, neck pain is quite common and is more likely to be related to surgical dissection and trauma than to facet resection.

F. **The patient undergoes postoperative MRI of the cervical spine for a different reason. What are the expected normal findings after a posterior cervical foraminotomy?**
In an appropriate foraminotomy, the mesial facet, including the mesial portion of the superior articular process, is resected. This is well shown on both sagittal and axial imaging (Figs 31.16A and B, respectively); note the greater foraminal volume in areas where bone is missing (arrows). The lateral facet, including the lateral aspects of the superior articular process, is preserved (Fig. 31.16C), which maintains the stability of the joint (arrow).
FIG. 31.16 Images to accompany Clinical Case 2, question F.
Cervical spine

Jason Harvey, Sushmith Ramakrishna Gowda

Core Procedures

- Anterior and posterior approaches to the occipitocervical region
- Anterior and posterior approaches to the subaxial cervical spine

Main indications for cervical spine surgery include excision of herniated discs with either a subsequent fusion or disc replacement, excision of tumours, reduction and stabilization of fractures or dislocations, and laminectomy to decompress the spinal cord, which may be combined with instrumented fusion or laminoplasty. Understanding the relevant anatomy and careful planning are prerequisites for successful surgical outcomes. In this chapter, key features of cervical spine anatomy and common surgical approaches – namely, anterior and posterior approaches to the occipitocervical (OC) and subaxial regions (C3–7) – will be outlined and discussed briefly.
Surgical surface anatomy

The neck extends from the pericranio-cervical line superiorly to the level of the clavicle, scapula and thoracic inlet (first rib and superior manubrium) inferiorly, where it is continuous with the thoracic cavity and upper limb. It is helpful to picture the neck in two portions – an anterior portion and a posterior portion (see Fig. 15.5). The anterior portion contains the ‘prevertebral’ muscles (draped in prevertebral fascia), trachea, oesophagus, thyroid and parathyroid glands and associated vessels, nerves and lymphatics centrally and the carotid sheath and its contents laterally, with the submandibular glands lying superiorly. The posterior portion consists of the cervical vertebral column, the cervical segment of the spinal cord and the postvertebral muscles (Ch. 15).¹

The spines of the second and seventh cervical vertebrae are the most prominent and may be palpated in the midline of the posterior neck (the former via deep palpation). The remaining cervical spines are indistinct because they are covered by the ligamentum nuchae, on either side of which lie the masses of the postvertebral muscles. The transverse process of the first cervical vertebra is palpable in the hollow region posteroinferior to the mastoid apex; the transverse process of the second cervical vertebra may be felt inferiorly on deep palpation. Anteriorly, in an adult, the body of the hyoid bone sits level with the fourth cervical vertebra; the upper border of the thyroid cartilage usually lies between the fourth and fifth cervical vertebrae. The firm, smooth anterior arch of the cricoid cartilage is palpable below the inferior border of the thyroid cartilage. The inferior border of the cricoid commonly sits at the level of the sixth cervical vertebra (range C5–T1). The sixth cervical vertebra is a useful landmark for the junction of the larynx with the trachea and the pharynx with the oesophagus. The vertebral arteries usually enter its transverse foramina and the carotid arteries can be compressed against its transverse processes (the carotid tubercles of Chassaignac).
Clinical anatomy

Cervical vertebrae

The cervical spine consists of seven vertebrae, of which four are typical (C3 to C6) and three are atypical (C1, C2 and C7) (Fig. 32.1). A typical cervical vertebra has a small, relatively broad vertebral body. The superior surface of the body is saddle-shaped, with flange-like lips, the uncinate processes, arising from most of its lateral circumference and articulating with the inferior aspect of the vertebra above, forming the uncovertebral joints (joints of Luschka). The anterior surface of the body is concave from above down. Several vascular foramina on the posterior surface of the body transmit basivertebral veins to the anterior internal vertebral plexus. The pedicles project posterolaterally and the laminae project posteromedially, enclosing a large, roughly triangular vertebral canal that accommodates the cervical enlargement of the spinal cord. The spinous process is short and typically bifid. Lateral to the body, each transverse process contains a foramen transversarium that normally transmits the vertebral artery, vertebral venous plexus and a branch from the cervicothoracic ganglion (vertebral nerve). The intervertebral foramina are bounded by the pedicles superiorly and inferiorly, posteriorly by the facet joints, and anteriorly by the uncovertebral joint and intervertebral disc.
The first cervical vertebra (C1, atlas) is a ring of bone consisting of two lateral masses connected by a short anterior and a longer posterior arch; it lacks a body and spinous process. The anterior arch is slightly convex anteriorly, and carries a roughened anterior tubercle to which the anterior longitudinal ligament is attached. Its upper and lower borders provide attachment for the anterior atlanto-occipital membrane and diverging lateral parts of the anterior longitudinal ligament. The posterior surface of the anterior arch carries a concave, almost circular, facet for articulation with the dens of the axis at the median atlanto-axial joint. The lateral masses are ovoid, their long axes converging anteriorly. Each bears a kidney-shaped...
superior articular facet for articulation with the respective occipital condyle. The inferior articular facet of the lateral mass is almost circular and is flat or slightly concave; it articulates with the axis at the lateral atlanto-axial joint. The posterior arch forms three-fifths of the circumference of the bony ring. Its superior surface bears a wide groove for the vertebral artery, venous plexus and the first cervical ventral ramus, which emerges above the posterior arch of the atlas and passes forwards lateral to its lateral mass and medial to the vertebral artery. The second cervical vertebra (C2, axis) is characterized by a large bifid spinous process and a superior bony projection from the body, the dens (odontoid process). On each side, the foramen transversarium is directed upwards and outwards as the vertebral artery turns abruptly laterally under the superior articular facet to reach the more laterally placed foramen transversarium of C1. The dimensions of the spinal canal are greatest at this level. The seventh cervical vertebra (C7, vertebra prominens) has a long spinous process that ends in a rounded tubercle, and is visible and may be palpated at the lower end of the nuchal furrow. The transverse foramina of C7 usually do not transmit the vertebral artery.

**Cervical muscles and ligaments**

Broadly speaking, the muscles that form part of the musculoskeletal column in the neck are grouped anterior, lateral or posterior to the cervical vertebrae. The anterior and lateral groups include longi colli and capitis; recti capitis anterior and lateralis; and scaleni anterior, medius, posterior and minimi (when present) (Fig. 32.2); the anterior and lateral group are often referred to as the prevertebral muscles and are innervated by ventral rami of the cervical spinal nerves. The posterior muscle group is composed of the cervical components of the intrinsic muscles of the back, overlaid by some of the extrinsic ‘immigrant’ muscles of the back that run between the upper limb and the axial skeleton (trapezius, levator scapulae) (see Fig. 30.3). The intrinsic muscles are arranged in superficial and deep layers and are innervated by medial and lateral branches of the dorsal rami of the cervical spinal nerves. The superficial layer contains splenius capitis and cervicis. The deeper layers include the transversospinal group (semispinales cervicis and capitis, multifidus and rotatores cervicis), interspinales and intertransversarii, and the suboccipital group (recti capitis posterior major and minor, and obliquus capitis superior and inferior).²
Of the superficial muscles, trapezius forms the first layer encountered after the skin and fascia are incised. It arises from the external occipital protuberance, the ligamentum nuchae and the spines of all the cervical vertebrae. Upper fibres insert into the lateral third of the clavicle, the middle fibres insert into the medial edge of the acromion and the superior margin of the spine of scapula, and the lower fibres ascend on to the spine of the scapula. Levator scapulae is the next layer. It originates via slips from each of the transverse processes of 1–4 cervical vertebrae and inserts on to the medial border of the scapula. Splenius capitis arises from the mastoid process and the rough surface on the occipital bone just below the lateral third of the superior nuchal line. Its fibres pass downwards and medially to reach the midline: the lower fibres insert into the tips of the spinous processes of the seventh cervical and upper three or four thoracic vertebrae and the intervening supraspinous ligaments. The tendons of the upper fibres interlace in the midline with those of the opposite side in the dorsal raphe of the ligamentum nuchae in the lower half of the cervical region. Splenius
cervicis is confluent with splenius capitis but covers more caudal regions of the neck and thoracic region. It arises from the transverse process of the atlas, the tip of the transverse process of the axis and the posterior tubercle of the third cervical vertebra. Its fibres pass downwards and medially, wrapping around the other posterior intrinsic neck muscles, to insert into the third to sixth thoracic spinous processes. Erector spinae lies beneath splenius. It is a large musculotendinous mass that differs in size and composition at different vertebral levels. Essentially, it is composed of three main columns (from lateral to medial): the iliocostalis, longissimus and spinalis muscles. Longissimus capitis is a narrow, flat band of muscle that arises from the posterior edge of the mastoid process, under cover of splenius capitis and sternocleidomastoid. It descends across the lateral surface of semispinalis capitis and is inserted by a series of tendons into the transverse processes of the lower three or four cervical and upper four thoracic vertebrae. Longissimus cervicis is a long, thin muscle that arises by tendons from the posterior tubercles of the transverse processes of the second to sixth cervical vertebrae. It descends into the thoracic region, between the tendons of longissimus capitis and longissimus thoracis, to insert by tendons into the transverse processes of the upper four or five thoracic vertebrae.

Despite its name, the ligamentum nuchae is not a ligament of the neck, in that it does not connect adjacent bones and lacks the internal structure typical of a ligament: it is a unique arrangement of tendons and fascia between the posterior muscles of the neck. It consists of a dorsal raphe and a median septal portion. The dorsal raphe lies superficially along the posterior midline of the neck, attached to the external occipital protuberance superiorly and the tip of the spinous process of C7 inferiorly. In its superior half it consists of the aggregated tendons of the most medial fibres of the cervical portion of trapezius.

The ligamenta flava connect laminae of adjacent vertebrae in the vertebral canal. Their attachments extend from facet joint capsules to the point where laminae fuse to form spines; the ligaments are thin, broad and long in the cervical region. The spinal cord lies directly beneath the ligamenta flava; the ligaments must therefore be removed carefully in order not to damage the spinal cord and its meningeal coverings. Distinctive interspinous ligaments are not evident at cervical levels, where they are represented by the median septum of the ligamentum nuchae as it passes between the cervical spinous processes. The posterior longitudinal ligament lies on the posterior surfaces
of the vertebral bodies in the vertebral canal, attached between the body of C2 and the sacrum.

**Cervical nerves**

There are eight pairs of cervical spinal nerves. Cervical ventral rami, except the first, appear between the anterior and posterior intertransverse muscles. Each receives at least one grey ramus communicans from sympathetic ganglia. The first cervical ventral ramus emerges above the posterior arch of the atlas, and passes forwards lateral to its lateral mass and medial to the vertebral artery (Fig. 32.3). It supplies rectus capitis lateralis, emerges medial to it, descends anterior to the transverse process of the atlas and posterior to the internal jugular vein, and joins the ascending branch of the second cervical ventral ramus. The second cervical ventral ramus passes between the vertebral arches of the atlas and axis, ascends between their transverse processes, passes anterior to the first posterior intertransverse muscle and emerges lateral to the vertebral artery, generally between longus capitis and levator scapulae. The third cervical ventral ramus appears between longus capitis and scalenus medius, and the remaining ventral rami emerge between scalenus anterior and scalenus medius. The first and second cervical dorsal root ganglia lie on the vertebral arches of the atlas and axis, respectively; the first cervical ganglion may be absent. The upper four cervical roots are small, and the lower four are large.
Occipital and vertebral vascular supply

The main vessels in the dorsal OC area are the occipital and vertebral arteries. The occipital artery arises in the neck from the external carotid artery in the front of the neck and runs dorsally and rostrally deep to the mastoid process. Accompanied by the greater occipital nerve, the artery enters the scalp by piercing the investing layer of deep cervical fascia that connects the cranial attachments of trapezius and sternocleidomastoid. It pierces trapezius 2.5 cm from the midline and gives off tortuous branches that supply the occipital belly of occipitofrontalis, and the skin and pericranium associated with the scalp as far forward as the vertex.

The vertebral artery arises from the first part of the subclavian artery, coursing between longus colli and scalenus anterior. It is described in four anatomical segments. The first segment (V1, extraosseous segment) runs from its origin to the transverse foramen of C6 (Fig. 32.4). In about 5% of the population, the artery enters the C7 transverse foramina. The second segment (V2, foraminal segment) is susceptible to injury during anterior procedures. It runs through the transverse foramina of all of the cervical vertebrae except the seventh, accompanied by a large branch from the
The inferior cervical ganglion and a plexus of veins that form the vertebral vein. The artery lies anterior to the ventral rami of the cervical spinal nerves (C2–6) and ascends almost vertically to pass through the transverse process of the axis, where it turns laterally to gain access to the transverse foramen of the atlas. The uncovertebral joints provide reliable intraoperative landmarks because the V2 segment takes a course lateral to them. The transverse foramina are less than 6 mm away from the medial margin of these joints and therefore they should limit the extent of neuroforaminal decompression. It is important to appreciate that the V2 segment medializes in the foramina from C6 to C3, and also progresses from a relatively anterior to a relatively posterior position between these levels. The use of intervertebral disc space distraction causes the uncovertebral joints to open by 3–6 mm; inadvertent instrumentation can therefore injure the artery. At the C6/7 level, the vertebral artery lies outside the protection afforded by a transverse foramen and lateral dissection beyond longus colli at this level renders the artery at risk of injury.

**FIG. 32.4** The level of entry of the vertebral artery into the foramina transversaria of the cervical vertebrae. Note that 90% enter at the level of the sixth cervical vertebra. (Redrawn with permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)

The third segment of the vertebral artery (V3, extraspinal segment) lies in
the suboccipital triangle (Fig. 32.5; see Fig. 32.3). It emerges from the transverse foramen of the atlas, medial to rectus capitis lateralis, and curves posteromedially behind the lateral mass of the atlas, with the first cervical ventral spinal ramus lying on its medial side. It lies in a groove on the upper surface of the posterior arch of the atlas before entering the vertebral canal by piercing the lateral angle of the posterior atlanto-occipital membrane about 1.5 cm from the midline. Calcification of the posterior atlanto-occipital membrane produces a foramen (arcuate foramen, ponticulus posticus) through which V3 passes and must be recognized preoperatively (Fig. 32.6); failure to do so can have catastrophic results if the lateral mass C1 screws are placed through the vertebral arteries. The final segment of the vertebral artery (V4, intradural segment) extends from the foramen magnum to the pontomedullary junction, where the right and left vertebral arteries unite in the midline to form the basilar artery.

**FIG. 32.5** The three-dimensional virtual reformat (3DVR) course of the vertebral artery (arrow) in the upper cervical spine. **A**, Posteroanterior view showing the course of the vertebral artery in relation to the lateral mass. **B**, The lateral view highlighting the proximity of vertebral artery (V3) to C1. (From D.-G. Huang, D.-J. Hao, B.-R. He, et al., Posterior atlantoaxial fixation: a review of all techniques, Spine J. 15 (2015) 2271–2281, Fig. 11.)
It is worth repeating that the consequences of injury to the vertebral artery can be catastrophic and potentially fatal. The incidence of injury is rare, with reported rates of between 0.3% and 0.5% for anterior cervical spine procedures. Injuries can range from subtle intimal flaps to complete occlusions or dissections with significant risk of neurological deficits.

It is vital for the surgeon to appreciate the anatomy of the vertebral artery and its anomalies. A three-dimensional anatomical study of the axial cervical spine with MRI scan classified vertebral artery anomalies in a cohort of symptomatic patients into three main groups: interforaminal, extraforaminal or interarterial. Interforaminal anomalies involve midline migration, which places the vertebral artery at direct risk during cervical spine surgery. Extraforaminal anomalies are related to the vertebral artery entering a transverse foramen at a level other than C6, which can increase the risk of
injury during the anterior approach. Interarterial anomalies may be fenestrated or hypoplastic. Despite adherence to well-described techniques, the presence of anatomical anomalies can predispose to iatrogenic injury. The rates described for anatomical variation range from 2.3% in the subaxial spine to up to 20% in the atlanto-axial spine. In the presence of a tortuous course, the uncovertebral joints of Luschka, which are the normal landmarks used during anterior surgery, may not be sufficiently reliable to prevent injury. An enlarged C2 vertebral groove has been reported in up to 20% of patients and can erode the pedicle and lateral mass. The vertebral artery may course over the posterior arch of C1 without first passing through the C1 transverse foramen. Radiological studies have identified a high-riding C2 transverse foramen, at least on one side, in 18% of the population, and this potentially places the vertebral artery at risk of injury during C1/2 transarticular fixation.\textsuperscript{6,7}

The risk of iatrogenic injury can be minimized by closely evaluating preoperative CT and MRI in order to identify the position of the vertebral artery and its relationship to bony landmarks and surrounding structures. MR angiography is useful where normal morphology is altered in cases of infection, tumours and rheumatoid arthritis.\textsuperscript{8}
Surgical approaches and considerations

Anterior approach to the occipitocervical region

The retropharyngeal space is anterior to the prevertebral muscles. The retropharyngeal approach to the upper cervical spine was described by Whitesides and McAfee and colleagues. This approach allows exposure of the ventral aspects of the axis and atlas, and also may permit exposure of the clivus and ventral aspect of the foramen magnum. The patient is positioned on an operative wedge frame and the neck is extended carefully. A modified transverse submandibular incision is made on the right side of the patient. The incision is carried through platysma and the marginal mandibular branch of the facial nerve is identified (Ch. 15). The facial vein runs obliquely back under platysma, lying superficial to the submandibular gland, digastric and stylohyoid. It is joined by the anterior division of the retromandibular vein just anteroinferior to the mandibular angle, and then descends superficial to the loop of the lingual artery, the hypoglossal nerve and the external and internal carotid arteries, to enter the internal jugular vein near the greater cornu of the hyoid bone. The superficial branches of the facial nerve are protected. The anterior border of sternocleidomastoid is mobilized by longitudinally transecting the superficial layer of deep cervical fascia. The submandibular salivary gland is resected and the submandibular duct is sutured adequately to prevent the formation of a salivary fistula. The digastric tendon and stylohyoid are identified, divided and tagged for later repair. The facial nerve can be damaged with retraction and care must be taken to protect the nerve. The hypoglossal nerve is mobilized from the base of the skull to the posterior belly of digastric. The dissection can then be carried on to the retropharyngeal space between the carotid sheath laterally and the pharynx medially (see Fig. 15.5). The superior thyroid artery and vein, lingual artery and vein, ascending pharyngeal artery and vein, and facial artery and vein are all ligated. The alar and prevertebral fasciae are split longitudinally to expose longus colli. It is important to maintain the orientation of the anterior tubercle of the atlas because rotation and lateral dissection may endanger the vertebral artery. The tubercle of the atlas can be palpated through the dorsal pharynx. Extension can be carried out cranially to reach the base of the skull and the clivus. With this approach, anterior decompression and fusion on the OC junction may be carried out.
Posterior approach to the occipitocervical region

A straight incision is made in the midline of the neck; the internervous plane is between the left and right paracervical muscles (supplied by segmental nerves of the respective dorsal rami of the cervical nerves). Using a Cobb elevator or cautery, the muscles are removed either unilaterally or bilaterally, depending on the exposure needed. The posterior approach to the specialized cervical vertebrae C1 and C2 involves extending the skin incision superiorly on to the external occipital protuberance, which can be palpated high in the midline of the skull over the midpoint of the superior nuchal line. Similarly, the fascia and the nuchal ligament are incised down to the large spinous process of C2. Two large cutaneous nerves cross the surgical field, the greater occipital nerve (C2) and the dorsal ramus of the third cervical nerve (C3). As they run upwards from a lateral position, lateral dissection and excessive retraction should be avoided to reduce the risk of iatrogenic injury to these nerves.13

The V3 segment of the vertebral artery crosses the operative field in the suboccipital triangle. The artery passes from the transverse foramen of the atlas, immediately behind the atlanto-occipital joint, courses posteromedially along a groove on the posterior arch of the atlas and pierces the lateral angle of the posterior atlanto-occipital membrane about 1.5 cm from the midline. It is vulnerable at this point. Dissection should remain within 12 mm of the midline on the posterior aspect of the bony ring and within 8 mm of the midline on its superior aspect to avoid damaging the artery. The subaxial spine can be stabilized with lateral mass screws, which are considered relatively safe in terms of their potential to cause vertebral artery injury.14,15 The V3 segment may be injured by a screw trajectory that is too low or too lateral during a posterior approach. The reported rates of injury range from 4.1% to 8.2%. A medially orientated screw trajectory can potentially lower the risk of injury. Nevertheless, care should be taken with C1 lateral mass screw fixation because of the close proximity of V3 as it exits the C2 transverse foramen.

Anterior approach to the cervical spine

The structures in the anterior part of the neck are described in Chapter 15. The anterior approach to the cervical spine exposes the anterior vertebral bodies from C3 to T1. The commonly used surgical approach to the anterior
cervical spine was described by Robinson and Smith in 1957 and later modified by Southwick and Robinson. The author's preference is to place a Mayfield head clamp on the patient and position him or her in a supine position on the operating table, with slight extension of the neck. The patient's arm is placed at his or her side after careful padding. Although the surface anatomy landmarks provide a marker for the underlying cervical level, it is essential to use intraoperative fluoroscopy to identify and check the desired level.

A transverse skin incision at the appropriate level of vertebral pathology can be employed. Surgeons also use a longitudinal incision overlying the centre of sternocleidomastoid. An incision three to four fingers’ breadths above the clavicle will expose C3 to C5 and an incision two to three fingers’ breadths above the clavicle will allow exposure of C5 to C7. In reality, perioperative fluoroscopy is used to ascertain the level because there can be significant variations between patients. The skin and platysma are very vascular and hence some surgeons inject the area with a dilute solution of adrenaline (epinephrine) (1 : 100,000) before incising the skin. The fascial sheath over platysma is incised in line with the skin incision and platysma is then split longitudinally using the tips of the index fingers, keeping the split parallel to the long fibres. Sternocleidomastoid is a prominent muscle, and once the anterior border is identified, the fascia is then incised (Fig. 32.7). The accessory nerve (supplying sternocleidomastoid and trapezius) is at risk of iatrogenic injury if the dissection is lateral to sternocleidomastoid. The infrahyoid strap muscles (together with the trachea and the oesophagus) must be carefully retracted medially. Blunt finger dissection and careful sharp dissection can be used to develop this plane.
The carotid artery within its sheath will then be palpable and a plane is developed between the medial edge of the carotid sheath and the midline structures (thyroid gland, trachea and oesophagus) (Fig. 32.8). This is done by cutting through the pretracheal fascia on the medial side of the carotid sheath and retracting it laterally along with sternocleidomastoid. Use hand-held retractors with rounded ends to avoid iatrogenic injury. Careful blunt dissection in the medial direction behind the oesophagus allows good visualization of the anterior surface of the cervical spine (Fig. 32.9). Gentle and controlled traction should minimize damage to the oesophagus. The prevertebral fascia covers the anterior longitudinal ligament (seen as a gleaming white structure) and longus colli (Fig. 32.10). Using peanut dissectors and blunt dissection, these layers must be separated carefully: the sympathetic chain lies on longus colli, just lateral to the vertebral bodies at the level of transverse processes, and damage or irritation to sympathetic nerves and the stellate ganglion can cause Horner's syndrome. It is important for any dissection on the prevertebral fascia to be centred on the vertebral body and not lateral to it or on longus colli. This will avoid inadvertent injury to the sympathetic chain, vertebral artery or recurrent laryngeal nerve. At this point, intraoperative fluoroscopy (lateral radiographs) should be used to check for the correct cervical level. Longus colli is gently reflected off the vertebral bodies that need to be exposed and dissected subperiosteally with the anterior longitudinal ligament (right and left of the midline) to expose
the anterior surface of the vertebral body. The retractor must be placed underneath longus colli on each side, protecting the recurrent laryngeal nerve, trachea and oesophagus. The resulting exposure is usually sufficient for wide debridement, decompression and instrumented fusion (Fig. 32.11).16

FIG. 32.8 The carotid artery is identified below the medial border of sternocleidomastoid. Further dissection is continued through the pretracheal fascia (note that omohyoid has been divided and retracted laterally).
FIG. 32.9  Dissection has progressed on to the anterior cervical spine, with the carotid artery gently retracted laterally with a vascular sling in situ.

FIG. 32.10  The anterior vertebral bodies and intervertebral discs are exposed after bluntly dissecting off the prevertebral fascia.
The recurrent laryngeal nerve is at risk from direct trauma or from retraction. Some surgeons advocate a left-sided approach because of the differing course and anatomical variations of the nerve on the right side (Ch. 18). However, this view is not supported by evidence in the literature. The superior and inferior thyroid arteries may limit the extension of the surgical field above C3–4 and occasionally either or both of them may have to be ligated and divided to open the plane. The recurrent laryngeal nerve is in close proximity to the superior thyroid artery. Exposure of the lower cervical spine and the cervicothoracic junction can injure the thoracic duct, especially through a left-sided approach (Ch. 15).¹⁷,¹⁸

**Posterior approach to the cervical spine**

The incision for a posterior approach is in the midline and the dissection is relatively safe. The posterior muscles run longitudinally and are supplied by segmental nerves. Proximally, the external occipital protuberance is palpable and the spinous process of C7 can easily be palpated distally. The spinous process of C2 is also palpable in most patients. The skin is thicker on the back of the neck and less mobile than the skin over the front of the neck. The incision runs perpendicular to the tension line of the skin, leaving a thicker scar (Fig. 32.12).
Before the incision, infiltration of the skin and subcutaneous tissue with dilute adrenaline (epinephrine) (1 : 100,000) is helpful to provide haemostasis. After the midline incision, sharp subcutaneous dissection is performed on to the investing layer of the cervical fascia over trapezius. Using cautery, the avascular plane can be developed on either side of the midline, staying within the thin white median raphe to avoid cutting the vascular muscle tissue. The paraspinal muscles can be elevated en masse from the spinous processes (Figs 32.13 and 32.14). Using a Cobb elevator, the laminae and the lateral masses of the vertebrae are exposed (Fig. 32.15). Deep surgical dissection involves identification of the ligamenta flava running between the laminae. Using a sharp blade, the ligamenta flava are removed from the leading edge of the lamina of the inferior vertebra. A laminectomy is performed; it may be either partial or complete, adequate enough to see the blue–white dura. Occasionally, the thin epidural veins can bleed persistently and this can be hard to control.
FIG. 32.13 Paraspinal muscles are removed subperiosteally from the posterior aspect of the cervical spine either unilaterally or bilaterally. Note that the vertebral artery is considerably anterior to the posterior facet joints.

FIG. 32.14 Subperiosteal dissection of the paraspinal musculature exposes the underlying spinous processes in the midline, the laminae and the interconnecting ligamenta flava.
Preoperative imaging modalities can include MR angiogram, especially in patients with malignant disease, infection and altered bony anatomy such as rheumatoid arthritis.

If far lateral decompression is necessary, the anterior walls of the transverse foramina should be removed and the vertebral artery should be retracted laterally.

The recurrent laryngeal nerves (RLN) are at risk; bilateral injuries to the RLN are catastrophic.

The left RLN lies in the tracheo-oesophageal groove whereas the right RLN lies anterior and lateral to the tracheo-oesophageal groove at C7. The right RLN has a variable course as it travels to the midline before entering the larynx; the right RLN may be non-recurrent (Ch. 18).

The vertebral artery can be damaged if the high-speed diamond burr is used off the midline or there is excessive lateral dissection of bone and disc. When dissecting laterally, small rongeurs and curettes should be used.

The V3 segment of the vertebral artery is at the highest risk of damage during instrumentation via the posterior approach because of its close...
proximity to C1 and C2.
Excessive retraction on the oesophagus and decreased mucosal perfusion are factors implicated in the aetiopathogenesis of postoperative dysphagia. Oesophageal perforation following anterior cervical spine surgery is a relatively rare occurrence. Exposure of the lower cervical spine and the cervicothoracic junction can injure the thoracic duct, especially through a left-sided approach. Complications of lateral mass fixation include injury to adjacent nerve roots, vertebral arteries or the underlying spinal cord.
References


10. Ebraheim NA, Lu J, Haman SP, Yeasting RA. Anatomic basis


**Single Best Answers**

1. The vertebral artery typically passes through the transverse foramina of which one of the following groups of vertebrae?
   
   A. T1 to C1  
   B. C7 to C2  
   C. C7 to C1  
   D. C6 to C1  
   E. C6 to C3  

   **Answer: D.**

2. At which one of the following levels can the carotid artery be palpated?
   
   A. C2  
   B. C5  
   C. C6  
   D. Mandible  
   E. C7  

   **Answer: C.**

3. At which one of the following levels is the hyoid bone?
   
   A. C1  
   B. C3  
   C. C5  
   D. Mandible  
   E. C2  

   **Answer: B.**
4. Which one of the following statements about performing anterior cervical spine surgery is true?
   A. The investing layer of deep cervical fascia is released along the lateral border of sternocleidomastoid
   B. The anatomy of the recurrent laryngeal nerve is the same on the left and right sides
   C. Proximal extension of the approach can be limited by the superior thyroid artery
   D. The external jugular vein is within the prevertebral fascia
   E. Exposure to the cervicothoracic junction through a right-sided approach can damage the thoracic duct

   **Answer: C.**

5. Which one of the following statements about the vertebral artery is true?
   A. It arises directly from the aorta
   B. For descriptive purposes, it is divided anatomically into four segments
   C. V2 (the second part) is most susceptible to injury during anterior cervical spine surgery
   D. It usually enters the transverse foramen of C7
   E. Lateral screw fixation at C1 is safe

   **Answer: B.**
Clinical Cases

1. A 49-year-old male presented to the spinal clinic with left shoulder pain and left arm weakness. There was no evidence of lower limb involvement, bladder and bowel function was normal and there was no significant past medical history of note. He smoked 10–15 cigarettes a day. Neurological examination revealed the gait to be normal with some difficulty in heel-to-toe walking. The range of movements in the cervical spine was within the normal limits. Upper limb examination revealed winging of the scapula on shoulder abduction with normal shoulder contours. The tone was normal in the upper limbs with intact sensation bilaterally. Power was 4/5 in the C6 and C7 myotomes in the left arm. The reflexes were reduced on the left side. There was mild clonus present in the left lower limb but otherwise the remainder of the neurological examination was unremarkable. MRI of the cervical spine confirmed cord impingement at the C5/6 disc but no signal change within it (Fig. 32.16). An anterior cervical decompression and fusion was carried out via the anterior approach. The postoperative radiographs are shown in Fig. 32.17.

FIG. 32.16  MRI scans showing C5 disc protrusion. A, Sagittal plane. B, Axial plane.
A. What symptoms would the patient experience with a C6 nerve root impingement?

Neck pain radiating to the arm can be the initial presenting symptom. Common symptoms include reduced or altered sensation over the dorsal aspect of the forearm and thumb, and weakness in elbow flexion and wrist extension. On physical examination, there will be altered sensation at the C6 dermatome (dorsal aspect of the thumb), weakness in elbow flexion and reduced biceps (C5/6) and brachioradialis (C6/7) reflexes.

B. Outline the structures that you go through during an anterior approach to the cervical spine.

Skin, platysma, investing layer of fascia, sternocleidomastoid, omohyoid, pretracheal fascia, prevertebral fascia, longus colli and vertebral body.

2. A 52-year-old female with known rheumatoid arthritis was referred to the spinal clinic complaining of bilateral upper limb symptoms of numbness and progressive weakness. A detailed history revealed problems with gait and recurrent falls, and a general deterioration in her ability to care for herself. She needed a carer twice a day. She denied any bladder or bowel dysfunction and there were no cardiovascular issues. Significant surgical history included bilateral ankle fusions, bilateral knee replacements, left total hip replacement, carpal tunnel decompression and tendon transfers in her hands. She was a non-smoker. Her regular medications included omeprazole, co-codamol, pregabalin, naproxen and steroids (15 mg a day). She used a
stick to help her mobility. On examination, she was not able to walk heel to toe. Cervical spine examination revealed a reduced range of movements but negative Spurling’s test. Although the tone and sensation were intact, power was markedly reduced in the upper limbs. The reflexes were brisk in both upper and lower limbs. Plain radiographs, CT and MRI scans were performed (Fig. 32.18). MRI of the cervical spine confirmed marked atlanto-axial instability, marked compressive myelopathy at C1/2 and multilevel subaxial disc degenerative changes, with marked chronic bilateral C5, C6 and C7 foraminal stenoses. Posterior decompression and occipitocervical fusion were carried out via the posterior approach. The postoperative radiographs are shown in Fig. 32.19.

A. Describe the anatomy of the vertebral artery.

The vertebral artery can be divided into four segments (V1–V4). V1, the extra-osseous segment, starts at the origin of the subclavian artery and usually enters the transverse foramen of the sixth cervical vertebra. V2, the foraminal segment, passes within the transverse foramina of C6 to C1. V3 exits the transverse foramen of C1, courses posteromedially along the upper surface of the posterior arch of C1 and then abruptly turns ventrally and cephalad to enter the foramen magnum. Once the artery penetrates the dura at the foramen magnum, it becomes the intradural segment, V4. At the pontomedullary junction, the right and left vertebral arteries unite to form the basilar artery.

B. What are the examination findings in patients with cervical myelopathy?

Patients present with upper motor neurone signs and symptoms in both upper and lower limbs. There is a progressive stepwise deterioration with relatively stable periods and periods of rapid functional decline. Patients complain of decreased coordination, loss of fine dexterity (such as buttoning a shirt, handwriting and manipulating small objects), and balance and gait problems. Bladder and bowel function can be affected. Falls and trips due to unsteady gait are common presentations. Examination can reveal wide-based gait, upper and lower limb weakness, altered sensation, hyper-reflexia, intrinsic muscle wasting in the hands, positive Babinski and Hoffman signs, and inverted radial reflexes.

C. What is Spurling's test?
Spurling's test is commonly used to assess cervical nerve root impingement. It is positive when simultaneous extension, rotation to the affected side, lateral bend and vertical compression of the cervical spine reproduce symptoms in the ipsilateral arm. Patients with a positive test may also complain of shooting pains or ‘electric shocks’ down the same arm.
Thoracic spine

Christopher Y Kong

**Core Procedures**

- Direct posterior exposure
- Costotransversectomy
- Transpedicular approach to the thoracic disc space
- Anterior open transthoracic exposure
- Endoscopic approach to the thoracic spine
- Lateral extracavitary approach
- Trans-sternal approach to the cervicothoracic junction
Surgical surface anatomy

There are limited reliable surface anatomy cues about the thoracic spine. This contributes to the increased risk of performing wrong-level surgery. The spinous process of the first thoracic vertebra can be palpated just distal to the vertebra prominens (C7). It is important to note, however, that there is significant variability as to which spinous process is actually most prominent in this region. With the patient's arms resting at their sides, the scapular spine and inferior angle can be used to approximate the level of the T3 and T7 spinous processes, respectively. Caution should be exercised when referring to such landmarks in the operating room because shoulders are often positioned in abduction, in forward flexion or under traction. Anteriorly, the T2–3 level can often be inferred by the suprasternal notch and the T4–5 level can be inferred by the sternal angle.
Clinical anatomy

Muscles

Posteriorly, the superficial layer of muscle consists of latissimus dorsi and trapezius. The intermediate layer consists of levator scapulae, rhomboïds major and minor, and serratus posterior. The deep layer is made up of erector spinae (iliocostalis, longissimus and spinalis from lateral to medial) and the transversospinalis group (semispinalis thoracis, multifidus and rotatores brevis and longus from superficial to deep).

Vascular supply

The aortic arch typically reaches the T4 level. As it descends, the aorta moves from being left-sided to more anterior beyond the T7 level. More distally, it courses along the left side of the thoracic vertebrae. The three major branches originating from the top of the arch are the brachiocephalic trunk, left common carotid artery and left subclavian artery. The segmental branches coming off the aorta run along the waist of the vertebral body, deep to the azygos or hemiazygos vein, thoracic duct and sympathetic trunk; they divide into the intercostal arteries and radiculomedullary branches that feed the paraspinal muscles.

The vertebral venous plexus (VVP) is a complex network of vessels distributed along the anterior body and posterior elements of the spine, as well as circumferentially around the thecal sac within the spinal canal. By virtue of being uniquely valveless, the veins of the VVP accommodate bidirectional flow. The plexus maintains continuity with the cerebral sinuses proximally and the sacral plexus distally. In men, the prostate venous plexus also directly communicates with the VVP. This relationship has been used to explain the heightened predisposition towards spinal metastases in the setting of prostate cancer. During surgery, air or even other materials like cement can inadvertently enter an injured venous plexus and embolize to the brain. The epidural veins transmit pressure to the thecal sac when using Valsalva manœuvres intraoperatively to check for cerebrospinal fluid (CSF) leaks. Distally, the VVP drains into the azygos vein on the right side of the thoracic spine and into the hemiazygos vein on the left side. Both the hemiazygos and azygos veins communicate with each other at multiple levels.1
Bones and joints: costovertebral anatomy

The head of a rib articulates with a vertebral body via costovertebral and costotransverse synovial joints; there are multiple costovertebral and costotransverse ligaments. The superior costotransverse ligament forms a tunnel with the spine through which the dorsal ramus of the spinal nerve and the dorsal branch of the intercostal artery pass. Within the intercostal neurovascular bundle, the vein is typically cephalad to the artery, which is cephalad to the nerve.
Surgical approaches and considerations

Direct posterior exposure

The direct posterior approach can be used for posterior decompression and instrumentation of the thoracic spine.

A midline skin incision is performed directly over the palpable spinous processes. Electrocautery is used to dissect through fat and release fascia covering trapezius, rhomboids major and minor, latissimus dorsi and erector spinae off the spinous processes. The segmental innervation of the paraspinal muscles allows for this approach to occur through an internervous plane. Subperiosteal dissection is advanced down the spinous processes, out laterally on to the laminae and transverse processes. The spinotransverse muscles are elevated off bone broadly by releasing their insertions rather than cutting their mid substance. The shingled laminae and spinous processes in the upper thoracic region protect the spinal canal from inadvertent entry. The dorsally projecting transverse processes are easily identifiable as they are more prominent than elsewhere in the spine.

The intertransverse membrane should be preserved. Care must also be taken not to violate the facet capsules, interspinous ligaments or supraspinous ligaments between levels that are not ultimately intended to undergo fusion. Overzealous exposure of the pars interarticularis will often injure a vein that is prone to brisk bleeding.²

Costotransversectomy

This dissection manoeuvre can be used to access the anterolateral vertebral body from a posterior approach. Indications include partial corpectomy, vertebrectomy and three-column osteotomy.

Following a standard direct posterior exposure, dissection with electrocautery is carried out laterally over the transverse process and rib. In order to access the T6–7 disc space, for example, dissection is extended laterally over the transverse process of T7 and the seventh rib. The transverse process is denuded of muscle and the dorsal periosteum of the medial 6 cm of rib is elevated using electrocautery along its length. The ventral aspect of the rib is then detached using a periosteal stripper. The transverse process is excised using a rongeur tool and the rib is cut using a rib-cutter. The rib head is disarticulated using a rongeur and the free 6 cm medial segment of rib is removed. The deep rib periosteum and parietal pleura are then visualized.
The intercostal artery may require ligation if injured. Blunt dissection is carried down along the lateral pedicle towards the anterior vertebral body. The segmental vessels may be encountered, wrapping transversely about the mid section of the vertebral body. These can be managed with bipolar cautery. To complete the exposure, a contoured retractor is then wedged anterior to the vertebra, protecting the great vessels, pleura and other mediastinal structures.

Alternatively, if only anterolateral vertebral body access is required, the spine can be approached through a curved, parasagittal longitudinal incision centred over the level of interest. Trapezius and the paraspinal muscles are split and the rib is exposed. The remainder of the exposure is as described earlier.³

**Transpedicular approach to the thoracic disc space**

The transpedicular approach facilitates safe, unilateral posterior access to intervertebral discs in the thoracic spine while avoiding iatrogenic instability and imposing no displacement of the spinal cord.

A direct posterior exposure is performed first. Intraoperative fluoroscopic imaging in the anterior–posterior projection is used to identify the extent to which the lamina/facet complex overlies the disc of interest. This determines the boundaries of the bony window to be created. A high-speed burr is used to perform a partial facetectomy and hemilaminotomy. The ligamentum flavum serves as a buffer to the canal contents as the burr advances the lower edge of the lamina/facet junction cephalad: this uncovers the ligamentum flavum up to its insertion. Direct burring down on to the proximal edge of the inferior adjacent lamina/facet junction is also performed. This releases the ligamentum flavum of its origin. It can then be fully excised by sweeping a curved microcurette along the inner edges of the established laminotomy.

With the ligamentum flavum removed, a curved microcurette or a nerve hook can be used to palpate the location of the pedicle. The burr is then used to widen the laminotomy far enough to see the medial half of the pedicle in cross-section. At this stage, the laminotomy should provide a window that shows the axilla of the exiting root, the shoulder of the traversing root, the lateral border of the thecal sac and, sometimes, the disc. An illustration of the operative window is shown on **Fig. 33.1**. Burring of the medial pedicle along its length is then performed if additional visibility or additional mobility of the neural elements is required to access the disc space. The
neural elements require protection with either nerve root retractors or Penfield instruments. Many epidural vessels are often encountered during this phase of the exposure and can be managed with bipolar cautery.⁴

**Fig. 33.1** A partial facetectomy provides access to the disc space and visibility of the thecal sac, the axilla of the nerve root and, more cephalad, the medial/inferior pedicle (cephalad to the bony window shown). (Adapted from C.B. Stillerman, T.C. Chen, J.D. Day, et al., The transfacet pedicle-sparing approach for thoracic disc removal: cadaveric morphometric analysis and preliminary clinical experience. J. Neurosurg. 83 (1995) 971–976.)

**Anterior open transthoracic approach**

Open thoracotomy allows for a wide exposure of the anterior thoracic spine. This provides access to the ventral cord and can be used to perform anterior corpectomy, tumour resection, anterior column reconstruction, discectomy or fusion.

The patient is positioned laterally with the operative side up. When exposing the upper thoracic spine, an approach from the right side is preferred because this helps to avoid encountering the heart, great vessels and, in most cases, the artery of Adamkiewicz. When exposing the lower thoracic spine, a left-sided approach is preferred so as to avoid encroachment by the liver. Bronchial intubation is used to allow for deflation of the ipsilateral lung once the pleural space is entered. When the patient is positioned, the shoulder is elevated forward to allow for proximal retraction of the scapula.
A curvilinear incision is used, spanning from a few centimetres distal to the inferior scapular angle anteriorly towards the inframammary line. Depending on the procedure intended, a thoracotomy can be performed either between ribs or with a partial rib resection. The intercostal space between ribs 5 and 6 is a preferred window of access to most thoracic levels. For the distalmost thoracic levels such as T10–12, the space between ribs 6 and 7 can be used. However, this can lead to some symptomatic clicking of the scapula as it glides over the healing bony callus and scar.

Following dissection of skin and fat, the underlying latissimus dorsi and serratus anterior are incised in line with the skin incision. Subperiosteal dissection is used over rib 6 or 7 and the intercostal muscles are elevated superiorly. If the rib is stripped of its periosteum circumferentially, a segment of rib can be cut and saved as autogenous bone graft. If the soft tissue attachments are left intact, the rib segment can still be cut, but used as a trapdoor that can assist closure at the end of the procedure.

The intrapleural space can then be entered through the floor of the rib periosteum. The release of negative pressure in the intrapleural space allows the lung to be deflated. Sponges and a fan retractor are used to mobilize the deflated lung anteriorly and medially. The lateral thoracic spine, covered in parietal pleura, is then visualized. The rib heads serve as useful anatomical landmarks. Ribs 2–10 straddle the disc space with demifacet articulations to the vertebral bodies above and below. For ribs 1, 11 and 12, the rib head tends to articulate entirely with its own vertebra. The intercostal artery and vein travel transversely across the body, in line with the inferior border of the rib. The disc spaces are within the intervals between segmental vessels. Prior to elevation of the parietal pleura off the spine, the segmental vessels that traverse the window of exposure should be ligated or cauterized with bipolar cautery. Meticulous localization of the correct level is crucial during this step. Excessive ligation of intercostal vessels can lead to unexpected devascularization of the spinal cord. The azygos vein and oesophagus overlie the anterolateral vertebral body on the right side. Once the parietal pleura is divided with cautery, these structures must be carefully mobilized anteriorly to access the lateral vertebrae and discs.

Other nearby structures that can be visualized during this approach are the ganglia of the sympathetic trunk and the thoracic duct. The ganglia overlie the heads of the ribs in the upper thoracic spine: they become more anterior in the lower thoracic spine. Sacrificing a few ganglia during rib/vertebral exposure is typically not problematic: care must be taken to
protect both the major trunk and the splanchnic nerves more distally. The thoracic duct appears as a white and delicate structure that can easily be injured during anterior exposure if it is not protected. About the lower thoracic spine, the thoracic duct is typically directly anterior to the vertebral bodies, while more cephalad, it deviates to the left at approximately the T5 level and ultimately empties into the left internal jugular vein or brachiocephalic vein (Ch. 3).\textsuperscript{5,6}

### Endoscopic approach to the thoracic spine

Thoracic endoscopy provides a minimally invasive means of accessing the anterior thoracic spine. It can be used for anterior discectomy, intervertebral graft placement and biopsy.

The patient is positioned laterally. If a scoliotic deformity is present, the convexity is placed upwards; otherwise, the right side is typically the entry side of choice. Bronchial intubation is used to allow for deflation of the upward lung. Care should be taken to drape widely enough to facilitate an open thoracotomy if needed. The shoulder is elevated forward to retract the scapula proximally. Three access portals are established using 2.5 cm incisions parallel to the ribs. Cautery dissection is performed through fat, latissimus dorsi or serratus anterior, down on to the rib. The ipsilateral lung is deflated by anaesthesia. Thoracic portals are established with blunt passage of a trochar/introducer tools over the cephalad edge of the ribs, caudal to the intercostal muscles. This minimizes the risk of injury to the subcostal neurovascular bundle about the inferior border of each rib. The scope portal is placed about the posterior axillary line at the level of interest or the apex of convexity. The accessory instrument portals can be placed up to three rib spaces proximal and distal to the scope portal along the anterior axillary line, anterior to latissimus dorsi. See \textbf{Fig. 33.2} for an illustration of the described portal placement. Use of a 45° scope allows for direct visualization down the disc space if a discectomy is performed. Once portals have been established, the lung can be mobilized anteriorly/medially with endoscopic swab sticks. Beyond this, the principles of deep dissection are identical to those of the anterior transthoracic approach.\textsuperscript{7}
The lateral extracavitary approach is used about the thoracolumbar spine. It serves as a means for both accessing the anterior spine and instrumenting the posterior spine through a single posterior incision. Indications include tumour excision, debridement of infection, circumferential stabilization or major reconstruction.

The patient is positioned prone with the approach side elevated with a combination of bolstering and table tilting. The skin incision is curvilinear. It starts and ends at the midline, three levels proximal and three levels distal to the level of interest: the apex of the curved incision is 7.5 cm lateral towards the side of the pathology. A flap of fat and skin is then elevated towards the midline. A direct posterior exposure is performed. This allows for latissimus dorsi and the paraspinal muscles to be mobilized laterally. At the apex of the curved incision, these muscles are incised vertically along their fibres and retracted medially to expose the ribs. An excision of the proximal 6 cm of rib is then performed, as described for costotransversectomy. This allows for
lateral/anterior access of the vertebrae and intervertebral space via blunt dissection. Following whatever work needs to be performed about the anterior spine, the posterior muscles can be retracted laterally again to allow for additional posterior instrumentation or decompression.\textsuperscript{8}

**Trans-sternal approach to the cervicothoracic junction**

Anterior exposure of the uppermost thoracic vertebrae can be achieved through the trans-sternal approach to the cervicothoracic junction. The distal limit is often described as being T3–4, but this will vary in patients depending on the location of their aortic arch.

The patient is positioned supine with the neck in slight extension. For a left-sided approach, the head can be rotated slightly towards the right. During a left-sided approach, extra care should be taken to look out for and protect the thoracic duct. During a right-sided approach, care should be taken to avoid injury to the recurrent laryngeal nerve.

The skin is incised along the anterior border of the distal sternocleidomastoid, down to the notch of the manubrium and then 3 cm distally down the midline. Proximally, platysma is divided and a myocutaneous flap is elevated laterally. More distally, as dissection is carried along the anterior border of sternocleidomastoid, the manubrium is exposed through release of the interclavicular ligament and the sternohyoid and sternothyroid muscles. It is important to remember that, immediately lateral to this exposure, the phrenic nerve overlies the scalene muscles. Blunt dissection is then used to mobilize the structures posterior to the manubrium. An oscillating bone saw cuts through the full length of the manubrium, down its midline to the level of the second to third intercostal space. At that level, a transverse cut through the sternum completes the osteotomy. An inverted T-shape can be employed if bilateral rib retraction is planned; otherwise, an L-shaped osteotomy can be used for unilateral retraction. The osteotomy is held open with a retractor. If the retractor is unable to maintain adequate exposure, the distal clavicle can be osteotomized, facilitating lateral mobilization of the manubrium and a wider field of view. See Fig. 33.3 for the relative anatomy at this stage. The window of exposure is then the common carotid artery on the left, the brachiocephalic artery and vein on the right, and the oesophagus as the floor. The right recurrent laryngeal nerve coursing under the brachiocephalic artery
may be observed. The oesophagus, trachea and recurrent laryngeal nerve are retracted to the right, while the internal jugular vein and carotid sheath are retracted to the left. Distally, the apices of the lungs are covered by both the pleura and an overlying transthoracic fascia (supracleural membrane, Sibson's fascia). With the midline structures retracted, the prevertebral fascia and underlying longus colli muscles are revealed. These can then be elevated off of the ventral spine using cautery dissection. During closure, the sternohyoid and sternothyroid muscles can be sutured back to their insertion points, and the manubrium and sternum can be fixed with either wires or plate and screw fixation.\textsuperscript{9,10}

Intercostal vessel injury requires immediate management with early cauterization or ligation: haemostasis can become very difficult once these vessels retract.
The thoracic spinal cord is relatively more susceptible to ischaemic injury compared to other regions in the spine. The upper thoracic cord is a watershed zone that is fed by radicular arteries. The artery of Adamkiewicz is the major feeder for the more distal cord: its exact location can be quite inconsistent and excessive segmental vessel ligation should therefore be avoided.
Unnecessary contact with the spinal cord should be avoided whenever possible. For example, a transpedicular approach should not be attempted if a wider approach is genuinely necessary to complete the goals of surgery.
Unique to the thoracic spine, an ongoing CSF leak can contribute to respiratory compromise through filling the pleural space.
The thoracic duct is a delicate structure that is easily injured if not protected during anterior exposure. A persistent postoperative chyle leak is associated with a high mortality rate if not repaired.
In order to avoid performing wrong-level surgery, make sure to count the number of cervical, thoracic and lumbar vertebrae as well as the number of ribs preoperatively. Make use of intraoperative fluoroscopy, portable plain-film X-rays, radio-opaque markers and intraoperative CT scans to avoid irreversible and unnecessary sacrifice of anatomy.
References


[Surgical Anatomy and Techniques to the Spine; 5 p].
Single Best Answers

1. In order to avoid performing wrong-level surgery, the surgeon must remember to use which one of the following topographical landmarks?

A. The inferior scapular angle, which indicates the T7 spinous process
B. The vertebra prominens, which demarcates the spinous process of C7
C. The scapular spine, which identifies the level of the T3 spinous process
D. Intraoperative radiography should be used because there are no truly reliable surface landmarks

**Answer: D.** While options A, B and C all provide approximations of thoracic spine levels, none is reliable or reproducible enough to prevent wrong-level surgery. Instead, preoperative films should be closely studied and compared to intraoperative radiography.

2. Which one of the following rib heads articulates with two vertebrae?

A. 1  
B. 2  
C. 11  
D. 12

**Answer: B.** Ribs 1, 11 and 12 are the only ribs whose heads articulate with a single vertebra. The heads of all other ribs articulate with the neighbouring vertebrae proximally and distally via demifacets.
Clinical Case

1. A 35-year-old male presents with symptoms consistent with thoracic myelopathy. An MRI reveals a single, large, right-sided disc herniation at T6/7. There is effacement of the CSF on T2-weighted axial images with flattening of the spinal cord. You decide to perform a decompression in the form of a discectomy.

A. What reason would there be to use a transthoracic approach as opposed to a transpedicular approach?

The effacement of the CSF and flattening of the spinal cord indicate that there is no way to manipulate or retract the thecal sac without contacting the spinal cord. An exposure wider than what would be allowed through a transpedicular approach is therefore necessary.
# Lumbar spine, sacrum and coccyx

Ronald A Lehman Jr, Lee A Tan

## Core Procedures

### Posterior Approach

- Microdiscectomy
- Foraminotomy
- Laminectomy
- Posterolateral fusion (PLF), posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF)
- Vertebroplasty, kyphoplasty
- Lumbar osteotomies

### Lateral Approach

- Lateral lumbar interbody fusion (LLIF)
- Oblique lumbar interbody fusion (OLIF)

### Anterior Approach

- Anterior lumbar interbody fusion (ALIF)
- Lumbar disc arthroplasty
Clinical anatomy

Lumbar spine

The lumbar spine usually consists of five vertebrae, although anatomical variations with either four or six lumbar vertebrae can exist in a small percentage of individuals. The vertebral canal is bound anteriorly by a vertebral body and intervertebral disc, dorsally by laminae, and laterally by pedicles and facet joints. The lumbar pedicles are thick, cylindrical bony structures that arise from the rostral half of the dorsolateral aspect of the vertebral body and connect the body to the posterior spinal elements (Fig. 34.1). The axial angle of the lumbar pedicles increases as they descend, from almost straight at L1 to a much more lateral–medial orientation at L5, which is clinically important during pedicle screw placement (Fig. 34.2). The nerve roots exit laterally in the foramen just below the pedicles at each level. The intervertebral disc (anteriorly) and the bilateral facet joints (dorsally) share and transmit the biomechanical load.2
FIG. 34.1  A, The first lumbar vertebra, superior aspect. Key: 1, body; 2, pedicle; 3, transverse process; 4, accessory process; 5, mammillary process; 6, spinous process; 7, vertebral foramen; 8, superior articular facet; 9, lamina; 10, inferior articular facet. B, A lateral radiograph of the lumbar spine, 24-year-old male. Key: 1, L3 transverse process; 2, L4 pedicle; 3, twelfth rib; 4, L2 superior articular facet; 5, L2 spinous process; 6, L3/4 intervertebral foramen. (A, From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 43.43. B, From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 43.44B.)
The superior and inferior articular processes from adjacent levels form the facet joints, also known as the ‘zygapophysial joints’, which are synovial joints with important biomechanical roles. The pars interarticularis is the portion of bone that bridges the superior and inferior articular processes at a given spinal level. Pars fractures, also known as ‘spondylolysis’ (Fig. 34.3), are present in approximately 6% of adolescents and usually affect L5; they can be associated with anterior subluxation of the corresponding vertebra, causing ‘isthmic spondylolisthesis’. The ligamentum flavum is a paired ligament running between adjacent laminae of the vertebral bodies and forming part of the posterior ligamentous complex of the vertebral column. On each side, it originates from the mid portion of the anterior surface of the upper lamina and inserts into the rostral lip of the lamina of the vertebra below (Fig. 34.4). In the lumbar region it extends laterally, forming the anterior portion of the facet capsule. Understanding the anatomy of the ligamentum flavum is extremely helpful during lumbar decompression procedures.
FIG. 34.3 Pars fractures (arrows), also known as spondyloysis. A, The left lateral lumbar spine. B, A lateral lumbar spine X-ray.
The intrinsic paraspinal muscles are usually detached from their bony attachments in the midline to provide surgical exposure and to obtain an adequate surgical corridor. Minimally invasive approaches utilizing tubular dilators can minimize tissue trauma by splitting the muscle fibres while preserving the muscles and their bony attachments. The erector spinae muscle contains three columns from lateral to medial, including iliocostalis, longissimus and spinalis; these intrinsic paraspinal muscles are responsible for extension and lateral bending of the lumbar spine. Quadratus lumborum is located anterolateral to erector spinae; it originates from the iliac crest and iliolumbar ligament, and is attached superiorly to the lower anterior surface of the twelfth rib, the lateral surface of T12, and the apices of the transverse processes of the upper four lumbar vertebrae, forming part of the posterior abdominal wall. Psoas major is a long muscle lying on either side of the lumbar vertebral column and the pelvic brim. It has a complex origin that includes the anterior surfaces and lower borders of the transverse processes of all the lumbar vertebrae and five digitations from the bodies of adjoining vertebrae and their intervertebral discs. The lumbar ventral rami that form the lumbar plexus pass laterally into the posterior part of the muscle, anterior to the transverse processes of the lumbar vertebrae. Psoas
major descends along the pelvic brim, continues posterior to the inguinal ligament and anterior to the capsule of the hip joint, and converges to a tendon (joined on its lateral side by most of the fibres of iliacus) before attaching to the lesser trochanter of the femur. Quadratus lumborum and psoas major are important anatomical landmarks during the lateral transpsoas approach to the spine (Fig. 34.6).

FIG. 34.5 The erector spinae muscle group. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 43.71.)
The relevant extrinsic muscles for the anterior approach in the lumbar region include rectus abdominis, external oblique, internal oblique and transversus abdominis (Fig. 34.7). Rectus abdominis is a paired, long, strap-like muscle that extends along the entire length of the anterior abdominal wall on either side of the linea alba; it originates from the middle ribs and inserts into the pubis to form the middle portion of the anterior abdominal wall. External oblique, internal oblique and transversus abdominis are located lateral to rectus abdominis, from superficial to deep; they are important during lateral and anterior approaches to the lumbar spine.
The first four lumbar ventral roots, together with a contribution from the twelfth thoracic ventral root (the dorsolumbar nerve), form the lumbar plexus (Ch. 76); a sound understanding of their location relative to the vertebral body and disc space at each level is essential to minimize the risk of iatrogenic nerve injury during the transpsoas approach. The lumbar plexus lies in a coronal plane that is in line with the posterior part of the vertebral body at L1 but becomes more anterior in the lower lumbar spine. The L1 ventral root gives rise to the ilioinguinal and iliohypogastric nerves, which pass inferolaterally, initially anterior to quadratus lumborum, before piercing the muscle near the anterior superior iliac spine. The L1 and L2 ventral roots give rise to the genitofemoral nerve, which descends obliquely forwards through psoas to emerge on its anterior surface nearer the medial border, opposite L3 or L4. It then descends beneath the peritoneum on psoas major, crosses obliquely behind the ureter, and divides into genital and femoral branches; it may divide close to its origin such that its branches emerge separately from psoas major. The L2, L3 and L4 roots give rise to the obturator and femoral nerves. The femoral nerve can be injured during the transpsoas approach, causing transient or permanent quadriceps weakness. Part of the ventral root of L4 and all of the ventral root of L5 form the lumbar part of the lumbosacral trunk, which appears at the medial margin of psoas major and descends over the pelvic brim, anterior to the sacroiliac joint, to join the S1 root (Fig. 34.8; see Fig. 34.6).
The aorta enters the abdomen through the aortic hiatus in the diaphragm at the level of T12 and bifurcates into the common iliac arteries, typically at the level of L4. The superior hypogastric plexus lies anterior to the aortic bifurcation, the left common iliac vein, median sacral vessels, fifth lumbar
vertebral body and sacral promontory, and between the common iliac arteries (Fig. 34.9). Iatrogenic injury to the sympathetic component of the superior hypogastric plexus during anterior lumbar interbody fusion (ALIF) exposure can lead to retrograde ejaculation as a result of disruption of the sympathetic supply to the bladder neck.\textsuperscript{4} Anterior radiculomedullary feeder arteries, derived from spinal branches of the lumbar arteries, anastomose with the anterior spinal arteries to form a single or partly double longitudinal vessel of uneven calibre along the ventral median fissure. The largest anterior medullary feeder, the great anterior radiculomedullary artery of Adamkiewicz, varies in level, arising from a spinal branch of either one of the lower posterior intercostal arteries (T9–11), or of the subcostal artery (T12) or, less frequently, of the upper lumbar arteries (L1 and L2). It most often arises on the left side (Fig. 34.10).
FIG. 34.9  The overall arrangement of the autonomic plexuses of the abdominal and pelvic viscera. Note the superior hypogastric plexus overlying the anterior surface of the aorta and the anterior part of the lumbosacral junction. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 59.2.)
The inferior vena cava is formed by the two common iliac veins anterior and paramedian to the right of L5. Direct tributaries in the region include the lumbar veins, the right gonadal vein, the renal veins, the azygos vein and the right suprarenal vein. The left gonadal vein, the left suprarenal vein and the hepatic veins all drain into the left renal vein. The four or five paired lumbar veins are connected vertically by the ascending lumbar veins on each side, and drain into either the inferior vena cava or the common iliac veins. The right and left ascending lumbar veins are located dorsal to psoas major and join the right and left subcostal veins to form the azygos and hemiazygos veins, respectively (Fig. 34.11).
Sacrum and coccyx

The sacrum is a large, triangular fusion of five vertebrae that forms the posterosuperior wall of the pelvic cavity. It is set obliquely and curved longitudinally; the dorsal surface is convex and the pelvic surface is concave. Its blunted, caudal apex articulates with the coccyx and its superior, wide base with the inferior articular process of L5 at the lumbosacral angle. The sacral alae, formed by fused transverse processes, articulate with the pelvis laterally at the sacroiliac joints. Ventral and dorsal roots of the sacral nerves exit the anterior (ventral) and posterior (dorsal) sacral foramina, respectively. The sacral plexus gives rise to the superior and inferior gluteal nerves, sciatic nerves, femoral nerves and pudendal nerves (Ch. 78).

The coccyx is formed by 3–5 fused rudimentary vertebrae that lack pedicles, laminae and spinous processes. The first coccygeal vertebra is the largest and resembles the last sacral vertebra; it is sometimes separate. Its base has an oval articular facet for articulation with the sacral apex.
Posterolateral to the base, two coccygeal cornua project upwards to articulate with sacral cornua (Fig. 34.12). Injuring the coccyx, which may occur with trauma or a fall, can give rise to a painful condition called coccydynia, which can be very debilitating; a long period of conservative management or possible surgical treatment may be required.

**FIG. 34.12**  The sacrum and coccyx. A, An anterior view. B, A posterior view. C, A lateral view. Abbreviation: LV, fifth lumbar vertebra. (From R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray’s Anatomy for Students, Elsevier, Churchill Livingstone. Copyright 2015, Fig. 5.22.)

The abdominal aorta bifurcates into two common iliac arteries anterior to L4 or the L4/5 intervertebral disc, slightly to the left of the midline; the angle of bifurcation is very variable (Fig. 34.13). The common iliac arteries bifurcate into the external and internal iliac arteries at the level of the L5–S1 disc. The right common iliac artery passes anterior to the left common iliac vein and then anterior and parallel to the right common iliac vein; the left common iliac artery runs lateral and parallel to the left common iliac vein. The
iliolumbar, lateral sacral and superior and inferior gluteal arteries arise from the common and internal iliac arteries. The venous anatomy generally mirrors the arterial anatomy, although it can be variable. The sympathetic trunks run on the anterior surface of the sacrum deep to the common iliac arteries.

**FIG. 34.13** The iliac vessels. The right common iliac artery crosses over the right common iliac vein to travel ventral and lateral to it at the bifurcation of the common iliac artery, whereas the left common iliac artery runs lateral and parallel to the left common iliac vein.
Surgical approaches and considerations

Posterior approach to the lumbosacral spine

The patient is placed in the prone position and a midline skin incision is made over the intended spinal levels. The subcutaneous tissue is divided down to the thoraco-abdominal fascia with monopolar cautery. The fascia is then divided in the midline over the spinous processes, and the paraspinal muscles are dissected away subperiosteally to minimize muscle bleeding. The spinous processes and laminae are exposed, while the facet joint capsules are preserved for decompressive procedures without fusion. The facet joints and transverse processes laterally are also exposed if facetectomy and fusion are required. Depending on the planned procedure, a laminectomy, facetectomy, pediculectomy or three-column osteotomy may be performed. A clear understanding of the local anatomical relationship between the neurovascular elements and the bony structures is essential to prevent complications, irrespective of the planned procedure.

Dorsal exposure of the sacrum is similar to exposure of the lumbar spine, and is usually required for long segment fusions that require spinopelvic fixation. The sacral and coccygeal nerve roots traverse the sacral canal. The dorsal foramina lie laterally at each level and can be a source of bleeding; dorsal nerve roots may be injured if the foramina are inadvertently entered. The bony ridge between the S1 and S2 dorsal foramina marks the entry point of the S2 alar-iliac (S2AI) screw for spinopelvic fixation.

Lateral approach to the lumbar spine

The spine can be accessed from the lateral position using either the transpsoas approach (lateral lumbar interbody fusion, LLIF) or the anterior-to-psoas approach (oblique lumbar interbody fusion, OLIF). The position for both approaches is similar, except that breaking the table to create a lateral bend is not needed for OLIF. Real-time neuromonitoring of the lumbar plexus and nerve roots is essential to ensure safety of tubular retractor placement during the transpsoas approach; however, this is probably not necessary for the anterior psoas approach. For the transpsoas approach, a nerve stimulation probe should be used during psoas dissection and tubular retractor placement to minimize the risk of nerve injury.

The patient is generally placed in the right lateral decubitus position with the left side up, on the grounds that it is riskier to manipulate the inferior
vena cava and an inadvertent venous injury is more difficult to repair than an arterial injury. For LLIF, the iliac crest is positioned at the break of the operating table and the table is ‘jack-knifed’ to open up the disc space (Fig. 34.14). The top leg (that is, the left leg if the patient is in the right lateral decubitus position) should be flexed to relax psoas major on the side of the approach, while the bottom leg is kept straight with a slight bend in the knee. An anteroposterior X-ray is obtained using fluoroscopy to ensure that the patient is positioned in a true lateral position. Using the direct lateral approach for access to L4/5 with a high-riding iliac crest makes access to that level very difficult, and often an anterior lumbar interbody fusion (ALIF) is needed. In contrast, access to the L4–5 and L5–S1 disc space is not affected by the iliac crest during OLIF, since the spine is approached in an oblique fashion anterior to the iliac crest.

![Image](image.png)

**FIG. 34.14** An intraoperative photograph demonstrating the iliac crest being positioned at the break of the operating table (arrow); the table is ‘jack-knifed’ to facilitate the lateral approach.

The incision is planned and marked using two K-wires or other radiopaque markers with fluoroscopy. The intended docking position for LLIF should be at the middle of the intended disc space approximately at the halfway point in the anterior–posterior dimension. If a single level is to be treated, then a 3 cm horizontal skin incision can be used; if multiple levels are to be treated, then a single vertical or oblique incision centred at the mid segment of these levels can be used. For OLIF from L2 to L5, a vertical skin incision is marked 3–5 cm anterior to the midpoint of the intended disc space(s). For OLIF at L5–S1, the incision is marked in three sequential steps: drawing a line through the L5–S1 disc space and extrapolating to the anterior abdomen;
drawing a line from the midpoint of the disc space vertical to the floor; and
drawing a line that is approximately 4 cm anterior to the anterior superior iliaco spine and connecting the previous two lines.

The skin incision is opened with a scalpel and the external oblique fascia is exposed after dissecting through the subcutaneous fat layer (this will be of variable thickness, depending on the patient's body habitus). A fascial incision is made with monopolar cautery along the orientation of the muscle fibres of external oblique. The underlying internal oblique and transversus abdominis muscles are then dissected through bluntly with a Kelly clamp.
The retroperitoneal space can be entered by making a blunt opening in the transversalis fascia that is just deep to transversus abdominis. The bright yellow appearance of the retroperitoneal fat provides immediate and obvious visual confirmation of entry into the retroperitoneal space. Psoas major, quadratus lumborum and the transverse process posteriorly can be palpated just deep to the retroperitoneal fat with blunt finger dissection. The peritoneum and abdominal contents can also be swept anteriorly with the finger to avoid injury to abdominal contents during docking of the tubular retractors. For OLIF, the approach is similar, except that the finger dissection needs to be directed more posteriorly to reach the retroperitoneal space after entering the transversalis fascia because the incision is placed more anteriorly.

For LLIF, a stimulation probe with 8 mA stimulation centred at the anterior half of the disc space is then carefully inserted into psoas major. If any neural structure is identified during probe insertion, then the probe is repositioned slightly anteriorly to avoid the traversing nerve. Once the probe is properly placed and confirmed by anteroposterior and lateral X-rays, a K-wire is laced through the probe cannula into the intended disc space. Additional anteroposterior and lateral X-rays are used to confirm proper location of the K-wire. The sequential dilators are then inserted over the K-wire. Any electromyography changes during the dilator insertion may indicate nerve compression, and reposition of the dilators is required. For OLIF, the probe is inserted into the disc space anterior to psoas major, approximately at the junction of the anterior third and posterior two-thirds of the disc space. Since the access is anterior to psoas major and the lumbar plexus, nerve injury is not as much of a concern as it is with LLIF. After the final tubular dilator is placed, retractor blades with proper depth are inserted and secured. The tubular retractor is expanded to provide visualization of the disc space and allow an adequate surgical corridor for the lateral procedure. Anteroposterior
and lateral X-rays are again used to confirm proper retractor placement.

The anulus pulposus is next incised with a scalpel or monopolar cautery and the disc material is removed completely. A Cobb elevator is then inserted into the disc space and a mallet is used to release the contralateral anulus/osteophyte under fluoroscopic guidance. Gentle tapping should be used; a sudden loss of resistance provides confirmation of adequate release of the contralateral side (along with radiographic confirmation). The end-plates are then carefully prepared and progressively larger trial spacers are used to distract the disc space until the desired disc height is reached for indirect foraminal decompression. The final interbody spacer is placed under fluoroscopic guidance. An optional lateral plating system can be used at this time if additional posterior instrumentation is not planned. The tubular retractor is then removed. The retraction time of psoas major should be minimized to reduce the risk of neuropraxia caused by nerve compression and/or stretch. The external oblique fascial layer is then carefully closed with interrupted sutures, taking care not to catch any traversing nerve in the muscle. The skin is finally closed in the usual fashion. The disc space preparation for OLIF is similar, but because of the oblique angle of entrance into the disc space, and to avoid entering the epidural space, discectomy must not be placed too posteriorly.

Preventing iatrogenic injuries to the lumbar plexus during the lateral retroperitoneal transpsoas approach is a key concern. The definition of anatomical ‘safe’ zones based on cadaveric dissection studies has proved controversial: although four safe zones have been described, another study found no zone of absolute safety and considered that the plexus was vulnerable to injury, even in the anterior third of psoas.6

OLIF offers another lateral access option and has been gaining popularity amongst spine surgeons.7-9 Similar to the transpsoas approach, the patient is positioned in the lateral decubitus position for OLIF with a lateral paramedian incision to access the retroperitoneal space (Fig. 34.15). However, access via OLIF completely avoids the lumbar plexus and significantly reduces the risk of nerve injury compared to the transpsoas approach.
Anterior approach to the lumbosacral spine

Although L2–5 can be accessed via the lateral approach, exposure of L4–5, L5–S1 disc spaces is more readily achieved through the anterior approach for most spine surgeons. As the popularity of OLIF increases, more surgeons may feel comfortable approaching the L4–5, L5–S1 discs in the lateral position. For ALIF, the patient is positioned supine with arms abducted at 90° on arm-holders. Continuous pulse oximetry of the left great toe is recommended to prevent limb ischaemia during retraction of the left iliac vessels. The intended disc levels are localized with fluoroscopy and a left transverse or oblique incision measuring approximately 6.5 cm is marked. A midline infra- or para-umbilical approach is also possible, depending on the access surgeon’s preference. The incision generally starts at the midline and extends just beyond the lateral border of rectus abdominis. After the skin incision is made with a scalpel, the subcutaneous dissection is carried down to the anterior rectus sheath with monopolar cautery. The anterior rectus
sheath is then cut to expose the belly of rectus abdominis, and the medial, lateral and posterior borders of the muscle are identified and dissected free, so that it can be retracted medially with ease. Next, a small vertical incision is made at the lateral border of rectus abdominis through the posterior rectus sheath and transversalis fascia, until the thin layer of peritoneum is visualized. Blunt finger-tip dissection is used to develop a plane in the retroperitoneal space, and the peritoneum and abdominal contents are gently retracted medially. As the peritoneum is peeled off psoas major posteriorly and medially, the left genitofemoral nerve and the left ureter are visualized coursing along the muscle; they are retracted medially together with the peritoneum to avoid iatrogenic injury (Fig. 34.16). Dissection of the left ureter off the peritoneum can lead to its devascularization and possible segmental necrosis of the ureter.
A key step during the anterior approach is to negotiate the major vessels to
obtain an adequate surgical corridor to the L4–5 and L5–S1 disc spaces. At the L4–5 level, the surgical window is generally lateral to the bifurcation of the great vessels. The iliolumbar vein must be ligated and divided to gain adequate medial retraction of the left iliac vein and to prevent avulsion of the iliolumbar vein, which can lead to significant blood loss. As the left iliac vessels are retracted medially, the L4–5 disc space can be readily accessed. The L2–3 and L3–4 discs are usually above the bifurcation of the great vessels and the iliac vessels usually do not have to be mobilized. However, the iliolumbar or ascending lumbar veins may be present and may require ligation in order to obtain adequate mobilization of the great vessels and access to the disc space at these levels.

At the L5/S1 level, the surgical corridor is usually obtained between the bifurcation of the great vessels (Fig. 34.17). The median sacral artery and/or vein are often encountered and may be ligated to gain access to the L5–S1 disc space. The superior hypogastric plexus runs on the anterior surface of the aortic bifurcation and down the lumbosacral promontory, and so all vertebral tissue and peritoneum should be carefully retracted away from the L5–S1 promontory with the initial blunt dissection. Electrocautery should be minimized to avoid possible injury to the superior hypogastric plexus, which can lead to retrograde ejaculation in male patients.

**FIG. 34.17** Access to the L5–S1 disc space between the bifurcation of the great vessels.
Once adequate surgical exposure is obtained, various table-mounted retractor systems can be used to maintain visualization of the disc space. The anulus is opened with a scalpel, and discectomy and end-plate preparation are completed with a combination of Cobb elevators, curettes, pituitary rongeurs and rasps. Progressively larger trial implants can be used to distract the disc space until the desired height is achieved. The interbody device is then inserted with fluoroscopic guidance to ensure the correct size and position of the implant (Fig. 34.18). Additional anterior screws and/or plates can be used, depending on the specific implant used.\textsuperscript{10,11}

The retractor blades are then slowly released and removed, and any sign of bleeding should be addressed immediately. The peritoneum and the abdominal contents are returned to the original position and the fascia, subcutaneous tissue and skin are closed in a layered fashion.

\section*{Tips and Anatomical Hazards}

\subsection*{Neural Complications}
Use gentle blunt dissection around the aortic bifurcation to avoid hypogastric plexus injury.  
Avoid excessive electrocautery during anterior and lateral dissection.  
Employ thorough preoperative planning and meticulous surgical technique to avoid iatrogenic injuries related to graft and screw placement.  
Form a solid understanding of lumbosacral plexus anatomy to avoid iatrogenic injury during the transpsoas approach.  
Avoid prolonged retractor time during the lateral transpoas approach to avoid stretch-related neuropraxia.  
Neurological sequelae are likely consequences of injuries to the lumbar and sacral roots; lumbosacral plexus; cauda equina; hypogastric plexus (risk of potential problems with retrograde ejaculation) and the sympathetic chain (risk of contralateral cold foot).

**Vascular Complications**

Identify anatomical variants carefully on preoperative imaging.  
Beware of calcified vessels and inflammatory changes that may predispose the vessel to injury.  
Be aware that osteophytic spurs associated with reactive changes in the disc can cause the vena cava to become adherent to the disc.  
Avoid excessive retraction of the iliolumbar vein, left iliac artery and other large vessels.

**Visceral Complications**

Anticipate adhesion in patients with prior abdominal surgery and consider a posterior approach instead.  
Identify the ureter early and sweep it medially and ventrally.  
Consult a specialist immediately if iatrogenic bowel/bladder/kidney injury occurs.  
Practise careful and multilayered closure to avoid abdominal hernias.  
Avoid denervation of the abdominal musculature to prevent pseudo-hernia.
References


1. At which of the following lumbar levels does ‘spondylolysis’ most commonly occur?
   A. L1  
   B. L2  
   C. L3  
   D. L4  
   E. L5

   **Answer: E.** Spondylolysis is a bony defect through the pars interarticularis, which connects the superior and inferior articular processes. This condition is present in up to 6% of the general population. The majority of spondylolysis occurs at the L5 level (approximately 90%); L4 is the second most commonly involved level (approximately 10%). Spondylolisthesis can develop in up to 80% of people with spondylolysis.

2. Which one of the following neural structures can be injured during the anterior approach to L5–S1, leading to retrograde ejaculation in male patients?
   A. Ilioinguinal nerve  
   B. Iliohypogastric nerve  
   C. Pelvic splanchnic nerves  
   D. Superior hypogastric plexus  
   E. Pudendal nerve

   **Answer: D.** The hypogastric plexus, which contains sympathetic innervation that is important in ejaculation in the male, is located on the anterior surface of the abdominal aorta. Iatrogenic injury to the hypogastric plexus during anterior lumbar interbody fusion (ALIF) exposure can lead to retrograde ejaculation.
3. Which one of the following vessels must be ligated to gain adequate retraction during the anterior approach to the L4–5 disc space from the left?
A. Left internal iliac vein
B. Median sacral vein
C. Median sacral artery
D. Iliolumbar vein
E. Ascending lumbar vein

**Answer: D.** At the L4–5 level, the surgical window is generally lateral to the bifurcation of the great vessels. The iliolumbar vein must be ligated and divided to gain adequate medial retraction of the left iliac vein and to prevent avulsion of the iliolumbar vein, which can lead to significant blood loss. As the left iliac vessels are retracted medially, the L4–5 disc space can be readily accessed.

4. Which one of the following is the most likely reason for placing a continuous pulse oximeter on the left toe during the anterior approach to the lumbar spine?
A. To act as a back-up pulse oximeter in case the other one malfunctions
B. To alert the surgeon if excessive retraction of the left iliac vessels causes left lower extremity ischaemia
C. To detect possible left lower extremity ischaemia caused by malposition of the leg
D. To detect increased blood flow in the leg caused by injury to the sympathetic plexus

**Answer: B.** Continuous pulse oximetry of the left great toe is recommended to prevent limb ischaemia during retraction of the left iliac vessels.
Clinical Case

1. A 57-year-old female presented with persistent and worsening low back and bilateral leg pain for over a year. She has failed multiple trials of conservative management. Her physical examination was significant for 4/5 weakness in bilateral quadriceps. X-rays of the lumbar spine revealed a grade 2 spondylolisthesis at L3–4 with complete collapse of the disc space (Fig. 34.19). MRI of the lumbar spine revealed severe foraminal stenosis bilaterally at L3–4, causing severe compression of L3 nerve roots (Fig. 34.20). After a thorough discussion, the patient decided to undergo surgical treatment with L3–4 oblique lumbar interbody fusion (OLIF) with posterior percutaneous screw fixation. She tolerated the procedure well and had an uncomplicated postoperative course. Postoperative X-rays demonstrated reduction of the L3–4 spondylolisthesis with proper position of the instrumentation (Fig. 34.21). She had almost complete resolution of her preoperative symptoms at her 6 months follow-up visit.

A. Which nerve roots are most likely to have been affected from the L3–4 spondylolisthesis, causing the patient’s quadriceps weakness?
L3 nerve roots.

B. What is the advantage of OLIF versus LLIF?
OLIF completely avoids the lumbar plexus and significantly reduces the risk of nerve injury compared to the transpsoas approach.
FIG. 34.19  X-rays of the lumbar spine revealing a grade 2 spondylolisthesis at L3–4 with complete collapse of the disc space (arrow). A, An anteroposterior view. B, A lateral view.
FIG. 34.20  MRI of the lumbar spine revealing severe foraminal stenosis bilaterally at L3–4, causing severe compression of the L3 nerve roots (arrows).
Anatomy of lumbar puncture and epidural analgesia

Christopher J Zarembinski

Core Procedures

- Epidural injections: commonplace in obstetrical anaesthesia, as well as in the treatment of radiculitis throughout the spine
- Epidural catheterization: permits continuous administration of an anaesthetic agent
- Lumbar puncture: single injection of local anaesthetic into the subarachnoid space via lumbar puncture offers excellent surgical anaesthesia for abdominal, pelvic and lower-extremity procedures

The epidural space is the potential space that lies outside the dura and is the outermost part of the vertebral (spinal) canal. Its upper limit is the foramen magnum, and its lower limit is the sacrococcygeal membrane. The dura encloses the arachnoid mater, subarachnoid space, cerebrospinal fluid (CSF) and spinal cord, and ends at approximately S2. The subdural space is the potential space between the dura and arachnoid mater (Fig. 35.1). It does not connect with the subarachnoid space but continues for a short distance along the cranial and spinal nerves. Accidental subdural catheterization may occur during epidural injections; injection of fluid into the subdural space may damage the cord either by direct toxic effects or by compression of the vasculature. The subarachnoid space contains the CSF in continuity around the brain and spinal cord. CSF is created in the choroid plexus and mainly absorbed in the arachnoid granulations, with a normal specific gravity of 1.004–1.006. The total volume of CSF in the normal adult is approximately 150 ml and is produced 25 ml per hour.¹²
FIG. 35.1 A sagittal section through the layers of the posterior vertebral (spinal) canal. Note the larger gauge epidural needle with a rounded tip located in the epidural space, deep to the ligamentum flavum. The smaller gauge spinal needle with a sharp tip is located in the subarachnoid space, deep to the dura mater and arachnoid mater.
Clinical anatomy of the epidural space

The posterior epidural space is widest in the upper thoracic region (7.5 mm), narrowing to 4.1 mm at the T11–T12 region, and 4–7 mm in the lumbar region. It takes 1.5–2 ml of local anaesthetic to block a spinal segment in the epidural space but far less (0.3 ml) for a similar block in the subarachnoid space.

Both the shape and size of the epidural space are dictated by the shape and size of the vertebral canal and the position of the dural sac. The space freely communicates with the paravertebral space via intervertebral foramina. The epidural space can be separated into cervical, thoracic, lumbar and sacral epidural regions. In the cervical epidural space, the spinal and periosteal layers of dura fuse at the foramen magnum, preventing intracranial extension. The lumbar epidural space extends from the lower margin of the L1 vertebra to the upper margin of S1. A line drawn between the iliac crests (intercristal line) across the back usually denotes the L4–5 interspace in adults and the L5–S1 level in infants. The sacral epidural space extends from the upper margin of S1 to the sacrococcygeal membrane. The space is bounded anteriorly by the posterior longitudinal ligament, vertebral bodies and intervertebral discs; the pedicles and intervertebral foramina form the lateral boundaries, and the ligamenta flava and vertebral laminae form the posterior boundary. The ligamentum flavum forms the anterior covering of the diarthrodial zygapophysial joint; haptic recognition of the ligamentum flavum is critical in successful cannulation of the epidural space (see Fig. 35.1).

Contents of the epidural space

The epidural space contains fat, lymphatics, arteries, connective tissue, spinal nerve roots and an extensive venous plexus. Epidural fat is the dominant constituent of the posterior spinal epidural space. It buffers the pulsatile movements of the dural sac; protects nerves; facilitates the movement of the dural sac over the periosteum of the spinal column during flexion and extension; and creates a reservoir for lipophilic substances. The fat is largely distributed along the dorsal margin of the space. The clinical significance of the epidural fat distribution is related to the pharmacokinetics of drugs injected into the epidural space: changes in fat content and distribution associated with different diseases may alter the absorption and distribution...
of drugs injected into the epidural space.

The internal vertebral venous plexus within the epidural space is thought to be involved in traumatic tap during needle placement. The plexus consists of four interconnecting longitudinal vessels, two anterior and two posterior, which receive a large contribution from the posterior aspect of each vertebral body via the basivertebral vein (Fig. 35.2A). Anterior and posterior external vertebral venous plexuses anastomose freely and are most developed in the cervical region. Anterior external plexuses are anterior to the vertebral bodies, communicate with basivertebral and intervertebral veins, and receive tributaries from vertebral bodies. Posterior external plexuses lie posterior to the vertebral laminae and around spinous, transverse and articular processes. They anastomose with the internal plexuses and join the vertebral, posterior intercostal and lumbar veins. The basivertebral veins are paired, valveless veins that drain the pars spongiosa of the vertebral bodies into the internal and external vertebral venous plexuses. In each segment, they emerge horizontally from foramina in the vertebral bodies. Posteriorly, they drain into the transverse branches of the anterior internal vertebral plexuses. Anteriorly, they drain directly into the anterior external vertebral venous plexus. These veins are predominantly in the anterolateral part of the epidural space; they connect deep pelvic veins draining the bladder, prostate and rectum to the internal vertebral venous plexus. Sparse lymphatics concentrated along the dural roots and the valveless venous system contribute to the haematogenous spread of infection or malignancy to the epidural space. Obstruction of the inferior vena cava, pregnancy or intra-abdominal tumours can cause distension of the venous plexus, leading to increased risk of trauma during needle or catheter placement in the epidural space. Spinal arteries entering each intervertebral foramen form an anterior and posterior spinal arterial arcade; these arteries arise from the vertebral arteries and the thoracic and lumbar aorta, and anastomose with the anterior spinal artery (Fig. 35.2B). The arteries in the lumbar epidural space are branches of the iliolumbar arteries, and because they are placed laterally in the space, they typically escape trauma during an epidural puncture.
Innervation of the vertebral column and its associated soft tissues is derived from the spinal nerves where they branch, in and just beyond the intervertebral foramina. There is an input from the sympathetic system either via grey rami communicantes or directly from thoracic sympathetic ganglia. The branches of the spinal nerve concerned are the dorsal ramus and the recurrent meningeal or sinuvertebral nerves (usually more than one at each level). The anterior dura is heavily innervated, whereas the posterior dura is sparsely innervated.\(^{11}\)

Anchoring meningovertebral ligaments divide the epidural space into anterior, lateral and posterior compartments.\(^{6}\) Fibrous bands of connective tissue in the anterior epidural space, Hofmann ligaments, connect the anterior dural sac to the posterior longitudinal ligament (PLL) and may play a supportive role in anchoring the dural sac to the bony vertebral canal (Fig. 35.3). The greatest numbers of ligaments have been observed in the lower thoracic spine.\(^{12}\)
Identification of the epidural space

Identification of the epidural space is of critical importance and accuracy of needle placement determines the success of epidural analgesia. The epidural needle, as inserted in the midline, pierces the skin and traverses successively the supraspinous ligament, interspinous ligament and ligamentum flavum (Fig. 35.4; see Fig. 35.1). The depth of the epidural space can be variable, particularly in an obese patient. Ravi\textsuperscript{13} correlated the distance from the skin to the epidural space based on body mass index (BMI). In most patients, this distance is in the range of 3–6 cm.
FIG. 35.4  A, A sagittal section of lumbar and sacral vertebrae illustrating the course of a lumbar puncture needle through (in order) the skin, subcutaneous tissue, supraspinous ligament, interspinous ligament between the spinous processes, ligamentum flavum and dura mater, into the subarachnoid space between the nerve roots of the cauda equina. B, A horizontal section of a lumbar vertebra illustrating the course of a lumbar puncture needle through (in order) skin, subcutaneous tissue, between the spinous processes and laminae, ligamentum flavum, epidural space and dura mater, into the subarachnoid space and between the nerve roots of the cauda equina. (With permission from J.M. Boon, P.H. Abrahams, J.H. Meiring et al., Lumbar puncture: anatomical review of a clinical skill, Clin. Anat. 17 (2004) 544–53.)

Methods of identification of the epidural space

Traditional methods of locating the epidural space depend on the negative pressure exhibited during introduction of an epidural needle into the space. The conventional method employs a loss of resistance (LOR) technique with the use of either air or saline. This technique uses continuous or intermittent pressure on the piston of an epidural glass or plastic syringe; the LOR is
noted when it becomes possible to inject easily through the syringe attached to the epidural needle, allowing the piston to move easily within the barrel of the syringe (Videos 35.1 and 35.2). This technique works because the ligamentum flavum is dense and injection into it is difficult. Rarely, LOR to air has been linked to paraplegia and pneumocephalus, while LOR to saline has been associated with dilution of injected local anaesthetic. Other techniques have been described. Ultrasound can predict skin to epidural depth and correlates with MRI identification of the epidural space. On MRI with T1 sequencing, the epidural space is seen as a bright signal displayed by epidural fat. A generous epidural space as seen on MRI with T1 sequencing may translate to ease of cannulation (Fig. 35.5).

**FIG. 35.5** MRI with T1 sequencing of the sagittal lumbar spine.

**Technical considerations**

Initial contact with the lamina before entry into the epidural space provides depth control, which is crucial for safety, especially in the cervicothoracic canal. Lateral and contralateral oblique images provide a measure of depth to enhance safety; contralateral oblique images should delineate the
spinolaminar line clearly and define accurate depth control. The importance of their use was highlighted by the observation that incomplete midline fusion of the ligamentum flavum can be seen in 67% of patients at C6–7 and C7–T1 levels. 

Safe cervical interlaminar epidural placement is aided by contralateral oblique fluoroscopic views. In the lumbar spine, contralateral oblique imaging will confirm needle placement when combined with anteroposterior images and has been shown to be especially useful when target landmarks are unclear in the lateral view: for example, in obesity, severe osteoporosis or atypical anatomy. Air at the time of LOR is clearly visible in contralateral images and facilitates reliable epidural cannulation without the use of contrast agent (Fig. 35.6).
Pathology affecting epidural entry

Congenital abnormalities that cause difficulties in epidural cannulation include achondroplasia, congenital adolescent scoliosis and spina bifida. Acquired abnormalities include ligamentum flavum hypertrophy, foraminal stenosis and disc herniation. Examination of MRI preoperatively may help predict any procedural challenges and avoid complications.
Clinical importance of the epidural space

The close proximity of the epidural space to neural structures means that lesions involving the space may present with symptoms of myelopathy or radiculopathy. MRI is the primary imaging modality to assess pathologies of the epidural space; clinical assessment and laboratory and imaging findings help the clinician to form a specific diagnosis. The epidural space is a focus for the purpose of inducing anaesthesia and analgesia. Injection into this space can be by single injection, whereas catheterization permits intermittent or continuous injection, including patient-controlled epidural analgesia (PCEA). Epidural injection of corticosteroids is commonly used to manage radicular pain caused by nerve irritation; steroids placed in the epidural space have a potent anti-inflammatory action and can decrease pain and improve function. Administration of local anaesthetics into the epidural space provides pain relief during labour, abdominal surgery and lower-extremity surgery. Implanted delivery systems may be used to manage cancer pain.
Clinical importance of the subarachnoid space

MRI is the primary initial imaging modality to assess the subarachnoid space. Single injection is the most common modality used for drug administration. Local anaesthesia administration offers excellent surgical anaesthesia for the abdomen, pelvis and lower extremities. The sensorimotor block produced by injecting into the subarachnoid space requires smaller doses of local anaesthetics, which means that local anaesthetic toxicity is rarely a concern. Subarachnoid narcotic administration is helpful for postoperative pain relief, as well as serving as a test for those patients being considered for an intrathecal narcotic pump. Conditions that result in increased abdominal pressure or engorgement of epidural veins, such as pregnancy, ascites and abdominal tumours, will increase the height of spinal blockade.

Tips and Anatomical Hazards

Meticulous technique is critical in avoiding hazards, such as inadvertent dural puncture, which can lead to spinal headache and places the spinal cord at risk with cervicothoracic approaches. Identification of laminar depth, recognition of landmarks on imaging, and haptic feedback during needle placement are critical skills to ensure safe practice. Complications such as epidural abscess and epidural haematoma are uncommon but are associated with significant morbidity. In intrathecal administration of local anaesthetic, an extremely high anaesthetic level to C2–3 can result in phrenic and intercostal muscle paresis, hypoxia and hypercarbia. An anaesthetic level of T1–4 can result in bradycardia and decreased myocardial contractility. The sympathectomy associated with a spinal anaesthetic produces hypotension primarily due to dilation of the venous capacitance vessels and decreased peripheral vascular resistance. Clearly, the ability to provide respiratory support, vasopressors and intravenous fluids is critical.
Contraindications for epidural or subarachnoid injection include hypovolaemia, coagulation disturbances, stenotic valvular disease and bacteraemia.

Spinal headache is reduced by using a small-gauge needle; spinal needles shaped with a pencil point may offer a smaller rent in the dura with a reduced incidence of postdural puncture headache.\textsuperscript{32,33}

Spinal anaesthesia has been associated with symptomatic deterioration in patients with multiple sclerosis.\textsuperscript{34}
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Single Best Answers

1. Which one of the following does a line drawn between the iliac crests across the adult back usually denote?
   A. L1–2 interspace
   B. L2–3 interspace
   C. L3–4 interspace
   D. L4–5 interspace
   E. L5–S1 interspace

   **Answer: D.** A line drawn between the iliac crests (intercristal line) across the back usually denotes the L4–5 interspace in adults and the L5–S1 interspace in infants.

2. Which one of the following expresses the approximate total volume of cerebrospinal fluid (CSF) in a normal adult?
   A. 25 ml
   B. 75 ml
   C. 150 ml
   D. 225 ml
   E. 300 ml

   **Answer: C.** CSF is created in the choroid plexus and absorbed in the arachnoid granulations, with a normal specific gravity of 1.004–1.006. The total volume of CSF in the normal adult is approximately 150 ml and is produced at 25 ml per hour.

3. In which one of the following is the width of the epidural space largest?
   A. Cervical spine
   B. Upper thoracic spine
   C. Lower thoracic spine
4. Which one of the following is the dominant component of the posterior spinal epidural space?
A. Fat
B. Lymphatics
C. Veins
D. Arteries
E. Spinal nerves
F. Connective tissue

**Answer: A.** The epidural fat buffers the pulsatile movements of the dural sac. It protects nerve structure; facilitates the movement of the dural sac over the periosteum of the spinal column during flexion and extension; and creates a reservoir for lipophilic substances.

5. From which one of the following can distension of the venous plexus in the epidural space result?
A. Inferior vena cava obstruction
B. Pregnancy
C. Intra-abdominal tumour
D. All of the above
E. None of the above

**Answer: D.** The venous plexus in the epidural space is
predominantly in the anterolateral part of the epidural space and is valveless. Obstruction of the inferior vena cava, pregnancy or intra-abdominal tumours can cause distension of the venous plexus, leading to increased risk of trauma during needle or catheter placement in the epidural space.
Clinical Cases

1. A 28-year-old, morbidly obese female is in labour and requires a labour epidural catheter placement.

A. Describe how to assess needle depth control during epidural placement.
   In this setting, needle contact with the spinous process provides tactile information regarding the location of the midline, whereas needle contact with the lamina provides a sense of depth control. Note that the depth of the epidural space can be variable in the obese patient. Ultrasound may be useful in assessing the distance from the skin to the epidural space. In the non-parturient, fluoroscopy with contralateral oblique imaging may be of particular use in depth assessment.

2. A 70-year-old male, with a normal coagulation status, underwent a lumbar epidural steroid injection for treatment of radiculitis. On follow-up 24 hours later, he complains of severe back pain and progressive bilateral leg weakness.

A. Describe how the patient will be assessed.
   Epidural haematoma is a rare complication associated with spinal procedures. Although it is an uncommon cause of acute myelopathy, it may require surgical evacuation. Physical examination and MRI assessment can be critical. The comparison of MRI signal on T1 and T2 weighted images can define the extent of the haematoma further. In this case, there was low signal intensity on T1 weighted imaging and high signal intensity on T2 weighted imaging that was consistent with an acute stage of haematoma formation. The differential diagnosis for intense back pain and progressive neurological deficits is intradural haemorrhage, spinal cord compression due to tumours, disc herniations, spinal cord infarction and so on.
SECTION 5
Upper Limb

OUTLINE

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CHAPTER 36
The upper limb functions as a series of articulated segments, which act in a coordinated manner to allow the hand to manipulate and sense its surrounding environment. The degree of coordination of these movements is such that the hand can be positioned with remarkable precision. The freedom of movement allowed by the highly mobile thoracoscapular and glenohumeral joints means that, when combined with the actions of the elbow and wrist joint, the hands can reach virtually anywhere in a sphere defined by the reach of the arms.
Skin and fascia

The skin of the neck and upper limb is thin and mobile, whereas the skin of the back of the neck, shoulder, arm and forearm is thicker and more hirsute. In the hand, the thick, hairless palmar skin is anchored to the palmar aponeurosis, while the skin over the dorsum of the hand is thinner and more mobile. The skin creases on the preaxial surface of the elbow, wrist and hand indicate where the skin is tethered to the deep fascia. The skin of the axilla is particularly mobile to allow for the extensive range of movement of the glenohumeral joint.

The superficial fascia is also thicker over the dorsal aspect of the neck and upper limb, and allows gliding to take place between the skin and deep fascia.

The deep fascia of the upper limb, the intermuscular septa of the arm and the interosseous membrane of the forearm divide the limb into discrete compartments. They also increase the area for the attachment of muscles. This compartmental arrangement is particularly important in limiting the spread of local infection and tumour but also acts to contain pathological swelling within the compartment.

A compartment syndrome may occur in the arm, forearm or hand. It arises, usually as the result of injury, when the tissue pressure in a compartment is elevated to a level that decreases the perfusion gradient across the capillary bed. Consequently, the peripheral pulses may remain palpable. Pain is often severe, disproportionate to the degree of injury and exacerbated by stretching the muscles in the affected compartment. Muscle and nerve ischaemia can occur within hours, leading to muscle necrosis and irreversible damage to the affected nerves. Treatment is by thorough decompression of the affected compartment (fasciotomy).
Bones and joints

The bones of the upper limb consist of the clavicle, scapula, humerus, radius, ulna, eight carpal bones, five metacarpals and 14 phalanges.

The pectoral girdle, formed by the clavicle, scapula and acromioclavicular joint, is linked to the axial skeleton only by the sternoclavicular joint and a series of powerful flat muscles: principally, serratus anterior, trapezius and the two rhomboids, and, to a lesser extent, levator scapulae. Its function is to act as a powerful, mobile but stable base on which the rest of the upper limb can move. Paralysis of these muscles significantly impairs upper limb function in terms of range and stability.

The glenohumeral joint is a synovial joint between the near-hemispherical head of the humerus and the shallow glenoid fossa of the scapula. The glenoid fossa is deepened by the glenoid labrum. The joint is surrounded by a fibrous capsule lined with synovium. The capsule is attached medially to the neck of the glenoid and laterally to the anatomical neck of the humerus just distal to its articular margin. It encloses the supraglenoid tubercle to which the intracapsular long head of biceps brachii is attached. The lateral part of the capsule is thickened by the tendons of supraspinatus superiorly, infraspinatus and teres minor posteriorly, and subscapularis anteriorly. The insertion of the long head of triceps to the infraglenoid tubercle blends with it inferiorly.

The elbow consists of a hinge joint between the humerus and the ulna, and two pivot joints: the humeroradial and proximal radioulnar joints. It is stabilized by a fibrous capsule that is reinforced by the radial and ulnar collateral ligaments of the elbow and by the anular ligament, which surrounds the radial head and stabilizes the proximal radioulnar joint. The elbow joint allows flexion from 0° to 150° and 180° of pronation/supination in conjunction with the distal radioulnar joint.

The shafts of the radius and ulna are connected by two syndesmoses: the oblique cord, the function of which is uncertain, and the interosseous membrane. The fibres of the interosseous membrane pass obliquely and distally from the radius to the ulna and give origin to the deep muscles of the forearm. Their central portion is thought to act, in conjunction with the radial head, to prevent proximal migration of the radius.

The distal radioulnar joint is a pivot joint between the head of the ulna and the ulnar notch of the radius. It contains an articular disc and is stabilized by a fibrous capsule that is thickest anteriorly and posteriorly.
The wrist (radiocarpal joint) is a synovial ellipsoid joint between the distal end of the radius and the articular portion of the triangular fibrocartilage complex (TFCC), and the scaphoid, lunate and triquetrum of the proximal carpal row. It is surrounded by a fibrous capsule that is reinforced by palmar radiocarpal and ulnocarpal ligaments, dorsal radiocarpal ligaments, and radial and ulnar collateral ligaments. The palmar ligaments are notably stronger than the dorsal. The radiocarpal joint can achieve approximately 140° of flexion/extension and 70° of combined abduction and adduction.

The intercarpal joints link the bones of the carpus. They are divided into a proximal row consisting of the scaphoid, lunate and triquetrum, and a distal row consisting of the trapezium, trapezoid, capitate and hamate. The pisiform articulates with the volar aspect of the triquetrum. The joint between proximal and distal row is designated the mid-carpal joint.

Of the carpometacarpal joints, the first is a saddle joint that allows opposition of the thumb. The second to fifth are synovial ellipsoid joints that become progressively more mobile towards the fifth. The metacarpophalangeal joints are almost bicondylar; the interphalangeal joints are uniaxial hinge joints.
Muscles

The muscles of the shoulder girdle may be divided into two groups: those that suspend the scapula and those that move it.

Muscles of scapular suspension

The principal muscles of scapular suspension are trapezius, which is attached to the spine of the scapula, the acromion and the lateral third of the clavicle; and pectoralis minor, which is attached to the coracoid. Trapezius stabilizes and suspends the scapula, whereas pectoralis minor depresses and protracts it. They are assisted in this by subclavius, which stabilizes the medial end of the clavicle. The acromion and coracoid are linked by the coracoacromial ligament, which completes the coracoacromial arch. Scapular suspension is impaired if there is disruption of any part of this system.

Muscles of scapular motion

The muscles of scapular motion are levator scapulae, the rhomboids and serratus anterior. Each is attached to the medial border of the scapula. Levator scapulae elevates the superomedial corner of the scapula, the rhomboids retract its medial border, and serratus anterior protracts the scapula around the chest wall: it is mainly involved in movements involving reaching or pushing. Paralysis of serratus anterior results in ‘winging’ of the scapula and is characterized by prominence of its medial border and an inability to sustain elevation of the arm. It can be elicited by asking a patient to push against a wall with both hands.

Muscles acting across the shoulder joint

The muscles acting across the shoulder joint also fall into three groups: a group of large muscles that arise from the axial skeleton, a second group that arise from the shoulder girdle, and a third group of smaller muscles that arise from the scapula and act to stabilize and centre the humeral head in the concavity of the glenoid.

Muscles that arise from the axial skeleton to act across the shoulder joint are the sternal head of pectoralis major, pectoralis minor and latissimus dorsi. Muscles arising from the shoulder girdle are deltoid, the clavicular head of pectoralis major and coracobrachialis. The tendons of the group of
smaller muscles arising from the scapula are collectively known as the rotator cuff. This consists of supraspinatus, infraspinatus, teres minor and subscapularis, all of which are attached to the head of the humerus. Subscapularis is principally an internal rotator, whereas infraspinatus and teres minor are external rotators. Supraspinatus abducts the shoulder.

The subacromial space lies between the upper surface of the rotator cuff and the lower surface of the coracoacromial arch. It contains the subacromial bursa, which extends laterally under deltoid as the subdeltoid bursa. Their function is to allow the rotator cuff to move smoothly beneath the coracoacromial arch. If the inferior aspect of the coracoacromial arch becomes roughened, usually as a result of degeneration of the acromioclavicular joint, or if the rotator cuff is degenerate or injured, the subacromial bursa can become inflamed, causing an impingement syndrome. This results in a painful arc of movement on abduction of the shoulder at around 90°. Treatment is by the injection of local anaesthetic and depot steroid, which reduces the inflammation of the bursa but does not affect the underlying problem; if the condition is more severe, treatment is by subacromial decompression, removing the undersurface of the acromion and, if necessary, part of the distal end of the clavicle.

Muscles acting principally across the elbow joint

Muscles that act principally across the elbow are biceps and triceps, which flex and extend the elbow, respectively. The long heads of each of these also cross the glenohumeral joint and insert into the superior (biceps) and inferior (triceps) aspects of the glenoid neck. Consequently, the tendon of the long head of biceps is intra-articular. Brachialis lies deep to biceps and also flexes the elbow.

Biceps is a flexor of the elbow and a supinator of the forearm. Its arterial supply is highly variable but is mainly from branches of the brachial artery. It is innervated by the musculocutaneous nerve (C5/6).

Triceps forms most of the extensor compartment of the arm and is the principal extensor of the elbow joint. Its blood supply is mainly from the profunda brachii artery and the superior ulnar collateral artery. It is innervated by the radial nerve (C6/7/8), one branch supplying each of its three heads.

Muscles of the forearm
The muscles of the forearm occupy the anterior (flexor) compartments and the posterior (extensor) compartment. Both have superficial and deep compartments.

The superficial flexor compartment contains, from lateral to medial, pronator teres, flexor carpi radialis, palmaris longus and flexor carpi ulnaris, all of which lie superficial to flexor digitorum superficialis. They are principally supplied by the anterior ulnar recurrent artery and median nerve except for flexor carpi ulnaris, which is supplied by three branches of the ulnar artery and the ulnar nerve (C7/8/T1). Pronator teres pronates the forearm; flexors carpi radialis and ulnaris and palmaris longus flex the wrist; flexors carpi radialis and ulnaris also contribute to abduction and adduction of the wrist, respectively. Flexor digitorum superficialis flexes the wrist, the metacarpophalangeal and proximal interphalangeal joints.

The deep flexor compartment contains flexor digitorum profundus, flexor pollicis longus and pronator quadratus. Flexor digitorum profundus flexes the wrist, metacarpophalangeal and distal interphalangeal joints. It is supplied by branches of the ulnar or common interosseous artery. The nerve supply to the bellies of the little and ring finger is from the ulnar nerve, while the bellies of the middle and index finger are supplied by the anterior interosseous branch of the median nerve (C8/T1).

The superficial extensor compartment consists of anconeus, brachioradialis and the extensors of the wrist and fingers. Anconeus, brachioradialis and extensor carpi radialis longus are supplied by the radial nerve, while extensor carpi radialis brevis may be supplied by either the radial or the posterior interosseous nerve. Extensor digitorum, extensor digiti minimi and extensor carpi ulnaris are supplied by the posterior interosseous nerve.

The deep extensor compartment consists of supinator, the extensors of the thumb and index finger, and abductor pollicis. All are innervated by the posterior interosseous nerve.

Muscles that cross the wrist and intrinsic muscles of the hand

Muscles that cross the wrist joint to act on the thumb ray are flexor pollicis longus, abductor pollicis longus and extensors pollicis longus and brevis.

Flexion and extension of the fingers are carried out by the extrinsic flexors digitorum superficialis and profundus and extensor digitorum in conjunction with the intrinsic interosseous and lumbrical muscles. The intrinsic muscles
of the hand consist of those of the thenar eminence, which act on the thumb, the interossei and lumbricals, and the muscles of the hypothenar eminence, which act on the little finger. The palmar interossei adduct the index, ring and little fingers towards the middle finger, flex the metacarpophalangeal joints and extend the interphalangeal joints. The dorsal interossei abduct the same three fingers. The four lumbricals arise from the tendons of flexor digitorum profundus and insert into the extensor apparatus of the fingers. Their function is mainly to increase extension of the interphalangeal joints, thereby enabling pulp-to-pulp pinch.

The intrinsic muscles of the hand are supplied by branches of the superficial and deep palmar arches. Their nerve supply is mostly from the ulnar nerve, with the exception of abductor pollicis brevis, which is invariably innervated by the recurrent motor branch of the median nerve. It should be noted, however, that the superficial head of flexor pollicis brevis and opponens pollicis and the first, second and sometimes third lumbricals, are also supplied by branches of the median nerve.
Vascular supply and lymphatic drainage

**Arterial supply**

The arterial supply to the upper limb is from the subclavian artery: this arises from the brachiocephalic trunk on the right and the arch of the aorta on the left. The principal branches from its first part, which lies anteromedial to scalenus anterior, are the vertebral artery from its superior surface, the internal thoracic artery from its inferior surface, and the thyrocervical trunk from its anterior surface. It continues as the axillary artery at the lateral border of the first rib. It then passes deep to pectoralis minor, which divides it into three parts. At the inferior margin of teres major it continues as the brachial artery, which divides into the radial and ulnar arteries just distal to the elbow. The radial artery passes deep to brachioradialis from the neck of the radius to the wrist, where its pulsation may be palpated. It gives off the radial recurrent artery proximally and muscular branches throughout its course. The ulnar artery lies on the medial aspect of the arm between flexors digitorum superficialis and profundus. It lies lateral to the ulnar nerve at the wrist before entering the hand. It gives off the anterior and posterior ulnar recurrent arteries and the common interosseous artery, which in turn divides to form the anterior and posterior interosseous arteries (Fig. 36.1).
The anterior interosseous artery passes down the anterior surface of the interosseous membrane, accompanied by the anterior interosseous nerve. It pierces the interosseous membrane and anastomoses with the posterior interosseous artery before passing deep to the extensor retinaculum and joining the dorsal carpal arch. It gives off the median artery, which supplies the median nerve, muscular branches to the deep extensor muscles, and nutrient branches to the radius and ulna.

The posterior interosseous artery passes dorsally across the proximal border of the interosseous membrane, then passes distally between extensor carpi ulnaris and extensor digiti minimi to join the anterior interosseous artery. Its principal branch is the posterior interosseous recurrent artery. At the wrist there are anastomoses between the radial and ulnar arteries to form the dorsal and palmar carpal arches. In the hand, they anastomose once again to form deep and superficial palmar arches (Fig. 36.2).
The superficial palmar arch is mainly derived from the ulnar artery. It gives off three common palmar digital arteries, each of which is joined by a palmar metacarpal arterial branch from the deep palmar arch before dividing to form the palmar digital arteries. The palmar digital arteries to the thumb are variable in origin.

The deep palmar arch is formed by the anastomosis of the ends of the radial artery and the deep palmar branch of the ulnar artery. It gives off three palmar metacarpal arteries, which anastomose with the three common palmar digital arteries of the superficial arch.

**Venous drainage**

The veins of the upper limb are divided into superficial and deep groups by the deep fascia. In the deep group, venae comitantes accompanying the radial artery drain the deep venous arch of the hand, while those with the ulnar artery drain the superficial arch. They join at the level of the elbow to
form the paired brachial veins (Fig. 36.3).
FIG. 36.3 The veins of the upper limb. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016. Fig. 46.4.)
The superficial group start as an arch on the dorsum of the hand. On the radial border of the wrist this drains into the cephalic vein, which ascends the lateral aspect of the forearm and arm before draining into the axillary vein at the level of the coracoid process. On the ulnar side the dorsal arch drains into the basilic vein, which passes along the medial aspect of the forearm, crosses the elbow and joins the brachial veins to form the axillary vein. The basilic and cephalic veins are linked in the antecubital fossa by the median cubital vein.

The axillary vein continues as the subclavian vein at the outer border of the first rib. It passes in front of scalenus anterior and deep to sternocleidomastoid, and joins the internal jugular vein to form the brachiocephalic vein at the medial border of scalenus anterior. The main lymphatic vessels drain into the subclavian vein close to this point. The subclavian vein also drains the external jugular and dorsal scapular veins, and on occasion the anterior jugular vein.

**Lymphatic drainage**

The lymphatic drainage of the upper limb has superficial and deep elements. The superficial vessels arise in the dorsal and palmar cutaneous plexuses of the hand. The palmar plexuses drain to both sides of the wrist. On the radial side they are joined by vessels from the thumb and from there they run with the superficial veins of the forearm and the basilic vein of the arm and drain into the lateral axillary lymph nodes. The dorsal vessels pass around both sides of the forearm to join the ventral vessels.

The deep vessels run with the principal neurovascular bundles and also drain into the lateral axillary nodes.

Vessels from the deep cervical nodes form the jugular trunks. The left usually drains into the thoracic duct and the right directly into the subclavian vein close to its junction with the internal jugular vein (Ch. 3).
Innervation

The upper limb is supplied by the outflow of the anterior primary rami of C5–T1 with the exception of the skin of the shoulder, which is supplied by C4, and that of the upper medial part of the arm, which is supplied by T2.

Trapezius is supplied by the accessory nerve, although may receive contributions from branches of the cervical plexus in its middle and lower portions. It is vulnerable to injury during exploration of the posterior part of the supraclavicular triangle.

The brachial plexus is described in detail in Chapter 37. However, it has two significant branches from its roots: the dorsal scapular nerve, which arises from the root of C5, and the long thoracic nerve (to serratus anterior), which arises from the roots of C5/6/7. The dorsal scapular nerve innervates the rhomboid muscles and levator scapulae.

The principal terminal branches of the brachial plexus are the axillary, musculocutaneous, median, ulnar and radial nerves.

Axillary nerve

The axillary nerve (C5/6) is a branch of the posterior cord. It passes posteriorly through the quadrilateral tunnel of Velpeau, gives a branch to teres minor and supplies deltoid, usually by three separate branches. It also supplies the skin over deltoid in the ‘regimental badge’ area.

Musculocutaneous nerve

The musculocutaneous nerve (C5/6/7) arises from the lateral cord of the plexus, usually at the level of the third part of the axillary artery, and supplies motor branches to biceps and most of brachialis and coracobrachialis before continuing as the lateral cutaneous nerve of forearm.

Median nerve

The median nerve arises from a lateral head from the lateral cord of the brachial plexus (C6/7) and a medial head from the medial cord (C8/T1). The ‘M’ configuration of its origin lies over the anterior aspect of the third part of the axillary artery, where it can be easily identified at operation. It has no branches in the arm until just above the medial epicondyle at the elbow, where it gives off the nerve to pronator teres (C6/7). Distal to this are branches to flexor carpi radialis (C6/7), palmaris longus (C7/8) and flexor
digitorum superficialis (C7/8/T1). At the level of the proximal tendinous arch of flexor digitorum superficialis it gives off the anterior interosseous nerve, which then gives branches to flexor digitorum profundus (to the index and middle fingers), flexor pollicis longus and pronator quadratus (C7/8). The trunk of the median nerve runs in the midline of the anterior compartment of the forearm, gives off a palmar branch proximal to the wrist, then passes under the flexor retinaculum through the carpal tunnel and gives motor branches to abductor pollicis brevis, flexor pollicis brevis, opponens pollicis and the first two lumbrical muscles (T1). In the palm, it divides to give sensory digital nerves to the thumb, index, middle fingers and the radial aspect of the ring finger.

**Ulnar nerve**

The ulnar nerve (C7/8/T1) is the continuation of the medial cord. It passes distally with the neurovascular bundle of the arm, through the arcade of Struthers, behind the medial epicondyle and through the cubital tunnel into the forearm, where it is accompanied by the ulnar vessels on its lateral side. At the level of the wrist it divides into superficial and deep branches. The superficial branch is principally sensory and innervates the skin of the medial one and a half fingers. The deep branch innervates all the muscles of the hand except those supplied by the median nerve (C8/T1).

It gives motor branches to flexor carpi ulnaris (C7/8/T1) and flexor digitorum profundus (to the ring and little fingers) (C7/8), and a sensory branch – the medial cutaneous nerve of forearm.

**Radial nerve**

The radial nerve (C5/6/7/8/T1) is the terminal continuation of the posterior cord. After arising at the level of the base of the coracoid process it passes distally, winding round the posterior aspect of the humerus in the spiral groove and piercing the lateral intermuscular septum. In the arm it supplies all three heads of triceps through separate branches (C6/7/8). In the forearm it divides into the superficial radial nerve, which supplies dorsal sensation to the lateral three and a half digits of the hand, and the motor posterior interosseous nerve, which supplies all the muscles of the extensor compartment (C7/8).
Surface anatomy

All of the bones and joints of the shoulder girdle are palpable to some extent. The sternoclavicular joint is subcutaneous and palpable lateral to the suprasternal notch. Moving laterally, the clavicle is subcutaneous and both visible and palpable along its whole length. The acromioclavicular joint is palpable as a ridge running anteroposteriorly at the lateral end of the clavicle. The anterior, superior and lateral margins of the acromion itself can be palpated and may be visible. The whole of the spine of the scapula and its medial border down to the inferior angle distal to the spine are usually palpable. The inferior angle of the scapula is at the level of the seventh rib. Anteriorly, the coracoid process is palpable approximately 2.5 cm below the clavicle beneath the anterior fibres of deltoid.

The humerus is almost entirely surrounded by muscles: principally biceps brachii and brachialis anteriorly and triceps posteriorly. Proximally, the greater and lesser tubercles and the bicipital groove between them may be palpated deep to the muscles. In the mid portion of the arm distal to the insertion of deltoid, the humeral shaft can be palpated through brachialis just anterior to the lateral head of triceps. The radial nerve lies close to this point as it winds around the middle third of the humerus in the spiral groove. On the medial side, the neurovascular bundle, containing the brachial artery and basilic vein, the median and ulnar nerves, and the medial cutaneous nerve of forearm, is palpable in the groove behind the short (medial) head of biceps and coracobrachialis. The only truly subcutaneous portions of the humerus are parts of the medial and lateral epicondyles at the elbow. Of these, the medial epicondyle is the more prominent but its supracondylar ridge is less marked than that of the lateral epicondyle. The ulnar nerve can be rolled beneath the fingers behind the medial epicondyle.

The posterior border of the ulna is subcutaneous from the tip of the olecranon proximally to the ulnar styloid distally. The tip of the olecranon forms a triangle with the medial and lateral epicondyles when the elbow is flexed. The radius is covered by both flexor and extensor muscles and is barely palpable in its proximal half. Distally, the anterior, lateral and posterior surfaces become more clearly defined. The radial styloid process is easily palpable, as is Lister’s tubercle on the dorsal aspect of the distal radius. The pulsation of the radial artery is palpable between the tendon of flexor carpi radialis medially and the radial styloid laterally. The anatomical snuff-box lies on the lateral border of the wrist. It is bounded on its radial side by
the tendons of abductor pollicis longus and extensor pollicis brevis, and on
the ulnar side by the tendon of extensor pollicis longus. The superficial radial
nerve lies over the tendon of extensor pollicis longus, where it is vulnerable
to injury. The pulsation of the ulnar artery is usually palpable lateral to the
tendon of flexor carpi ulnaris. The ulnar nerve lies between the two at the
wrist.

The surface marking of the wrist joint is a convex line joining the tips of
the radial and ulnar styloid processes at the level of the proximal wrist
crease. The hook of the hamate, the tubercles of both scaphoid and
trapezium, and the pisiform are all palpable. These also act as points of
reference for the flexor retinaculum.

In the hand, all the bones and joints are palpable on their dorsal surface
but are relatively impalpable from the palmar aspect, being covered by the
paired flexor tendons.
Development of the upper limb: summary

The early limb bud develops through a series of tissue interactions between the lateral body wall surface ectoderm and underlying somatopleuric mesenchyme. An imaginary axial line defines the proximodistal axis of the limb bud, with preaxial and postaxial borders defined as cranial or caudal to the axial line. The length of the apical ectodermal ridge at the distal end of the limb bud is related to the number of cartilage elements developing within the limb; the proximity to the zone of polarizing activity specifies the most postaxial digit. Dorsal and ventral ectodermal surfaces give rise to the region-specific adult posterior and anterior epidermal structures. As the limb bud lengthens, the somatopleuric mesenchyme forms cartilaginous skeletal elements, joints and associated ligaments; it also generates signals for the organization of limb muscles, which arise from the dermomyotome of the somites and migrate into the limb as dorsal and ventral premuscle masses. Motor nerves enter the limb ahead of sensory nerves. The arteries arise from an axial artery and the veins from pre- and postaxial marginal tributaries. Embryonic and fetal movements are necessary for the normal development of limb tissue and the overlying skin.

The upper limb bud is visible as a lateral protrusion at stage 12 (30–32 days post fertilization). Development of this early shoulder region is complex because it overlaps with the development of the back, the head and neck, and the lowest pharyngeal arches. The lateral portion of the scapula is derived from somatopleuric mesenchyme, whereas the medial border and the attachments of the rhomboid muscles are derived from the dermomyotomes of the somites, producing hypaxial muscle populations. The muscles innervated by the accessory nerve are attached to the pectoral girdle via tendons, ligaments and connective tissue derived from neural crest mesenchyme.

By stage 14 (32–34 days post fertilization), the limb bud has a longer preaxial border and is directed caudally, level with the ventricles of the developing heart. Shoulder and upper arm regions can be identified externally at stage 15, and a hand plate can be seen. By stage 17 (39–41 days post fertilization), the elbow and forearm regions can be discerned and digital rays identified in the hand plate. The ventral aspect of the limb bud is flattened and the dorsal aspect bulges into the amniotic cavity. At stage 18 (42–44 days post fertilization), the ventral surface of the limb is opposite the surface ectoderm of the heart and both pre- and postaxial borders are of
comparable length. At stage 20 (47–50 days post fertilization), the shoulder, elbow and wrist regions are evident and the fingers are separating. The distal phalangeal portions of the fingers enlarge at stage 21 (50–52 days post fertilization), forming nail beds.

The main upper limb artery is derived from the lateral branch of the seventh intersegmental artery; it becomes the axillary and brachial arteries proximally, and continues distally as the anterior interosseous artery and deep palmar arch. The superficial veins of the arm are derived from the marginal vein running along the periphery of the extending limb bud beneath the pre- and postaxial limb borders; the preaxial vein is the cephalic vein and the postaxial vein becomes the basilic vein.
Further Reading


Single Best Answers

1. Which one of the following statements is correct?
   A. The wrist is a synovial hinge joint
   B. The proximal row of the carpus consists of the scaphoid, lunate and trapezoid bones
   C. The upper limb contains 32 bones
   D. The first metacarpophalangeal joint is a synovial joint that allows opposition of the thumb

   Answer: C.

2. Which one of the following structures is intracapsular?
   A. Supraglenoid tubercle
   B. Anular ligament of the elbow
   C. Lister's tubercle
   D. Ligament of Struthers

   Answer: A.

3. Which one of the following is not a muscle of scapular motion?
   A. Levator scapulae
   B. Rhomboid major
   C. Serratus anterior
   D. Sternal head of pectoralis major

   Answer: D.

4. Which one of the following is not contained in the deep flexor compartment of the forearm?
   A. Flexor digitorum profundus
   B. Pronator teres
C. Flexor pollicis longus
D. Pronator quadratus

Answer: B.

5. Which one of the following statements about the anterior interosseous artery is NOT correct?
A. It passes down the anterior surface of the interosseous membrane
B. It passes deep to the extensor retinaculum to join the palmar carpal arch
C. It anastomoses with the posterior interosseous artery
D. It supplies the median nerve

Answer: B.
Supraclavicular and infraclavicular regions

Alistair C Ross

Core Procedures

- Excision of a lump from the neck
- Exploration of the supraclavicular brachial plexus
- Excision of the first rib
- Exploration of the infraclavicular brachial plexus
- Anaesthetic nerve blocks
Surgical surface anatomy

The margins of the posterior triangle, the superior border of the clavicle, the lateral border of sternocleidomastoid and the anterior border of trapezius are all palpable. The upper trunk of the brachial plexus can usually be palpated in the scalene groove and in its anteroinferior course. The pulsation of the subclavian artery may be palpable in the inferomedial angle of the triangle. The various groups of lymph nodes are not usually palpable unless significantly enlarged. In the infraclavicular region, the deltopectoral groove is easily identified between the inferomedial border of deltoid and the superolateral border of pectoralis major.
Clinical anatomy

Posterior triangle of the neck

The posterior triangle of the neck is bounded by the middle third of the clavicle inferiorly, the posterior border of sternocleidomastoid anteromedially and the anterior border of trapezius posterolaterally. It is divided by the inferior belly of omohyoid into the occipital triangle superiorly and the supraclavicular triangle inferiorly. Its roof consists of skin, a zone of loose connective tissue containing platysma and the three supraclavicular nerves in its lower part, and the deep cervical fascia.

The floor of the occipital triangle is formed by splenius capitis, levator scapulae and scaleni medius and posterior. The floor of the supraclavicular triangle consists of the first rib and scaleni medius and anterior (see Fig. 15.1A).

The most significant structure in the occipital triangle is the accessory nerve, which emerges from sternocleidomastoid, crosses levator scapulae obliquely and enters the deep surface of trapezius, where it is vulnerable to damage when the mid portion of the posterior triangle is being explored. Other structures encountered include branches of the cervical plexus, the transverse cervical vessels and the more proximal elements of the brachial plexus.

The supraclavicular triangle contains the three trunks of the brachial plexus; the suprascapular nerve (which arises from the upper trunk); the subclavian artery; and the suprascapular vessels. The latter generally lie behind the clavicle and pass posterolaterally to join the suprascapular nerve in its path towards the suprascapular notch (Fig. 37.1). The subclavian vein does not usually appear in the triangle but may occasionally be encountered in its anteroinferior corner, where it lies in front of scalenus anterior.
FIG. 37.1 Vessels and nerves of the neck, left lateral view. The left sternocleidomastoid, the greater part of the infrahyoid group of muscles, numerous vessels and the medial part of the clavicle have all been removed in order to expose deeper structures. Compare with Fig. 15.3B, which shows a more superficial level of dissection. The letters V, VI, VII, VIII refer to the ventral primary rami of C5, C6, C7 and C8, respectively. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed. Elsevier, Urban & Fischer. Copyright 2013.)

Lymph nodes lie along the posterior border of sternocleidomastoid (jugular groups) and in the supraclavicular fossa (transverse cervical or supraclavicular group). Lymph nodes in the occipital triangle are present around the spinal accessory nerve (posterior triangle or spinal accessory group). Together they form the lateral cervical group. Consequently, an
enlarged lymph node can present almost anywhere in the posterior triangle. Virchow's node is the enlargement of a node in the left supraclavicular fossa, where the thoracic duct empties into the left subclavian vein. Classically, it is the result of metastasis from a gastric malignancy, although it may be caused by spread from other thoracic, intra-abdominal or pelvic tumours. Occasionally, it is due to lymphoma. Its enlargement is known as Troisier's sign. It can be distinguished from a reactive lymphadenitis by fine needle aspiration cytology.

**Brachial plexus**

The brachial plexus is formed by the ventral (anterior) primary rami of C5 to T1. The roots of C5 and C6 join to form the upper trunk. The upper trunk gives rise to the suprascapular nerve, which passes posterolaterally through the suprascapular notch to supply supraspinatus and infraspinatus. The root of C7 continues to become the middle trunk; the roots of C8 and T1 join to form the lower trunk. The upper trunk divides into its anterior and posterior divisions just above the clavicle. The middle and lower trunks divide deep to the clavicle. The anterior divisions of the upper and middle trunks join to form the lateral cord, which gives off the lateral pectoral nerve before dividing into the musculocutaneous nerve and the lateral head of the median nerve. The anterior division of the lower trunk forms the medial cord and may be supplemented by a branch from the anterior division of the middle trunk. The medial cord gives off the medial pectoral nerve, the medial cutaneous nerve of arm and medial cutaneous nerve of forearm before dividing into the medial head of the median nerve and the ulnar nerve. The posterior divisions join to form the posterior cord, branches of which are the superior and inferior subscapular nerves, the thoracodorsal nerve and the axillary nerve, before continuing as the radial nerve (**Fig. 37.2**).
Brachial plexus injuries

Injuries of the brachial plexus range from mild neurapraxia, through axonotmesis, neurotmesis and avulsion of the spinal nerve roots to total avulsion of the upper limb. The more severe the injury, the more likely is there to be concomitant arterial injury.

Brachial plexus injuries are classified as supraclavicular or infraclavicular, depending on the site of the lesion. They may affect all or part of the plexus. While they may be sustained at any point in life, they occur most commonly
at birth or in adulthood.

Obstetric injuries are usually the result of shoulder dystocia, when a shoulder becomes stuck at the level of the pelvic floor and the head continues to descend, whether naturally or after the application of forceps. They can be complete or partial.

Erb's palsy, an injury principally to the upper trunk (C5/6), results in a lack of abduction of the shoulder from paralysis of deltoid (axillary nerve) and supraspinatus (suprascapular nerve), internal (medial) rotation of the glenohumeral joint from paralysis or paresis of infraspinatus (suprascapular nerve), extension of the elbow joint from paralysis of the elbow flexors (musculocutaneous nerve), and flexion of the wrist from paralysis of the wrist extensors (posterior division of the upper trunk). The overall posture of the arm is referred to as the waiter's tip position.

Klumpke's palsy is an injury principally confined to the lower trunk (C8/T1). It paralyses the intrinsic muscles of the hand (ulnar nerve) and the flexors of the wrist and fingers (flexor carpi ulnaris and the ulnar half of flexor digitorum superficialis).

Adult brachial plexus injuries are usually the result of traction from a fall, often from a motorcycle, but can also be caused by inflammation (Spillane–Parsonage–Turner syndrome), tumour or radiation. Lesser injuries may be caused by contact sports. Occasionally, they may be the result of direct injury by knife or bullet.

Traction injuries are the result of forces that distract the neck and ipsilateral shoulder. The most severe cause avulsion of one or more nerve rootlets from the spinal cord; there may be associated injury to the subclavian or axillary artery. Currently, avulsion injuries cannot be repaired by primary means. Traction injuries to the supra- or infraclavicular plexus are classified in the same way as other nerve injuries into neurapraxia, axonotmesis or neurotmesis, depending on their severity. These should be investigated and treated early by those experienced in their care. The options for treatment depend on the severity of the injury and range from supervised observation through nerve grafting to secondary reconstruction by tendon transfer. Each of these has to be augmented by regular physiotherapy to prevent joint stiffness and contracture. In cases of avulsion, special measures may have to be taken to control pain.

**Surgical approaches to the posterior triangle of the neck**

This chapter will confine itself to dealing with the lower part of the posterior
triangle. In practical surgical terms, this means the supraclavicular triangle and the lower part of the occipital triangle up to the level of the accessory nerve. It contains most of the principal lymph nodes, which, when enlarged, can be investigated by fine needle aspiration or biopsy; it also contains neurovascular structures, which are subject to injury (brachial plexus injuries in adults and children), compression (thoracic outlet syndrome/cervical rib) and tumour. It is also a region subjected to a variety of anaesthetic blocks.

Although the posterior triangle can be exposed through an incision that follows the posterior border of sternocleidomastoid and then turns laterally just above the clavicle, the most frequently used approach is a simple supraclavicular incision sited a finger's breadth (2 cm) above the clavicle (Fig. 37.3). Superior and inferior flaps containing loose connective tissue and platysma are then reflected, taking care to preserve the supraclavicular nerves beneath. The lateral 2–3 cm of the clavicular head of sternocleidomastoid may then be released and retracted. The next structure to be identified is the inferior belly of omohyoid (Fig. 37.4). This can, on occasion, be retracted inferiorly far enough to gain access; if this is not possible, it is divided between stay sutures. The ends must be reapproximated at the end of the procedure.

**FIG. 37.3** The transverse supraclavicular approach to the inferior portion of the right posterior triangle.
The skin, superficial fascia and platysma incised and reflected as composite superior and inferior flaps. The inferior belly of omohyoid (white arrow) lies transversely over a fat pad that covers the trunks of the brachial plexus and subclavian artery. The clavicular head of sternocleidomastoid has been reflected medially and the middle supraclavicular nerve retracted laterally.

The levels deeper than this are not for the inexperienced surgeon. Beneath omohyoid there is a fat pad, within which lie the transverse cervical artery and vein. The level at which they occur varies somewhat, as does the size of the vessels. They almost always require ligation and division. Immediately deep to the fat pad are the upper trunk of the brachial plexus and suprascapular nerve. Once identified, they are marked with coloured vascular sloops. Gentle traction on the upper trunk will serially reveal the middle and lower trunks. Once again, these are marked with vascular sloops of different colours (Fig. 37.5). Deep to the lower trunk lies the first rib, covered by the insertion of scalenus medius. Lying immediately in front of it on the first rib is the subclavian artery. This emerges from behind the insertion of scalenus anterior and passes over the first rib to become the axillary artery at its outer margin. It is important not to overlook the suprapleural membrane (Sibson's fascia) and the dome of the pleura lying in the concavity of the first rib. Damage to these will cause a pneumothorax. Fortunately, this can usually be treated by introducing a suction drain at the end of the procedure, provided it has been recognized. In cases of doubt, irrigation of the wound and positive pressure ventilation by the anaesthetist will produce a flow of bubbles if a pneumothorax is present. An early postoperative chest X-ray should be obtained in any event. The lymph nodes of the supraclavicular group are not usually apparent unless enlarged.
FIG. 37.5  The supraclavicular brachial plexus dissected. It usually emerges through the scalene triangle behind scalenus anterior and in front of scalenus medius. In this case, the roots of C5 (yellow sloop) and C6 (upper blue sloop) pierce scalenus anterior. The phrenic nerve (white arrow) is seen to lie on the anterior surface of scalenus anterior. The white sloop surrounds the middle trunk, and the red sloop the lower trunk of the brachial plexus. The lower blue sloop is controlling the subclavian artery. The tip of the left retractor rests on the mid portion of the first rib, where it is covered by the distalmost insertion of scalenus medius. The subclavian vein is not visible.

This approach allows repair of the injured supraclavicular brachial plexus, as long as it has not retracted beneath the clavicle, as can occur after a traction injury, excision of anomalous ribs and bands, and excision of the first rib for thoracic outlet syndrome. Just as importantly, it allows surgeons who are excising a deeply placed lump in the neck – often a pathological lymph node – to be certain that they are not causing inadvertent damage to the major neurovascular structures. A short incision placed immediately over a lump that is being biopsied or excised runs the risk of inadequate exposure of the major neurovascular structures, particularly if the lump proves to be more deeply situated than anticipated.
Excision of the first rib

While the first rib can be excised through the axilla (the Roos approach), there is potential for damage to the intercostobrachial nerve(s), which lie(s) directly in the path of the approach: this leads some surgeons to prefer a supraclavicular approach, as injury to the intercostobrachial nerve can cause variable numbness on the lateral side of the chest, breast, axilla and arm, which is a particular problem for women.

The approach to the first rib requires considerable care but is essentially identical to that needed for exploration of the brachial plexus. Having identified the trunks of the brachial plexus and applied vascular sloops as described earlier, it is necessary to mobilize the subclavian artery. The structures lying on the upper surface of the first rib from its anterior to posterior aspects are subclavius; the subclavian vein; the tendinous insertion of scalenus anterior, which arises from the scalene tubercle; the subclavian artery and lower trunk of the brachial plexus, which lie in the scalene groove; the insertion of scalenus medius; and, on the neck of the rib, the stellate ganglion. On its medial border is the suprapleural membrane; the first digitation of serratus anterior is attached to the lateral border, which is covered posteriorly by scalenus posterior in its path to the second rib.

Depending on the specific underlying problem, collectively referred to as thoracic outlet syndrome but in practice resulting from a variety of different conditions, the first rib may be removed in part or in its entirety. Clearly, given its relations, the most posterior and most anterior portions of the rib are the most problematic. In each case, however, the structures attached to each of the surfaces need to be detached under direct vision using meticulous sharp dissection and a fine periosteal elevator. The anterior rib cut is best made using a 2 mm right-angled Kerrison rongeur. Posteriorly, once mobile, the rib may either be divided well away from the neurovascular structures, or be gently rocked and avulsed from its articular facets. Care must be taken throughout not to cause a pneumothorax or place excessive traction on the trunks of the plexus.

Anaesthetic nerve blocks

Regional anaesthesia is widely used for surgery of the upper limb, usually with the assistance of an ultrasound probe or a nerve stimulator. Only two areas of the upper limb are not innervated by the brachial plexus. One is the skin over the shoulder, which is supplied by cutaneous branches of the cervical plexus, and the other is the posteromedial aspect of the arm, which is
supplied by the intercostobrachial nerve. There are two principal nerve blocks for which a thorough understanding of the anatomy of the supraclavicular plexus is needed: the interscalene block and the supraclavicular block.

The interscalene block, which blocks the roots, is preferred for surgery of the shoulder and upper arm. The patient's head is turned to the side away from the site of the proposed block, thereby bringing sternocleidomastoid into relief. Local anaesthetic is introduced within the prevertebral fascia over the roots of the brachial plexus at the level of the interscalene groove between scalenus anterior and scalenus medius. The surface markings for this are the posterior border of sternocleidomastoid and the cricoid cartilage, which lies at the level of the sixth cervical vertebra. The external jugular vein has been used but is unreliable because its position is somewhat variable; if the vein is encountered, injection should be posterior to it. If a nerve stimulator is used, muscle twitch should be seen in deltoid, biceps or triceps. If muscles distal to the elbow are stimulated, the position of the needle is too distal. Similarly, if the diaphragm is stimulated, the needle is too medial; if trapezius contracts, it is too posterior. Because the roots of C8 and T1 are relatively distant from the site of injection, it usually fails to block the distribution of the ulnar nerve. The site of injection is also close to the stellate ganglion, which lies on the neck of the first rib, and the phrenic nerve on the anterior aspect of scalenus anterior. Consequently, either of these can be temporarily blocked, resulting in a Horner's syndrome in the case of the stellate ganglion, or a hemidiaphragmatic palsy if the phrenic nerve is involved.

The supraclavicular block anaesthetizes the trunks and proximal divisions of the plexus, and is used when the whole arm needs to be anaesthetized. The most common technique is the subclavian perivascular approach. The interscalene groove is identified by palpation and followed distally until the pulsation of the subclavian artery is identified. The trunks of the plexus lie just behind the artery within the fascial sheath. The needle should point inferolaterally as the suprapleural membrane and the apex of the lung lie medially in the concavity of the first rib. This block is highly effective but traditionally associated with a higher risk of pneumothorax.

**Infraclavicular region**

For the purposes of this chapter, the infraclavicular region will be defined as
the deltopectoral triangle (infraclavicular fossa) and its contents, and its extension as the deltopectoral groove and its contents.

The deltopectoral triangle is bounded by the clavicle superiorly, the anterior border of deltoid laterally and the lateral border of the clavicular head of pectoralis major medially. The deltopectoral groove is the apical continuation of this triangle between the borders of pectoralis major and deltoid.

Lying superficially in the fossa is the clavipectoral fascia, which takes origin from the clavicle, splits to enclose subclavius, passes distally to surround pectoralis minor and continues as the suspensory ligament of the axilla. The cephalic vein and lymphatics from the arm pass through the clavipectoral fascia from without to within, while the thoracoacromial vessels and lateral pectoral nerve pass from within to without. The thoracoacromial artery has four main branches, which often pierce the fascia separately, while the thoracoacromial veins drain to the cephalic vein before it pierces the fascia.

Deep to the clavipectoral fascia and pectoralis minor lies the axillary artery, surrounded by the infraclavicular brachial plexus; the axillary vein lies on its medial side. Anatomically, the axillary artery is divided into three parts by pectoralis minor. The first part, which lies above its upper border, is surrounded by the divisions of the brachial plexus, which only take their nominated positions – medial, lateral and posterior to the second part of the artery – deep to pectoralis minor. The third part, which lies distal to the posterolateral border of pectoralis minor, is characterized by the formation of the median nerve from its lateral and medial heads, which form an ‘M’ on the anterior aspect of the artery.

The distribution of branches of the axillary artery is easy to remember. There is one branch from the first part – the superior thoracic artery; two from the second part – the thoracoacromial and lateral thoracic arteries; and three from the third part – the subscapular, anterior and posterior circumflex humeral arteries. Those arising from the third part are particularly vulnerable to injury during open surgery of the shoulder, as they arise at the level of the distal border of subscapularis. The axillary artery as a whole can sustain damage ranging from intimal tears to complete rupture as a result of a traction lesion of the infraclavicular plexus.

**Surgical approach to the infraclavicular region**
The infraclavicular brachial plexus and axillary artery are approached
through an incision that lies directly over the deltopectoral triangle and groove (Fig. 37.6). If this forms an extension of an exploration of the supraclavicular brachial plexus, the infraclavicular limb usually starts at the junction of the middle and distal thirds of the supraclavicular incision and is carried distally as far as necessary. If essential, the clavicle may be divided but this is usually unnecessary, as the retroclavicular structures can be seen by elevating the clavicle with a stout circumferential tape. Dividing the clavicle requires it to be plated at the end of the procedure; subsequent non-union is not unknown.

The first significant structure to be encountered is the cephalic vein. This is best not ligated and divided, but rather should be preserved by retracting it medially or laterally. It has a number of feeder vessels from both directions but more drain from the lateral side. There are also more branches in the proximal half of the incision than in the distal half.¹ Consequently, in most patients, it would seem advisable to retract the cephalic vein laterally, having tied off or coagulated the medial vessels.

Dissection between the borders of deltoid and pectoralis major reveals the clavipectoral fascia. The coracoid process is next identified, as are, if necessary, the conjoined tendons of the short head of biceps and coracobrachialis. When the shoulder joint is approached through this
incision, the coracoclavicular portion of the clavipectoral fascia is incised along the medial border of the conjoined tendon. However, to approach the infraclavicular brachial plexus and axillary artery, the incision in the fascia is more medial. Pectoralis minor is the key to this approach. This takes origin from the upper margins and outer surfaces of the third, fourth and fifth ribs, and passes superolaterally across the neurovascular bundle to its insertion on the medial border and convex superior surface of the coracoid process, where it can easily be identified intraoperatively. Given that the clavipectoral fascia splits around pectoralis minor, and that the axillary artery is usually palpable, incision of the fascia medial and lateral to the muscle, once pectoralis minor has been identified, will reveal the first and third parts of the axillary artery, surrounded respectively by the divisions and terminal branches of the brachial plexus (Fig. 37.7).

**FIG. 37.7** The infraclavicular brachial plexus and axillary artery dissected. The musculotendinous portion of pectoralis minor crosses the axillary artery, dividing it into three parts that are proximal (red sloop), posterior and distal to the muscle. The yellow sloop passes around elements of the upper trunk, i.e. the suprascapular nerve and the anterior and posterior divisions. The blue sloop passes around the division of the lateral cord into the musculocutaneous nerve and lateral head of the median nerve. The white sloop shows the lateral cord of the brachial plexus. The pale blue backing material lying on the distal portion of the axillary artery highlights the characteristic 'M'-shape formed by, from lateral to medial, the musculocutaneous nerve, lateral head of median nerve, medial head of median nerve and ulnar nerve; the latter two arise from the medial cord. The posterior cord lies behind the artery.
**Tips and Anatomical Hazards**

Three major problems can occur when trying to excise a lump from the neck:

- Inadvertent damage, usually to the upper trunk of the brachial plexus and/or suprascapular nerve.
- Damage to the spinal accessory nerve when excising a lymph node from the adjacent group.
- Inadvertent biopsy or excision of an intrinsic tumour (schwannoma or neurofibroma) from one of the trunks of the brachial plexus without realizing that it is an intrinsic tumour and not a lymph node.

Litigation after such an adverse event is difficult to defend.
Reference

**Further Reading**


Single Best Answers

1. Which one of the following statements about the accessory nerve is true?
   A. It crosses the supraclavicular triangle
   B. It is surrounded by lymph nodes
   C. It enters trapezius from its outer surface
   D. It supplies a motor branch to the shoulder joint

   **Answer: B.**

2. Which of the following structures is NOT included in the normal lateral cervical group of lymph nodes?
   A. Jugular group of nodes
   B. Transverse cervical/supraclavicular group of nodes
   C. Posterior triangle group of nodes
   D. Virchow's node

   **Answer: D.**

3. Which one of the following statements about the brachial plexus is true?
   A. It is formed by the ventral (anterior) primary rami of C5 to T1
   B. It gives rise to all elements of the phrenic nerve
   C. It divides into cords from the three major trunks
   D. It innervates the skin over the shoulder

   **Answer: A.**

4. Which one of the following structures crosses, or is attached to, the body of the first rib?
   A. Subclavian vein
B. Scalenus medius
C. Stellate ganglion
D. Subclavius

**Answer:** C.

5. Which one of the following vessels is a branch of the second part of the axillary artery?
   A. Subscapular artery
   B. Anterior circumflex humeral artery
   C. Lateral thoracic artery
   D. Posterior circumflex humeral artery

**Answer:** C.
Clinical Cases

1. A 19-year-old male presents in the accident and emergency department, having fallen off his motorcycle at 50 mph. He has a flail insensate dominant right arm with fractures of the ipsilateral clavicle and avulsion of the transverse process of C7.

   A. Describe the possible types and sites of injury.
   The clinical signs and symptoms suggest a severe injury to the right brachial plexus. It may be an avulsion injury or a severe supra- or infraclavicular traction injury.

   B. Describe the optimal management of the patient.
   Provided the patient is clinically stable and other injuries do not take precedence, early exploration of the brachial plexus, with a view either to establishing an essentially untreatable injury or to effecting its repair, gives the best chance of recovery and an early opportunity to plan for the patient's subsequent management.

2. A 58-year-old female has had a 'lymph node' removed from the left supraclavicular fossa. Postoperatively, she complains of weakness of elbow flexion and has numbness over the lateral border of the arm and forearm, and the thumb and index finger of the left hand.

   A. What structures may have been injured and how should the patient be managed?
   The most likely injury is to the upper trunk of the brachial plexus. This may be a simple neurapraxia or the damage may be more severe, up to and including division of the trunk. The brachial plexus should be explored by a surgeon experienced in the management of brachial plexus injuries. If the injury proves to be a neurapraxia, the wound may simply be closed and the patient advised that a full recovery is likely. An axonotmesis will take many months to recover, and recovery may not be complete. Complete division of the upper trunk will require nerve grafting.
# Axilla

**John T Vetto**

## Core Procedures

- Axillary dissection
- Sentinel node biopsy
- Axillary reverse mapping (ARM) procedure
- Removal of tail of Spence during total mastectomy

The lymph of the upper limb, most of the breast, and the skin of the trunk above the umbilicus (that is, above Sappey's line\(^1\)) drains ultimately into the axillary nodes, making a knowledge of the anatomy of the axillary region essential for general and oncological surgeons.\(^2\) Although some would argue that the ongoing reduction in the extent of classical axillary operations, often stemming from recent clinical trials that show no survival benefit from more extensive nodal operations for cancer,\(^3\)\(^–\)\(^5\) may make such knowledge less important, the opposite might also be true. The expansion of sentinel node biopsy for melanoma in thinner and thicker tumours\(^6\)\(^,\)\(^7\) and the need to perform this operation with limited exposure, as well as the very real risks of sentinel node biopsy (stemming mostly from damage to the nerves and lymph vessels),\(^8\) reflect the importance of a sound knowledge of axillary anatomy. Furthermore, an increasing focus on the reduction of postoperative arm lymphoedema\(^9\) has led to the development of operations such as the axillary reverse mapping (ARM) procedure,\(^10\) which actually needs a detailed knowledge of nodal drainage patterns through the axilla.
Surgical surface anatomy

The anterior axillary fold is formed mostly by pectoralis major, and the posterior fold mostly by latissimus dorsi; the space between is the axillary fossa. With the arm abducted, the short head of biceps brachii can usually be seen anteriorly; coracobrachialis is posterior. The axillary artery extends from the midpoint of the clavicle to the medial margin of biceps brachii opposite the posterior fold. In thinner individuals, the axillary pulse can be felt along the extent of the artery. The brachial plexus is often palpable in the neck, and the cords may be palpable around the axillary artery. The axillary nerve lies in a horizontal line through the middle of deltoid.
Clinical anatomy

The axilla is located inferior to the glenohumeral joint at the junction of the arm and chest, and acts as a passage for neurovascular and lymphatic structures to enter and exit the arm and upper chest. It is pyramidal in shape. The apex (axillary inlet) is the upper end of the axilla and continues into the root of the neck (posterior triangle, or level 5, of the neck) through the bony cervico-axillary canal formed by the lateral border of the first rib, the superior border of the clavicle and the posterior border of the scapula. The axilla is bounded laterally by the humerus, coracobrachialis and biceps brachii; medially by four or five ribs covered by the intercostal muscles and serratus anterior; anteriorly by pectoralis major, pectoralis minor and subclavius; posteriorly by subscapularis and teres major; and posterolaterally by latissimus dorsi (Fig. 38.1). The base of the pyramid is essentially open and is formed by the skin and soft tissue of the chest wall, and the anterior and posterior axillary folds.
The main contents of the axilla are the axillary artery and vein; axillary lymph nodes; the brachial plexus; and biceps brachii and coracobrachialis (the muscles travel through the axilla to attach to the coracoid process of the scapula) (Fig. 38.2). Most key contents enter or exit the axilla through the apex. The axillary nerve and posterior circumflex humeral artery (a branch of
the axillary artery) enter through the quadrangular space, a gap in the posterior wall of the axilla. The cephalic vein enters the axilla, and the medial and lateral pectoral nerves leave it, through the clavipectoral triangle formed by pectoralis major, deltoid and the clavicle (Fig. 38.3).
FIG. 38.2 The axilla, anterior view. (From F. Netter, Atlas of Human Anatomy, seventh ed. © Elsevier, 2018, Plate 419.)
The axillary artery begins at the lateral border of the first rib as a continuation of the subclavian artery and ends at the lower border of teres major, where it becomes the brachial artery. The artery is enclosed by the cords of the brachial plexus in the axillary sheath, a connective tissue sheath that is continuous cephalad with the prevertebral fascia. Pectoralis minor crosses anterior to the axillary artery, dividing it into three parts that are proximal, posterior and distal, respectively, to the muscle. The first part of the axillary artery is bounded anteriorly by pectoralis major, posteriorly by the long thoracic nerve, laterally (superiorly) by the three cords of the brachial plexus, and medially (inferiorly) by the axillary vein. The second part of the axillary artery is bounded anteriorly by pectoralis major and minor, posteriorly by the posterior cord of the brachial plexus and subscapularis, laterally (superiorly) by the lateral cord of the brachial plexus, and medially (inferiorly) by the medial cord of the brachial plexus and the axillary vein. The third part of the axillary artery is bounded anteriorly by pectoralis major and distally by the medial head of the median nerve, posteriorly by subscapularis, latissimus dorsi and teres major, laterally by coracobrachialis, biceps brachii and the humerus, and medially by the ulnar nerve, axillary vein and the medial cutaneous nerve of the arm. The ulnar, radial and medial nerves typically lie around the third part of the artery in a triangle (ulnar at
1–2 o'clock, radial at 5–6 o'clock and median at 11–10 o'clock). The axillary vein is the continuation of the basilic vein; it runs proximally on the medial (inferior) side of the axillary artery and ends at the lateral border of the first rib, where it becomes the subclavian vein. The major tributaries of the vein are similar to those of the artery, the most important being the superior thoracic, lateral thoracic and thoracodorsal veins and the thoraco-acromial trunk.

**Lymphatic drainage: axillary node anatomy**

The lymph nodes of the axilla drain the chest, breast and arm; knowledge of their anatomy is critical for surgeons operating in this area in order to stage disease properly, remove nodes safely and minimize postoperative morbidity.

The axillary nodes are arbitrarily divided into five groups. The lateral nodes lie behind the axillary vein laterally and drain the upper limb. The pectoral nodes lie along the lateral thoracic veins and the lower border of pectoralis minor, and primarily drain the breast. The posterior or subscapular nodes lie along the subscapular vein at the lateral border of the scapula, where they sit anterior to subscapularis and primarily drain the posterior shoulder. The central nodes lie near the base of the axilla and drain the first three groups of nodes; they are the ‘lowest’ nodes in the axilla and the easiest nodes to palpate. The apical nodes lie medial to the axillary vein and the upper border of pectoralis minor behind the clavipectoral fascia (Fig. 38.4). They receive lymph from all the other groups, and drain via two or three subclavian lymph trunks into the confluence of the jugular and subclavian veins. These trunks may or may not first fuse into a common lymphatic duct. The apical nodes lie along the chest wall around the thoracic inlet and below subclavius (Halsted's ligament).
The lateral and central groups of nodes each contain 10–14 nodes. The other groups each consist of 1–7 nodes. A complete axillary node dissection may therefore contain anywhere from 23 to 59 nodes. The node count may actually be higher in some cases, such as patients with low-grade lymphomas in whom normal, tiny, rudimentary nodes not seen in most people become pathologically enlarged.

For the purpose of surgical dissection, the five groups of nodes are usually consolidated into three ‘levels’, based on their relation to pectoralis minor (see Fig. 38.4). Level 1 nodes are lateral to the inferolateral border of pectoralis minor and include the lateral and posterior nodes and some pectoral nodes. Level 2 nodes are posterior to pectoralis minor and include the central nodes and some pectoral nodes. Level 3 nodes are medial to the medial border of pectoralis minor and are mainly apical nodes.

Removal of level 1 nodes (‘one-level node dissection’) can cause arm, shoulder and chest swelling, which can worsen if level 2 nodes are also removed (‘two-level node dissection’). Lymphoedema rates are highest when level 3 nodes are also removed (‘three-level node dissection’ or ‘complete axillary dissection’) because removal of the apical nodes disrupts the jugular–subclavian lymph trunk and greatly obviates any benefit from collateral lymph channel development that may occur after one- or two-level node dissection. Not surprisingly, the almost routine appearance of arm
lymphoedema from three-level node dissection can be lowered to 3–10% by limiting nodal dissection to levels 1 and 2. Conversely, the addition of radiation to any level of node dissection increases the risk of lymphoedema fivefold. Axillary web syndrome (lymphatic cording), where a rope-like soft-tissue density develops in the axilla, presenting as a tight band of tissue in the axilla on shoulder abduction, may occur following sentinel lymph node biopsy or axillary lymph node dissection.

**Anomalies and variants**

Congenital anomalies of the axilla are very common. The axillary vein, which is formed by the union of the paired brachial veins and the basilic vein, may appear to be bifid in the axilla if these structures enter high. Sollazzo et al found an 18% incidence of venous anomalies in the axilla, most commonly a bifid axillary vein in 10% of patients and an angular vein, which is a large branch of the subscapular vein that runs along the chest wall with the long thoracic nerve, in 5% of patients. The axillary artery can also be bifid if it bifurcates in the axilla (seen in 5–10% of patients).

Nerve anomalies mostly involve the intercostobrachial nerves and probably arise during the fifth week of gestation; they are highly variable and very common. The lateral cutaneous branch of the second intercostal nerve pierces serratus anterior, crosses the axilla to the medial side of the arm and joins the medial cutaneous nerve of the arm (medial brachial cutaneous nerve), which supplies sensation to the medial and posterior portions of the upper arm. Although considered to be a single nerve, the intercostobrachial nerve often divides into two or more branches as it crosses the axillary space. The third intercostal nerve frequently gives off a lateral cutaneous branch. As a consequence of splitting of the intercostobrachial nerve, the possibility of another nerve arising from the third intercostal nerve and/or a prominent medial brachial cutaneous nerve, a surgeon dissecting the axilla may therefore expect to encounter anywhere from one to four cutaneous nerves; the branches of cutaneous nerves crossing the axilla should not be expected to be consistent from one patient to another.

Anomalies of the lymph vessels and muscles of the axilla are also well recognized. Lymphangiommas of the axilla can occur in utero and may be one cause of stillbirth; these benign tumours can grow quite large, can cause bleeding in utero and are usually associated with a normal karyotype. They can now be recognized in utero by ultrasound and treated. The most common
muscular anomaly is an axillary arch, a functionally insignificant extension of muscle most often lying between latissimus dorsi and pectoralis major, which occurs in 7–27% of the population and has multiple subvariants, depending on where the muscle is attached. This has implications for axillary dissection: if the arch is mistaken for latissimus dorsi, the operating surgeon may dissect the axilla too laterally, leaving level 1 tissue and possibly injuring the axillary artery or the brachial plexus. Surgeons who carry out axillary dissection need to be able to recognize the presence of an axillary arch and simply divide it.18
Surgical approaches and considerations

Axillary dissection

A two-level node dissection is standard for the clearance of macroscopic nodal metastases. Three-level dissection is less indicated today except in those rare instances of gross involvement of the level 3 nodes.

The patient is placed supine with the arm extended on an arm board. The arm should be secured to the board with towels and tape. The author does not generally place a sandbag under the shoulder, to avoid traction on the plexus. Similarly, the author avoids circumferentially prepping the arm, which reduces the risk of pulling up on the arm and stretching the plexus. The arm is prepped free only if there is particularly bulky disease and/or if removal of pectoralis minor is planned. The patient is usually not paralysed, so that nerves may be identified. After wide sterile prepping and draping of the axilla, upper chest and shoulder, the operation is carried out in nine main steps.

Raising flaps

An incision is made from the posterior edge of pectoralis major to the anterior edge of latissimus dorsi, two fingers’ breadths below the axillary crease, staying below the hairline if possible. Using Senn (catspaw) retractors and diathermy, flaps are raised cephalad to the axillary crease and caudally to the chest wall, thickening the flaps as they are made.

Exposure of level 1 nodes

Goulet retractors are placed anteriorly to dissect the flaps with diathermy over the lateral edge of pectoralis minor. The retractors are then placed laterally and diathermy is used to dissect out the anterior edge of latissimus dorsi. By staying on the edge of the muscle (and not dissecting medial to it), injury to the thoracodorsal structures is avoided. This step exposes the level 1 nodes (lateral and posterior nodes).

Exposure of level 2 nodes

Tissue overlying the lateral aspect of pectoralis major is grasped with Allis soft tissue forceps and peeled off in a medial to lateral direction to expose pectoralis minor. The fascia lying laterally is opened, taking care to identify and preserve the medial pectoral neurovascular bundle. This spares
pectoralis minor, allowing it to be retracted against the chest wall, thereby exposing the level 2 (mostly pectoral and central) lymph nodes. The surgeon may choose to start this step by excising the fascia lateral to pectoralis minor if removal of the interpectoral (Rotter's) nodes is not necessary.

**Identifying the long thoracic nerve**

The fascia attaching the level 2 nodes to serratus anterior is then sharply excised. By inserting two fingers between serratus anterior and the nodes, the surgeon can, by blunt dissection, open the plane all the way down to the long thoracic nerve. Care should be taken to stay superficial to serratus anterior; opening this fascia risks nerve injury and causes unnecessary bleeding. A Goulet retractor can be used to retract the nodes laterally, ‘opening up’ the plane and identifying the nerve inferiorly. The author does not feel against the chest wall for the nerve, as it is often running with the lymph node packet. Once the nerve is seen, lateral attachments holding it to the nodes can be excised sharply with dissecting scissors and the nerve pushed back on to the chest wall along the length of the nerve. The nerve can be gently squeezed with DeBakey forceps to see that serratus anterior contracts. This nerve is small and fatigues easily, so handling and squeezing the nerve must be kept to a minimum.

The plane just described between serratus anterior and level 2 nodes does not have a name; the author calls it the ‘plane of Morton’ in memory of Donald Morton M.D., who taught his students this manoeuvre.

**Identifying the axillary vein**

Starting laterally, the anteroinferior border of the axillary vein is exposed and dissected in a lateral to medial direction toward pectoralis minor.

**Identifying the thoracodorsal nerve**

Branches of the axillary vein coursing from its inferior aspect into the nodes are divided between clips and ties. These branches are often referred to as ‘fooler veins’ because they fool the novice surgeon into thinking they are the thoracodorsal vein. That vein courses straight down towards subscapularis from the posterior aspect of the axillary vein and usually runs with the thoracodorsal artery. The ‘fooler’ veins are usually more superficial and are not paired with arteries. To be safe, larger ‘fooler’ veins can be left intact until the thoracodorsal vein has been identified, at which point they can be
ligated. After ligation of the ‘fooler’ veins and identification of the thoracodorsal vascular structures, the thoracodorsal nerve can usually be identified: it lies medial to the vascular structures, in about the same plane as the long thoracic nerve, but is larger than that nerve. A gentle squeeze with DeBakey forceps results in contraction of latissimus dorsi.

**Removal of level 2 nodes**

The level 2 nodes are now visible between the two motor nerves. Starting below the medial aspect of the axillary vein, the highest level 2 nodes are detached with clips and ties, working in an anterior to posterior direction, until the fascia of subscapularis is reached. At this point, the nodes can be peeled in a cephalad to caudal direction off the subscapularis fascia, staying outside the fascia at all times to avoid undue bleeding. This allows the surgeon to pull the specimen laterally and out of the incision, a manoeuvre facilitated by detaching the specimen inferomedially off serratus anterior, staying away from the long thoracic nerve. These inferior attachments contain multiple small vessels and at least 1–2 branches of the lower intercostobrachial nerves, which must be divided between clips and ties to avoid bleeding and neuromas. The intercostobrachial nerves are easily identified because they run superficial to the motor nerves, are often larger, and do not cause muscle contraction when squeezed. Cephalad or caudal branches of the intercostobrachial nerve can often be spared.

**Removal of the specimen**

At this point the specimen can be mobilized laterally out the wound and dissected in a medial to lateral direction sharply and bluntly off the thoracodorsal nerve, dissecting until the nerve enters latissimus dorsi. Often there are small branches of the thoracodorsal neurovascular bundle that require clipping. With gentle sharp and blunt dissection, the lateral nodes lying between the undersurface of the axillary vein and the thoracodorsal nerve can be swept with the specimen. For primary tumours that are not in the arm, these lateral nodes can be at least partially spared, further limiting the risk of lymphoedema.

Once the specimen is completely free of the thoracodorsal nerve, it can finally be detached from the previously identified anterior border of latissimus dorsi.19
Closure

The wound is irrigated, inspected for haemostasis, injected with local anaesthetic, and closed over a single closed suction drain in layers with absorbable sutures. No dressing or compression is needed. The author does not find it necessary to limit activity or advise physiotherapy.

Sentinel node biopsy

Sentinel lymph node biopsy (SNLB) (Fig. 38.5) is currently indicated for breast cancer and tumours of the arm and trunk that may drain into the axilla, including melanoma, Merkel cell carcinomas and some high-risk squamous cell cancers. Generally, both lymphazurin blue (patent blue, isosulfan blue) and a fat-soluble protein that is tagged to a gamma emitter, such as technetium-sulphur colloid, are injected to identify the SLN (dual dye technique). The radioactive dye is given first, usually with immediate planar lymphoscintigraphy using a gamma camera, or single-photon emission computed tomography (SPECT) to locate the area of uptake.

The patient is then taken to theatre, usually within a few hours (to avoid excessive decay of the radioisotope, which has a half-life of 6 hours and is 95% decayed in 24 hours), and is anaesthetised; the blue dye is injected just
before prepping the patient. The blue dye is usually visible at the surgical site within 10 minutes. The SLNs are defined as any ‘hot’, ‘blue’ or ‘hot and blue’ nodes detected and are removed through a small incision placed in line with a future completion node dissection (for example, two fingers’ breadths below the axillary crease), if needed. Nodes are removed until the background count in the wound is less than 10% of the ‘hottest’ node (‘10% rule’). The wound can usually be closed with an absorbable suture without a drain. If a completion node dissection is needed later (for example, for tumour in the sentinel node), the previous scar should be removed en bloc with the larger subsequent incision.

**Axillary reverse mapping (ARM) procedure**

The ARM procedure is based on the hypothesis that distinct, non-overlapping nodes drain the arm and the breast, and so resecting exclusively axillary nodes and their draining lymphatics from the breast during SLNB or axillary lymph node dissection (ALND) procedures should reduce the incidence of postoperative upper limb lymphoedema. One or both of the dual dyes used for SLNB that would not otherwise be used for the axillary procedure is/are injected into the ipsilateral upper inner arm at the same time points used for SLNB. During the subsequent axillary operation, a gamma probe and/or visual inspection can be used to identify the lymph channels and nodes that drain the arm and should be spared. Clinical studies suggest that the ARM procedure is feasible and there is some evidence to support the introduction of ARM in addition to SLNB for selected breast cancer surgical patients, although surgeons should be alive to the possibility of crossover SLN-ARM nodes or metastatic ARM nodes.

**Removal of tail of Spence during total mastectomy**

The tail of Spence is the eponym given to the normal extension of the upper outer quadrant of breast tissue into the anterior axilla. It can enlarge during pregnancy, causing the well-known ‘axillary breast’. In order to perform a truly total mastectomy and avoid leaving this structure (which can account for up to 10% of the breast tissue), the surgeon performing the procedure should extend the lateral dissection to the anterior edge of latissimus dorsi in order to expose and remove the tissues anterior and lateral to level 2. By
definition, this procedure removes a few of the lateral (level 1) nodes, so the pathology report from a true ‘total’ mastectomy should include a few lymph nodes.

**Lymphoedema**

In the USA and Western countries, lymphoedema occurs most commonly as a complication of lymph node dissection for the treatment of cancer. Although most often associated with breast cancer, a recent meta-analysis of 8000 patients revealed an overall 16% incidence in individuals treated for melanoma, sarcoma, and head and neck, urological and gynaecological cancers. In the American College of Surgeons Oncology Group (ACoSOG) Trial Z-11, the incidence of lymphoedema was 13.5% for two-level node dissection compared to 6.5% for SLNB.

As the treatment of lymphoedema remains suboptimal and is usually palliative, the focus has often been on a number of measures proposed to prevent it, although many such measures are anecdotal and not evidence-based. The above mentioned meta-analysis of the literature regarding prevention of lymphoedema found conflicting lower-level data regarding needle stick avoidance, no data to support avoidance of blood pressure measurement, and level 1 data refuting the notions of avoiding extremes of temperature or vigorous exercise. A randomized clinical trial of weight loss after lymph node surgery showed less lymphoedema in the intervention group. The findings from this trial support a large amount of evidence linking obesity to the development of cancer-related lymphoedema. The author therefore advises patients to maintain a healthy weight after axillary lymphadenectomy.

As previously mentioned, intraoperative manoeuvres, such as limiting the extent of node dissection and use of the ARM procedure, may limit lymphoedema. Postoperatively, the condition should be treated early and aggressively.

**Paraesthesia/hyperaesthesia**

Paraesthesia is an abnormal sensation such as tingling, tickling, pricking, numbness or burning of a person’s skin as a result of compression, traction or division of a nerve. Compression produces an anoxic, physiological block of both axoplasmic transport and ion channel functions along the affected
axon.

Loss of function and paraesthesia are usually temporary: release of the compressive agent usually results in rapid and complete recovery of function and relief of pain. Prolonged compression or traction may cause significant ischaemia and demyelination whereas a divided nerve will not recover unless repaired.

Paraesthesia around the axilla is most often the result of surgical manipulation or resection of the intercostobrachial nerves, and is therefore usually felt in the posterior and medial surfaces of the upper arm.

Paraesthesiae may be transient or chronic. In the ACoSOG Z-11 trial, the incidence of paraesthesiae was 78% for two-level axillary node dissection compared with 32% for axillary SLNB\textsuperscript{27}; paraesthesiae from SNLB were more limited and transient than those resulting from axillary dissection. Paraesthesiae in the intercostobrachial nerve region generally fade with time as the areas affected are reinnervated, although the process may worsen temporarily, during which time the patient is hypersensitive to cutaneous stimuli to the arm, a phenomenon known as hyperaesthesia.

Patients who are particularly troubled by hyperaesthesia may respond to a limited and carefully tapered course of gabapentin.

**Winged scapula**

Primary scapular winging may occur as a result of paralysis of serratus anterior, trapezius, rhomboid major and minor, and/or levator scapulae.\textsuperscript{29}

The symptoms of this deformity vary widely between patients. Serratus anterior normally anchors the scapula to the chest wall, but damage or sacrifice of the long thoracic nerve may cause ‘winging’ where the scapula is drawn upwards and towards the spine by the unopposed action of trapezius, levator scapulae and the rhomboids. (Where winging follows a lesion of the accessory nerve, the scapula is displaced downwards and away from the spine at rest).

A number of methods of treatment are available to symptomatic patients. These usually begin with massage therapy, which can be an effective initial approach to relax the damaged muscles. In more severe cases, physiotherapy (to strengthen the affected and surrounding muscles) or surgery may be needed. Surgical options include neurolysis, intercostal nerve transfer, scapulothoracic fusion, arthrodesis (capsulodesis), or scapulothoracic fixation without arthrodesis (scapulopexy).\textsuperscript{30}
Massive axillary mass

The author suggests the following steps should be followed when the surgeon is called upon to remove a massive axillary mass (including large involved lymph nodes) that obscures the normal anatomy.

The incision should be longer than usual, extending anteriorly, and incorporating a skin paddle overlying the mass, so that the skin and fat closest to the mass are resected en bloc. This serves to improve both visibility and surgical margins. Similarly, the arm can be prepped and draped free so that it can be moved during the case: this will also improve intraoperative visualisation. Skin resected with such masses is often stretched and redundant, so the incision can still be closed primarily. The plane of Morton should be opened and the long thoracic nerve identified: the nerve is usually not involved, even by very large masses, and can usually be spared. The thoracodorsal neurovascular structures should be identified and resected if they are involved. This leaves little deficit, especially if the nerve and vessels are already non-functional from chronic compression or encasement. If the axillary vein cannot be identified easily, it should be traced from lateral to medial, starting in the arm. It may be encased by larger masses and can be resected en bloc with the mass by multiple firings of a TA-30V stapler. This may not result in much arm swelling, especially if the vein has been chronically occluded by compression or encasement and collateral vessels have formed. The surgeon should consider resecting pectoralis minor en bloc.

The muscle can be detached from the chest wall caudally and from the coracoid process cranially: this greatly improves visualisation of the anatomy of the axilla. Removal of pectoralis minor is facilitated by draping the arm free and carefully abducting it during the procedure, taking care not to stretch the brachial plexus unduly.

Tips and Anatomical Hazards

- Identify and divide axillary webs.
- Think of lymph nodes in three surgical levels, based on their relation to pectoralis minor.
- Bluntly open the plane of Morton to identify the long thoracic nerve.
- Recognize and ligate ‘fooler veins’ when looking for the thoracodorsal
structures.
Know that level 2 nodes lie between the long thoracic and thoracodorsal nerves.
Reduce lymphoedema by modifying node removal (avoid removing level 3 nodes, nodes lateral to the thoracodorsal nerve, and the most cephalad level 2 nodes when operating for low disease burden) and considering the ARM procedure.
When removing massive axillary masses, consider draping the arm free, extending the incision laterally, removing redundant skin and soft tissue en bloc, and resecting pectoralis minor, thoracodorsal neurovascular structures and/or the axillary vein as needed.


30. Martin RM, Fish DE. Scapular winging: anatomical review,
1. Which one of the following statements about the thoracodorsal nerve is true?
   A. It is usually lateral to the thoracodorsal vessels
   B. It supplies pectoralis minor
   C. Sacrifice results in a ‘winged scapula’
   D. It should be traced out during the lateral portion of an axillary dissection

   **Answer: D.**

2. Between which of the following pairs of structures does an ‘axillary arch’, an abnormal slip of muscle, most often stretch?
   A. Latissimus dorsi and pectoralis major
   B. Latissimus dorsi and coracoid process
   C. Pectoralis major and coracoid process
   D. Pectoralis major and pectoralis minor

   **Answer: A.**

3. Which one of the following is NOT a named group of nodes in the axilla?
   A. Posterior
   B. Pectoral
   C. Medial
   D. Central

   **Answer: C.**

4. Which one of the following describes the incidence of arm oedema after sentinel node biopsy in the American College of
Surgeons Oncology Group (ACoSOG) Z-11 Trial?
A. Less than 1%
B. 3%
C. 6.5%
D. 13.5%

**Answer: C.**

5. For which of the following options does pectoralis minor serve as the dividing line?
A. The three parts of the axillary artery
B. The three surgical levels of axillary nodes
C. The location of the three intercostobrachial nerves
D. A and B

**Answer: D.**
Clinical Cases

1. A 37-year-old female who has had a lumpectomy only for ductal carcinoma *in situ* (DCIS) presents with an enlarged axillary node. A fine needle aspiration is positive for ductal carcinoma cells. Resection is planned and she requests an ARM procedure to limit her risk of lymphoedema.

A. Describe the potential benefits, anatomy and conduct of the operation planned for this patient.

The key to this procedure is to remove the nodes draining the breast while leaving nodes draining the arm. While there is some overlap in nodal drainage patterns, lymphoedema can be minimized by focusing on the nodes that drain the breast: the enlarged node is by definition one of these. The additional goal of minimizing local failure in the axilla can be achieved by removing additional nodes that drain the breast and that may also harbour microscopic disease. Using the 5-nodal group (anatomical) nomenclature, the pectoral and central nodes should be the focus of resection, as they primarily drain the breast. In fact, the central nodes are usually the first nodes to become palpable and most likely contain the node in question. Conversely, the lateral nodes mostly drain the arm and should be left; as much as possible, the posterior nodes should also be spared. Removal of the apical nodes leads to higher rates of lymphoedema, and should definitely be avoided. Anatomical studies have shown that these nodes are usually the last to be involved by tumour, even in cases of macroscopic disease. Using the three-level (surgical) nomenclature (see Fig. 38.4), level 3 nodes and the cephalad half of level 2 nodes should always be spared whenever possible.

Some reports have suggested that the nodes to be spared can be identified using the middle branch of the intercostobrachial nerve, limiting the dissection to the nodes below this branch (see Fig. 38.2). However, because the location or even the existence of this branch varies between individuals, this may not be a clinically useful method of reducing lymphoedema.

A more reliable method of intra-operatively identifying and sparing those nodes that primarily drain the arm is the axillary reverse mapping (ARM) procedure. In this operation vital blue dye,
radiotracer, or both are injected into the subdermal layer of a site in the ipsilateral upper arm. The radiotracer is usually given 1 hour before operation, and the blue dye just 10 minutes before incision. The surgeon then proceeds with the axillary dissection per routine, sparing 'blue' and 'hot' nodes, especially as the operation proceeds laterally, posteriorly, and apically.

2. A 67-year-old male with a history of a large invasive squamous cell cancer of the arm presents 2 years after resection with no local recurrence but an enlarging axillary mass. MRI shows a 10 × 15 cm mass in the axilla with compression of the axillary vein. Fine needle aspiration shows squamous cell cancer. A metastatic work-up is negative. The patient is ‘cleared’ for general anaesthesia.

**A. Describe the anatomy and conduct of the operation planned for this patient.**

Removal of a large axillary mass can be difficult and technically challenging, as the mass can obscure normal anatomy, leading to excessive bleeding and inadvertent removal of normal structures. In fact, because such masses often push normal structures away rather than invade them, it is often possible to spare such structures (and thus preserve function) if the surgeon approaches the operation as a standard axillary dissection, with the following special steps:

- a. Create an ‘S-shaped' transverse incision, extending the incision anteriorly over pectoralis major. creating a 'paddle' of the skin and soft tissue that may be adherent to the mass, to be removed en bloc with the specimen. This improves both visibility and margins.
- b. Raise the cephalad and caudal skin flaps from this incision.
- c. Working in an anterior to posterior direction, strip the mass off pectoralis major, minor, and serratus anterior in sequence.
- d. Open the plane of Morton bluntly and find the long thoracic nerve at the bottom on the plane. This is the most important nerve in the dissection to identify and preserve whenever possible. In some cases it may be adherent to the specimen but can be dissected free.
- e. Pull the specimen inferiorly and determine if it can be dissected away from the axillary vein. If the vein is completely compressed or encased, the involved segment of
the vein can be removed. This is easily done with proximal and distal firings of a TA-30V stapler. Reconstruction of the vein is usually not necessary – such vein involvement is usually chronic enough that collateral vessels have developed and removal of the section of the vein does not often result in a significant increase in arm swelling. The artery, conversely, is rarely involved but requires reconstruction if taken.

f. Pull the specimen laterally and identify and preserve the thoracodorsal neurovascular bundle if possible. This structure is often compressed posteriorly and can be saved. If encased it can be sacrificed with surprisingly little deficit.

g. Complete the dissection laterally per the usual axillary dissection and close over drain(s). Because the skin has often been stretched out by the mass, the wound can usually be closed without the need for flap or graft, even after removal of the redundant skin and soft tissue *en bloc* with the mass (as described in step a, above).
Shoulder girdle and upper arm

Simon M Lambert

Core Procedures

Surgical Exposures Around the Shoulder Girdle and Upper Arm

- Approaches to the shoulder girdle
- Approaches to the shoulder joint
- Medial extensile exposures
- Distal (brachial) extensile exposures

While arthroscopy has allowed access to the glenohumeral, sternoclavicular and acromioclavicular joints and to the subacromial–subscapular space, enabling surgeons to undertake a variety of reconstructive procedures, it is not always possible to use a minimally invasive approach for complex and traumatic conditions of the shoulder. In particular, complex reconstruction and revision of the shoulder joint for arthritis and complex fractures of the shoulder girdle require extensive exposures, which are often beyond the routine practice of the surgeon.

Patients with disorders of the shoulder girdle and upper arm present with syndromes that include pain leading to maladaptive muscle activity, and abnormalities of movement due to disordered or pathological biomechanics, often on a background of progressive tissue degeneration. When non-operative treatment has failed to relieve pain and re-establish normal movement, surgical intervention may be considered. Surgery has to address, first, the anatomy of pain and, second, the pathological anatomy of disordered biomechanics: these may not be concordant. The surgical exposure must respect neural pathways and the vascular supply of intact tissues: if possible, surgical exposures should be interneural (i.e. between or respecting neural territories) and intervascular (i.e. between or respecting vascular territories, or angiosomes). Successive layers of the surgical...
exposure (integument, deep fascia, muscle and joint) have overlapping, but not necessarily identical, innervation and blood supply; most exposures around the shoulder girdle and upper arm are dictated by knowledge of the anatomy of the trunk nerves, the major vessels and the territories that they support.
Surgical surface anatomy

The sternal end of the clavicle is readily palpated at the sternal notch. The anterior border of the clavicle is superficial, while the posterior border of the lateral two-fifths of the bone is often obscured by the attachment of trapezius along its superior surface. The surface anatomy of the superior exposure for the acromioclavicular region and superior compartment of the shoulder (acromion; subacromial space; superior rotator cuff; rotator interval; tendon of the long head of biceps) is shown in Fig. 39.1.
FIG. 39.1  Surface topography of the right shoulder. The patient is reclining in the
deckchair position with the head at the top of the view. Three reliable and readily
palpable surface markings are marked with stars: the tip of the coracoid (yellow), the
posterior angle of the acromion (white), and the notch between the medial border of
the acromion and the posterior aspect of the distal clavicle (which must therefore
indicate the posterior margin of the acromioclavicular joint, blue) (1). The lateral
border of the coracoacromial ligament is marked (2). The posterior margin of the
supraspinatus part of the superior rotator cuff is indicated by a line (3) that is a
projection of the line describing the anterior border of the spine of the scapula (which
must therefore be the posterior boundary of the supraspinatus fossa). The humeral
head is described by a circle marked by palpation between index, middle and thumb.

These landmarks allow precise placement of a surgical incision over known
pathology of the rotator cuff. This incision respects the position and direction of the
lateral supraclavicular nerve while permitting adequate exposure of the superior
compartment of the shoulder. The distal extent of the incision respects the potential
course of the axillary nerve from posterior to anterior on the deep surface of deltoid.

The surface marking of the axillary nerve is useful and simple (Fig. 39.2); it
helps to guide the exposure of the posterior scapula and shoulder joint.
FIG. 39.2  Surface marking of the axillary nerve. The deltoid tuberosity is at the midpoint of the humerus (1), on a line (black) midway between the lateral border of the acromion (2) and the lateral epicondyle (3). With the arm in abduction, the inferior border of the posterior part of deltoid is a straight line (brown) between the medial border of the scapula at the base of the spine of scapula (4) and the deltoid tuberosity (1). The axillary nerve passes directly posteriorly, towards the palpating finger at the midpoint of the posterior border of deltoid (5). It then passes around the humerus at about the midpoint of the posterior border of deltoid (5). The literature is replete with many estimations of the variability of the distance between the acromion and the axillary nerve deep to deltoid; this rule of thumb is practical and based on the individual’s size. Incisions for the exposure of the posterior aspect of the shoulder joint and for the scapula (e.g. for fixation of a scapular fracture, posterior stabilization of the shoulder, and latissimus dorsi tendon transfer, dotted orange line) are medial to this point (5). The posterior cutaneous nerve of the upper arm passes from deep to the posterior border of deltoid at (5) and supplies the skin at (1).
Clinical anatomy

Clavicle, acromioclavicular and sternoclavicular joints

The general anatomical arrangement of the medial and lateral ends of the clavicle is similar. Both the sternoclavicular\(^2\) and acromioclavicular joints and the metaphyseal regions of the clavicle associated with them are characterized by asymmetrical, highly variable surfaces that form the articulations; relatively strong intrinsic ligaments that reinforce a thin joint capsule; and complex extrinsic ligaments that create fulcra around which the clavicle rotates on the sternum and the scapula rotates on the distal clavicle. Both are reinforced by a muscular envelope, which also provides stability. The sternal facet of the clavicle is larger than its counterpart on the sternum, which is very variable in shape, size and orientation. The acromial facet of the clavicle is larger than its counterpart, which is also variable in its shape, size and orientation. Both joints have an intra-articular disc, which becomes meniscoid in early adult life, and fimbrial or nearly absent later. This allows the wide range of translation, rotation and gliding at each end of the clavicle that enable the scapula to move in a wide arc around the chest wall, thereby positioning the glenoid fossa in space. The function of subclavius and its relation to the sternoclavicular and acromioclavicular joints is shown in Video 39.1\(^3\).

The scapula rotates at the acromioclavicular joint, guided by the concentric–eccentric activity of the medial and lateral intrinsic stabilizers of the scapula (rhomboid, middle trapezius and serratus groups, respectively) and its vertical rotators/stabilizers (levator scapulae and upper and lower trapezius, acting with subclavius and pectoralis minor). The important stabilizers of the acromioclavicular joint are the posterior acromioclavicular capsule and the middle fibres of trapezius. The inferior acromioclavicular capsule and coracoacromial ligament may have the greatest density of proprioceptors and nociceptors in the shoulder region,\(^3\) suggesting a role for the joint not only as a mechanical fulcrum but also as the afferent field for the scapulothoracic joint, given that the mass of muscle spindles is insufficient for kinaesthesia to be generated simply by the periscapular muscle afferents. Resection of the joint should be carefully considered.
Deltoid

The function of deltoid is complex: the anterior part contributes to flexion–abduction and internal rotation, and the posterior part to extension–abduction and external rotation of the shoulder joint. The middle part of the muscle is morphologically very different from the anterior and posterior parts, which are simple delta-shaped muscles with convergent and slightly spiralling fibres. The middle part is rhomboidal with a complex interdigitation of several columns of muscle fibres, facilitating powerful abduction of the arm by a form of bipolar ratcheting action. Deltoid moves the elbow in space relative to the midline axis; coracobrachialis acts as part of the opposing force-couple. Deltoid and pectoralis major form a continuous muscular envelope around the shoulder girdle and upper arm. There is an interval anteriorly between the two muscles in most people; however, continuity is often seen and the cephalic vein may be absent. The motor innervation of this muscular envelope is derived from the anterior divisions of C3,4 (flexor component) and C5,6 (extensor component). Pectoralis major is innervated via the small-calibre lateral and medial pectoral nerves, suggesting a simple ‘on–off’ mass action, whereas the axillary nerve, which innervates deltoid, is of large calibre, suggesting a greater afferent component (from muscle spindles) and subtlety in the function of the middle part of the muscle. Approaches that incise the middle part of deltoid should be made carefully because the muscle does not possess a true raphe (the so-called ‘deltoid raphe’ is a misnomer) but rather a series of aponeurotic laminae. The muscle fibres can be parted from these laminae to leave the fibres intact and attached proximally (Figs 39.3 and 39.4). The anterior approach to the shoulder joint is described in Video 39.2.
FIG. 39.3  Dissection through deltoid. **A**, The anterolateral corner of the acromion is marked with a blue star. The anterior leaf of deltoid has been sharply dissected from the anterior internal aponeurosis, which remains attached to the lateral border of the acromion, revealing the underlying parietal layer of the subdeltoid bursa. The anterior leaf can be elevated from the anterior border of the acromion if needed, without detaching this important aponeurotic cable within deltoid. The white arrow shows the most anterior of the several intramuscular aponeuroses of the deltoid, which serves as a guide to the atraumatic dissection of deltoid in this exposure. **B**, The cauterized acromial artery lies in the slender fat-filled space (white arrow) between the deep surface of deltoid and the coracoacromial ligament, under which the scalpel has been placed. The aponeurotic part of deltoid can be retracted firmly while the less robust anterior leaf must be retracted with care. The acromion is marked with a blue star. **C**, The beginning of the repair: the anterior leaf is pulled back under the anterior margin of the posterior leaf (white arrow). The remainder of the muscle is sutured in two layers: the deep layer with the parietal bursa, and the superficial epimysial layer, restoring the normal anatomy.
Dissection around the shoulder

There are a multiplicity of surgical approaches to the shoulder girdle, shoulder joint and upper arm. For simplicity, the principal exposures are grouped into those for the shoulder girdle, those for the shoulder joint and those for the upper arm (which are extensile developments of the exposures of the shoulder joint). All exposures share several common features and follow similar principles. The essential feature of all surgical exposures of the shoulder and upper arm (and for all limb exposures) is the common task of identifying the neurovascular structures, on the basis of which the musculoskeletal structures are exposed.

All surgical exposures of the shoulder girdle, shoulder joint and upper arm are developed in layers. Each layer is characterized by relevant concepts that aid the safe exposure of structures and optimize surgical decision-making.
and outcomes (Table 39.1). The local exposures (of the proximal humerus and glenoid fossa) can be extended distally (into the upper arm) and medially (for the brachial plexus anteriorly and for exposure of the scapula posteriorly). Extensile exposure of the infracoracoid brachial plexus allows exposure of the axillary nerve when scarring obliterates normal relationships in the axilla (exposure 7 in Table 39.1). The anterior exposures can be combined with exposure of the clavicle for an extensile exposure of the entire brachial plexus, associated vessels and forequarter.

**TABLE 39.1**
Core procedures and pitfalls

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<tr>
<td>Anteromedial</td>
<td>Proximal humerus and glenoid fossa (posterior rim)</td>
<td>Suprascapular nerve and vessels; axillary nerve</td>
<td>Exposure of and/or traction lesion of the nerve to infraspinatus and the axillary nerve</td>
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<td>--------------</td>
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<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Posterior</td>
<td>(9) and neck and body of scapula</td>
<td>Suprascapular nerve; circumflex scapular artery</td>
<td>Exposure of and/or traction lesion of the nerve to infraspinatus and the axillary nerve</td>
</tr>
<tr>
<td>Posterior</td>
<td>(9) and posterior shaft of humerus</td>
<td>Relationship of the radial nerve to the medial head of triceps</td>
<td>Exposure of the radial nerve</td>
</tr>
</tbody>
</table>

Key: 1–5, approaches to the shoulder girdle; 6 and 9, approaches to the shoulder joint; 7 and 10, medial extensile exposures; 8 and 11, distal (brachial) extensile exposures.
Surgical approaches and considerations

To gain access to the joints, the surgeon must negotiate the neurovascular plane, whether from an anterior or posterior approach (Table 39.2). The short, relatively immobile nerves close to the shoulder joint either remain deep to the internal investing fascia (suprascapular) or penetrate it distally (axillary). The long, relatively mobile nerves of the shoulder girdle and upper arm either are outside the internal investing fascia (long thoracic, spinal accessory) or pass through it (dorsal scapular, musculocutaneous, radial). This pattern renders the nerves of the shoulder joint susceptible to traction injury, while the nerves of the shoulder girdle are relatively less susceptible. The nerves of the upper arm are susceptible to injury at or near regions of fascial perforation. Both the zone of adhesions (the outer gliding plane) and the zone of contractures (the inner gliding plane) are amenable to arthroscopic techniques. However, it is more difficult to deal with neurovascular structures of the outer gliding plane using minimally invasive techniques. Most complications of surgery around the shoulder joint are the result of inadequate management of the neurovascular structures: failure of biomechanics or fixation can often be ascribed to incomplete exposure of the musculoskeletal structures due to a lack of confidence in exposure of the neurovascular bundles.
TABLE 39.2
Combined surgical and anatomical concepts in exposure of the shoulder girdle and shoulder joint from outside in

<table>
<thead>
<tr>
<th>Anatomical stages of surgical exposure</th>
<th>Correlated anatomical and biomechanical concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin incision</td>
<td>Superficial and deep fascia: external investing fascia</td>
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<tr>
<td>Deltoid – pectoral muscle envelope</td>
<td>Scapular (glenoid fossa) suspension</td>
</tr>
<tr>
<td>Scapular spine – acromioclavicular joint – clavicle – coracoid</td>
<td>Subscapular – subdeltoid – subacromial gliding plane</td>
</tr>
<tr>
<td>Subscapulo – subacromio – subdelto – coracoid bursa</td>
<td></td>
</tr>
<tr>
<td><strong>Bursal barrier (zone of adhesions): outer gliding plane</strong></td>
<td></td>
</tr>
<tr>
<td>Pectoralis minor – coracoid – short flexor compartment</td>
<td>Clavipectoral fascia: internal investing fascia</td>
</tr>
<tr>
<td><strong>Neurovascular plane</strong></td>
<td></td>
</tr>
<tr>
<td>Rotator cuff – capsule complex</td>
<td>Fibromuscular mobile ‘acetabulum’/container</td>
</tr>
<tr>
<td>Labrum – long head of biceps tendon complex</td>
<td>Synergetic with the rotator cuff and elbow joint stabilizers</td>
</tr>
<tr>
<td><strong>Synovial barrier (zone of contractures): inner gliding plane</strong></td>
<td></td>
</tr>
<tr>
<td>Articular surface</td>
<td>Glenoid Osseocartilaginous surface gliding plane</td>
</tr>
<tr>
<td>Humerus</td>
<td></td>
</tr>
<tr>
<td>Extra-articular scapula</td>
<td>Bony support structures</td>
</tr>
<tr>
<td>Extra-articular humerus</td>
<td></td>
</tr>
</tbody>
</table>

The outer gliding plane is the space between the deep surface of the outer envelope of the deltoid and pectoral muscles and the superficial surface of the rotator cuff, but it is not limited to the various bursae around the shoulder. It is frequently the site of adhesions that limit movement but do not cause adverse translation of the humeral head on the glenoid. This space is not readily accessible to arthroscopic techniques. The inner gliding plane is the articular space: its boundary (the capsule and associated ligaments) is frequently the site of contractures that limit movement and cause adverse translation of the humeral head on the glenoid. This articular space is readily accessible to arthroscopic techniques. Clinical examination can determine the site of limitation of movement and therefore the surgical exposure required. The outer gliding plane and neurovascular plane are intimately related: surgical exposure of structures deep to the outer gliding plane must therefore include the ability to identify the brachial plexus and axillary artery and vein.

Skin incisions

For optimal cosmetic appearance, incisions should generally follow ‘lines of least skin tension’. However, exposure of the underlying structures should
not be compromised and therefore incisions are likely to have to cross lines of least skin tension; crossing at a shallow angle is preferable. Incisions should avoid crossing natural skin folds and creases perpendicularly; for example, they should pass lateral to the anterior axillary skin at the front of the shoulder when the anterior approach to the shoulder is undertaken. The skin of the shoulder girdle and upper arm is copiously perfused in well-described vascular territories (angiosomes) (Fig. 39.5). Incisions generally heal well, but multiple parallel incisions in the same angiosome should be avoided to reduce the possibility of poor skin healing. The skin over the dorsal aspect of the shoulder girdle is thick, coarse and deeply attached to the bony prominence of the spine of the scapula and the acromion through vertical fascial ‘ligaments’; it possesses poor discriminatory sensibility. The skin of the anterior aspect of the shoulder girdle is thinner and more mobile, and has finer two-point tactile and thermal sensory discrimination.
The skin of the upper anterior chest wall is supplied by the medial, middle and lateral supraclavicular nerves, all of which are at risk of division during exposure of the clavicle. Neuromas caused by surgical division are not uncommon and are difficult to treat. Dysaesthesiae of the upper chest are of concern: the region of dysaesthesiae may reach as far as the upper part of the breast, which has been noted by some female patients after treatment for fractures of the clavicle.

The skin of the upper lateral part of the upper arm is supplied by the upper lateral posterior cutaneous nerve of the upper arm, which is a branch of the axillary nerve arising at the posterior aspect of the quadrilateral space. This is at risk of traction or of being crushed during exposures in which the inferior border of the posterior deltotid is retracted (Video 39.3).
Epifascial dissection

The deep external investing fascia of the shoulder girdle comprises the enveloping fascia of pectoralis major in continuity with the fascia enveloping deltoid, which in turn is in continuity with the fascia over infraspinatus and trapezius dorsally and the brachial muscles distally. The deep external investing fascia of the shoulder is a boundary. For example, infection external to the fascial layer will remain extrafascial, provided that the fascia has remained intact. Conversely, infection deep to the fascia can remain contained. Dorsally and proximally, the fascia, being thicker, provides support through attachment and containment of the musculature of the shoulder girdle and, when incised, should be repaired.

The blood supply to the skin is derived from fascial perforators. This means that while it is possible to reflect skin flaps widely around the shoulder girdle, epifascial dissection (i.e. on the external surface of the fascia) should respect the cutaneous perforators, particularly when dealing with skin through which previous surgery has been performed.

Subfascial dissection

The axillobrachial fascia surrounding the axial vessels and brachial plexus lies deep to the internal investing fascia. This important surgical ‘boundary’ layer comprises the clavipectoral fascia and its lateral extension, the parietal layer of the subscapularis bursa and the investing fascia of the humerus, which is contiguous with infraspinatus fascia dorsally. The neurovascular plane lies deep to this fascial layer. The bursae of the shoulder lie between the two layers of investing fascia, forming an outer gliding plane (see Table 39.2). It follows that since the neurovascular plane is deep to the clavipectoral fascia, the nerves and vessels that pass either to more superficial structures or between compartments have to perforate the deep fascia. Examples include the axillary nerve, which passes through the quadrilateral space to the deep surface of deltoid, giving branches to the capsule of the shoulder joint, teres minor and the posterior part of deltoid; the radial nerve, which pierces the lateral intermuscular septum in moving from the posterior to the anterior compartments of the arm; and the ulnar nerve, which pierces the medial intermuscular septum in moving from the anterior to the posterior compartments of the arm. At these points of perforation the nerves are relatively ‘fixed’ and therefore predisposed to traction injury.

If the anatomy of the quadrilateral space is obscured, then exposing the
posterior cord and axillary nerve behind coracobrachialis is difficult. In such cases, exposure of the brachial plexus medial to coracobrachialis is the safe option: the lateral cord and musculocutaneous nerve are the key anatomical landmarks in this dissection. The relationship of the lateral cord to the axillary artery is consistent, so the vessel can be identified confidently. The posterior cord lies deep to the artery. The first lateral branch of the posterior cord is the axillary nerve, which passes laterally and distally to approach the first major lateral branch of the axillary artery (the posterior circumflex artery and its smaller anterior counterpart, the anterior circumflex artery) distal to the coracoid before passing distal to the inferior rounded border of subscapularis. It is important to identify the axillary nerve to avoid inadvertent injury during dissection of the inferior capsule of the shoulder joint in any exposure of the joint (see Table 39.1).

The investing fascia of the shoulder extends to the infraspinatus fascia, with which the deltoid fascia is blended inferiorly and medially. The infraspinatus fascia is exposed after incision of the deltoid fascia and elevation of the inferior margin of deltoid, and defines the posterior compartment of the scapula, being attached to the margins of the body of the scapula below its spine. Deltoid takes partial origin from the superficial aspect of the infraspinatus fascia superiorly and medially; the fascia has to be incised approximately 1 cm distal to the spine of the scapula to gain access to the superior border of infraspinatus and the posterior aspect of the scapula medial to the spinoglenoid notch. This allows exposure of the posterior incisura of the rotator cuff and the infraspinatus branch of the suprascapular nerve. The interval between teres minor and teres major is marked by the circumflex scapular vessels, from which a branch passes to the skin over the lateral border of the scapula: this branch can be identified in the epifascial dissection and leads to the intermuscular interval. The interval between infraspinatus and teres minor is more difficult to define but is best seen at the lateral border of the scapula, from which teres minor takes origin. Infraspinatus does not have a strong origin from the lateral border of the scapula: the deep fibres of the muscle take origin 1–1.5 cm medial to the dorsal prominence of the lateral border of the scapula, a feature that permits placement of a buttressing plate along the lateral border, where required for scapular fracture fixation, without detachment of infraspinatus muscular fibres.

Deltoid is retracted more easily if the arm is rotated externally at the shoulder and abducted in extension relative to the scapular plane. The
axillary nerve and its quadrifurcation (posterior deltoid branch; branch to teres minor; cutaneous branch; anterior deltoid branch) are then readily and safely exposed distal to the inferior border of teres minor, which is enveloped by the infraspinatus fascia.

**Specific surgical approaches**

**Posterior shoulder girdle and shoulder joint**

Exposure of the posterior aspect of the shoulder joint and scapula is achieved by an interneural, intervascular approach between infraspinatus (suprascapular nerve) and teres minor (axillary nerve), and between teres minor and teres major (subscapular nerve). Deltoid can either be elevated from the spine of the scapula and retracted laterally for exposure of the superior aspect of the glenoid, or split in its posterior part for exposure of the posterior glenoid rim. The inferior border of deltoid can be elevated, but does not need to be detached, to expose the interval between infraspinatus and teres minor, thereby exposing the infraglenoid region and axillary nerve from below. The nerve to infraspinatus should be exposed in the superior part of the dissection and the spinoglenoid ligament divided to allow mobilization of the nerve when exposing the posterior neck of the scapula. The same approach can be extended distally to facilitate mobilization of latissimus dorsi and its tendon for transfer into the posterior and superior facets of the greater tubercle of the humerus (Video 39.4).

**Anterior upper arm**

The dissection of the anterior compartment of the upper arm (Video 39.5) is determined by the course and distribution of the musculocutaneous nerve. The two parts of biceps brachii can be split, like triceps brachii, down a seam, exposing the musculocutaneous nerve and the anterior aspect of the shaft of the humerus: the entire biceps brachii and brachialis muscle group can be reflected laterally from the humerus, to expose the anteromedial aspect of the shaft for fixation of fractures. This avoids concern over how much of the lateral part of brachialis is supplied through small branches of the radial nerve (Fig. 39.6).
FIG. 39.6  Extensive exposure of the anterior compartment: cadaveric dissection. A, Biceps brachii is exposed epifascially; the seam between the two heads is visible superiorly (white arrow). B, The seam is developed to the distal intramuscular aponeurosis; the musculocutaneous nerve is seen between the two heads of biceps brachii (white arrow). C, Detail of the musculocutaneous nerve; brachialis has a segmental supply, whereas the heads of biceps brachii have an axial supply. D, The musculocutaneous nerve penetrates the deep (clavipectoral) fascia (upper white arrow), while the neuromuscular bundle of the arm remains deep to the fascia at this level. The ulnar nerve, which has no branches in the proximal four-fifths of the upper arm, is seen on the deep surface of the deep brachial fascia (lower white arrow). E, The short head of biceps brachii has been retracted laterally, demonstrating the musculocutaneous nerve on the superficial surface of coracobrachialis. There is an anomalous muscle crossing the brachial bundle as a slip from the short head of biceps to the medial intermuscular septum (white arrow).

Posterior upper arm

The dissection of the posterior compartment of the upper arm is determined by the course and distribution of the radial nerve. This nerve is best identified proximally, at the level of the inferior border of deltoid. It trifurcates high, giving branches to the long and medial heads of triceps and passing through the lateral intermuscular septum, at or immediately distal to the point at which the posterior cutaneous nerve of the forearm is given off. This nerve is a useful guide to the radial nerve and its passage from the posterior to the anterior compartments in lateral approaches to the distal humerus. Dissection of triceps from distal to proximal is difficult, whereas the muscle splits readily into the two superficial parts along its intramuscular aponeurotic lamina when dissected from its proximal end. The entire triceps can be elevated with the radial nerve from medial to lateral, exposing the whole posterior aspect of the humerus from the olecranon fossa to the surgical neck of the humerus at the level of the axillary nerve (Video...
Arthroscopy of the shoulder girdle and shoulder joint

Arthroscopic instrumentation of the shoulder joint and shoulder girdle (scapulothoracic, sternoclavicular and acromioclavicular joints, and subacromial–subdeltoid bursae) bypasses the neurovascular plane using portals planned to avoid the major nerves and vessels. Nevertheless, distorted anatomy due to trauma, and distension and displacement due to haemorrhage or fluid extravasation may place the neurovascular structures at risk of injury during instrumentation. Preoperative surface topographical planning is essential to reduce the risk of such injuries. Portals are placed to view the relevant cavities and to pass instruments at angles incident to the viewing arthroscope to permit ‘triangulation’ of the instruments within the cavity. Portals are therefore planned central or perpendicular to the space being instrumented for viewing, and peripheral or oblique to the space for working instruments. Those portals placed away from the centre of the space being viewed put the neurovascular tracts most at risk and are most safely used when the tissues bounding the joint or space are lax.
Developmental Anomalies

The outer end of the spine of scapula has at least two primary centres of ossification. Failure of fusion of the anterior and posterior ossification centres results in a pro-os acromiale, which can be mistaken for ossification within the coracoacromial ligament. Failure of fusion of the ossification centres of the posterior acromion and scapular spine results in a meso-os acromiale, which develops a synovial pseudarthrosis that is prone to degenerative arthropathy (Fig. 39.7). The blood supply to the distal clavicle, acromioclavicular joint and acromion is derived from the acromial branch of the thoracoacromial artery, which passes close to the anteroinferior capsule of the acromioclavicular joint, and anterior and inferior to the bony margin of the acromion between the coracoacromial ligament and muscular insertion of deltoid on the acromion (Video 39.6). The artery is therefore at risk during surgical exposure from an anterior approach: the resulting devascularization of the anterior part of the acromion increases the potential for persistent non-union of the pseudarthrosis after surgical treatment. It is important to identify a symptomatic os acromiale preoperatively (by CT or MRI scanning) so that a posterior or posterosuperior surgical approach can be used.
The anterior acromion can be harvested as a vascularized pedicled graft for the treatment of non-union of the clavicle. The clavicle, coracoid and acromion are frequently dysplastic and deformed in paralytic conditions of the shoulder, such as obstetric brachial plexus palsy, before maturity. It appears that the dysplasia is determined prenatally, while the postnatal deformity may be the result of abnormal muscle tethers and asymmetrical muscle action. The superior approach can be combined with the anterior or posterior approach, in order to expose and manage associated tethering of the anterior rotator cuff in such cases.

Failure of scapular descent and aberrant development in utero result in a syndrome of scapular and spinal deformities with functional consequences (Fig. 39.9). The surgical exposure of the scapula is a direct dorsal medial
parascapular approach, elevating the (normal) trapezius from the scapular spine to expose the medial border of the scapula. In such cases, care to expose the superior pole of the scapula in order to define the dorsal scapular neurovascular bundle is warranted: retraction of the dorsal scapular vein and artery into the posterior triangle of the neck could result in the accumulation of a haematoma behind the brachial plexus, leading to a (reversible) plexopathy.

![FIG. 39.9](image)

**FIG. 39.9** Congenital undescended scapula syndrome. **A**, The high position of the scapula relative to the cervical spine is evident. The cleithrum, a failure of differentiation of the descending elements of the embryonal scapula from lateral plate mesoderm, is marked with a blue star. The scapular ratio (height : width) is virtually unity. The embryonal fusion line of the glenocoracoid part of the scapula is clearly seen (white arrow). The entire medial border of the scapula either has been tethered to the spine by the cleithrum (and therefore distorted by the effect of disproportionate growth of the clavicle) or is the result of intramembranous ossification of myotomal elements. **B**, An intraoperative view of the dorsal aspect of the thorax of a different patient: the cleithrum (C) is exposed in preparation for excision, and the cleavage plane between it and the true scapula is shown (white arrow). There was no evidence of normal rhomboid musculature or of dorsal scapular vessels and nerve. The lower part of trapezius (blue star) is well developed.

The glenoid fossa is frequently dysplastic or hypoplastic in patients with arthritis of the glenohumeral joint. Both anterior and posterior exposures of the shoulder joint may be needed to reconstruct the glenoid completely during total shoulder replacement.

**Tips and Anatomical Hazards**
The pitfalls of all surgical exposures around the shoulder girdle and upper arm are largely related to failure to expose and protect the neurovascular structures (see Table 39.1). Incomplete exposure of the anteromedial, anteroinferior and posteromedial neurovascular tracts is the cause of incomplete release of contracture and poor exposure of the glenoid and neck of the scapula.

The most difficult dissection is frequently that of the axillary nerve at the inferomedial aspect of the shoulder joint, where it lies behind coracobrachialis. The nerve comes from behind to join the posterior circumflex artery, and the two structures then pass obliquely into the quadrilateral space. With the arm in abduction at the shoulder, which is the common position during surgery, this space becomes more like a cleft than a true space because the superior border of teres major, obscured by the tendon of latissimus dorsi, overlaps the inferior border of subscapularis.

External rotation and abduction of the arm is often recommended to protect the axillary nerve from harm during dissection but this is not the case in clinical practice. By contrast, internal rotation relaxes the nerve and allows it to fall back medially during dissection.

Control of the posterior circumflex vein, which lies anterior to the artery, is paramount. The vein is large and very thin-walled: if it is avulsed from the axillary vein, rapid haemorrhage will occur and obscure the axillary nerve. For this reason, it is sensible to have a vascular sling around both the axillary artery and vein, which can be tensioned to reduce haemorrhage while control of the vessels is gained if bleeding is a concern. Revision shoulder arthroplasty and many trauma procedures require such precautions.

Note that the cephalic vein is not a constant guide to the interval between deltoid and pectoralis major.

Preserve fascia carefully: repair of the fascia will improve muscle function, particularly in posterior exposures of the shoulder girdle and shoulder joint.

Exploration of the axillary nerve can be difficult: if in doubt, dissect medial to coracobrachialis through the clavipectoral fascia to expose the musculocutaneous nerve. Use this as a guide to the axillary artery and vein. The posterior cord of the brachial plexus lies posterior to the artery; the first lateral branch of the posterior cord is the axillary nerve. Full (safe) exposure may require detachment of the short flexors (the
so-called conjoint tendon) from the coracoid (Fig. 39.8).

**FIG. 39.8** The relevance of extensile exposure of the shoulder region: complex revision arthroplasty after infection of the shoulder joint. A, The clinical problem: deep tethering, limited motion and distorted anatomy. B, The anterior exposure with infraclavicular extension. C, Epifascial dissection to create flaps and expose the clavicular head of pectoralis major for later transfer; there is little recognizable anatomy. D, Deep dissection of the infracoracoid plexus. The yellow sloop shows the musculocutaneous nerve; the red sloop shows the axillary vessels; the blue sloop shows the median nerve. The lower retractor is displacing coracobrachialis laterally. E, A magnified image of D. The vascular sling is proximal to the branching of the circumflex humeral artery and vein to control haemorrhage if those vessels are damaged.

Use an electrical probe (a peripheral nerve stimulator) to stimulate infraspinatus and teres minor: this will demonstrate the interval between the two muscles, which can otherwise be difficult to define. Remember that deltoid can be split without division of its muscle fibres, particularly in the middle part of the muscle. Undertake exposure of the front or back of the upper arm from proximal to distal, rather than the reverse.
References


Single Best Answers

1. Which one of the following defines the deltopectoral interval?
   A. Cephalic vein
   B. Basilic vein
   C. Deltoid artery
   D. Thoracoacromial artery
   E. None of the above

**Answer: E.** The cephalic vein is variable and is not a reliable guide to the deltopectoral interval. The so-called fatty streak in which it is traditionally exposed is highly variable and often absent. In the absence of a normal cephalic vein, more superficial, often traversing veins draining into the lateral pectoral vein or venae comitantes of the deltoid artery may be present. Dissection of these veins does not lead to the deltopectoral interval but to a frustrating barrier (the confluence of the traversing veins with the deltoid arteriovenous system) at the mid and upper parts of the dissection. The basilic vein is not present above the elbow. The deltoid artery is consistent. It arises from the thoracoacromial trunk above and medial to the coracoid. The artery, which may be doubled, pierces the clavipectoral fascia and runs obliquely across the upper part of the deltopectoral interval in fat tissue, accompanied by branches of the lateral pectoral nerve, one of which may pass to the anterior part of deltoid. One or more branches of the artery may be given off to pectoralis major, accompanied by branches of the lateral pectoral nerve. Thus the deltoid artery forms a variable plexus in the upper part of the deltopectoral interval. It can appear as large as the cephalic vein and is therefore often mistaken for it. The deltoid artery proper then courses down the medial aspect of the anterior border of deltoid, often within the muscle or on its deep surface, to anastomose with terminal
branches of the posterior circumflex artery close to the distal end of the bicipital sulcus. In fractures of the proximal humerus associated with rupture or occlusion of the circumflex vessels, the deltoid artery may be the most consistent source of perfusion of the humeral head through this anterior anastomosis: in such cases it should be preserved in the dissection.

2. Which one of following statements about the clavipectoral fascia is true?

A. It invests the lesser and greater tubercles of the humerus
B. It invests pectoralis major before merging with the clavicular periosteum
C. It invests pectoralis minor before merging with the clavicular periosteum
D. It is pierced by the musculocutaneous nerve inferior to the coracoid process
E. It is pierced by the cephalic vein

**Answer: C.** The clavipectoral fascia (CPF) forms as the medial continuation of the investing fascia of the shoulder, merging with the aponeurosis of the short head of biceps anteriorly and investing coracobrachialis posteriorly (which together form the conjoint tendon). The CPF then covers the gap between the medial border of the short head of biceps and the inferior border of pectoralis minor before investing that muscle and covering the interval between the superior border of pectoralis minor and the clavicle, investing subclavius before merging with the periosteum of the clavicle. The CPF merges with the inferior tendinous border of subclavius and the falciform extension of the tendon of that muscle to the medial border of the coracoid process. The tip of the coracoid process is therefore enveloped by the periosteal extension of the trapezoid ligament superiorly, the coracoacromial ligament and investing fascia of the shoulder.
laterally, the CPF medially, and the aponeurosis of the short head of biceps and coracobrachialis inferiorly. It is suspended from the clavicle by the CPF, the falciform extension of subclavius, and the coracoclavicular ligaments, acting as a dynamic fascial layer extending into the upper arm through coracobrachialis and the short head of biceps. The CPF therefore has a mechanical role in the linkage of clavicular and scapular motions. From the surgeon's perspective, the CPF defines the neurovascular plane that lies behind the CPF. The anterior aspect of the axillobrachial fascial sheath merges with the deep surface of the CPF. The corollary is that incising the CPF medial to the short head of biceps immediately brings the surgeon into the neurovascular plane. The most superior oblique structure crossing the interval between pectoralis minor and the short head of biceps is the lateral cord of the brachial plexus and its continuation, the musculocutaneous nerve, with accompanying vessels. A thin branch of the musculocutaneous nerve may leave the main trunk of the nerve behind pectoralis minor and cross the interval superior and parallel to the main trunk of the musculocutaneous nerve to supply the short head of biceps. This nerve is at risk of injury by incision or traction if the coracoid is used as a bone graft for surgical stabilization of the shoulder joint (the Bristow–Latarjet procedure and its modifications).

3. Which one of the following is used to define the interval between teres major and teres minor?
   A. Electrostimulation of each muscle
   B. Identification of the dorsal scapular artery
   C. Identification of the subscapular artery
   D. Identification of the circumflex scapular artery
   E. Identification of the axillary nerve

**Answer:** D. The superior border of teres major overlaps the
inferior border of teres minor; the interval between the two muscles is usually an oblique cleft. Teres minor takes origin from the posterior aspect and lateral edge of the lateral margin of the scapula immediately distal to the infraglenoid tubercle; the footprint of attachment is approximately 3 cm long. Teres major takes origin from the remainder of the posterior aspect of the lateral border of the scapula. It is a bulky rhomboidal muscle passing anterior to the long head of triceps before attaching to the medial crest of the bicipital sulcus on the anteromedial aspect of the humerus, immediately behind and separate from the tendon of latissimus dorsi. The subscapular artery and its branch, the thoracodorsal artery, lie anterior to teres major, which is supplied by either or both arteries, accompanied by the thoracodorsal nerve. The circumflex scapular artery leaves the subscapular artery at or near the lower border of teres minor and courses posteriorly and medially to the posterior surface of the scapula between the origins of teres minor and teres major. As it does so, the circumflex scapular artery gives off a fasciocutaneous pedicle, the supply to the parascapular flap, which is a useful fasciocutaneous flap that can be rotated to cover cutaneous defects of the axilla and the back of the upper arm. Identification of this pedicle, which perforates the fascia vertically above the lateral border of the scapula, leads to the interval between teres minor and teres major and the circumflex scapular artery. The interval can be developed without detaching either muscle completely from the lateral border of the scapula. If the interval between teres minor and infraspinatus is then developed, the whole lateral border of the scapula can be exposed from the infraglenoid region to the inferior pole, without further muscular detachment. This is of value in the surgical treatment of scapular fractures, and obviates the need to elevate infraspinatus from its scapular attachment, as in the Judet approach (a technique that leads to weakness of infraspinatus).
Clinical Case

1. A 37-year-old man sustained multiple injuries in a motorcycle accident. His injuries included an infracoracoid brachial plexus injury, resulting in complete axillary nerve and suprascapular nerve palsies, and rupture of the intima of the axillary artery behind pectoralis minor, which required vascular grafting for reperfusion of the upper extremity. On examination 36 weeks postoperatively, there was poor rotator cuff function, with pain and limitation of external rotation and elevation. Three-dimensional CT images revealed malunion of a complex scapular body fracture (Fig. 39.10).

**FIG. 39.10**  
A. Describe the bony malunion seen in Fig. 39.10. What do the white, blue and grey arrows indicate?

Fig. 39.10A is an anteroposterior view and shows extensive heterotopic ossification within the clavipectoral fascia; the grey arrow marks the medial extent of this ossification. The white arrows mark widely displaced, fixed acromioclavicular separation. The blue arrow marks the tip of the coracoid process, which is tilted inferiorly by the weight of the arm and unopposed action of pectoralis minor. The clavicle is held in ventral rotation by the heterotopic ossification linking it to the coracoid. Fig. 39.10B is a coronal view. The white arrow marks malunion of the lateral border of the scapula; there is shortening and angular displacement of approximately 45°. The scapula is held forwards in relation to the clavicle. The blue arrow again shows the tip of the coracoid process. Fig. 39.10C is a posterolateral view and confirms the scapular body malunion with a complex fracture pattern. The white arrows indicate the major fracture exit lines superiorly through the spine of the scapula and laterally through the lateral border. Fig. 39.10D is a posterior view en face. The major fault is a curved fracture line (white line) between the lateral border of the scapula and the midpoint of the spine of the scapula. This had permitted the glenoid fossa, and therefore the shoulder joint, to rotate downwards, forwards and medially.

B. What is the clinical challenge for revision surgery?

The clinical challenge is three-fold: restoration of the scapular form and shape; restoration of the scapular suspension; and restoration of rotator cuff function (for external rotation of the shoulder). Fig. 39.11 illustrates the planning, positioning and extensile exposure for the three requirements of the intervention.
FIG. 39.11  Planning, positioning and extensile exposure for the three requirements of the intervention. The patient is lying on his right side, with the head to the upper right in figure parts B–D. The goals of reconstruction required an extensile approach to the infraclavicular space, the acromioclavicular joint and the scapula. With the patient placed in the lateral decubitus position, the arm could be freely moved and the entire scapula and periclavicular space exposed as needed. A, An incision (dotted line) was planned to permit elevation of the skin laterally. B, The incision was based on the circumflex scapular artery perforator (pink arrow). The white arrow marks the malunion of the spine of the scapula. C, The lateral border of the scapula was exposed using the fenestration approach as described in Video 39.4, with no muscle detachment from the scapular body. Deltoid was detached from the spine of the scapula and folded laterally, keeping the axillary nerve and posterior circumflex vessels laterally. The major fracture line of the spine of the scapula (white arrow) and the fracture line of the lateral border (marked by the forceps) were exposed by dissection under infraspinatus (ISP) without traction on the infraspinatus branch of the suprascapular nerve (to facilitate its recovery, if possible). The acromioclavicular separation was noted with the associated rupture of the distal attachment of trapezius, which characterizes this degree of separation (white arrow). This exposure permitted a curved osteotomy through the malunion of the scapular body and, once the heterotopic ossification had been excised from the clavipectoral fascia, correction of the malalignment and malrotation of the scapula. The osteotomy was then fixed with plates. D, The acromioclavicular joint was reconstructed using an allograft ligament replacement, and splinted with an internal plate. Finally, teres major (TMaj) was detached from the medial bicipital crest and transferred to the posterosuperior aspect of the greater tubercle of the humerus.
Deltoid was then repaired. Other abbreviations: TMin, teres minor.

C. Describe the changes seen in the postoperative radiographs (Fig. 39.12).

The postoperative radiographs show correction of the length and orientation of the lateral border of the scapula and of the alignment and length of the spine of the scapula. The shape and form of the scapula have been restored. This will optimize what function the rotator cuff might have, and create the appropriate length–tension relationship for optimal mechanical action of the transferred teres major. The acromioclavicular relationship has been realigned, so that scapular suspension has been restored. The glenoid fossa, and therefore the centre of rotation of the shoulder joint, are oriented anatomically with respect to the midline. The essence of the operation has been to place the shoulder joint in its correct position in space and so improve function in the shoulder girdle.
CHAPTER 40
Elbow and forearm

Adam C Watts, Dafydd S Edwards

The primary function of the elbow is to help position the hand in space. This is achieved by means of three joints: the radiocapitellar, humero-ulnar and proximal radio-ulnar joints. The functional range of movement has been described by Morrey et al as being 30–130° of flexion, 50° of pronation and 50° of supination, but for modern living more flexion is required.\(^1\)

**Core Procedures**

- Lateral, medial, anterior and posterior approaches to the elbow
- Approaches to the radius and ulna
Surgical surface anatomy

The medial and lateral epicondyles of the distal humerus are palpable on the inner and outer aspects of the elbow, respectively. Posteriorly, the tip of the olecranon lies midway between the two epicondyles. The ulnar nerve is found at the midpoint of a line drawn between the olecranon and the medial epicondyle. Midway down the humerus, the ulnar nerve lies between the medial intermuscular septum and the medial head of triceps. From there, it passes into a sulcus behind the medial epicondyle and continues distally to pass between the two heads of flexor carpi ulnaris. It is commonly compressed behind the medial epicondyle, causing a cubital tunnel syndrome.

The bulk of the lateral aspect of the forearm is formed by a group of muscles known as the ‘mobile wad of Henry’. The ‘wad’ consists of brachioradialis, extensor carpi radialis longus and extensor carpi radialis brevis. The distal tendon of biceps brachii can be palpated in the antecubital fossa by performing O'Driscoll's hook test. An intact tendon will allow the examiner to hook an index finger under the intact biceps tendon from the lateral side.
Clinical anatomy

Bones and joints

The proximal side of the elbow joint is formed by the distal end of the humerus. This flares into the lateral epicondyle and capitulum laterally, and the medial epicondyle and trochlea medially. (For the avoidance of doubt, ‘capitulum’ is the term used by anatomists, whereas ‘capitellum’ and ‘capitellar’ are commonly used by surgeons: all terms refer to the same structure). Anterior and posterior fossae accommodate the coronoid and olecranon processes, respectively, at the extremes of range of elbow movement. The two ulnar processes join at the bare area to create the greater sigmoid notch of the elbow, with a lateral and medial facet separated by a central ridge. The proximal radius consists of a head and neck, and a medial bicipital tuberosity, around which the biceps tendon winds to become attached to its dorsal aspect. The proximal surface of the radius is a shallow concave fovea that articulates with the capitulum. On its medial side, the cylindrical head of the radius articulates with the radial notch of the ulna to form the proximal radio-ulnar joint (Fig. 40.1).
FIG. 40.1  X-rays of the left elbow joint of an adult. A, Anteroposterior view. Key: 1, olecranon fossa; 2, medial humeral epicondyle; 3, shadow of olecranon superimposed on trochlea; 4, humero-ulnar joint; 5, radial head articulating with radial notch of ulna; 6, lateral humeral epicondyle; 7, capitulum; 8, humero-radial joint; 9, head of radius; 10, radial tuberosity. B, Lateral view. Key: 1, head of radius; 2, profile of capitulum; 3, profile of trochlea; 4, olecranon. (From S. Standring (ed.),
The primary constraints of the elbow include the humero-ulnar joint, the medial collateral ligament (MCL) and the lateral collateral ligament (LCL) complex.

The MCL consists of two functional parts that take origin from the anteroinferior portion of the medial humeral epicondyle. The anterior bundle is the strongest of all the elbow ligaments and inserts into the sublime tubercle on the medial surface of the coronoid. It resists valgus forces between 60° of flexion and full extension. The posterior bundle inserts into the medial surface of the olecranon.

The LCL complex has four components: the lateral ulnar collateral ligament (LUCL); anular ligament; radial collateral ligament (RCL) and accessory ligament. The RCL and LUCL take origin from the lateral epicondyle, where they blend with the muscular common extensor origin (CEO). The RCL and LUCL form a single broad band that inserts into the anular ligament and supinator crest. The LUCL is taut throughout the full range of elbow movement when a varus stress is applied. Injury to the LUCL results in a posterolateral rotatory instability (PLRI). The anular ligament is attached to the anterior and posterior margins of the radial notch of the proximal ulna and forms a sling around the radial head and neck, to which it has no attachment (Fig. 40.2).
Cubital fossa

The cubital fossa (antecubital fossa) forms part of the anterior aspect of the elbow and is in the shape of an inverted triangle. It is defined superiorly by an imaginary line joining the lateral and medial epicondyles, medially by the lateral border of pronator teres, and laterally by the medial border of brachioradialis. From superficial to deep, the roof of the triangle is formed by the skin, deep fascia of the forearm, cubital vein, medial cutaneous nerve of the forearm (a direct branch of the medial cord of the brachial plexus) and the bicipital aponeurosis. The deep contents, from medial to lateral, are the median nerve, the terminal branch of the brachial artery, the tendon of biceps
brachii, the superficial branch of the radial nerve and the posterior interosseous nerve. Brachialis forms the floor of the triangle.

**Muscles**

The elbow is primarily flexed by brachialis, which is attached anterior to the coronoid process of the ulna. Biceps brachii also contributes to flexion but is primarily a supinator of the forearm (Video 40.1). It inserts as two distinct heads into the radial tuberosity: the long head proximally and the short head distally. These are ensheathed by the lacertus fibrosus, which wraps around the flexor–pronator mass. Biceps brachii is innervated by the musculocutaneous nerve. Posteriorly, triceps is the primary extensor of the elbow. It has three heads: the long and lateral heads are superficial and tendinous distally, while the deep medial head is muscular almost to the point of its insertion. It is innervated by the radial nerve.

**Anterior compartment of the forearm**

**Superficial compartment**

The muscles of the superficial group all arise from the medial epicondyle, or common flexor origin (CFO).

Pronator teres has two heads. The principal head arises from the medial epicondylar ridge, while a smaller (ulnar) head originates from the medial surface of the coronoid process. Together, they cross the forearm obliquely and insert into the lateral border of the radius at its point of maximum convexity. The principal action of pronator teres is to pronate the forearm but it is also a weak flexor of the elbow. Pronator teres is innervated by the median nerve, which passes between the two heads of the muscle; this is a site of potential entrapment.

Flexor carpi radialis (FCR) originates from the medial epicondyle of the humerus and inserts into the base of the second and third metacarpals. The radial artery and median nerve lie lateral and medial to it, respectively, in the forearm. FCR is a flexor and abductor of the wrist joint and is innervated by the median nerve.

Flexor digitorum superficialis (FDS) arises from the medial epicondyle of the humerus, the sublime tubercle of the ulna (ulnar head) and the entire length of the anterior oblique line of the radius (radial head). The muscle gives rise to four tendons, which pass deep to the flexor retinaculum
(through the carpal tunnel) and insert into the bases of the middle phalanges of the index, middle, ring and little fingers. These flex the proximal interphalangeal joints of the fingers. FDS is innervated by the median nerve.

Palmaris longus is occasionally absent. When present, it originates at the common flexor origin and inserts into the palmar fascia as a long broad tendon that is closely related to the deeper median nerve. Palmaris longus is a weak flexor of the wrist. It is innervated by the median nerve.

Flexor carpi ulnaris (FCU) is the most dorsal tendon of the common flexor origin and has a broad secondary origin from the medial surface of the olecranon. At the leading edge is a fibrous band that connects the lateral epicondyle and olecranon (Osborne's ligament). It has a superficial fascia and a strong deep fascia (Osborne's fascia), which extends up to 9 cm from the medial epicondyle. Both can cause entrapment of the ulnar nerve. The tendon of FCU inserts into the pisiform and is a flexor and adductor of the wrist. FCU is innervated by the ulnar nerve.

Deep compartment

Flexor digitorum profundus (FDP) arises deep to the superficial tendons. It takes origin from the proximal three-quarters of the anterior and medial aspects of the ulna and the anterior ulnar half of the interosseous membrane. The muscle ends in four tendons in the forearm, which run through the flexor retinaculum and insert into the palmar surface of the bases of the distal phalanges. FDP is capable of flexing all the joints over which it passes but is the only muscle able to flex the distal interphalangeal joints. The medial part of FDP, i.e. the muscle bellies to the little and ring fingers, is innervated by the ulnar nerve. The lateral part, i.e. the muscle bellies to the middle and index fingers, is innervated by the anterior interosseous branch of the median nerve, C8 and T1.

Flexor pollicis longus (FPL) arises from the anterior surface of the radius distal to the anterior oblique line and inserts into the base of the distal phalanx of the thumb. It is the only flexor of the interphalangeal joint of the thumb and is innervated by the anterior interosseous nerve.

Pronator quadratus is a flat quadrangular muscle on the anterior aspect of the distal forearm. It arises from the distal quarter of the anteromedial shaft of the ulna and inserts into the distal quarter of the anterolateral shaft of the radius. It pronates the forearm and assists in maintaining stability of the distal radio-ulnar joint. Pronator quadratus is innervated by the anterior interosseous nerve.
Posterior compartment of the forearm

The common extensor origin (CEO) is an area on the anterior and lateral surfaces of the lateral epicondyle and is the origin of the common, or fused, tendon of extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi and extensor carpi ulnaris. At the wrist joint, the tendons are held in position by the extensor retinaculum, which is divided into six compartments (Table 40.1). Anconeus originates on the posterior aspect of the lateral epicondyle of the humerus. The muscle is triangular in shape and diverges to insert into the lateral side of the ulna. Posteriorly, its fibres blend with triceps. It is a weak extensor and dynamic stabilizer of the elbow and is innervated by the radial nerve.

**TABLE 40.1**

<table>
<thead>
<tr>
<th>Compartment number</th>
<th>Contents</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Abductor pollicis longus, extensor pollicis brevis</td>
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<tr>
<td>2</td>
<td>Extensor carpi radialis longus and brevis</td>
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<tr>
<td>3</td>
<td>Extensor pollicis longus</td>
</tr>
<tr>
<td>4</td>
<td>Extensor indicis, extensor digitorum</td>
</tr>
<tr>
<td>5</td>
<td>Extensor digiti minimi</td>
</tr>
<tr>
<td>6</td>
<td>Extensor carpi ulnaris</td>
</tr>
</tbody>
</table>

Brachioradialis arises from the upper two-thirds of the lateral epicondylar ridge. It becomes a flattened tendon as it reaches the midpoint of the forearm and subsequently inserts into the radial styloid. The radial nerve and artery are important relations of the posterior surface of the muscle and tendon. Brachioradialis is a flexor of the elbow and helps to bring the forearm into mid-pronation; it is innervated by the radial nerve.

Extensor carpi radialis longus (ECRL) arises deep to brachioradialis from the distal third of the lateral epicondylar ridge. It continues posterior to brachioradialis in the forearm before passing deep to the thumb muscles and inserting into the base of the second metacarpal. ECRL is an extensor and abductor of the wrist joint and is innervated by the radial nerve.

Supinator has two parts. The deep part originates from the supinator crest of the ulna and the superficial part from the lateral epicondyle, lateral collateral ligament and anular ligament. The muscle inserts into the neck and shaft of the radius. It is a supinator of the forearm, acting alone when the arm is in extension. Supinator is innervated by the posterior interosseous nerve, which passes between the two heads of the muscle; this is a site where
compression may occur.

Extensor carpi radialis brevis (ECRB) arises from the CEO, travels down the forearm deep to ECRL and inserts into the base of the third metacarpal. ECRB is an extensor and abductor of the wrist and is innervated by the posterior interosseous nerve.

Extensor digitorum (extensor digitorum communis) arises from the CEO and the antebrachial fascia of the forearm. In the forearm, the muscle divides into four tendons, which insert into the extensor expansion of the middle and distal phalanges of the index, middle, ring and little fingers. The tendons to the ring and little finger are often fused, with only a small slip passing to the little finger distally in the hand. Extensor digitorum is innervated by the posterior interosseous nerve.

Extensor indicis (proprius) arises from the posterior surface of the ulna and the adjacent interosseous membrane, and runs distally to insert ulnar to the tendon of extensor digitorum. It assists in extending the index finger but because this function is also served by the index tendon of extensor digitorum, the proprius tendon can be used for tendon transfer. Extensor indicis is innervated by the posterior interosseous nerve.

Extensor digiti minimi arises as a small tendinous slip from the CEO, which inserts, through its tendon, into the extensor expansion of the little finger. It is often joined by the small slip from extensor digitorum. Extensor digiti minimi is innervated by the posterior interosseous nerve.

Extensor carpi ulnaris (ECU) is the final and most distal muscle arising from the CEO. Distally, it inserts into the base of the fifth metacarpal. ECU is an extensor and adductor of the wrist and can easily be palpated in the groove of the ulnar styloid if such movement is resisted. It is innervated by the posterior interosseous nerve.

Abductor pollicis longus (APL) arises from the proximal and posterior surface of the ulna, the adjoining interosseous membrane and the middle third of the posterior surface of the radius. It descends on the lateral aspect of the forearm, having crossed superficial to the extensors of the wrist, where a painful intersection syndrome may arise. It inserts into the base of the first metacarpal and extends and abducts the thumb at the CMC joint. APL is innervated by the posterior interosseous nerve.

Extensor pollicis brevis (EPB) arises from the posterior surface of the radius, distal to abductor pollicis longus, and from the adjoining interosseous membrane. It inserts into the base of the proximal phalanx of the thumb and extends the metacarpophalangeal joint. EPB is innervated by
the posterior interosseous nerve.

Extensor pollicis longus (EPL) arises from the lateral, middle third and posterior surface of the ulna and the adjacent interosseous membrane. Having passed through the extensor retinaculum, it slings around Lister's tubercle to insert into the base of the distal phalanx of the thumb. It extends the interphalangeal joint and metacarpophalangeal joint of the thumb and is innervated by the posterior interosseous nerve.

**Interosseous membrane**

The interosseous membrane is a fibrous structure that links the shafts of the radius and ulna. It maintains the interosseous space during pronation and supination, and transmits loads from the radius to the ulna. The interosseous membrane consists of five parts, termed the proximal oblique, dorsal oblique, accessory, central and distal oblique bands (Fig. 40.3). The central band, thought to be the most important, passes between the radius and ulna at a mean angle of 21°; it maintains longitudinal stability, while the distal oblique band contributes to stability of the DRUJ. ⁵
FIG. 40.3  The five components of the interosseous membrane of the forearm.

The membrane is at risk in two distinct types of injury: the Essex-Lopresti injury and the Galeazzi fracture. The Essex-Lopresti injury was originally described as radial neck fracture with dissociation of the distal radial ulnar joint. However, this cannot occur without rupture of the central condensation of the membrane, which causes longitudinal instability. A Galeazzi fracture is described as a diaphysial fracture of the distal radius with disruption of the distal radio-ulnar joint. Typically with this injury, only the distal oblique band of the interosseous membrane is injured.

Innervation
Median nerve (C6, 7, 8, T1)
As it enters the cubital fossa, the median nerve (Video 40.1) lies on brachialis, deep to the bicipital aponeurosis. It leaves the fossa between the humeral and ulnar heads of pronator teres, passes superficial to the ulnar artery and gives off the anterior interosseous branch. It travels down the forearm on the surface of flexor digitorum profundus and deep to flexor digitorum superficialis. The anterior interosseous nerve arises just below the two heads of pronator teres and continues closely related to the anterior surface of the interosseous membrane. It ends deep to pronator quadratus, which it supplies.

Ulnar nerve (C8, T1)
At the elbow, the ulnar nerve runs behind the medial humeral epicondyle in a shallow groove enclosed by the arcuate (Osborne’s) ligament and enters the forearm between the two heads of flexor carpi ulnaris. As the nerve continues down the forearm, it lies deep to flexor carpi ulnaris on flexor digitorum profundus, medial to the ulnar artery. Occasionally, a transverse muscle, anconeus epitrochlearis, crosses between the medial epicondyle and olecranon, and may compress the nerve.

Radial nerve (C5, 6, 7, 8, T1)
The radial nerve enters the cubital fossa lying deep to brachioradialis. It divides into its terminal branches (superficial cutaneous branch and posterior interosseous nerve) as it passes over the lateral epicondyle on brachialis. The superficial cutaneous branch runs over supinator, pronator teres and flexor digitorum superficialis and deep to brachioradialis for the entire length of the forearm. The posterior interosseous nerve passes into the posterior compartment between the two heads of supinator and gives off its muscular terminal branches in the plane between the superficial and deep compartments.
Surgical approaches and considerations

The surgical approaches to the elbow and forearm are summarized in Table 40.2.

<table>
<thead>
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<th>Approach</th>
<th>Tissue plane</th>
<th>Indication</th>
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<td>Elbow</td>
<td>Lateral</td>
<td>Kocher: ECU–anconeus</td>
<td>Replacement/excision/ORIF radial head</td>
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<tr>
<td></td>
<td></td>
<td>Kaplan: ED–ECRL/ECRB</td>
<td>LCL repair</td>
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<tr>
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<td></td>
<td>ORIF-capitulum (capitellum)</td>
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<tr>
<td>Medial</td>
<td>Hotchkiss</td>
<td>FCU–PL/FCR</td>
<td>ORIF coronoid</td>
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<tr>
<td>Anterior</td>
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<td>Proximal Brachioradialis–brachialis</td>
<td>Neurovascular repairs</td>
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<td></td>
<td>Brachioradialis–PT</td>
<td>Biceps tendon repair</td>
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<tr>
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<td>Universal</td>
<td>Boyd: Lateral para-olecranon</td>
<td>ORIF distal humerus</td>
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<tr>
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<td></td>
<td></td>
<td>Removal of loose body</td>
</tr>
<tr>
<td>Forearm</td>
<td>Anterior</td>
<td>Henry: Brachioradialis–PT/FCR</td>
<td>ORIF/osteotomy radius</td>
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<td>Superficial radial nerve decompression</td>
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<td></td>
<td>Posterior</td>
<td>Thompson: Proximal ECRL/ED</td>
<td>ORIF/osteotomy radius</td>
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<td>Distal ECRB/EPL</td>
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<tr>
<td>Ulnar</td>
<td>Direct</td>
<td></td>
<td>ORIF/osteotomy radius</td>
</tr>
</tbody>
</table>

Abbreviations: ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; ED, extensor digitorum; FCR, flexor carpi radialis; FCU, flexor carpi ulnaris; LCL, lateral collateral ligament; ORIF, open reduction and internal fixation; PL, palmaris longus; PT, pronator teres.

**Lateral approach to the elbow**

**Kocher approach**

The skin incision starts posterior to the lateral epicondyle and extends along the line of the ulna approximately 10 cm distal to the olecranon. The fascia of the forearm is incised to reveal the internervous plane between ECU (innervated by the posterior interosseous nerve) and anconeus (innervated by the radial nerve). Injury to the posterior interosseous nerve can be avoided
by pronating the forearm fully during deep dissection. Once the internervous plane has been opened, the capsule of the elbow will be seen in its depth. The capsule can be incised to access the capitulum and radial head but care must be taken not to divide the lateral ulnar collateral ligament.

**Kaplan approach**

This anterolateral approach uses the internervous plane between extensor carpi radialis longus (radial nerve) and extensor digitorum (posterior interosseous nerve). The incision begins at the lateral epicondyle and curves distally down the forearm. On deeper dissection, first, extensor carpi radialis brevis is identified, then the transverse fibres of supinator. The distal extent of the approach is marked by supinator and the posterior interosseous nerve (which passes between the two heads of supinator).

**Medial approach to the elbow**

**Hotchkiss approach**

The medial approach popularized by Hotchkiss begins with a curvilinear incision centred over the medial epicondyle. Dissection is continued in the internervous plane between palmaris longus and flexor carpi radialis (median nerve), and flexor carpi ulnaris (ulnar nerve). The interval can be identified by a perforating vessel within the plane. The dissection continues from distal to proximal on the front of the ulna, preserving the anterior bundle of the medial collateral ligament: the joint can be opened anterior to this.

**Anterior approach to the elbow**

**Henry approach**

The incision starts superior to the anterior elbow crease, one finger's breadth lateral to the biceps tendon. It then extends distally in a ‘lazy S’ fashion to continue on the ulnar border of brachioradialis. Superficial dissection of the forearm fascia and bicipital aponeurosis reveals the contents of the cubital fossa. Proximally, the internervous plane lies between brachialis (musculocutaneous nerve) and brachioradialis (radial nerve). Distally, the plane is between brachioradialis and pronator teres (median nerve).
Posterior approach to the elbow

The global approach to the posterior aspect of the elbow begins with a single midline longitudinal incision through the skin. The ulnar nerve is identified and decompressed. A complete decompression involves release of the nerve from the medial intermuscular septum, Osborne's ligament and the two heads of FCU. Many ‘windows’ to the elbow joint have been described.

Alonso-Llames approach

This was originally described for the management of supracondylar fractures in children. Following the global incision, the medial and lateral borders of triceps are identified. Triceps is dissected from the lateral and medial intermuscular septa and elevated from the posterior aspect of the distal humerus. The joint capsule is then incised to access the joint.

Boyd lateral para-olecranon approach

Boyd described this approach for the management of Monteggia fracture–dislocations, fractures of the radial head and reconstruction of the anular ligament. Anconeus and supinator are elevated subperiosteally from the lateral surface of the ulna. The lateral collateral ligament can be released to improve access but its repair is recommended to restore stability.

Wrightington approach

The Wrightington approach uses a supinator crest osteotomy, which is repaired with bone anchors to improve healing. This interval can be extended proximally by separating the lateral one-third of triceps from the medial two-thirds while maintaining its insertion to the olecranon. This gives suitable exposure for the fixation of fractures of the distal humerus or elbow arthroplasty without having to detach triceps.

Trans-olecranon osteotomy

Attributed to MacAusland, the trans-olecranon approach gives good exposure to the whole elbow joint for the fixation of comminuted intra-articular fractures. Once the olecranon has been exposed, anconeus is elevated from the lateral aspect of the olecranon and FCU from its medial aspect. An incomplete chevron osteotomy is then fashioned with an oscillating saw and completed with an osteotome. The olecranon and triceps
are elevated proximally to expose the distal humerus. Anconeus can be elevated on a proximally based pedicle to preserve its nerve supply through this approach.

**Approaches to the forearm**

**Anterior approach to the radius/forearm (Henry approach)**

The incision starts at the anterior elbow crease one finger's breadth lateral to the biceps tendon. It continues in a linear fashion towards the radial styloid. In its proximal half, the internervous plane lies between brachioradialis (radial nerve) and pronator teres (median nerve). Distally it lies between brachioradialis and flexor carpi radialis (median nerve). Superficial dissection continues on the medial border of brachioradialis. Proximally, transverse blood vessels (the leash of Henry) will be encountered and must be cauterized. The superficial radial nerve lies on the posterior surface of brachioradialis and should be mobilized with the muscle to avoid damage. Staying lateral to the biceps tendon, the proximal third of the radius can be approached through supinator. To avoid damage to the posterior interosseous nerve, the forearm must be maximally supinated to reveal the most anterior part of the insertion of supinator, which can be detached. To approach the middle third of the radius, the forearm is pronated to reveal the lateral insertion of pronator teres, which can be detached. The distal third is approached by elevating the muscular insertion of flexor pollicis longus and pronator quadratus from the most lateral border of the radius and retracting them medially.

**Posterior approach to the radius/forearm (Thompson's approach)**

The incision starts anterior to the lateral epicondyle and extends to the ulnar border of Lister's tubercle at the wrist. Proximally, dissection continues between extensor carpi radialis brevis (radial nerve) and extensor digitorum (posterior interosseous nerve). Distally, the plane lies between extensor carpi radialis brevis and extensor pollicis longus (posterior interosseous nerve). The posterior interosseous nerve must be identified and protected to continue with this approach. It can be seen as it leaves the superficial and deep heads of supinator. With the forearm supinated, supinator can be detached from its anterior insertion and elevated subperiosteally so as not to
damage the nerve. The middle third of the radius can be seen by retracting extensor pollicis brevis and abductor pollicis longus. In the distal third, no deep dissection is required.

**Approach to the ulna**

The ulna is subcutaneous throughout its entire length in the forearm. The incision should be placed where the ulna is most easily palpable. This subcutaneous approach creates an internervous plane between extensor carpi ulnaris (posterior interosseous nerve) and flexor carpi ulnaris (ulnar nerve).

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**Tips and Anatomical Hazards**

The posterior interosseous nerve is at risk during approaches to the lateral side of the elbow. The Kaplan approach is favoured by some, as it takes the surgeon further away from the lateral ligament, but it does place the nerve at greater risk.

The nerve wraps around the radius about 4 cm distal to the radiocapitellar joint line and is endangered with plating of fractures of the proximal radius.

Retractors should never be placed around the front of the radius when using these lateral approaches, as they may compress the nerve.

The elbow can be approached using a combination of techniques to provide windows to the joint while preserving important soft tissue structures such as the collateral ligaments and tendon attachments, and avoiding neural structures. This is especially useful for arthrolysis surgery to treat the stiff elbow.

The close proximity of important nerves makes approaches to the elbow joint hazardous. A sound knowledge of the neural anatomy is required to prevent injury.
References

Single Best Answers

1. Which one of the following structures does NOT need to be released in complete decompression of the ulnar nerve at the elbow?
   A. Anconeus epitrochlearis
   B. Osborne's ligament
   C. The two heads of flexor carpi ulnaris
   D. Cubital tunnel
   E. Lateral intermuscular septum

   **Answer: E.**

2. Which one of the following muscles is NOT supplied by the posterior interosseous nerve?
   A. Extensor carpi radialis longus
   B. Extensor carpi radialis brevis
   C. Supinator
   D. Extensor indicis
   E. Extensor carpi ulnaris

   **Answer: A.**

3. Which one of the following approaches can NOT be utilized to access the posterior elbow?
   A. Wrightington approach
   B. Boyd approach
   C. MacAusland approach
   D. Henry approach
   E. Alonso-Llames approach
Answer: D. The Wrightington, Boyd, MacAusland and Alonso-Llames approaches all give access to the posterior aspect of the elbow. The Henry approach is one that is utilized to access the anterior aspect of the forearm.

4. Which one of the following muscles/tendons is occasionally absent?
   A. Flexor digitorum profundus
   B. Flexor digitorum superficialis
   C. Extensor indicis
   D. Palmaris longus
   E. Extensor digiti minimi

   Answer: D.

5. Which one of the following is a flexor of all the joints of the fingers?
   A. Flexor digitorum superficialis
   B. Flexor digitorum profundus
   C. Flexor pollicis longus
   D. Extensor digitorum
   E. Extensor digiti minimi

   Answer: B.
Clinical Cases

1. A 24-year-old right-hand-dominant manual worker presents with a sudden onset pain and swelling in the elbow, associated with weakness in supination. The onset of his symptoms was during heavy weightlifting.

   A. Describe the boundaries of the cubital fossa.
   The antecubital fossa forms part of the anterior aspect of the elbow and is in the shape of an inverted triangle. It is defined superiorly by an imaginary line joining the lateral and medial epicondyles, medially by the lateral border of pronator teres, and laterally by the medial border of brachioradialis. From superficial to deep, the roof of the triangle is formed by the skin, deep fascia of the forearm, cubital vein, medial cutaneous nerve of the forearm and the bicipital aponeurosis. The deep contents, from medial to lateral, are the median nerve, the terminal branch of the brachial artery, the tendon of biceps brachii, the superficial branch of the radial nerve and the posterior interosseous nerve. Brachialis forms the floor of the triangle.

   B. What are the specific risk factors for biceps tendon rupture?
   Eccentric loading, smoking and use of anabolic steroids.

   C. What clinical signs would you look for on examination to confirm a biceps rupture?
   A ‘Popeye sign’, visible in the upper arm due to shortening of the biceps; change in contour of the muscle, proximally; medial ecchymosis; a palpable defect; loss of more supination than flexion strength. The distal biceps tendon can be palpated by performing O’Driscoll’s hook test. The hook test is performed with the shoulder abducted by 90° while actively supinating the forearm with the elbow flexed to 90°. An intact tendon will permit the examiner to hook an index finger under the intact biceps tendon from the lateral side.

   D. What single radiological modality is most likely to confirm the diagnosis?
   An MRI of the elbow is the most sensitive modality for diagnosing a distal biceps rupture, which is best seen with the elbow imaged in the flexion/abduction/supination (FABS view) position.

2. A 49-year-old female presents with a gradual onset of worsening pain
in the medial aspect of the right elbow. She describes it as a
generalized dull ache, which is worse at night-time, radiates to the
ulnar border of the hand and is associated with altered sensation in
the little finger.

A. What is your differential diagnosis?
Medial epicondylitis; cubital tunnel syndrome (ulnar nerve entrapment);
cervical radiculopathy

B. What is the course and distribution of the ulnar nerve in the upper
limb?
The ulnar nerve arises from the medial cord of the brachial plexus (C8 and
T1 roots of the cervical spinal cord). The nerve passes distally in the arm
medial to the brachial artery and lying on coracobrachialis. At the midpoint
of the humerus, it leaves the anterior compartment by passing posteriorly
through the medial intermuscular septum. It continues between the septum
and the medial head of triceps. At the elbow, the ulnar nerve runs behind the
medial humeral epicondyle and enters the forearm between the two heads of
flexor carpi ulnaris. As it continues down the forearm, it lies deep to flexor
carpi ulnaris on flexor digitorum profundus, medial to the ulnar artery.

C. What are the causes and sites of ulnar entrapment in the upper
limb?
Between the two heads of flexor carpi ulnaris/aponeurosis (the most
common site); within the arcade of Struthers (hiatus in the medial
intermuscular septum); between Osborne's ligament and the medial
collateral ligament (MCL); medial head of triceps; medial intermuscular
septum; medial epicondyle; Guyon's canal of the wrist; anconeus
epitrochlearis (an anomalous muscle from the olecranon to the medial
epicondyle); aponeurosis of the proximal border of flexor digitorum
superficialis; fractures of the medial epicondyle; osteophytes on the medial
aspect of the elbow.

D. Describe the surface anatomy and surgical exposure of the ulnar nerve
at the elbow.
The medial and lateral epicondyles of the distal humerus are palpable on
the inner and outer aspects of the elbow, respectively. The tip of the
olecranon lies posteriorly, midway between the two epicondyles. The ulnar
nerve is found at the midpoint of a line drawn between the olecranon and the
medial epicondyle. With the patient in a lateral position, the elbow in a
gutter support and an upper limb tourniquet in place, a 10 cm curvilinear
incision is made directly over the course of the ulnar nerve in the cubital
tunnel. Skin flaps are developed as needed to identify the cubital tunnel and its overlying fascia. The nerve is most easily found in the proximal part of the wound; a complete decompression involves release of the nerve from the medial intermuscular septum, Osborne's ligament and the two heads of flexor carpi ulnaris.
Wrist and hand

Grey EB Giddins, David J Shewring

Core Procedures

• Dorsal and palmar approaches to the wrist, e.g. for access to joints, fractures; for tendon, ligament and nerve repair (see Table 41.1)

TABLE 41.1
Core procedures: wrist

<table>
<thead>
<tr>
<th>Region</th>
<th>Approach</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal</td>
<td>Arthroscopic</td>
<td>Triangulo-fibro-cartilaginous complex (TFCC) injuries, synovectomy, ganglia</td>
</tr>
<tr>
<td>Dorsal midline</td>
<td>Open reduction internal fixation (ORIF) fractures, wrist fusion, wrist replacement proximal row carpectomy, etc.</td>
<td></td>
</tr>
<tr>
<td>Mid-ulnar/dorso-ulnar</td>
<td>Access to distal radio-ulnar joint, TFCC</td>
<td></td>
</tr>
<tr>
<td>Anatomical snuffbox (De Quervain’s)</td>
<td>De Quervain’s release, ORIF scaphoid fracture, grafting scaphoid non-union</td>
<td></td>
</tr>
<tr>
<td>Palmar</td>
<td>Radial (Henry, trans-flexor carpi radialis, palmar extensile)</td>
<td>ORIF scaphoid fractures, palmar (volar) plate fixation, tendon and nerve repair</td>
</tr>
<tr>
<td>Ulnar</td>
<td>Carpal tunnel decompression, palmar ligament repair, ORIF Barton’s fracture</td>
<td></td>
</tr>
<tr>
<td>Midline</td>
<td>Exploration/repair of the median nerve, release of flexor tendons for spastic disorders, harvesting palmaris longus</td>
<td></td>
</tr>
</tbody>
</table>

• Dorsal, palmar and lateral approaches to the hand, e.g. for access to fractures; for tendon and nerve repair; for carpal tunnel release (see Table 41.2)
<table>
<thead>
<tr>
<th>Region</th>
<th>Approach</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal</td>
<td>Metacarpals</td>
<td>Fractures</td>
</tr>
<tr>
<td></td>
<td>Metacarpophalangeal (MCP) joints</td>
<td>Comminuted fractures of the metacarpal head, ‘fight bite’ injuries, MCP joint replacement</td>
</tr>
<tr>
<td></td>
<td>Proximal interphalangeal (PIP) joints</td>
<td>PIP joint fusion, replacement</td>
</tr>
<tr>
<td></td>
<td>Proximal and middle phalanges</td>
<td>Open reduction internal fixation (ORIF) fractures</td>
</tr>
<tr>
<td></td>
<td>Distal interphalangeal (DIP) joints</td>
<td>DIP joint fusion, palmar (volar) plate repair</td>
</tr>
<tr>
<td>Palmar</td>
<td>Carpal tunnel</td>
<td>Carpal tunnel release</td>
</tr>
<tr>
<td></td>
<td>Mid and distal palm</td>
<td>Fasciectomy, nerve and tendon repair</td>
</tr>
<tr>
<td></td>
<td>A1 pulleys</td>
<td>Trigger finger, washout of flexor tendon sheath infection</td>
</tr>
<tr>
<td></td>
<td>Digits</td>
<td>ORIF fractures, nerve and tendon repair</td>
</tr>
<tr>
<td></td>
<td>Base of proximal phalanx</td>
<td>ORIF fractures</td>
</tr>
<tr>
<td></td>
<td>Pulp and terminal phalanx</td>
<td>Drainage of pulp space infection</td>
</tr>
<tr>
<td>Lateral</td>
<td>Mid lateral</td>
<td>ORIF digital fractures</td>
</tr>
<tr>
<td></td>
<td>MCP joint of the thumb</td>
<td>Injuries of the radial and ulnar collateral ligaments</td>
</tr>
</tbody>
</table>

The key anatomical features of the wrist and hand are described in Chapter 36. There are, however, a number of specific anatomical factors to be considered when operating on the wrist and hand.
Surgical surface anatomy

The line of the wrist joint runs between the radial and ulnar styloid processes and is slightly curved proximally. It is represented on the palmar skin by the proximal of the two wrist creases. A tubercle (Lister's tubercle) is easily palpable on the dorsal aspect of the distal end of the radius; extensor pollicis longus grooves its ulnar aspect. In the wrist itself, the pisiform, the hook of the hamate, the tubercle of the scaphoid and the crest of the trapezium are all palpable. The radial artery is palpable to the lateral side of flexor carpi radialis; the median nerve, covered by palmaris longus, lies on the medial side of the tendon. If palmaris longus is absent (16%), the median nerve lies close to the skin surface, where it may be injured. Two of the four tendons of flexor digitorum superficialis can usually be palpated deep to the median nerve. Flexor carpi ulnaris is easily palpable on the ulnar aspect of the flexor surface of the wrist. The tendons of extensors carpi radialis longus and brevis, and extensor carpi ulnaris and extensor digitorum are palpable on the dorsal aspect of the wrist on resisted movements. Intraoperative radiographs (image intensifier) should clarify the location.

In the hand, all bones are palpable dorsally but are covered on the palmar surface by the tendons of flexors digitorum superficialis and profundus and by the small muscles of the hand. The palmar skin presents a number of skin creases but these are not helpful as points of reference. The superficial palmar arch lies at the level of the fully extended and partially abducted thumb. The deep palmar arch lies approximately 1 cm proximal to the superficial arch.

The terms ‘palmar’ and ‘volar’ are often used interchangeably in clinical practice, whereas the Terminologia Anatomica favours ‘palmar’; in this chapter, the term ‘palmar’ will be used.
Clinical anatomy/surgical approaches to the wrist

The anatomical bases of the principles of operating on the wrist are listed in Table 41.1.

It is essential to avoid damaging nerves. If tendons, vessels or bone are divided, these can be repaired and recovery is usually satisfactory. However, if nerves are divided and repaired, recovery is always incomplete in adults, although there may be excellent recovery in children.

In the wrist, the approaches may be dorsal (arthroscopic portals; dorsal midline incision; mid-ulnar/dorso-ulnar incision; De Quervain's release/anatomical snuffbox approach) or palmar (palmar radial; palmar midline; palmar ulnar).

Dorsal approaches

Arthroscopic portals

The arthroscopic portals are for access to the radiocarpal and mid-carpal joints. The radiocarpal portals are 3–4, 4–5 and 5 ulnar (5U), and 6 radial (6R)² (Fig. 41.1). Although a 6 ulnar (6U) portal has been used, it is not recommended because of the proximity of the superficial sensory branch of the ulnar nerve and therefore it will not be discussed. For the mid-carpal joints there are radial and ulnar mid-carpal portals.
**Radiocarpal portals**

The 3–4 portal is situated between the third and fourth dorsal compartments and gives access to the radial side of the radiocarpal joint and, with manipulation, to the ulnar side. The third dorsal compartment contains the tendon of extensor pollicis longus (EPL), which runs on the ulnar side of Lister's tubercle. The fourth dorsal compartment contains the tendons of the finger extensors. The clinical landmark is Lister's tubercle; the entry point is just distal and ulnar to the tubercle, which is found by palpation. The key to protecting the soft tissues is sharp dissection through the skin only and then blunt dissection through deeper tissues, typically with an artery clip, until the joint is entered. The skin incisions can be longitudinal or transverse. Transverse incisions seem more logical because they follow Langer's lines. Longitudinal incisions are more commonly used, probably as a legacy of arthroscopy of other joints.

The 4–5 portal is between the fourth and fifth dorsal compartments and primarily gives access to the ulnar half of the wrist joint. The fifth dorsal compartment contains the tendon of extensor digiti minimi (EDM). The clinical landmark is not obvious, but is essentially at the level of the distal radio-ulnar joint (DRUJ) and is found by palpation. The entry point is just distal to the distal radial articular surface.

The 5U portal is between the fifth and sixth dorsal compartments and gives access to the far ulnar side of the wrist joint. The sixth dorsal compartment contains the tendon of extensor carpi ulnaris (ECU), which normally is easily
palpable on the dorsum of the ulna. The entry point is just distal to the head of the ulna, radial to the ECU tendon.

**Mid-carpal portals**

The radial mid-carpal portal primarily gives access to the radial side of the mid-carpal joint. It does not have a definite landmark. The aim is to enter the mid-carpal joint between the capitate and the ulnar side of the scaphoid; the entry point is about 1 cm distal to and slightly ulnar to the 3–4 portal and is identified by palpation of the radial side of the mid-carpal joint. The ulnar mid-carpal portal primarily gives access to the ulnar side of the mid-carpal joint. It lies 1–1.5 cm to the ulnar side of the radial portal and is identified by palpation of the ulnar side of the mid-carpal joint. Often, one portal seems easier to enter than the other; once the portal is entered, the arthroscope can be inserted into the joint and the light shone across to identify the level of the mid-carpal joint.

**Dorsal midline incision**

The dorsal midline incision is the ‘work horse’ approach to the wrist (Fig. 41.2A). Some surgeons use this incision almost exclusively, although dorso-ulnar and dorsoradial incisions can also be used (see below). The skin incision runs in the midline of the wrist, typically 5–10 mm ulnar to Lister's tubercle. Some variation is allowed to access specific parts of the wrist joint. It is an extensile approach that can be extended up to the metacarpal heads: for example, for extensor tendon transfers, or proximally in the forearm. One of its advantages is that it uses a watershed between the dorsal sensory branches of the radial and ulnar nerves and is therefore safer and less likely to damage the terminal branches of the nerves and cause subsequent painful neuromas.

There are usually one or two large veins deep to the skin that cross the midline and require ligation. Deep to the veins, the extensor retinaculum runs across the whole width of the dorsum of the wrist. Various approaches can be taken. A longitudinal incision through the retinaculum is now less favoured. A zig-zag incision through the retinaculum is a recognized technique, as is an oblique incision in the line of the tendon of extensor digiti minimi, which is preferable to a true longitudinal incision. The retinaculum is raised from ulnar to radial (Fig. 41.2B), dividing the vertical septa that separate the compartments. It is important to identify the tendon of extensor pollicis longus (EPL) at Lister's tubercle and to preserve it. It does not necessarily need to be lifted from its tunnel, particularly in the distal half; in theory, leaving it there improves the line of pull of the tendon. Even if the EPL tendon rides out to the radial side of Lister's tubercle, this does not typically cause a functional problem (Fig. 41.2C,D).

The capsule of the wrist may be opened using the Mayo approach (Fig. 41.3). This is a ligament-sparing approach from the proximal radius to the triquetrum or just beyond, and then distal radial towards the trapezoid, creating a V-shaped flap with the base to the radial side. Variants of this are used. The capsule can be elevated from the distal radius in continuity with the periosteum but should subsequently be repaired. The radiocarpal and mid-carpal joints are then exposed. It is easy to get lost in the wrist and in particular to mistake the proximal pole of the capitate for the proximal pole
of the lunate. Their shapes are different and careful observation of other articulating bones, as well as longitudinal traction, will aid their correct identification. When closing, the capsule and retinaculum are repaired separately with absorbable or non-absorbable sutures.

![Image](Image.png)

**FIG. 41.3** The Mayo approach to the wrist capsule.

**Dorso-ulnar approach**

The dorso-ulnar approach is a longitudinal extensile incision that curves around the radial side of the ulnar styloid to avoid damage to the superficial sensory branch of the ulnar nerve. This nerve is very intolerant of injury, which often results in a painful neuroma. It should be identified if operating within 2–3 cm of the ulnar styloid or palmar to the midline. With the forearm in neutral the superficial sensory branch of the ulnar nerve runs truly mid-lateral, i.e. over the ulnar styloid. Depending on exactly what access is needed, the incision can be dorso-ulnar or even truly mid-ulnar, centred on the ulnar styloid in a line running proximally towards the tip of the olecranon. It is important to note that the skin of the forearm rotates quite significantly relative to the forearm bones. Thus an incision that is longitudinal in one position of the forearm will be rather more oblique in another (Fig. 41.4).
Deep to the superficial sensory branch of the ulnar nerve is the extensor retinaculum, lying over the sixth dorsal compartment. It continues ulnarwards and merges with the flexor retinaculum at the ulnar border of the forearm; the retinaculum is adherent to the subcutaneous (ulnar) border of the ulna. Approaches to the ulnar side of the joint and ulnar head can be longitudinal, overlying the tendon of extensor carpi ulnaris (ECU), retracting it either way, or with a more radial-based flap elevating the ECU tendon. The line of the incision will usually run between the fifth and sixth dorsal compartments. Below it are the capsule of the wrist and the attachments of the triangulo-fibro-cartilaginous complex (TFCC).

De Quervain's/dorsoradial approach (De Quervain's/snuffbox approach)
This incision can be longitudinal, transverse or a little oblique and is centred on, or proximal to, the radial styloid, which is palpable at the proximal palmar end of the anatomical snuffbox.

Deep to the skin is a layer of subcutaneous fat, beneath which runs the superficial sensory branch of the radial nerve. The nerve fans out from approximately 3 cm proximal to the wrist crease, and runs over the tendon of brachioradialis and the first dorsal compartment, which contains the tendons of abductor pollicis longus (APL) and extensor pollicis brevis (EPB). Almost any approach in this area will risk injury to this nerve, and it should therefore be formally identified and protected; injury will often produce a painful neuroma. Deep to the nerve are the tendons of the first and second dorsal compartments, the latter containing the tendons of extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB), and, more distally, the EPL tendon. Below them is the radial capsule of the wrist, which is typically opened longitudinally but can be opened transversely or obliquely, depending on surgical need. The dorsal branch of the radial artery runs obliquely from proximal radial to distal ulnar in the distal end of the anatomical snuffbox. Division is not usually problematic but should be avoided. The artery may sometimes be of use for revascularization procedures and so ideally it should be preserved.

**Palmar approaches**

**Palmar radial incision**

This is another extensile approach through a longitudinal incision based on the tendon of flexor carpi radialis (FCR). A small T-extension distally, about 1 cm in width at the level of the wrist crease, can be quite useful to avoid tension on the wound for approaches at the distal end of the distal radius. The key structure to preserve is the superficial sensory branch of the median nerve. It is easy to make the longitudinal incision a little too ulnar and, with an aggressive skin incision, cut through the nerve before it is identified. It is better to err on the radial side, aiming then to dissect longitudinally down the radial side of the FCR tendon. A little further radially is the radial artery and its venae comitantes but this is quite large and should be easy to identify. The incision can be extended distally and is typically slightly curved in the line of the scaphoid to approach the palmar side of the scaphoid. Having made a careful skin incision, it is sensible to use blunt dissection down to the FCR tendon, clearly identifying the tendon and thereafter incising deep to it.
through the radial side of the tendon sheath. Distal to this are the muscles of
the thenar eminence. The fascia can be incised in the line of the muscles,
which run obliquely from proximal ulnar to distal radial about 30° to the long
axis, and then dissected bluntly to avoid damage to the muscle fibres
themselves. The approach is developed through the centre of the bed of the
FCR tendon sheath, down to the radius. If the dissection is intended only to
expose the distal radius, it is important not to extend the approach too far
distally and risk damage to the palmar radial carpal ligaments, which may
result in stiffness. To gain access to the scaphoid, these ligaments are usually
divided, but if the scaphoid fracture is either in the mid waist or distal, then
it is normally possible to keep some of the proximal parts of the palmar
radial ligaments, particularly the radio-scapho-lunate ligament, which may
give better stability and less stiffness in the long term.

Deep to the tendon bed of FCR is the tendon of flexor pollicis longus (FPL),
which is identified by its muscle running to the level of the wrist joint and by
flexing of the thumb. This tendon is retracted radially, further protecting the
radial artery. A self-retaining retractor must be carefully positioned and
gently applied because overzealous use can cause damage to the median
nerve. Deep to this is pronator quadratus; it may be possible to retract the
muscle and to apply a plate to the radius beneath it, or just elevate its most
distal part. Often, the whole of pronator quadratus is elevated as an ulnar-
based flap. It is incised distally at the level of the watershed line of the distal
radius and then along the radial border of the distal radius. It is next raised
off the bone with a periosteal elevator. Reattachment is often futile and has
not been shown reliably to improve outcomes. Only a limited closure is
necessary, with repair of the capsule over the scaphoid and the distal bed of
the FCR tendon.

**Palmar midline incision**

This approach can be used for extension of a carpal tunnel release or for
approaches to the flexor compartment in the distal forearm. This is a midline
incision: that is, midway between the radial and ulnar styloid processes. If
the wrist crease is crossed, this should ideally be done in a zig-zag or oblique
manner to avoid a longitudinal incision across the flexor crease (Fig. 41.5).
The zig-zag need only be 3–4 mm across. Palmaris longus is deep to the skin,
if present (it is absent in about 16%), and the median nerve is deep to
palmaris longus. Dissection in this area needs to be careful, particularly if
palmaris longus is absent. It is important not to go either too deep or too
radial. The contents of the carpal tunnel (the digital flexor tendons and the median nerve) run deep to the fascia. Deeper dissection is facilitated by gentle spreading of the tendons to expose pronator quadratus and the radius and ulna. The palmar capsule of the wrist is distal to the radius and ulna. The wrist is not normally opened through this approach, but if it is, then a ligament-sparing incision is recommended. This is essentially transverse but oblique from proximal radial to distal ulnar in the line of the palmar carpal ligaments, similar to the extrinsic ligaments. The only closure needed is of the wrist capsule (if opened) and the skin.
Occasionally, several palmar transverse stab incisions (≤1 cm) are used over palmaris longus in order to harvest it for use as a tendon graft. Blunt dissection is carried out with scissors down to the tendon, which is lifted out through the incisions and identified prior to division.

**Palmar ulnar approach**

This approach is used to access the palmar/ulnar aspect of the distal radio-ulnar joint (DRUJ). It can be extended to access Guyon's canal by crossing the flexor crease of the wrist with zig-zag or oblique incisions. The key landmark is the pisiform. The incision should start 2–3 mm to the radial side of the
bone, going proximal from the wrist crease overlying the line of the DRUJ.

Deep to the incision is the flexor retinaculum and below that is the tendon of flexor carpi ulnaris (FCU); the ulnar neurovascular bundle lies deep and to its radial side. This bundle should be formally identified, protected and mobilized towards the ulnar side to give access to the DRUJ beneath pronator quadratus and the joint capsule. Either pronator quadratus can be retracted proximally or the distal third can be elevated from the distal ulna. Closure is typically of just the joint capsule and skin.
Clinical anatomy/surgical approaches to the hand

The anatomical bases of the principles of operating on the hand are listed in Table 41.2.

Dorsal approaches

Metacarpals

The metacarpals are approached through straight dorsal incisions. A longer single incision may be used to access two adjacent metacarpals. Larger veins need to be ligated; smaller vessels can be sealed using bipolar diathermy. On the radial side of the hand, the terminal branches of the superficial sensory branch of the radial nerve, and on the ulnar side, the terminal branches of the dorsal sensory branch of the ulnar nerve all need to be preserved. Access to the metacarpal bones is through a longitudinal incision directly down to bone through the intermuscular raphe between the interossei (which lie on either side of the metacarpal shaft) and the underlying periosteum. The raphe can be repaired later if carefully elevated from the shaft of the metacarpal in a single layer, which in theory improves stability and haemostasis.

Metacarpophalangeal joints

The metacarpophalangeal (MCP) joints are approached through a longitudinal incision directly over the joint. The extensor mechanism is split in the line of its fibres and the two halves retracted. This avoids damaging the sagittal bands to the side of the tendon, which might destabilize the tendon and also provides better access. The capsule is opened longitudinally and can be elevated from the metacarpal head and base of the proximal phalanx to increase the exposure. This approach is useful for dealing with comminuted fractures of the metacarpal head, as well as management of clenched fist ‘fight bite’ injuries to the MCP joints (Fig. 41.6).
Proximal interphalangeal joints

Either a straight longitudinal or a curved skin incision centred over the proximal interphalangeal (PIP) joint is made; some veins are usually encountered and require diathermy. The joint can be accessed either between the central slip and lateral band of the extensor mechanism or by a direct midline approach through the central slip, depending on the indication for surgery. If joint function is to be preserved and extensive access is not needed, an approach between the central slip and lateral band on one side or the other is less destructive and more forgiving. If the joint is to be fused, then a direct midline approach is preferable because this gives better access. The extensor tendon proximal to the joint is split and the central slip peeled away from the base of the middle phalanx. The underlying periosteum can be elevated from the distal part of the proximal phalanx. These structures can be repaired.

Proximal and middle phalanges

This approach is recommended when access to the dorsal aspect of the base of the phalanx is required. The shafts of the proximal or middle phalanges can easily be accessed through a straight dorsal approach, when the extensor tendon is split longitudinally to expose the phalanx. This approach may be associated with a postoperative extensor lag caused by adherence of the extensor tendon to the periosteum.
**Distal interphalangeal joints**

An H-shaped incision is best if the entire joint needs to be accessed, as when performing a fusion. A curved, oblique or transverse incision can also be used. If joint function is not to be preserved, as when fusing the joint, a transverse incision is made in the extensor tendon over the joint; the collateral ligaments are released or excised, and the joint can be opened up like a shotgun. If the palmar (volar) plate is released from the base of the distal phalanx, the exposure is maximized. If joint function is to be preserved, then either an H-shaped or an oblique skin incision is made and the extensor tendon retracted to one side. If the joint is hyperextended, the extensor tendon is relaxed and access is improved to the dorsal aspect of the joint.

**Palmar approaches**

**Carpal tunnel**

A curved longitudinal incision of 3–4 cm is made parallel to the thenar eminence in the deepest part of the sulcus between the thenar and hypothenar eminences. The incision is made in line with the ulnar border of the ring finger and about 6 mm ulnar to the thenar eminence in order to avoid the palmar cutaneous branch of the median nerve, which must not be damaged. The incision starts just distal to the transverse wrist crease ([Fig. 41.7](#)) but can be extended across the crease in a zig-zag manner if access to the distal wrist is needed. The subcutaneous fat is negotiated by separating the lobules rather than cutting them; a watershed between the lobules can usually be found. Any larger terminal branches of the palmar cutaneous and ulnar sensory nerves crossing the operative field are preserved if possible. The palmar fascia is incised and the fat beneath the proximal area of the fascia retracted. Division of the small vertical fascial tethering restraints within this fat will considerably facilitate this process. The flexor retinaculum and distal part of the antebrachial fascia can then be visualized and divided under direct vision.
Occasionally, thenar muscle can be seen extending across the midline of the retinaculum. Extra care should be taken in such circumstances because this may herald one of the anatomical variants of the motor branch of the median nerve. More particularly, an aberrant branch may arise from the body of the median nerve within the carpal tunnel and pierce the roof of the tunnel, which is formed by the flexor retinaculum.

**Approach to the mid and distal palm**

Zig-zag incisions are centred over the area to be accessed. If access to two rays is needed, as for a fasciectomy, the incisions can be joined with a transverse element, which can be left open if the skin is contracted, to allow correction of the flexed digits. The palmar fascia is found immediately deep to the skin. Perforating vessels that traverse the transverse palmar fascia to supply the overlying skin should be preserved. The flexor tendons and neurovascular bundles are deep to the longitudinal and transverse elements of the palmar fascia.

**A1 pulleys**

The A1 pulleys may need to be accessed in order to divide them in cases of ‘trigger finger’, or to wash out the flexor sheath in cases of flexor tendon sheath infection. The A1 pulleys are palmar to the metacarpal heads, which are palpable. Transverse, oblique or longitudinal incisions can be made to access a single pulley; if access is required to two or more pulleys, a transverse incision gives excellent access. After the skin is incised, the edges
are elevated with skin hooks to create tension on the underlying fat; this is pressed with a fresh blade longitudinally and in the midline of the tendon to allow it to separate. The fat can be separated from the pulley by inserting the points of closed dissecting scissors down to the surface of the pulley and gently spreading the tips longitudinally to expose the pulley. Care is taken to stay in the midline of the tendon to avoid the digital neurovascular bundles running in the fat to each side of the tendons.

**A1 pulley of the thumb**

The A1 pulley of the thumb is accessed through either a transverse incision at the base of the thumb or a V-shaped incision centred on the crease at the base of the thumb. The subcutaneous fat is separated as described above. The digital nerves are situated more in the midline of the operative field, which means that the radial digital nerve is particularly at risk as it crosses the operative field from the ulnar to the radial side of the thumb. As the procedure is typically undertaken with the thumb MCP joint in extension, this increases the vulnerability to injury of the digital nerves, which are subcutaneous.

**Digits**

The palmar approach to the digits should be essentially midline. A straight incision can be made with Z-plasties at each crease. The skin at the distal interphalangeal (DIP) joint transposes poorly and so a V-shaped incision centred on the crease is preferable. This approach gives particularly good access to both sides of the digit, as well as lengthening the incision, which makes it especially well suited to performing regional fasciectomy for Dupuytren’s disease (Fig. 41.8). Alternatively, a longitudinal oblique incision with the incision angled at each crease can be made. Where the flexion crease is wide, as at the MCP and PIP joints, two angles should be created, resulting in a more midline incision and better access. The subcutaneous fat is separated through the midline to access the flexor mechanism; it is important to remember that the digital neurovascular bundles reside in the fat at either side of the digit.
FIG. 41.8  
A, The incision marked for a palmar fasciectomy with a straight incision over the digit, angled at the distal joint crease, and at the creases in the palm.  
B, After fasciectomy the wound is being closed with Z-plasties at the proximal interphalangeal and metacarpophalangeal joint creases.

Z-plasty

Z-plasty is a transposition ‘random pattern’-type flap that employs the viscoelastic properties of the skin and its subsequent ability to remodel. It is used to increase the length of an incision and also to change the direction of an incision, converting a straight incision into one that is angulated. The most common version is the 60° Z-plasty in which the limbs of the Z are of equal length and the angles between the limbs are at 60°; the central limb is elongated by 75% when the two flaps are transposed. It is important to measure the angles when planning and marking because a common mistake is to make the angle too acute, usually at 45°. Multiple smaller Z-plasties can be used in series or V-Y-plasties can be used. The latter also convert some width to length, but the lengthening achieved is less than with Z-plasties.

Base of the proximal phalanx

Occasionally, access to the palmar aspect of the base of the proximal phalanx
and MCP joint will be needed: for example, when carrying out internal fixation of a displaced avulsion fracture of the base of the proximal phalanx. An angled incision is made on the relevant side of the palmar aspect of the hand, centred over the crease at the base of the digit and extending proximally into the palm. The digital nerve is protected and an approach is made dorsal to the flexor mechanism and palmar (volar) plate but palmar to the insertion of the collateral ligament. The metacarpal head and base of the proximal phalanx can then be visualized (Fig. 41.9).

![Fig. 41.9](image)

**Fig. 41.9** A palmar approach for an avulsion fracture from the base of the proximal phalanx. **A**, The marked incision, centred on the metacarpophalangeal joint. **B**, The fracture at the base of the proximal phalanx is being reduced with a skin hook, prior to fixation with a lag screw. The flexor mechanism is being retracted with a further skin hook.

**Pulp and terminal phalanx**

If access to the pulp and palmar surface of the terminal phalanx is required, a
longitudinal midline incision is made and can be extended proximally if necessary with an angled extension across the DIP joint crease. This uses the watershed between the territories of the two digital nerves and provides good access to the entire palmar surface of the terminal segment of the finger. There is a theoretical risk of scar tenderness but in practice this is rarely a problem. If access to both palmar and dorsal aspects of the terminal phalanx is required, it can be provided by a fish-mouth incision around the tip of the digit. The sterile matrix of the nail and paronychial folds can then be elevated from the terminal phalanx: removal of the nail plate will be necessary to facilitate this.

**Nail bed**

The nail plate must be removed if access to the sterile or germinal matrix of the nail is required. This can be done using the rounded end of a Mitchell’s trimmer in the manner of a small periosteal elevator in order to separate the nail plate from the underlying matrix with minimal damage to the matrix. The nail can be cleaned and replaced as a protective dressing at the end of the procedure and secured with a figure of eight stitch between the tip of the pulp and the eponychium. If access to the germinal matrix is needed, one or two oblique incisions are made proximally from the junctions of the eponychium and paronychium, and the eponychium is then elevated to expose the sterile matrix.

**Lateral approaches**

**Mid lateral approach**

A mid lateral approach gives good access to the shafts and condyles of the proximal and middle phalanges when dealing with fractures. A longitudinal incision is made at the junction of the dorsal and glabrous palmar skin. The proximal end of the incision is curved dorsally at the web to increase access (Fig. 41.10). The dorsal branch of the digital nerve is identified and protected. The nerve is somewhat variable in position but tends to be situated around the middle of the shaft of the proximal phalanx; it can be mobilized and retracted dorsally. The oblique and vertical retinacular fibres are incised and the extensor mechanism retracted dorsally to reveal the phalanx and lateral aspect of the PIP joint. The retinacular fibres are repaired at closure. For proximal access to the proximal phalanx, part of the lateral band can be excised on one side of the finger.
Fig. 41.10 A, B, A lateral approach for a spiral fracture of the proximal phalangeal shaft (arrow).

Metacarpophalangeal joint of the thumb

Ulnar side

Access to the ulnar aspect of the MCP joint of the thumb is necessary when dealing with injuries to the ulnar collateral ligament. An S-shaped incision is made, centred over the joint. The proximal limb of the incision is more dorsal and runs parallel to the extensor tendon; the distal limb is more palmar and extends along the junction of the dorsal and palmar glabrous skin (Fig. 41.11). A simple curved incision can also be made. The terminal branches of the superficial radial nerve are identified and protected. The posterior edge of the adductor aponeurosis, which inserts dorsally into the tendon of EPL, is identified and the aponeurosis is incised longitudinally from the mid point of its posterior edge and extended distally. The two leaves of the aponeurosis are retracted to reveal the MCP joint and collateral ligament beneath.
Radial side

Access to the radial aspect of the MCP joint of the thumb is necessary when dealing with injuries to the radial collateral ligament. An S-shaped incision is made, centred radially over the joint with the proximal limb of the incision more dorsal and the distal limb more palmar. The tendon and muscle of abductor pollicis brevis (APB) are exposed and split in line with its fibres, which are retracted to reveal the underlying radial collateral ligament. More extensive exposure of the base of the proximal phalanx can be obtained by elevating the insertion of the APB and periosteum from the base of the phalanx as a continuous layer, which can be repaired prior to closure.
Tips and Anatomical Hazards

Wrist

The flexor and extensor retinacula are essentially bands across the wrist that maintain the flexor and extensor tendons of the wrist and fingers close to the underlying skeleton and act as pulleys to prevent them bowstringing. Provided that part of the retinaculum is preserved for each tendon or tendon group, this will normally be sufficient to prevent bowstringing. Sometimes, allowing the tendon to lie outside the retinaculum can still give good function, such as with the EPL tendon.

It is important to be aware of the location of the superficial sensory branches of the main trunk nerves because these are especially prone to painful neuromas if damaged.

The superficial sensory branch of the median nerve arises from the radial side of the main trunk of the median nerve 5–6 cm proximal to the wrist crease and then usually runs in close proximity to the ulnar border of the FCR tendon sheath where it crosses the wrist. It then gives both radial and ulnar branches. It is important to avoid damaging the nerve, particularly at surgery around the FCR tendon. At operation, it is therefore important to identify the FCR tendon and incise the sheath on its radial side.

The superficial sensory branch of the ulnar nerve arises 5–6 cm proximal to the wrist, running from palmar/ulnar in a dorsal/distal direction. It crosses the ulnar styloid at the mid wrist; with the wrist in neutral, the superficial sensory branch largely overlies the ulnar styloid but is sometimes a little proximal or distal. With the forearm in pronation, the nerve, which is attached to the soft tissues, tends to run a little more anteriorly, and in supination it runs more dorsally. Any dissection within the last 2–3 cm of the forearm – that is, 2–3 cm proximal to the ulnar styloid – should involve active efforts either to find and protect the nerve or to avoid it clearly.

The superficial sensory branch of the radial nerve spreads out from the distal radial border of the forearm over the dorsoradial aspect of the hand, running over the tendon of EPL. It can run over quite a broad area that needs to be protected in any surgery around the radial or
dorsoradial border of the distal forearm and wrist.

Hand

Most of the underlying structures run longitudinally, which means that approaches are essentially longitudinal, giving best access and greater potential for extension of the incision if increased access is needed. The skin incision should always be planned and marked using a fine sterile skin marker. Existing wounds should ideally be incorporated into the incision, which should be carefully planned to avoid skin necrosis and scar contracture. Extensions branching from the middle of the original wound should be avoided because this converts a linear wound into a stellate wound with the potential for necrosis at the tips of the skin flaps.

The flexion creases run transversely; if these are traversed by a straight incision, there is a risk of a hypertrophic scar and subsequent scar contracture. Flexion creases should therefore be negotiated by angling the incision at each crease in a zig-zag manner, with the apex of the angle in the crease. The angle should not be too acute: to avoid ischaemia and necrosis at the tip of the flap, the ideal angle is approximately 60°. Straight incisions can be made through the flexion creases, which improves access to both sides of the digits, but such an incision should be closed using Z-plasties to avoid scar contracture.

The skin over the palmar surface of a digit is frequently inadequate where there is a significant flexion contracture of the PIP joint. In Dupuytren's disease, although there is no skin loss, the shortening of the diseased fascia allows the skin, which is viscoelastic, to shorten. Management of the skin is a major part of the treatment of Dupuytren's disease. Many techniques have been described and there are two broad classifications. ‘Redistribution’ techniques use the viscoelastic properties effectively to ‘redistribute’ the skin, and include skin-lengthening incisions and open palm techniques. Alternatively, the skin can be excised and replaced, usually with a full-thickness skin graft.

Palmar skin may be lost through trauma or surgically excised because of its extensive involvement with Dupuytren’s disease. Defects can be
covered using full thickness skin grafts, which provide excellent cover and are aesthetically satisfactory. They are more robust and have less tendency to split or contract than split skin grafts. The most convenient donor site is the medial aspect of the antecubital fossa, where the skin is loose and hairless. If a tangential elliptical incision is used, the resulting cosmetic defect at the donor site is satisfactory. The graft is perforated multiple times using a blade prior to application: this helps the graft to conform and reduces the chance of a haematoma forming beneath the graft.

The pulleys of the flexor sheath are well described but it is important to appreciate that the A1 pulleys do not necessarily follow the line of the resting position of the fingers exactly; rather, they follow the line of the spread-out position of the fingers – that is, the pulley in the index finger tends to be slightly more inclined from proximal ulnar to distal radial and vice versa in the little finger.
References


Single Best Answers

1. Which one of the following is described as the ‘work horse’ approach to the wrist?
   A. Palmar midline
   B. Dorso-ulnar
   C. De Quervain's
   D. Midline dorsal
   E. Palmar radial

   **Answer: D.** The midline dorsal longitudinal incision can be extended and can be used to address almost any problem on the dorsum of the wrist; it can be employed to access radial- and ulnar-sided wrist problems.

2. Which one of the following statements about the palmar cutaneous branch of the median nerve is correct?
   A. It arises from the ulnar side of the main trunk
   B. It passes to the radial side of flexor carpi ulnaris
   C. It has a radial branch
   D. It is at no significant risk during carpal tunnel surgery
   E. It supplies the skin over the dorsal web space

   **Answer: C.** The cutaneous or superficial sensory branch of the median nerve arises approximately 6 cm proximal to the wrist crease and runs along the ulnar border of the flexor carpi radialis tendon until it crosses the wrist, when it spreads both radially over the skin overlying the thenar eminence and ulnarly over the mid-proximal palm. It is at particular risk in carpal tunnel surgery and volar plating of the distal radius.

3. Which one of the following statements about incisions in the
hand is correct?
A. They should cross the skin creases at 90°
B. They should avoid pre-existing scars
C. They should be closed in a zig-zag manner with an apex angle of 30°
D. They may be prone to necrosis if misplaced
E. They should sacrifice the perforating palmar vessels

Answer: D. Dorsal scars can be longitudinal but palmar (volar) scars should zig-zag across the flexor creases with apex angles of 30–60°. They should be raised with the perforating vessels where possible. If these principles are not followed, flap tip necrosis may occur, especially with very narrow flaps (<30° apex angle) and if very thinned: that is, dividing the perforating vessels.

4. Which one of the following statements about the incision for open carpal tunnel decompression is correct?
A. It should curve towards the radial side of the retinaculum
B. It risks injury to the motor branch of the median nerve
C. It regularly involves dividing part of the thenar muscles
D. It risks injury to flexor carpi radialis
E. It risks injury to the triangulo-fibro-cartilaginous complex (TFCC)

Answer: B. At open carpal tunnel release, the scar should head proximally and run more towards the ulnar side to reduce the risk of injury to the median nerve. Muscle fibres from the hypothenar eminence may need to be divided. Division of muscle fibres from the thenar eminence implies that the incision is too radial and places important structures at risk. The tendon of flexor carpi radialis and the TFCC should be nowhere near this
5. Which one of the following statements about the A1 pulleys of the fingers is correct?

A. They lie palmar to the metacarpal heads
B. They should be approached only through a longitudinal incision
C. They lie immediately under the skin
D. They are crossed by the radial digital nerve towards the midline
E. They should always be closed if incised

**Answer: A.** The A1 pulleys lie over the metacarpal head. They can be approached through a transverse longitudinal or oblique incision but the thumb flexor crease should not be divided longitudinally. A layer of fat under the skin is often thinner over the thumb A1 pulley. The digital nerves run well to either side of the pulley and at operation they can be either identified and protected, or avoided. The pulleys will reform enlarged after division; this is rarely a functional problem and so the A1 pulleys do not need to be repaired.
Clinical Cases

1. A fit 55-year-old male presents with pain and paraesthesiae in the ulnar 1½ fingers with weakness of the intrinsic muscles, flexion of the ring and little fingers, and adduction of the thumb. On examination, there is a degree of clawing of the ring and little fingers and intrinsic muscle wasting.

A. What is the likely diagnosis?
Ulnar nerve compression in Guyon's canal.

B. What is the differential diagnosis?
Compression of the ulnar nerve in the cubital canal. However, more proximal compression tends to result in less clawing but greater involvement of the extrinsic muscles innervated by the ulnar nerve. A Tinel sign may be positive over the cubital canal.

C. What are the possible causes of this condition?
Repetitive or prolonged compression of the ulnar nerve in Guyon's canal can be seen in cyclists and is known as a handlebar palsy. The most common pathological condition is a ganglion cyst in the canal but any space-occupying lesion or inflammation can cause it, as can fractures and non-unions of the hook of the hamate.

D. How would you investigate it?
X-rays and CT scans are helpful to exclude fracture or other degenerative conditions. An MRI will detect most space-occupying lesions or inflammatory change within the canal. Arteriography is indicated if abnormalities of the ulnar artery are likely but these are rare. Nerve conduction studies will localize the lesion.

E. What is the management?
Avoidance of repetitive injury, if present; decompression of the canal with excision of the injurious pathology as identified; or tendon transfers in cases of chronic irreversible paralysis.

2. A fit 63-year-old female falls on her dominant outstretched hand and sustains a comminuted fracture of the distal end of the radius and ulna. She also notes persistent pain, numbness and tingling in the thumb, index and middle fingers of the hand.
A. What is the likely diagnosis?
Compression of the median nerve in the carpal tunnel by haematoma or fracture fragments. There may be direct injury to the median nerve.

B. What is the appropriate management of her condition?
Urgent open reduction and internal fixation of the fracture with exploration and decompression of the carpal tunnel.

C. What surgical approach(es) might be used if surgery is considered?
A midline palmar or Henry approach to the distal forearm, extending into the carpal tunnel.

D. What are the potential complications of this injury?
Infection; fracture non-union and malunion; injury to the median nerve, including its recurrent motor and palmar cutaneous branches; recurrent compression; and complex regional pain syndrome type 2, among others.
SECTION 6
Thorax

OUTLINE

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Overview of the thorax and diaphragm and surgical anatomy of the chest wall

Edward Black, Steven C Griffin, Arvind Singh, Inder paul Birdi

Core Procedures

- Chest drain (tube) insertion
- Sternotomy
- Three-port thoracoscopic approach
- Posterolateral thoracotomy
- Anterolateral thoracotomy
- Left anterior thoracotomy
- Left thoraco-abdominal incision
- Right anterior mini-thoracotomy and minimally invasive approach to the mitral valve
- Hemi-sternotomy and minimally invasive approach to the aortic valve

The chest wall is commonly affected in patients with both blunt and penetrating thoracic injury. The surgical approach to rib fractures, sternal fractures, flail chest and thoracic spine trauma, the management of wall deformities or tumours, and access to thoracic viscera all require a detailed understanding of the anatomy of the chest wall.
Development of the chest wall

Several congenital anomalies of the chest wall that lend themselves to surgical correction are seen in clinical practice.

Ribs develop from the costal processes of the thoracic vertebrae. It is important to note that costal processes of other vertebrae do not form ribs, possibly as a result of differential gene expressions and cellular interactions in the precursor tissues; when this process is disturbed, extra ribs may form, as in the case of cervical or lumbar ribs. The sternum develops from paired longitudinal condensations of somatic mesoderm that fuse in the midline to form a cartilaginous plate. Ossification centres form along this cartilaginous model in a segmental fashion. While those for the body fuse, that of manubrium remains separate; the xiphoid centre does not ossify until after birth.

The diaphragm develops from four sources: the lateral body wall; septum transversum; pleuropertitoneal canal; and mesentery of the oesophagus. Deficits in any of these sources produce a hernia: for example, a posterolateral defect as a result of a deficit in the contribution made by the pleuropertitoneal canals.

The ribs at birth are horizontal and the muscle efficiency is low: the newborn and infant ventilation is therefore predominantly abdominal. With the growth of the abdomen and as the ribs acquire their oblique orientation, the diaphragm increases the dome configuration while the baby's crawling and walking movements allow the abdominal breathing at birth to improve the component of chest ventilation gradually.

Surgical treatment of pes excavatum

Pes excavatum is thought to be due to overgrowth of the costal cartilage. The timing of surgery is in either late adolescence or early adulthood because earlier repairs are beset with constrictive chest wall effects and recurrences. In the open procedure (Ravitch), the patient is supine and the defect is approached via a standard sternotomy incision; the costal cartilages are raised from the perichondrium and divided at the sternocostal junctions. An anterior sternotomy allows placement of the sternum normally and a metal strut is passed behind the sternum and kept in place for a minimum of 1 year.

In the minimally invasive Nuss procedure, two inframammary incisions are made from the mid-clavicular line and extended laterally, on either side of
the depression, 2–3 cm proximal to the xiphoid. These are tunnelled through the skin to the chosen intercostal space. With the use of guides, a metal bar is then introduced retrosternally from one end of the incision and exits through the opposite incision. The bar is introduced with the convex side posterior; it is then turned to face anteriorly, and is held in place using stabilizers on either end for 2–4 years.
Surface anatomy of the chest wall

The manubriosternal angle is usually more pronounced in men than women. It is palpable at the junction of the manubrium with the sternal body and serves as a useful landmark for the level of the sternal plane and the medial ends of the second costal cartilages, and so offers an accurate point at which to start counting ribs. In most adults, the sternal angle is located between the fourth thoracic vertebra and the upper half of the fifth thoracic vertebra (it varies from the lower half of the second thoracic vertebra to the lower half of the sixth thoracic vertebra, a distance of about 8 cm); the plane lies at a slightly higher vertebral level in women. The sternal plane represents the lower border of the superior mediastinum, and at this point, the right and left pleurae are in contact with each other: it is therefore a useful starting point when delineating the surface markings of the parietal pleura. The sternal plane is conventionally described as lying over the tracheal bifurcation, the concavity of the aortic arch and the point where the azygos vein enters the superior vena cava. CT analysis places these three major surface landmarks typically a little lower, at the level of the fifth or sixth thoracic vertebra (Fig. 42.1).
FIG. 42.1  Surface anatomy of the great vessels and tracheobronchial tree relative to bony landmarks. Key: 1, internal jugular vein; 2, subclavian vein; 3, formation of the brachiocephalic vein posterior to the sternoclavicular joints; 4, formation of the superior vena cava, posterior to the right second costal cartilage or first intercostal space; 5, manubriosternal joint; 6, concavity of the aortic arch, typically sitting inferior to the sternal plane, level with the upper half of the fifth thoracic vertebra; 7, azygos vein entering the superior vena cava, typically sitting inferior to the sternal plane, level with the lower half of the fifth thoracic vertebra; 8, tracheal bifurcation, typically sitting inferior to the sternal plane, level with the upper half of the sixth thoracic vertebra; 9, bifurcation of the pulmonary trunk, level with the upper half of the sixth thoracic vertebra, approximately 3 cm inferior to the sternal angle. (Redrawn with permission from S. Mirjalili, S. Hale, T. Buckenham, et al., A reappraisal of adult thoracic surface anatomy, Clin. Anat. 25 (2012) 827–34.)

The xiphisternal joint and xiphoid process are palpable at the inferior end of the sternum; the joint usually lies at the level of the ninth thoracic vertebra. The costal margin is palpable passing inferolaterally from the xiphisternum. Posteriorly, the free ends of the eleventh and twelfth ribs may be palpable and the spinous processes of the thoracic vertebrae are palpable. The spinous process of the first thoracic vertebra sits below that of the seventh cervical vertebra (vertebra prominens) and is often more prominent. Tracing the twelfth rib superomedially aids identification of the spinous process of the twelfth thoracic vertebra. The angles of the ribs are palpable several centimetres lateral to the spinous processes of the vertebrae. The surface anatomy of the posterior chest wall is covered in Chapters 30 and 33. Radiological studies of cross-sectional imaging have revealed variations in surface anatomy affected by age, gender, posture, phase of respiration, build
and ethnicity\(^1\) (Table 42.1).

**TABLE 42.1**

Landmarks used in common surgical procedures involving the chest

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Structure</th>
<th>Applied aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suprasternal notch</td>
<td>Upper border of manubrium sterni</td>
<td>Incision for mediastinoscopy, median sternotomy</td>
</tr>
<tr>
<td>Anterior axillary fold</td>
<td>Lower border of pectoralis major</td>
<td>Siting of axillary ports for minimally invasive operations, chest drains</td>
</tr>
<tr>
<td>Posterior axillary fold</td>
<td>Lower border of latissimus dorsi</td>
<td>Siting of axillary ports for minimally invasive operations, chest drains</td>
</tr>
<tr>
<td>Manubriosternal joint</td>
<td>Second costal cartilage</td>
<td>Counting of ribs and intercostal spaces</td>
</tr>
<tr>
<td>Sternal plane</td>
<td>Horizontal plane at manubriosternal joint</td>
<td>Separation of superior mediastinum from rest of mediastinum</td>
</tr>
<tr>
<td>Sternum</td>
<td>Midline bone anteriorly from manubrium to xiphoid</td>
<td>Guide for midline incisions, insertion of costal cartilages on its lateral edge</td>
</tr>
<tr>
<td>Xiphoid process</td>
<td>Lowermost part of sternum</td>
<td>Subxiphoid pericardial tap or drainage</td>
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<tr>
<td>Costal margin</td>
<td>Cartilaginous ends of seventh to tenth ribs</td>
<td>Palpation of lower edge of thoracic cage with liver, spleen and kidneys in immediate relation</td>
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<tr>
<td>Inferior angle of scapula</td>
<td>Located by following medial border of scapula to its inferior end</td>
<td>Landmark for pleural tap, planning of incision for posterolateral thoracotomy</td>
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Clinical anatomy of the Thorax

The thorax is the upper part of the trunk. It consists of an external musculoskeletal cage, the thoracic or chest wall, and an internal cavity that contains the heart, lungs, oesophagus, trachea and principal bronchi, thymus, vagus and phrenic nerves, right and left sympathetic trunks, thoracic duct, lymph nodes, and major systemic and pulmonary blood vessels. Inferiorly, the thorax is separated from the abdominal cavity by the diaphragm; superiorly, it communicates with the neck and the upper limbs (Video 42.1).

The skin and soft tissues of the chest wall cover a musculoskeletal frame consisting of twelve pairs of ribs, which articulate with twelve thoracic vertebrae posteriorly and (except for the last two pairs of ribs) with the sternum anteriorly, via their costal cartilages; intrinsic muscles and muscles that connect the chest wall with the upper limb and the vertebral column; and numerous blood and lymphatic vessels and nerves that supply the components of the musculoskeletal frame and the overlying skin and breast tissue.

The skeletal framework of the thoracic wall provides extensive attachment sites for muscles associated functionally with the neck, abdomen, back and upper limbs. Some of them (scalenes, infrahyoid strap muscles, sternocleidomastoid, serratus anterior, pectoralis major and minor, external and internal obliques, and rectus abdominis) function as accessory muscles of respiration, although they are usually active only during forced respiration. The thoracic wall offers protection to some of the abdominal viscera: the greater part of the liver lies under the right dome of the diaphragm; the stomach and spleen lie under the left dome of the diaphragm; and the posterior aspects of the superior poles of the kidneys lie on the diaphragm and are anterior to the twelfth rib on the right, and to the eleventh and twelfth ribs on the left.

Thoracic cavity

The right and left pleural cavities are separate compartments on either side of the mediastinum. Each encloses a lung and its associated bronchial tree, and vessels, nerves and lymphatics. The left pleural cavity is the smaller of the two pleural cavities because the heart extends further to the left (Chs 46 and 47). The mediastinum lies between the right and left pleural sacs in and
near the median sagittal plane of the chest. It extends from the sternum anteriorly to the vertebral column posteriorly. A horizontal plane passing through the manubriosternal joint, and the intervertebral disc between the fourth and fifth thoracic vertebrae separates the mediastinum into superior and inferior portions.

Bones and joints

The thoracic skeleton consists of twelve thoracic vertebrae and their intervening intervertebral discs (midline, posterior); twelve pairs of ribs and their costal cartilages (predominantly lateral); and the sternum (midline, anterior). When articulated, they form an irregularly shaped osteocartilaginous cylinder, reniform in horizontal section, which is narrow above, broad below, flattened anteroposteriorly and longer behind. Laterally, the thoracic cage is convex and is formed by the ribs; anteriorly, it is slightly convex and is formed by the sternum and the distal parts of the ribs and their costal cartilages.

Thoracic vertebrae

The twelve thoracic vertebrae have the following typical features: small bodies that bear costal facets for articulation with the head of ribs; transverse processes with articular facets for the tubercles of ribs; round vertebral foramina; and long thoracic spines. The pedicles form the intervertebral foramina for nerve passages while the laminae serve as attachment points for the interlaminar ligaments.

Ribs

The ribs form the greater part of the thoracic skeleton and articulate posteriorly with the thoracic vertebrae. Their number may be increased by cervical or lumbar ribs or reduced if the twelfth pair is absent. The first seven pairs of ‘true’ ribs articulate with the sternum by costal cartilages; the lower five ‘false’ ribs either join the superjacent costal cartilage or ‘float’ free at their anterior ends as relatively small and delicate structures tipped with cartilage. The tenth rib may also float: the incidence varies from 35% to 70%, depending on ancestry.

The ribs and costal cartilages provide the necessary stiff support for the extrinsic muscles (pectoralis major and minor, serratus anterior, diaphragm) to exert outward force of the chest, thus expanding the lungs and resulting in
inhalation. Without the ribs, the chest will collapse down on to the lung. This can be exploited by thoracoplasty, a surgical procedure to remove the ribcage and collapse the chest wall on to a destroyed lung, such as may occur with severe infections of the lung (Fig. 42.2).
A typical rib has a shaft and anterior (costal) and posterior (vertebral) ends. The smooth internal surface of the shaft is marked by a costal groove, bounded below by the inferior border. The posterior end has a head, neck and tubercle. The head presents two facets, separated by a transverse crest; the lower and larger facet articulates with the body of the corresponding vertebra, and the crest is attached to the intervertebral disc above. In situ, typical ribs present medial and lateral surfaces and superior and inferior borders. The first rib has superior and inferior surfaces and medial and lateral borders. The posterolateral curvature of the ribs, from their vertebral ends to the angles, produces a deep internal groove, the paravertebral gutter, on either side of the vertebral column. The ribs and costal cartilages are separated by intercostal spaces, which are deeper anteriorly and between the upper ribs. Each space is occupied by three layers of flat muscles and their aponeuroses, neurovascular bundles and lymphatic channels.

The medial border of the first ribs on each side, together with the body of the first thoracic vertebra posteriorly and the superior border of the manubrium sterni anteriorly, forms the bony margins of the thoracic inlet;
structures that pass between the thorax and the upper limb therefore pass over the first rib, the apices of the lungs and the apical pleurae, and may be damaged in pathologies affecting the first rib, including fractures and tumours.

**Thoracic outlet syndrome**

In this condition, the subclavian vessels and/or the brachial plexus are compressed as they exit the thorax via the space between the first rib, the clavicle and the scalene triangle. Patients typically complain of pain and paraesthesiae in the arm, hand or finger. Thoracic outlet syndrome is most commonly neurogenic; venous and arterial thoracic outlet syndromes are less common. Treatment involves resection of the first rib and scalenectomy.

In the core common axillary approach, the patient is placed in the lateral position with the axilla, arm and chest wall prepared. The arm is held in place using retractors. A transverse incision is made, extending between latissimus dorsi and pectoralis major, taking care not to injure the long thoracic or intercostobrachial nerves. The brachial plexus and subclavian artery are visualized within the axilla (Ch. 38). All muscular attachments are dissected from the first rib using blunt dissection and periosteal elevation; once the lower border is free, the scalene muscles are identified, isolated and divided, and the first rib is resected using bone cutters. If a cervical rib is present, it is excised at this time. The subclavian vein anteriorly, the first thoracic nerve root posteriorly and the pleura are all at risk during this procedure.

**Sternum**

The sternum is an elongated, flattened bone that forms the middle portion of the anterior wall of the thorax and the anterior boundary of the mediastinum. It articulates with the clavicles at the sternoclavicular joints and with the cartilages of the first seven pairs of ribs. It is divided into a manubrium, body and xiphoid process. The manubrium is level with the third and fourth thoracic vertebrae; its superior border contains a central jugular (suprasternal) notch between two oval fossae, the clavicular notches, for articulation with the sternal ends of the clavicles (see Fig. 42.1). The body of the sternum is level with the fifth to ninth thoracic vertebrae. It articulates with the manubrium at the level of the sternal angle (manubriosternal joint, angle of Louis), which typically lies opposite the inferior border of the body of the fourth thoracic vertebra. Asymmetry is common: the manubriosternal joint may not form an angle or the joint/angle may be displaced more
inferiorly. The xiphoid process is in the epigastrium. The anterior surface of the sternum is subcutaneous and facilitates procedures through the sternum, including punctures and access to the heart. The arch of the aorta and its main branches, the brachiocephalic vein, pleura and lungs are posterior relations of the manubrium. The heart and pericardium, sternopericardial ligaments and thymus are posterior relations of the body of the sternum. The internal thoracic (mammary) artery, a key source of grafts for artery revascularization, runs close to the lateral parasternal line. A number of muscles are attached to the sternum: sternothyroid, sternohyoid, sternocleidomastoid, pectoralis major, transversus thoracis (sternocostalis) and the diaphragm.

Sternal clefts and bifid xiphoid processes represent products of sternal maldevelopment that occasionally presents challenges to clinicians.

Intervertebral joints are described in Chapter 31.

**Muscles of the chest wall**

**Muscles of the anterior chest wall**

The intrinsic muscles of the chest wall are the intercostals, subcostales, transversus thoracis, levatores costarum, serratus posterior and, occasionally, sternalis. The extrinsic muscles are the scapular muscles and the muscles that connect the upper limb, chest wall and vertebrae: that is, trapezius, latissimus dorsi, rhomboids major and minor, levator scapulae, pectorales major and minor, subclavius, supra- and infraspinatus, teres major and teres minor. Various combinations of these muscles will be encountered during different surgical approaches to the thorax.

**Intercostal muscles**

Eleven pairs of external intercostal muscles extend from the tubercles of the ribs, where they blend with the posterior fibres of the superior costotransverse ligaments, almost to the costal cartilages, where each continues forwards to the sternum as an aponeurotic layer, the external intercostal membrane. Eleven pairs of internal intercostal muscles begin anteriorly at the sternum, in the interspaces between the cartilages of the true ribs, and at the anterior extremities of the cartilages of the ‘false’ ribs; they are thickest in this intercartilaginous (parasternal) part. The internal intercostal muscles continue back as far as the posterior costal angles, where each is replaced by an aponeurotic layer, the internal intercostal membrane,
continuous posteriorly with the anterior fibres of a superior costotransverse ligament, and anteriorly with the fascia between the internal and external intercostal muscles. Each muscle descends from the floor of a costal groove and adjacent costal cartilage, and inserts into the upper border of the rib below; their fibres are directed obliquely, nearly at right angles to those of the external intercostal muscles.

Transversus thoracis spreads over the internal surface of the anterior thoracic wall. It is attached to the lower third of the posterior surface of the sternum, xiphoid process and costal cartilages of the lower three or four true ribs near their sternal ends. Its fibres diverge and ascend laterally as slips that pass into the lower borders and inner surfaces of the costal cartilages of the second, third, fourth, fifth and sixth ribs. The lowest fibres are horizontal and are contiguous with the highest fibres of transversus abdominis; the intermediate fibres are oblique; and the highest are almost vertical. Transversus thoracis varies in its attachments, not only between individuals but even on opposite sides of the same individual.

The intercostal muscle is a convenient muscle to be used as a muscle graft based on the intercostal artery for its blood supply. It is employed mostly to reinforce a bronchial anastomosis after, for example, resection of the right upper lobe and reimplantation of the bronchus intermedius to the carina, as in Fig. 42.3.
FIG. 42.3  A, An endobronchial tumour protruding from the right upper lobe and obscuring the lumen of the right main bronchus. B, The open carina being reconnected to the bronchus intermedius. C, The intercostal muscle harvested as a pedicled flap based on the intercostal artery.

Vascular supply and lymphatic drainage

Arterial supply

The skin of the thorax is supplied by direct cutaneous vessels and musculocutaneous perforators, which reach the skin primarily via the intercostal muscles, pectoralis major, latissimus dorsi and trapezius. Branches from the thoraco-acromial axis, lateral thoracic, internal thoracic, anterior and posterior intercostal, thoracodorsal, transverse cervical, dorsal scapular and circumflex scapular arteries are the major contributing vessels. Muscles of the thoracic wall receive their blood supply from the internal thoracic artery (either directly or via the musculophrenic artery), the superior
intercostal artery (from the costocervical trunk), superior thoracic artery (from the axillary artery), descending thoracic aorta and the subcostal artery. Additional contributions come from vessels that supply the proximal muscles of the upper limb: namely, suprascapular, superficial cervical, thoraco-acromial, lateral thoracic and subscapular arteries.

Anteriorly, the internal thoracic and musculophrenic arteries give off paired anterior intercostal arteries that run into each of the upper nine anterior intercostal spaces. Posteriorly, the first two intercostal spaces are supplied by branches from the superior intercostal arteries from the costocervical branch of the subclavian artery. The next seven spaces are each supplied by a single posterior intercostal artery from the aorta.

**Venous drainage**

The intercostal veins accompany the similarly named arteries in the intercostal spaces. The small anterior intercostal veins are tributaries of the internal thoracic and musculophrenic veins; the internal thoracic veins drain into the appropriate brachiocephalic vein. The posterior intercostal veins drain backwards: most drain directly or indirectly into the azygos vein on the right and the accessory hemiazygos veins on the left. The azygos veins exhibit great variation in their origin, course, tributaries, anastomoses and termination. Anteriorly, anterior intercostal veins join the internal thoracic vein, which drains into the brachiocephalic vein. Posteriorly, the patterns differ on the right and left sides of the chest. On the right side, the first intercostal space is drained by the brachiocephalic vein; the second and third intercostal spaces are drained by the superior intercostal vein, which drains into the azygos vein; the remaining intercostal spaces are drained by intercostal veins into the azygos vein, which drains into the internal jugular vein. On the left side, the first three intercostal veins form the superior intercostal vein, which drains into the brachiocephalic vein. Intercostal veins in the fourth to seventh spaces form the superior hemiazygos vein and those in the eighth to eleventh intercostal spaces form the inferior hemiazygos vein. The hemiazygos veins cross to the right to join the azygos vein.

**Lymphatic drainage**

Superficial lymphatic vessels of the thoracic wall ramify subcutaneously and converge on the axillary nodes. Lymph vessels from deeper tissues of the thoracic walls drain mainly to the parasternal, intercostal and diaphragmatic lymphatic nodes.
Innervation

**Spinal nerves**

There are twelve pairs of thoracic spinal nerves. The ventral rami, unlike their cervical and lumbar counterparts, have retained a largely segmental distribution to the body. The upper eleven lie between the ribs (intercostal nerves) and the twelfth lies below the last rib (subcostal nerve). Each is connected with the adjoining ganglion of the sympathetic trunk by pre- and postganglionic branches (white and grey rami communicantes, respectively). Intercostal nerves are distributed primarily to the thoracic and abdominal walls. The greater part of the first thoracic ventral ramus passes into the brachial plexus, together with a variable proportion of the second. The next four ventral rami supply only the thoracic wall, and the lower five supply both thoracic and abdominal walls. Communicating branches link the intercostal nerves posteriorly in the intercostal spaces, and the lower five nerves communicate freely in the abdominal wall. Thoracic dorsal rami divide into medial and lateral branches, which supply the intrinsic muscles of the back and the overlying postvertebral skin on a segmental basis.

The supraclavicular branches of C4 from the cervical plexus innervate the skin over the clavicle and may communicate with the anterior cutaneous branches of the ventral ramus of C2. The lateral cutaneous branch of the second intercostal nerve is the intercostobrachial nerve; it crosses the axilla to gain the medial side of the arm and joins a branch of the medial cutaneous nerve of the arm. The long thoracic nerve runs on the lateral aspect of the chest wall and innervates serratus anterior. The pectoral nerves are branches from the brachial plexus and innervate pectoral muscles.

**Autonomic nerves**

The autonomic nervous system in the thorax consists of right and left sympathetic trunks and vagus nerves, and the cardiac, oesophageal and pulmonary plexuses (Ch. 46). The ganglionated sympathetic trunks lie anterior to the heads of the ribs; the ganglia are arranged segmentally. Preganglionic sympathetic axons originate from neurones in the lateral grey column of the spinal cord from T1 to L2, and leave the spinal cord with the corresponding ventral roots as white rami communicantes. Some enter the sympathetic trunk, where they either synapse in their segmental ganglion, or ascend or descend in the trunk to synapse in cervical or lumbar ganglia. Many of the preganglionic axons that originate in the lower thoracic spinal
segments (T5–12) do not synapse locally but enter the abdominal cavity as the thoracic splanchnic nerves; they synapse either in prevertebral ganglia, especially the coeliac ganglion, or around the medullary chromaffin cells of the suprarenal gland. Axons destined for the cervical ganglia are derived from preganglionic neurones in T1. Preganglionic parasympathetic fibres arise from neuronal cell bodies in the dorsal motor nucleus of the vagus in the medulla. Those destined for the thoracic viscera travel in the pulmonary, cardiac and oesophageal branches of the vagus and synapse in minute ganglia in the visceral walls. Axons travelling in cardiac branches join the cardiac plexuses and synapse in ganglia distributed over both atria. Pulmonary branches contain axons that relay in ganglia of the pulmonary plexuses; they are bronchoconstrictor to the circular non-striated muscle fibres of the bronchi and bronchioles, and secretomotor to the mucous glands of the respiratory epithelium.
Clinical Anatomy of the Respiratory diaphragm

The diaphragm is a domed musculofibrous sheet that separates the thoracic and abdominopelvic cavities. The mainly convex superior surface faces the thorax, and the concave inferior surface is directed towards the abdomen. The positions of the domes (cupulae) of the diaphragm are extremely variable; they are influenced by body build (often higher in the short and obese compared to the tall and asthenic), position and ventilatory phase. Conditions resulting in lung over-inflation, such as emphysema, cause marked diaphragmatic depression. Usually, after forced expiration, the right cupula is level anteriorly with the fourth costal cartilage and the right nipple, whereas the left cupula lies approximately one rib lower. On full inspiration, the cupula will descend by as much as 10 cm; on a plain chest X-ray, the right dome coincides with the anterior end of the sixth rib. The diaphragm lies more superiorly in the supine compared to the erect position, and the dependent half of the diaphragm will be considerably higher than the uppermost one in the decubitus position.

A number of structures pass between the thorax and abdomen via apertures in the diaphragm. Three large openings allow the passage of structures between the thorax and the abdomen for the aorta, oesophagus and inferior vena cava, and a number of smaller ones. The aortic hiatus is the most posteroinferior of the large openings, and is found at the level of the lower border of the twelfth thoracic vertebra and the adjacent intervertebral disc, slightly to the left of the midline. It transmits the aorta, thoracic duct, lymphatic trunks from the lower posterior thoracic wall and, sometimes, the azygos and hemiazygos veins. The oesophageal hiatus at the level of T10 is anterosuperior to, and a little to the left of, the aortic hiatus. It transmits the oesophagus, vagal trunks and gastric nerves, oesophageal branches of the left gastric vessels and some lymphatic vessels. The caval opening, the most superior of the three large openings, lies at about the level of the intervertebral disc between the eighth and ninth thoracic vertebrae. It is quadrilateral, with aponeurotic margins, located at the junction of the right leaf with the central area of the tendon and traversed by the inferior vena cava, which adheres to the margin of the opening, and by some branches of the right phrenic nerve. During inspiration, dilation of the caval hiatus, combined with increased intra-abdominal pressure, increases cardiac venous return.
There are two lesser apertures within each crus; one transmits the greater splanchnic nerve, and the other, the lesser splanchnic nerve. The ganglionated sympathetic trunks usually enter the abdominal cavity posterior to the diaphragm, deep to the medial arcuate ligaments. Openings for minute veins frequently occur in the central tendon. There are small areas where the muscle fibres are replaced by areolar tissue on each side of the diaphragm. One, between the sternal and costal parts, contains the superior epigastric branch of the internal thoracic artery and some lymph vessels from the abdominal wall and convex surface of the liver. The other, between the costal part and the fibres that spring from the lateral arcuate ligament, is less constant; when it is present, the posterosuperior surface of the kidney is separated from the pleura only by areolar tissue. Additional, smaller fascial spaces may also be found throughout the lateral aspects of the diaphragmatic domes without evidence of vascular penetration. Although these spaces are found on both left and right sides, they appear to be more numerous on the left.

**Neurovascular anatomy**

The profuse arterial supply of the diaphragm is derived from anastomoses between the lower five intercostal and subcostal arteries, the superior and inferior phrenic arteries, and the pericardiacophrenic and musculophrenic arteries.

The superior surface of the diaphragm is drained by tributaries of the musculophrenic and pericardiacophrenic veins that run alongside the corresponding arteries. The inferior surface of the diaphragm is drained by tributaries of the right and left inferior phrenic veins.

The diaphragm is drained by anterior, middle and posterior groups of lymph nodes that lie on its superior surface; they also drain the superior portion of the liver, the gastro-oesophageal junction and the abdominal surface of the diaphragm. In addition, lymph drains anterosuperiorly to parasternal and anterior mediastinal nodes, and posterosuperiorly to posterior mediastinal and brachiocephalic nodes.

The diaphragm receives its motor supply via the phrenic nerves (C3, 4, 5). Sensory fibres are distributed to the peripheral part of the muscle by the lower six or seven intercostal nerves.
Surgical approaches to the chest wall

A good understanding of the anatomy of the chest wall is essential for safe and effective insertion of chest drains and exposure of the heart, lungs, pleura, oesophagus, major vessels and mediastinal lymph nodes.

Insertion of intercostal chest drains

An intercostal space is the space between two adjoining ribs; its upper limit is formed by lower border of the upper rib and lower limit by the upper border of lower rib (Fig. 42.4). The neurovascular bundle (intercostal nerve, artery and vein) runs just deep to the lower border of a rib. Access to the chest cavity, other than in the midline, is almost always between two adjoining ribs through an intercostal space.

The insertion of an intercostal chest drain is indicated when there is a need to remove air, fluid or blood from the thoracic cavity. Trauma, elective surgery, pleural effusions and pneumothorax are the most common
indications. The landmark for counting intercostal spaces is the manubriosternal joint. The position of the nipple varies according to the shape, age and gender of the patient and should not be used. Apart from intercostal nerve blocks, any access through an intercostal space is governed by the principle of keeping instrumentation just above the lower rib of that space because the intercostal artery, vein and nerve are shielded by the costal groove (but only in the anterior and lateral positions). Posteriorly, the neurovascular bundle does not lie within this intercostal groove but lies between the ribs and is shielded only by intercostal muscles, which renders the bundle more vulnerable to trauma when inserting a chest drain posteriorly. During intercostal nerve blocks, where the aim is to reach the lower border of the upper rib to deliver the anaesthetic agent around the intercostal nerve, it is important to maintain the standard practice of aspiration before injection to avoid delivering the drug into an intercostal vessel. The triangle of safety is the area in the axilla bordered by the posterior edge of pectoralis major, the anterior border of latissimus dorsi and a line taken from the nipple to the tip of the scapula: an intercostal chest drain inserted within this triangle is unlikely to damage any nerves or important vessels, and resistance to insertion will be minimized because the drain will not encounter any significant muscles.

While inserting a chest drain, it is important to be aware of the inferior limits of the thoracic cavity, as defined by the position of the domes of the diaphragm and the costodiaphragmatic recesses, and of the closeness of underlying abdominal viscera, which, although anatomically separated from the thorax, may be injured by an inappropriately placed chest drain. The surgeon should also be fully aware that pathology is likely to alter the normal anatomy, and that patient variables, such as body size, habitus, position and gender, should be considered in addition to anatomical landmarks. The diaphragm may be displaced superiorly as a result of obesity, contraction from inflammation (in empyema), phrenic nerve palsy, or decreased lung volume due to previous resection or collapse.

Despite being in the correct intercostal space and avoiding the subdiaphragmatic viscera, chest drains have inadvertently been inserted into the heart (on either side), the right atrium or the left ventricle. These errors are usually the result of paying inadequate attention to patient factors (such as a small, thin patient) and/or to pathological factors (such as cardiac chamber enlargements bringing the respective chambers closer to the chest wall, or an enlarged and dilated left ventricle almost touching the chest wall).
Injury to the underlying lung is best prevented by positioning the patient in a lateral position and entering the intercostal space using a blunt finger rather than a sharp instrument. In the case of a narrow intercostal space with crowding of ribs, or in children, gentle layer-by-layer separation of the intercostal muscles with tissue forceps allows entry without applying too much force, which can cause a sudden ‘give’ and jerky penetration of the pleural space, when lack of control of the instrument tip may injure the underlying lung.

The probability of these complications should be lessened by performing chest drain insertion under radiological guidance, using ultrasound or CT scan to help plan or monitor in real time the exact site, depth and direction of drain insertion.2

Surgical access to the lungs

Posterolateral thoracotomy provides the safest and most effective approach that allows access to either lung (for resection for malignant disease or intrapleural infection) and to the oesophagus. The patient is placed in the lateral position with the upper shoulder mobilized forward to allow for access to multiple intercostal spaces. The surface landmarks are created as follows. The first mark is one finger's breadth below the tip of the scapula. Then an imaginary line is created from three fingers’ breadths superior to the tip of the scapula to the vertebral column. The second mark is made on this imaginary line halfway between the posterior margin of the scapula and the vertebral column. The third mark is made depending on the areas of most concern. For example, during a routine lung resection it is made a few centimetres below the nipple. If the gastro-oesophageal junction and diaphragm are of more concern, then the third point is made further towards the costal margin, so that the incision forms more of a straight line with the first two marks.

After division of the subcutaneous fat, the external muscles, trapezius, latissimus dorsi and, deeper, serratus anterior are exposed (Fig. 42.5). Latissimus dorsi is divided: this bulky muscle is usually very vascular and cutting diathermy is mandatory. The scapula is elevated and retracted to allow palpation of the ribs. The most superior palpable rib is the first rib, which has a characteristically flat shape and orientation; the succeeding ribs are counted down to the desired space. Access is afforded to posterolateral aspects of ribs 3–7. If it is necessary to take the incision anteriorly, serratus
anterior is also divided as inferiorly as possible to avoid denervating the muscle fibres. The whole shoulder girdle is then allowed to move superiorly, the intercostal muscles are divided along the superior surface of the ribs to avoid the neurovascular bundle (usually an avascular plane) and the pleural cavity is entered.

![Image](image_url)

**FIG. 42.5** Posterolateral thoracotomy, major muscle groups: left posterolateral thoracotomy. Trapezius, latissimus dorsi and serratus anterior have been exposed.

A posterior thoracotomy is created by enlarging the auscultatory triangle. The landmarks are similar to those for a posterolateral thoracotomy, except that the anterior extent is much shorter. Once the skin and subcutaneous fat have been divided, the two edges are raised as cutaneous flaps, exposing latissimus dorsi and trapezius. The fascial tissue between these muscles is divided and they are retracted without dividing them. Access is thus afforded to the posterior aspects of ribs 3–7 and the appropriate space is entered as described previously (**Fig. 42.6**).
Minimally invasive approaches to the lungs

Minimally invasive approaches to the lungs, pleura and oesophagus can be modified to suit multiple variables, such as the anatomical location of the pathology, the patient's shape, surgical instruments available and surgical preference. Video-assisted thoracoscopic surgery (VATS) to remove lung tissue, and in particular to perform an anatomical lobectomy, can be performed through a variety of incisions (in both number and location of incisions). One method is the anterior approach. The utility incision is placed between the anterior border of latissimus dorsi and the posterior border of pectoralis major, and at the level of the third or fourth intercostal space. The camera port is created in the mid-axillary line in the sixth or seventh intercostal space and the second instrument port is placed one or two spaces below the scapula (Fig. 42.7). The surgeon will vary the approach according to the patient's characteristics, paying particular attention to the position of the tumour, the diaphragm and (on the left) the heart.
Surgical approaches to the heart

The pericardial cavity can be entered from the anterior aspect or via left or right lateral approaches in order to perform all aspects of cardiac surgery for both congenital and acquired conditions. Current practice is evolving; there is an increasing emphasis on more limited incisions and the use of video technology for imaging in conjunction with trans-oesophageal echo imaging of the heart. The use of median sternotomy remains commonplace.

Median sternotomy

For the vast majority of operations involving the heart, the access is via a median sternotomy (Fig. 42.8). With the patient in the supine position and with the neck extended, an incision is made in the midline between the suprasternal notch and the inferior tip of the xiphoid.
After division of the subcutaneous fat and the medial attachments of pectoralis major, the sternum is exposed and divided with a saw. The medial extension of the pleura often crosses the midline and can be damaged with the sternal division. Following sternotomy, the thymus is found directly posteriorly. The pericardium, heart and major vessels are then accessible. For improved cosmesis, the full length of the incision is rarely used. In current practice for minimal access surgery, median sternotomy is often modified, allowing the surgeon to approach the aorta and aortic root without exposing the remainder of the heart.

**Left anterolateral thoracotomy**

The patient is placed in a supine position with a sand bag or equivalent under the left shoulder and hip, which rolls the patient $20^\circ$ to the horizontal. The incision is marked directly over the intercostal space required for access to the left lateral aspect of the heart, usually the left sixth or seventh intercostal space (Fig. 42.9). In females, it may be necessary to move the breast superiorly in order to facilitate palpation of the ribs. The incision is made, pectoralis major is divided and the intercostal space is entered directly. If the incision is taken close to the midline, special care is needed either to avoid or to divide and ligate the internal thoracic artery and veins. The pericardium will be visible directly in the left pleural space and can be entered.
Right thoracotomy

The patient is placed in the right lateral position with the shoulder mobilized forward to allow for access to multiple intercostal spaces. The incision is made along part of a line from a point midway between the medial edge of the scapula and the spine that crosses a point 2 cm inferior to the tip of the scapula to a point 2 cm inferior to the nipple (Fig. 42.10). In females with a large breast, the inframammary crease is a satisfactory surface landmark. In most cases, only the medial part of this incision is required for adequate access to the right aspect of the pericardium and heart. Once the skin and subcutaneous fat have been incised, latissimus dorsi is divided with cutting diathermy. The intercostal spaces are counted by direct palpation and, after the initiation of single lung anaesthesia, the selected intercostal space is entered. The fifth space is suitable for access to the heart. The incision can be modified to allow for minimal access techniques and may be no longer than 5 cm in many surgical cases.
Minimally invasive cardiothoracic incisions

Minimally invasive operations offer less pain as one of the important advantages during postoperative recovery. However, if intercostal nerves undergo any damage, especially as a consequence of forceful retraction using robust retractors through a small incision and causing excessive pressure, the likelihood of neuralgia is high, causing significant discomfort and disappointment to the patient. The surgeon should therefore use soft tissue retractors to perform minimally invasive operations, such as aortic valve replacement via an anterior right thoracotomy, or mitral valve surgery via a small right thoracotomy. If the intercostal space is small because of either a diminutive stature or the underlying pathology has caused crowding of the ribs, placement of ports for video-assisted operations can compress the intercostal nerves and cause significant postoperative neuralgia.

Median sternotomy gives excellent access to the heart, ascending aorta and arch of the aorta. Landmarks used for this incision are the suprasternal notch and xiphisternum. Some surgeons use a smaller skin incision than the full length of the bone; however, this involves significant stretching of the skin to achieve full retraction. Curvatures of the sternum associated with kyphoscoliosis sometimes make it difficult to maintain the midline with the sternal saw.

The availability of options to perform peripheral cannulation for establishing cardiopulmonary bypass means that an increasing number of cardiac operations are now performed using a minimally invasive approach.
Given that various factors can alter the relative anatomy of structures inside the chest, a preoperative CT scan significantly aids in planning the incisions and approaches.

The aortic valve can be approached via a partial upper ministernotomy (Fig. 42.11) or a right anterior thoracotomy. The landmarks for an upper ministernotomy are the suprasternal notch and the manubriosternal angle, which is the extent of the midline skin incision. The second intercostal space is marked on the right side, inferior to the insertion of the second costal cartilage at the level of the manubriosternal angle. Sternotomy is then commenced at the suprasternal notch and angled to the right from the midline on to the second intercostal space inferior to the manubriosternal angle. The extension in the second intercostal space should only be up to the lateral margin of the sternum in order to avoid injuring the right internal thoracic vessels. An anterior right thoracotomy becomes a suitable approach when CT scan shows that the ascending aorta lies principally on the right side behind the sternum, with the aortic valve oriented towards the right shoulder. Most often, the right second intercostal space is suitable, unless the aortic valve itself is inferiorly placed, which is possible with ascending aortic dilation. The landmark for this incision is to locate the intercostal space after identifying the attachment of the second costal cartilage at the level of the manubriosternal angle. A 5 cm incision is placed horizontally, starting from the lateral sternal border. It is imperative to identify the internal thoracic vessels deep to the intercostal muscles and divide them carefully after double ligation on either side because they are likely to retract and will not be easily accessible in case of bleeding.
FIG. 42.11  Landmarks for an upper ministernotomy: the suprasternal notch and the manubriosternal angle (which marks the extent of the midline skin incision). A, Hemisternotomy for aortic valve surgery revealing the ascending aorta. B, Exposure of the aortic valve during cardiopulmonary bypass and cardioplegic arrest via hemisternotomy. This exposure allows for adequate visualization of leaflets, commissures, coronary ostia and the sinutubular junction.

In both of these minimal access approaches to the aortic valve, inserting anchoring sutures just above the commissures facilitates lifting of the valve and anulus towards the incision, easing the insertion of valve sutures in the
anulus. The most difficult of these will be the ones along the right coronary sinus, which will be facilitated by raising the head end of the operating table and taking everting sutures from the atrial side rather than inverted from the left ventricular side. The availability of rapid deployment sutureless valves circumvents all of these difficulties and aids aortic valve replacement significantly by decreasing the operative steps at the aortic anulus.

The mitral valve can be approached via a minimally invasive operation (Fig. 42.12), usually through the right fourth or fifth intercostal space, a submammary incision, or a half-circumferential incision along the outer border of the areola in men. The incision can be as small as the size of the mitral ring or the valve that needs to be inserted at the operation. Using soft tissue retractors gives the best outcomes in terms of pain control in the postoperative period.
Minimally invasive direct coronary artery bypass (MIDCAB) is performed through a left anterior thoracotomy in the fourth intercostal space through a submammary incision. This incision has been used to harvest right as well as left internal thoracic arteries. The most commonly performed anastomosis is of the left internal thoracic artery to the left anterior descending artery, although revascularization of all coronary territories has been successfully performed through this incision.

**Surgical access to the great vessels**

The ascending aorta and proximal arch can be accessed safely via a median sternotomy. The distal arch and descending aorta are accessed via a left thoracotomy. The distal arch may be accessed through the third and fourth
intercostal spaces and the descending aorta may be accessed through the seventh space; the skin incision and chest wall approach are as described for a posterolateral thoracotomy.

**Surgical access to the oesophagus**

Surgical access to the oesophagus can be made from the left or right side. The oesophagus is a central structure that lies towards the left at its lower and upper ends but towards the right during its mid-course. Right thoracotomy is used for oesophageal surgery only after the stomach has been mobilized via a laparotomy. A left-sided posterolateral thoracotomy (see above) in the seventh intercostal space extending across the diaphragm gives access to the lower two-thirds of the oesophagus, stomach and proximal duodenum.

**Surgical biopsy of mediastinal lymph nodes**

Mediastinal lymph nodes are central and adjacent to the trachea and great vessels. Surgical biopsy is required for diagnostic and staging purposes in lung disease and lymphoproliferative disorders. There are no therapeutic interventions requiring access to these nodes. Paratracheal and subcarinal nodes can be accessed via a superior approach; hilar nodes can be accessed via the anterior approach. The patient is placed in the supine position with the neck extended. For hilar or aortopulmonary window nodal biopsy, the incision is made over the third intercostal space.

**Surgical approach to the superior mediastinal lymph nodes**

**Cervical mediastinotomy**

For a cervical mediastinotomy, the incision is made 1–2 cm superior to the sternal notch (Fig. 42.13). The skin and subcutaneous fat are divided and the infrahyoid strap muscles are exposed and retracted laterally. The inferior pole of the thyroid is often visible and can limit vision; it should be retracted superiorly. Once the pretracheal fascia has been identified, it can be divided; the dissection becomes digital, with careful separation of the soft tissues in the superior mediastinum. The trachea is posterior, the brachiocephalic artery and aorta are anterior, and the lungs and superior vena cava are to the right.
Anterior mediastinotomy

With the patient in the supine position, the skin landmark is the manubriosternal junction; the incision is made transversely from the lateral edge of the sternum. Skin, subcutaneous fat and pectoralis major are separated in the line of the incision. The intercostal muscles are divided to expose the internal thoracic artery and vein, which can be either ligated or retracted. The pleural space is then entered. This approach can be used on either side.
Trauma

Rib fractures are common injuries. Approximately one-third of patients with rib fractures require some time in hospital and one-third of these (admitted) patients will develop nosocomial pneumonia, respiratory failure or even death, depending on their comorbidities and the extent of injury.\textsuperscript{4,5} Lung injuries and traumatic pneumothoraces are caused more often by rib fractures than by any other penetrating injury. Both blunt and penetrating chest injuries can cause bleeding from vessels in either the chest wall or underlying thoracic viscera. Intercostal drainage or surgical intervention to reconstruct the chest wall and control the site of bleeding is required to manage major or uncontrolled haemorrhage. If multiple ribs are fractured, and if they are fractured in more than one place, the resulting flail chest will likely compromise chest wall mechanics and result in respiratory failure: flail chest is often an indication for surgical fixation. The disease burden from multiple rib fractures does not end with hospitalization. Patients lose an average of 70 days of work during recovery from multiple rib fractures, and in those with flail chest injuries more than 50% have long-term disabilities or fail to return to full-time employment.\textsuperscript{6,7} While surgical management had been used sporadically for more than half a century, it was only after two small randomized controlled trials published 20 years ago that surgical stabilization of the chest wall became more systematically applied and studied.\textsuperscript{8,9} These two trials demonstrated that patients who underwent surgical stabilization of flail chest segments spent less time in intensive care, required fewer days of mechanical ventilation and returned to normal lung function more quickly than those treated conservatively.

Surgical stabilization of the chest wall

The variety of fracture patterns is (mathematically) huge, considering the possible shape of the fracture line, the presence or absence of flail segments, comminuted fractures, the number of ribs involved, cartilaginous fractures, associated fractures of the clavicle, spinal injuries, lung injuries and so on. The classification, investigation and treatment of these injuries are correspondingly complex. Absolute fracture pattern classifications, such as the AO rib fracture classification, provide a nomenclature with which to describe each fracture; other classifications enable pragmatic management decisions as to whether or not to operate, and aim to optimize repair with
minimal procedural morbidity.\textsuperscript{10–13}

In order to fix the chest wall, the surgeon must consider a number of points when deciding on the incision to use, including the number of fractures that will be reached; how to limit the muscle injury required to expose the ribs; the type of fixation device; the additional surgery required through the incision (such as lung or diaphragm repair); and cosmesis. When the fixation device is being selected, it is important to appreciate that a rib has a thin cortex, which becomes thinner from posterior to anterior. For practical purposes, the surgical approaches can be divided into anterior and lateral ones.\textsuperscript{14–16}

**Anterior approach**

With a median incision between the two pectoralis muscles, the sternum can be reached to fix fractures of the manubrium and sternum. By retracting the muscles medially and laterally without extending the skin incision, the costal cartilage of ribs 2–7 can be exposed and fixed with metal plates and screws: for example, on the anterior surface (Fig. 42.14). Useful variations include raising the whole pectoralis muscle group (Fig. 42.15).
FIG. 42.14  **A**, Axial CT scan showing anterior rib and costal cartilage fractures (arrows) and pneumothoraces.  **B**, The anterior approach. Key: **A**, split (not cut) fibres of pectoralis major; **B**, plate and screws.
FIG. 42.15  The anterior approach for flail anterior chest wall with combined repair of fractures of the sternum, rib and costal cartilage by raising the pectoralis muscle group. A, The axillary approach with the long thoracic nerve exposed (arrow). B, The axillary approach with percutaneous instrumentation for fixation (arrow). C, The
Lateral approach

Variants of the traditional lateral thoracotomy incision provide access to the lateral aspects of ribs 3–9. The incision is modified according to the site of the fractures: either anteriorly or posteriorly; or by combining both in a single large incision, or as two incisions with a connecting tunnel under the superficial muscles (latissimus dorsi and trapezius) and a mobilized deep muscle (serratus anterior). If the incision is made higher in the axilla, ribs 2 and 3 can be accessed. In these lateral approaches, the main muscles to protect are latissimus dorsi and trapezius, which are the most superficial and in the same plane, along with serratus anterior, which lies in a deeper plane. Preservation of the breast gland is very important, especially in the younger female patient (Fig. 42.16). Another option, especially in the anterolateral position, is to stay anterior to the anterior border of latissimus dorsi and detach serratus anterior at its attachments on the ribs as required, enabling the surgeon to roll the muscle out of the operative field: it can be reattached with soluble sutures at the end of the operation. This option completely protects the neurovascular supply of serratus anterior.
For more posterolateral fractures, latissimus dorsi and serratus anterior can be reflected anteriorly while trapezius is retracted posteriorly, extending the ‘auscultatory triangle’. Fractures in the mid-lateral position require special attention to ribs 2–5 because of the presence of the scapula. As most fixation devices require drilling and/or screwing of plates to an external bony surface, special right-angled drills and screwdrivers are needed here. The scapula is most readily manipulated by moving the arm during the operation, enabling significant exposure of the ribs. Alternatively, special rib
clips that need only to be ‘squeezed’ on to a rib can be used underneath the scapula from a modest distance away. For ribs 5–10, options include combination of the two incisions mentioned earlier (an anterior incision with detachment of serratus anterior and a posterior incision with extension of the auscultatory triangle) and tunnelling between them; or a single skin incision, taking care to protect the muscles, or a vertical or transverse skin incision with splitting of latissimus dorsi along the line of its fibres (Fig. 42.17).\textsuperscript{16}
FIG. 42.17 The lateral approach by raising flaps to preserve trapezius, latissimus dorsi and serratus anterior to fix posterolateral fractures and decortication of empyema. A, A preoperative chest X-ray with posterolateral fractures and empyema. B, A posterolateral incision to facilitate access to the fractures and decorticate the lung. Abbreviations: L, latissimus dorsi; T, trapezius. C, A postoperative chest X-ray.
Internally placed plates, secured with a totally thoracoscopic approach, are an area of investigation that would mitigate these concerns about the scapula, reduce the surgical morbidity and allow plating of the posterior rib (posterior to the costotransverse joint).\textsuperscript{17}

**Tips and Anatomical Hazards**

Chest drains can rarely be inserted too high. If the triangle of safety is used, intercostal drains are usually safe.

Rib counting from the first down is essential to open a thoracotomy at the correct intercostal space.

All cardiac operations can be carried out via a median sternotomy, although there is a trend towards less invasive approaches via limited thoracotomies.

The sternal angle (of Louis) is the common surface landmark for the second costosternal joint and the T4–5 vertebral level; the imaginary plane separating the superior and inferior mediastinum; the upper border of the fibrous pericardium and the bifurcation of the trachea.

The oesophageal opening in the diaphragm is a common site of herniation. Crural anatomy and the immediate anatomical relations of the diaphragm in this region must be borne in mind during surgery for hiatus hernia.

Rib fractures are common presentations in emergency departments. Ribs commonly fracture at the angles, which are their weakest points. A flail chest and multiple painful rib fractures impair breathing and increase morbidity and mortality in trauma. The pain may be treated by intercostal nerve blocks in the posterior intercostal spaces and internal fixation.

The internal thoracic artery is readily accessible just lateral to the lateral sternal line and is a common arterial graft in coronary artery surgery. The lung, when fully expanded, lies immediately deep to the chest wall and can be damaged during trauma or a surgical approach.

In children, the brachiocephalic artery runs superior to the upper border of the sternum and can be damaged during cervical mediastinoscopy.

In cases of heart failure and left ventricular dilation, the left ventricle
can be directly adjacent to the left anterolateral wall of the chest and can be damaged during any chest wall procedure. Needles are inserted or incisions to access the thorax are made just superior to a rib in order to avoid damaging the neurovascular bundle lying in the costal groove.

The intercostal neurovascular bundle can be damaged during chest drain insertion, especially in the posterior region of the chest, where these structures are not reliably shielded because they do not lie in an intercostal groove.

The first rib forms much of the lateral boundary of the thoracic inlet. A rare extra (cervical) rib may compress the lower part of the brachial plexus, particularly the lower trunk, and the subclavian artery.

The tenuous pattern of blood supply to pectoralis major, latissimus dorsi and rectus abdominis may frustrate reconstructive surgery of the chest wall and adjacent regions of the neck or abdomen.

The diaphragm is innervated by the phrenic nerve (C3–5). If the spinal cord is damaged above the level of C3, the patient will require mechanical ventilation.

**Acknowledgement**

The authors would like to acknowledge the contribution of Professor Hassan Saidi who sadly died whilst preparing this chapter.
References

Clinical cases

1. A 25-year-old male is admitted via the accident and emergency department with blunt right-sided chest trauma. The chest X-ray shows a haemo-/pneumothorax and multiple rib fractures. An intercostal drain has already been inserted but the drainage from it is excessive and the patient's blood pressure is falling, despite fluid resuscitation. He is showing signs of type 1 respiratory distress.

**A. Describe the surgical approach required.**
A right posterolateral thoracotomy will be required; the site of the bleeding is unknown and therefore a sixth intercostal space entry is advised.

**B. Why is this knowledge important?**
The source of the bleeding could be anywhere within the chest; a sixth interspace entry gives maximum operative view.

**C. When would direct rib fixation be appropriate?**
In the presence of multiple rib fractures and a flail segment of chest wall, the physiology of breathing is greatly improved by chest wall fixation.

2. A 70-year-old male presents with cough, haemoptysis and a change in voice. Imaging suggests lung cancer with enlarged and metabolically active lymph nodes in the aortopulmonary window.

**A. Describe the surgical approach required to biopsy these enlarged nodes.**
With the patient in the supine position, a transverse incision is made in the line of the left second intercostal space.

**B. What chest wall vessel is at risk during this procedure?**
The left internal thoracic artery, as it runs posterior to the costal cartilages.
Core procedures

- Mastectomy: simple; skin-sparing; nipple-sparing, skin-sparing
- Wide local excision of breast lesion
- Wire-localized wide local excision
- Sentinel lymph node biopsy
- Microdochectomy
Development

Developmentally, the breast is a modified and highly specialized apocrine gland, composed of glandular tissue and ducts making up the breast parenchyma, supported by a connective tissue framework, adipose tissue and vasculature, which make up the breast stroma. Breast development begins in utero and continues in stages during infancy, puberty, pregnancy and lactation. It involves complex epithelial–mesenchymal interaction, driven by signalling, growth factors and hormonal pathways.\(^1\) During development, ingrowths of ectoderm into the mesenchyme become the breast parenchyma, and the mesenchyme becomes the stroma.

Embryology and prenatal development

Our understanding of prenatal breast development has been largely drawn from mammalian studies, particularly in mice. There is variation in stages of human fetal breast development at particular gestational ages between individuals.\(^2\) Prenatal breast development is identical in males and females, and usually begins around the fifth to sixth weeks in utero. Firstly, two ventral ectodermal ridges, around 2–4 cell layers thick – the ‘mammary bands’ or ‘milk streaks’ – develop from the axillae to the inguinal regions bilaterally.\(^3\) Next, in the sixth to seventh weeks, the ‘mammary crest’ develops. This is a disc-shaped thickening, 4–6 cells wide, on the mammary band, at the fourth intercostal space on the anterior thorax, indicating the future nipple position. The third stage involves proliferation and invagination of the mammary crests, penetrating downwards as diverticuli into the underlying mesenchyme, forming the primary breast buds (Fig. 43.1A).\(^4\) Around the same time, the remaining mammary bands start to involute.
From weeks 12–20, secondary epithelial outgrowths from the deep surface of the primary breast buds arise, penetrating further into the mesenchyme (Fig. 43.1B). These mammary sprouts, or primitive ducts, have a slender stalk with a bulbous end. They undergo progressive elongation, branching and canalization until term, when around 15–20 lobes of glandular breast tissue, each connected to a lactiferous duct, have formed (Fig. 43.1C). The epithelial cells lining them are arranged in two layers of cuboidal cells: the innermost luminal layer is secretory in function, and the basal layer differentiates into myoepithelial cells.\(^5\)

Formation of the primary breast bud and subsequent secondary epithelial outgrowths are regulated by hormonal and growth factor signalling from the lipid-rich extracellular matrix of the surrounding adipose tissue in the mesoderm in the first and second trimesters.\(^6\) In the third trimester, canalization of the ducts occurs under the influence of placental oestrogens entering the fetal circulation. Throughout the second and third trimesters, the mesenchyme differentiates into the supporting breast stroma, containing adipocytes, collagens, fibroblasts, smooth muscle and nerve cells. The stroma is also rich in immune cells such as macrophages and eosinophils.\(^7\)

The nipple is formed in the third trimester, at the site of initial epidermal downgrowth: the mammary pit (Fig. 43.1D). The overlying epidermal cells
differentiate into nipple skin, with associated Montgomery’s tubercle apocrine glands on the areola. The mesenchyme proliferates and differentiates to circular smooth muscle fibres arranged both longitudinally and circularly, and the nipple and areola become pigmented.

**Infancy**

In most infants born at term there are palpable breast nodules. Following the withdrawal of maternal oestrogens at parturition, fetal prolactin is produced from the pituitary gland, causing transient production of colostrum, which can continue for 3–4 weeks.\(^8\) From around 3–4 months after birth, the breasts undergo involution, similar to changes seen in the postmenopausal breast, and remain quiescent until puberty.

**Puberty**

In females, pubertal breast development begins between the ages of 9 and 13 years, at an average of 11 years, and takes between 3 and 5 years to complete. At a histological level, changes occur in both the breast parenchyma and the stroma. In the parenchyma, ductal elongation and branching morphogenesis occur. Cells are arranged in an outer myoepithelial layer and an inner luminal layer, which is further divided into ductal luminal epithelial cells lining the ducts, and alveolar luminal cells, capable of secretory function. More alveoli arise with each menstrual cycle but the number only increases significantly with pregnancy.\(^9\) In the stroma, there is an increase in size and elasticity of the connective tissues, with enhanced vascularity and adiposity.

Pubertal mammary branching is dependent on increased levels of circulating oestradiol, exerting its effect through oestrogen receptors, predominantly ER\(\alpha\) and, to a lesser extent, ER\(\beta\), in both the parenchyma and the stroma.\(^10\) Breast development is also dependent on growth hormone, insulin-like growth factor-1 and prolactin.\(^11\)

At a macroscopic level, the changes seen in the breast at puberty have been described in five stages, originally by Tanner (Fig. 43.2; Table 43.1).\(^12\)
Pre- and postpubertal development and structure of the female breast, demonstrating changes in the contour of the breast. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 53.29.)

### TABLE 43.1

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Pre-adolescent, elevation of the nipple only</td>
</tr>
<tr>
<td>II</td>
<td>Breast bud stage, glandular subareolar tissue develops, nipple and breast project from the chest wall as a single mound</td>
</tr>
<tr>
<td>III</td>
<td>Breast and areola further enlarge as a single mound, areola pigments and increases in diameter; glandular breast tissue proliferates and enlarges</td>
</tr>
<tr>
<td>IV</td>
<td>Nipple and areola further enlarge and pigment, and project as a distinct mound above the level of the main breast mound</td>
</tr>
<tr>
<td>V</td>
<td>Mature stage, development of smooth contour to the breast with no projection of the areola and nipple above the breast</td>
</tr>
</tbody>
</table>
Polythelia is the presence of an accessory nipple and occurs in up to 5% of the adult population. Polythelia may be found at any site along the line of the embryological mammary band, most commonly in the thoracic, axillary or abdominal regions (Fig. 43.3).

Polymastia is the presence of accessory or ectopic breast tissue, occurring in 2–6% of adults. The axilla is the site of accessory breast tissue in 60–70% and may be bilateral. Other reported sites include the thoraco-abdominal wall, down to the level of the groin, the vulva and subscapular regions. Ectopic tissue can undergo physiological fluctuation with the menstrual cycle and often enlarges in pregnancy, with patients often only first realising its
presence during a pregnancy. If the accessory breast has an associated nipple, it may function during lactation post-partum.

Adolescent macromastia and juvenile breast hypertrophy occur when the breasts become excessively large, the former at a steady rate throughout puberty, and the latter at a dramatic rate over 6–12 months. Both can result in marked asymmetry and psychological upset. The aetiology is idiopathic, although one theory proposes breast hypersensitivity to normal levels of circulating oestrogens.\textsuperscript{16} Breast development is complete by the age of 20, and at this stage reduction mammoplasty may be considered in some patients with macromastia.

**Hypoplastic breast abnormalities**

Hypoplastic breast abnormalities can be unilateral or bilateral, and if bilateral, may be symmetrical or asymmetrical. An absence of any stage of breast development by the age of 14 years warrants concern. Hypoplasia is underdevelopment of the breast. Amastia is the congenital absence of breast, nipple and areolar tissue. Amazia is the absence of breast tissue with the presence of a nipple and may be congenital or acquired. The most common acquired reason is iatrogenic injury by biopsy of a pubertal or infant breast, in effect excising most of the breast bud and resulting in marked deformity. It is crucial that such intervention is always avoided. Other acquired reasons include childhood radiation for intrathoracic disease, thoracostomy tube placement or injuries such as severe burns.\textsuperscript{17} Athelia is the absence of a nipple; however, this is more common on accessory breast tissue.

Poland's syndrome is a congenital condition characterized by unilateral hypoplastic or absent breast tissue, with hypoplastic or absent pectoral muscles, combined with shortening of the ipsilateral upper limb and digits.\textsuperscript{18} There is wide variation in clinical presentation, with some patients having further chest wall anomalies, including deformed or absent ribs.

Tuberous breast deformity is an anomaly characterized by hypoplasia of the lower pole of the breast, in either the lower medial or the lower lateral quadrant, or in both. Reconstruction with augmentation and/or mastopexy can be challenging due a smaller skin envelope and higher-sitting inframammary fold on the affected side.\textsuperscript{19}

**Pregnancy**
After puberty, the breast undergoes a degree of involution until pregnancy, when massive remodelling occurs. At pregnancy, there is further duct and lobule formation, with secondary and tertiary ductal branching, and increased numbers of secretory acini. Alveoli increase dramatically in number and individually increase in size, with reduction in the stromal adipose tissue (Fig. 43.4). Macroscopically, there is significant breast enlargement, dilation of superficial veins and increased pigmentation of the nipple/areolar complex. Pregnant breast development relies primarily on progesterone and prolactin, both crucial for ductal side branching and development of alveoli, in addition to oestrogens, lactogen and chorionic gonadotrophin.

**FIG. 43.4** Changes in the breast during lactation. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 53.23B.)
Lactation

At parturition there is a sudden drop in placental lactogen and ovarian sex steroids, which, throughout pregnancy, have inhibited the lactogenic effect of prolactin on breast epithelium. Lactation usually begins at 1–4 days post-partum and can continue for 3 years or so, dependent on prolactin and oxytocin secretions from the anterior and posterior pituitary, respectively, in response to infant suckling. When the breast is no longer lactating, involution of the glandular tissue occurs due to apoptosis of epithelial cells. Atrophy of the breast parenchyma is accompanied by increased deposition of adipocytes, returning the breast to a pre-pregnant state, ready for subsequent pregnancies.

Menopause

At the menopause, there is a decrease in overall volume of the breast, with involution of the glandular breast tissue. There is increased deposition of fatty tissue and regression of connective tissues in the stroma.

Male breast

The male breast remains rudimentary from infancy and does not form lobules or alveoli. However, it can hypertrophy, resulting in gynaecomastia. This occurs most often at puberty when boys will often notice a small amount of breast tissue behind the nipple. Occasionally, this will develop further either unilaterally or bilaterally. In later life, typically between the ages of 50 and 80 years, gynaecomastia may also occur. Often the aetiology is obscure but commonly recognized causes include drugs such as histamine H2-receptor antagonists, spironolactone, and antiandrogens used in prostatic carcinoma. Recreational drugs, including marijuana, alcohol and anabolic steroids, are also identified as causes.
Surgical surface anatomy

In the adult female, the base of the breast extends superiorly to inferiorly from the second to the sixth rib, and medially to laterally from the sternal edge to the mid-axillary line. The superolateral quadrant extends towards the axilla along the inferior and lateral border of pectoralis major (Fig. 43.5). A small portion may extend through the clavipectoral fascia into the axilla itself, as the axillary tail of Spence. The breast lies upon a deep fascia, with two-thirds of it overlying pectoralis major as the pectoral fascia, and the remaining one-third lying laterally and inferiorly as fascia over serratus anterior. Inferiorly, this deep fascia is continuous, overlying the upper portion of external oblique and its aponeurosis. Ligamentous fibrous bands, known as Cooper's ligaments, run through the breast. They connect the deep fascial layer to the superficial fascia or fibrous tissue of the dermis, forming an interlobular fascial framework within the breast. The retro​mammary space lies between the breast tissue and the deep pectoral fascia, and allows for a degree of movement of the breast on the chest wall. It contains lymphatics and small vessels.
The breast is composed of skin, subcutaneous tissue and breast tissue, which is further divided into glandular epithelial tissue and stroma.
Clinical anatomy

Skin

The skin overlying the breast contains sebaceous glands, hair follicles and eccrine sweat glands, in keeping with skin elsewhere on the torso. Langer's lines describe the orientation of collagen fibres in the skin, and in the breast they are essentially circular arising outwards from the areola. Kraissl also described lines of maximal skin resting tension, and in the breast these run in a more transverse orientation to Langer's lines. When making an incision in the breast, a scar placed as parallel as possible to these lines will provide the best aesthetic outcome in the long term, with less incidence of keloid and hypertrophic scarring. Tumours in the central portion of the breast, and even those some distance away, can be excised through a circumareolar incision. In the lower poles, an incision in the inframammary fold may be used. It is often possible to make a single incision incorporating the breast specimen and access to the axilla, for either sentinel lymph node biopsy or axillary node clearance, particularly for excisions in the upper, outer quadrant.

Nipple/areolar complex

The nipple and areola are pigmented, ranging from pale pink through to dark brown, and vary in size between women, affected by age, race and hormonal changes. Both apocrine sweat glands and modified sebaceous glands open on to the areola. The modified sebaceous glands, or Montgomery glands, open on to the areolar skin at the slightly raised tubercles of Morgagni (Fig. 43.6A). Embryologically, they are related to both sebaceous and mammary glandular tissue, and secrete an oily, milky substance to lubricate the nipple/areolar complex in breast feeding. The tubercles of Morgagni become more prominent during pregnancy. Hair follicles are also present on the areola.
The nipple has an irregular cobblestone surface with tiny openings leading to ductal orifices. Although more than 20 ducts drain to the nipple, there is a smaller number of orifice openings at the nipple skin surface, with multiple ducts sharing a common draining orifice (Fig. 43.6B). In a study using multiple complementary in vivo and in vitro approaches, over 90% of nipples were found to contain between 5 and 9 ductal orifices. The orifices can become blocked by keratin debris. Ducts are located in a central bundle within the nipple with a peripheral duct-free surrounding area.

Smooth muscle is arranged in mostly concentric circular layers with a prominent bundle at the base of the nipple papilla around all the ducts, contraction of which would lead to the nipple becoming erect. Towards the surface of the nipple, smooth muscle is arranged around individual ducts to aid ejection of milk in breast feeding.

There is an absence of functional breast tissue, the terminal duct lobular unit, in the nipple papilla, making nipple-sparing mastectomy an oncologically safe option for reducing risk of breast cancer in high-risk patients.

Inframammary fold

The inframammary fold marks the site where the skin and superficial fascia of the lower pole of the breast meet the chest wall. The position is variable between patients, and there is no reliable relationship to pectoral muscles or a specific rib; however, it is usually around the level of the fifth or sixth rib. Preserving the inframammary fold at mastectomy creates a native skin
envelope that provides the most optimal aesthetic, in terms of ptosis and inferior pole contour, for breast reconstruction. The inframammary fold is not a true ligament as such, rather a zone of adherence of the dermis and superficial fascia to the pectoral fascia.

### Subcutaneous tissue

Below the dermis of the skin of the breast there is a layer of subcutaneous adipose tissue of variable thickness, and further below this is the breast tissue itself. This plane between the subcutaneous fat and the breast tissue is used as the plane of dissection during mastectomy. The presence of a true superficial fascia at this level has been debated by surgeons and anatomists. There is certainly an absence of any true fascia in almost half of mastectomy specimens and in the remainder it is often poorly developed, so that, even if present microscopically, it may be difficult to identify macroscopically. The ideal thickness of skin flaps to raise during a mastectomy can therefore vary between patients. Surgeons must raise flaps thick enough not to compromise the skin viability, causing skin flap necrosis, while also not compromising oncological resection margins by not excising all breast tissue. This can be especially difficult in skin-sparing and nipple-sparing mastectomies when the skin flaps are of greater area than in simple mastectomy. There is, however, a consistent, distinct layer of non-breast-bearing subcutaneous tissue between the dermis and breast parenchyma, which is the correct plane of dissection and is around 1 cm thick.

### Breast tissue

The breast glandular epithelial parenchyma is a network of multiply branching, increasingly smaller ducts, extending from the principle ducts at the nipple to multiple alveoli and to epithelium. Around 5–9 major collecting ducts drain on the surface of the nipple. Below this, approximately 20 or so lactiferous ducts converge beneath the areola, each dilating into the lactiferous sinus, then draining into the major nipple ducts. Each lactiferous duct drains a lobe, of which there are 20 or more in each breast. Lactiferous ducts branch into segmental and then subsegmental ducts. Further branching of the subsegmental ducts eventually leads to terminal ductules.

Each lobe is made up of 20–40 lobules, and each lobule contains 10–100
acini. Each lobule, with its associated terminal duct and surrounding intralobular stroma, is termed the terminal duct lobular unit.\textsuperscript{42} This is the physiologically functional component of breast tissue, and the site where breast cancers arise.

The number of lobes in each breast can vary widely between patients (range 11–48, median 27, in one study of 72 mastectomy specimens\textsuperscript{43}). Each lobe and its associated lactiferous duct contribute a variable amount to the overall volume of the breast. The distribution and position of lobes does not follow the radial pattern, like the ‘spokes of a wheel’, that is typically described: each duct may drain not only a localized segment, but also a wide area of breast glandular tissue.\textsuperscript{44} There is a variable amount of overlap between lobes, in the manner of the intertwining roots of a tree.\textsuperscript{45}

**Microscopic structure**

Breast density is the relative proportion of parenchyma to stroma. It varies between patients, and also within patients at different times in their lives, being affected by age, pregnancy and the menopause. Breast parenchyma is a branching network of ducts lined with two layers of cells: an inner luminal epithelial layer and outer myoepithelial layer (Fig. 43.7).\textsuperscript{46} The connective tissue stromal framework consists of fibroblasts, adipocytes, macrophages, lymphocytes, neutrophils and eosinophils, and is relatively less cellular than the parenchyma.
FIG. 43.7 The microstructure of breast epithelium. **A**, Note that the myoepithelial process is actually about half the relative size of that shown in the lower diagram. **B**, The peripheral part of a lactating breast lobule enclosed by a connective tissue septum (left). The alveoli are distended by milk secretion. Milk protein appears as eosinophilic material in the lumen and milk fat as pale cytoplasmic vacuoles in the
Vascular supply and lymphatic drainage

**Arterial supply**

The arterial supply to the breast is a well-developed superficial vascular network arising from three main sources: the internal thoracic artery, the lateral thoracic artery and the anterior intercostal arteries. The internal thoracic (internal mammary) artery is the dominant supply in most women.\(^47\) It arises as a branch from the undersurface of the first part of the subclavian artery, about 2 cm above the level of the clavicle.\(^48\) From here, it runs vertically downwards, passing posterior to the sternoclavicular joint, continuing downwards 1–2 cm lateral to the border of the sternum, in a plane just posterior to the costal cartilages and intercostal muscles.\(^49\) Numerous perforating branches arise at each intercostal space to supply the anteromedial and central breast and skin. Large perforators have been described arising at the second intercostal space\(^50\) and at the fifth or sixth intercostal space a few centimetres above the level of the inframammary fold;\(^51\) care should be taken to try to preserve these during mastectomy. The second to fourth anterior intercostal arteries also arise from the internal thoracic artery with branches perforating the pectoral muscles more laterally, supplying the lateral and more inferior aspects of the breast. The lateral thoracic artery arises either as a direct branch from the axillary artery or from the thoraco-acromial artery, itself a branch of the axillary artery.\(^52\) It runs along the lateral border of pectoralis minor and supplies the axillary lymph nodes, pectoral muscles and serratus anterior. Its multiple branches supply the lateral breast and anastomose with branches of the internal thoracic artery (Fig. 43.8). Further branches of the axillary artery including the supreme thoracic, pectoral branches of thoraco-acromial and subscapular arteries, also contribute to the superior and lateral aspects of the breast.
Venous drainage

The veins draining the breast largely accompany the main arteries described above. They form a superficial circular venous plexus around the areola and a deeper mammary plexus within the glandular breast tissue. Multiple anastomoses are present between the systems, eventually contributing to the axillary vein laterally, and to the internal thoracic vein and perforating branches of the intercostal veins.53
Lymphatic drainage

Lymph is absorbed from the interstitial space into a network of lymphatic capillaries confluent over the whole body, flowing from superficial to deep. In the skin, small-diameter, valveless capillaries in the superficial dermis drain to larger precollectors and then to subdermal collecting lymphatic vessels. In the breast, these merge into a subareolar plexus, first described by Sappey in the 1850s.\textsuperscript{54} From here, more than 95\% of lymph will drain to the axilla,\textsuperscript{55} and the remainder will penetrate through the deep fascia and drain to the internal thoracic (mammary) nodes. Occasionally, lymph from the breast can drain to other lymph nodes, including supraclavicular, infraclavicular, interpectoral (Rotter's lymph nodes) and intercostal regions (Fig. 43.9). Small lymph nodes can exist within the breast itself, particularly in the axillary tail and inframammary fold regions. The axilla is the predominant lymph node basin for the breast, regardless of the site of a primary tumour within the breast.\textsuperscript{56} The sentinel node is the first node reached by any breast cancer cells from a primary breast tumour and sentinel node biopsy is now the standard method for staging the clinically and radiologically node-negative axilla. The dual tracer technique will identify the sentinel node accurately, with a false-negative rate of only 5–8\%.\textsuperscript{57,58} Intradermal or subdermal injection of patent blue dye and radiolabelled $^{99}$Tc around the areola in the region of the tumour will flow through the lymphatic channels and eventually to the sentinel node, identified by its colour and radioactivity detected with a gamma probe.
### Innervation

The breast is innervated by sensory and sympathetic nerve fibres from the lateral and anterior cutaneous branches of the second to sixth intercostal nerves, with contributions from the supraclavicular nerves in the superior breast. The nipple/areolar complex is supplied by anterior and lateral cutaneous branches of the fourth intercostal nerve, with minor additional
cutaneous branches from the third and fifth intercostal nerves. The nipple is innervated by two branches from the fourth intercostal nerve, one passing superficial to the breast tissue and the other running through the retromammary space to form a subdermal plexus deep to the areola.
Surgical Approaches and Considerations

Mastectomy

Simple

Indicated in large, multifocal tumours, T4 or inflammatory breast cancer (Fig. 43.10A). Patients may also opt for mastectomy if they cannot have radiotherapy to the breast e.g. recurrent breast cancer in a breast previously treated with conservation surgery and radiotherapy. An elliptical incision is centred on the nipple areolar complex through the skin and subcutaneous tissue. Dissection is in the mastectomy plane to the limits of breast tissue on the chest wall, extending superiorly towards the clavicle and, inferiorly to the inframammary fold. The breast is dissected from the pectoral fascia, all breast tissue is excised and the ellipse is closed, creating a smooth flat wound which can accommodate a prosthesis. Ideally skin flaps should be closed smoothly without excess lax skin to avoid large seroma accumulation: the aim is to create a flat chest wall so that a prosthesis can be accommodated in a bra.
FIG. 43.10  A, Simple mastectomy. This patient has undergone a simple mastectomy as treatment for breast cancer. A flat wound is created on the chest wall so that a prosthesis can be worn within a bra. B, Skin-sparing mastectomy with latissimus dorsi reconstruction. This patient has had a skin-sparing mastectomy performed via a circumareolar incision, excising all breast tissue down to the pectoral fascia. The latissimus dorsi muscle is harvested from the back, and used as a pedicled flap maintained on the thoracodorsal pedicle in the posterior axilla. The muscle is transferred through the axilla into the breast pocket skin envelope and shaped to recreate a breast mound. An ellipse of skin is harvested from the back with the muscle, and this then fills the defect previously occupied by the areola: the linear scar on the back is well concealed in the bra line. C, This patient has an inherited mutation in the BRCA1 gene and has undergone bilateral risk-reducing mastectomies with implant reconstruction. Appearance at 1 week postoperatively.

There is no survival advantage over breast-conserving surgery with radiation.\textsuperscript{63}

### Skin-sparing

This approach is suitable for large or multifocal tumours but is contraindicated in T4 breast cancer (involving skin): it is usually accompanied by immediate breast reconstruction with autologous flap (± implant (e.g. muscle-sparing latissimus dorsi flap)\textsuperscript{64} (Fig. 43.10B). A circumareolar incision is made and dissection undertaken circumferentially in the mastectomy plane. All breast tissue is resected, incorporating en bloc nipple/areolar complex skin.\textsuperscript{65} The native skin envelope provides enhanced aesthetic contour for reconstruction: the skin paddle from the flap fills the void created by resection of the nipple/areola and can be used to monitor flap perfusion. The remaining skin on the flap is de-epithelialised

### Nipple-sparing skin-sparing
A nipple-sparing, skin-sparing approach is suitable as a risk reducing mastectomy option for patients with inherited genetic mutations such as BRCA1 and 2\(^66\) (Fig. 43.10C). It is also increasingly used in breast cancer and *in situ* disease patients where disease is clearly separate from the nipple area. In these cases a retroareolar shave should be taken separately from the main specimen for histology. A positive margin mandates later excision of the nipple.

A curvilinear skin crease incision is made along the inframammary fold\(^67\) or a hockey stick incision is made around the lower border of the areola and extended radially to the lateral crease of the breast. Intraoperative frozen sections of retro-areolar tissue (when available) are often used prior to committing to a nipple-sparing procedure. Immediate reconstruction may be undertaken with either an implant or tissue expander placed subpectoraly.

**Wide local excision**

A wide local excision of a breast lesion that leaves a margin of surrounding healthy tissue, often in combination with adjuvant radiotherapy, has replaced mastectomy as standard of care for most breast cancers.\(^68\) Final pathology comments concern the radial margins, the distance of disease to the excision edge of the specimen: an involved margin mandates a return to theatre for further excision of that area. In the UK this is generally 1mm for *in situ* and invasive disease.

When excising a cancer the surgeon should be sure not to lose the orientation before the specimen is excised and use an agreed logical procedure for marking with a stitch or clips (eg stitch length – short superior, medium medial, long lateral).

**Localised wide local excision**

Localised wide local excision is used to treat impalpable lesions (mostly those detected by breast screening programme).\(^69\) Impalpable lesions are either a true breast mass measuring less than 1cm diameter or a mammographic abnormality, such as calcification, asymmetry or distortion,\(^70\) which may correspond to *in situ* or invasive carcinoma. Traditionally a wire was placed under either mammography or ultrasound guidance preoperatively into a breast lesion, exiting through the skin. The direction of wire pass and the position of the lesion relative to the skin entry site was
then confirmed by mammography and the lesion is resected \textit{en bloc} with the wire in position.

Increasingly, markers that are placed internally within the breast (magnetism, radioisotopes or radiofrequency) are used with the appropriate localisation probe. The advantage is that these markers can be placed several days before surgery, avoiding a delay to theatre start time on the operation date and they are also less likely to be dislodged than a wire.

En bloc resection of a lesion is undertaken with the wire / marker clip in position. The specimen should be orientated with marking sutures and/or clips and then X-rayed to confirm that the lesion has been excised. Radiologists should be consulted to confirm this or to determine if a further margin should be excised from the cavity.

\textbf{Sentinal lymph node biopsy}

The axilla is the predominant lymph node basin for the breast regardless of the site of a primary tumour within the breast.\textsuperscript{71} Sentinel node biopsy is now the reference standard for staging the clinically and radiologically node-negative axilla as determined by pre-operative clinical examination and axillary ultrasound.\textsuperscript{72} The sentinel node is the first node reached by any breast cancer cells from a primary breast tumour. The dual tracer technique will identify the sentinel node accurately, with a false negative rate of only 2–5\%.\textsuperscript{73} Intradermal or subdermal injection of radiolabelled technetium 99 ($^{99m}$Tc) around the areola in the region of the tumour injected prior to theatre and patent blue dye injected just prior to the start of surgery will flow through the lymphatic channels and eventually to the sentinel node. A gamma probe is used to detect the location of radioactivity and the blue dye can be tracked visually in order to identify the correct node(s). Up to 4 nodes may be excised from the axilla.

\textbf{Axillary lymph node dissection/axillary node clearance}

The increasing use of pre-operative axillary ultrasound and sentinel node biopsy has markedly reduced the frequency of axillary node clearance.\textsuperscript{74} However, the procedure may be indicated if a heavy nodal burden is detected clinically or radiologically and confirmed by pre-operative biopsy. An incision is made either in the low axilla or can be incorporated into a mastectomy or wide local incision (in the upper outer quadrant). All axillary contents are excised to the level of the axillary vein at the apex of the axilla superiorly.
superior and posterior to pectoralis minor. The landmarks of the resection margins are latissimus dorsi laterally and latissimus dorsi and subscapularis posteriorly.\textsuperscript{75} Care must be taken to identify and protect the long thoracic nerve (innervating serratus anterior) and the thoracodorsal pedicle, including the vessels and nerve to latissimus dorsi, throughout the procedure.

**Microdochectomy**

Microdochectomy involves the excision of one or more duct(s) and is indicated in unilateral persistent single duct discharge or blood stained discharge.\textsuperscript{76} The offending duct is identified and cannulated with a lacrimal probe, a circumareolar incision is made over the top of the cannulated duct, and the duct is identified and excised\textsuperscript{77} (Fig. 43.11).
FIG. 43.11  A, Discharging duct is identified by gentle expression at the nipple. B, The duct is cannulated with a lacrimal probe and a circumareolar incision marked on the skin. C, The skin of the nipple is dissected from the retro-areolar ductal tissue and the probe within the offending duct identified. D, The duct is excised from the healthy breast tissue. E, The duct is sent to histopathology for analysis.

**Tips and Anatomical Hazards**

Never compromise oncology for aesthetics, but consider your placement of an incision to excise a breast cancer and if possible place it off the breast in the lateral crease or inframammary fold, or around the areola.

Beware of the large medial perforator vessels in a mastectomy – watch out for them to avoid injury to minimise risks of skin flap necrosis.

Be sure to maintain the orientation of a wide local excision and mark it clearly and consistently as agreed with your pathologist.

In sentinel node biopsy do not excise more than 4 nodes to minimise the risks of lymphoedema.

If no radio-isotope or blue dye is detected in the axilla a 4 node sample is a suitable alternative.

In axillary clearance be sure to identify your key anatomical landmarks early and preserve them throughout – the long thoracic nerve, thoracodorsal pedicle and axillary vein.
References

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Single Best Answers

1. Fetal breast development begins with development of bilateral mammary bands. Which one of the following best describes when this occurs?
   A. Weeks 2–3
   B. Weeks 5–6
   C. Weeks 9–10
   D. Weeks 12–13
   E. Week 20+

   **Answer: B.** Two ventral ectodermal ridges begin to develop at weeks 5–6 *in utero*, forming the mammary bands or ‘milk streaks’.

2. Poland’s syndrome is a congenital abnormality of breast and chest wall development. Which one of the following best describes the characteristic features of the condition?
   A. Bilateral underdeveloped breast and pectoral muscles
   B. Bilateral underdeveloped breast, pectoral muscles and chest wall, with shortening of one or both upper limbs and digits
   C. Bilateral underdeveloped breast, pectoral muscles and chest wall, with shortening of both upper and lower limbs and digits
   D. Unilateral underdeveloped breast, pectoral muscles and chest wall, with shortened ipsilateral arm and digits
   E. Unilateral underdeveloped breast, pectoral muscles and chest wall, with shortened contralateral arm and digits

   **Answer: D.** Poland’s syndrome is characterized by unilateral hypoplastic or absent breast tissue and chest wall muscles. Some patients may also have abnormalities of the arm or fingers on the same side.

3. From which one of the following intercostal nerves does the
nipple receive innervation?
A. 2
B. 3
C. 4
D. 5
E. 6

**Answer:** C. The nipple/areolar complex is supplied by anterior and lateral cutaneous branches of the fourth intercostal nerve.

4. Which one of the following best describes the approximate false-negative rate of sentinel lymph node biopsy?
A. 0.5%
B. 1–2%
C. 3–4%
D. 5–8%
E. 10%

**Answer:** D. The false-negative rate of sentinel lymph node biopsy is approximately 5–8%. Use of a radioactive tracer in addition to blue dye significantly lowers the false negative rate.

5. More than 20 lactiferous ducts converge beneath the areola. How many orifice openings are on the surface of the nipple?
A. More than 20
B. 15–20
C. 10–14
D. 5–9
E. Less than 5

**Answer:** D. More than 20 lactiferous ducts converge beneath the
areola with a smaller number of ducts opening on the nipple skin as multiple ducts drain through a shared orifice.
Clinical Cases

1. A 56-year-old female presents with a lump in the upper outer aspect of her right breast. It is confirmed that she has a breast cancer. A wide local excision and sentinel node biopsy is planned as her initial treatment.

A. Describe the surface anatomy of the breast.
   The boundaries of the breast base are: superiorly second rib, inferiorly sixth rib, medially sternal edge, laterally mid-axillary line. The superolateral quadrant extends towards the axilla as the axillary tail of Spence. The breast lies on top of the deep fascia overlying pectoralis major, with the inferolateral portion over serratus anterior.

B. Explain the blood supply to the breast.
   The arterial supply to the breast arises from three main sources:

   i. The internal thoracic (mammary) artery, a branch of the subclavian artery, runs on the under surface of the lateral edge of the sternum. It gives off perforating branches that arise through the intercostal spaces and supply the medial and central breast and overlying skin. The largest perforators originate in the second and sixth spaces.

   ii. The anterior intercostal arteries, branches of the internal thoracic artery, give off branches that perforate the pectoral muscles more laterally and supply the lateral and inferior aspects of the breast.

   iii. The lateral thoracic artery, a branch of the axillary artery, supplies the lateral breast, axilla, pectoral muscles and serratus anterior.

C. What is the pattern of lymphatic drainage of the breast and how does a surgeon identify the sentinel lymph node?
   Lymph is absorbed from the interstitial space into lymphatic capillaries, which then drain to the subareolar plexus of Sappey in the breast. From here, most lymph drains to the axillary lymph nodes; some also drains to the internal mammary or supraclavicular lymph nodes. There may also be small lymph nodes within the breast itself, particularly in the axillary tail or
inframammary fold regions. In sentinel node biopsy a radioactive colloid and patent blue dye are injected into the dermis of the breast at the areola in the same region as the tumour. These agents progress through subdermal collecting lymphatic vessels to the sentinel lymph node, which can be identified visually as blue in colour and hot radioactivity is detected with a gamma probe.

2. A 47-year-old female is seen in the breast clinic with a persistent left-sided blood-stained nipple discharge.

A. Delineate the anatomy of the breast with particular attention to the ductal epithelial system.

The breast is composed of glandular epithelial tissue and stroma. The latter includes the supporting connective tissue framework of the breast, adipose tissue, blood vessels and lymphatics.

The glandular epithelial tissue includes all the ductal parenchymal tissue of the breast. About 20 major collecting ducts converge beneath the surface of the areola and extend radially out into the breast as multiply branching, increasingly smaller-calibre ducts, like the roots of a tree. Each major collecting duct drains one lobe of the breast, and divides into multiple segmental, then subsegmental ducts that eventually lead to terminal ductules. Each lobe contains 20–40 lobules, which each contain 10–100 acini. The terminal duct with its surrounding stroma is termed the terminal duct lobular unit. It is the physiologically active part of the breast tissue and is also where breast cancers originate.

B. What is the innervation of the nipple/areolar complex?

The nipple is innervated by sensory and postganglionic sympathetic fibres via the fourth intercostal nerve.

C. What are the indications for surgery in this patient? Describe the procedure which may be performed.

In unilateral persistent single duct discharge, where cytology has confirmed the presence of blood or epithelial cells, an excision of the offending duct should be performed as a microdochectomy. Under general anaesthetic, the discharging duct is identified at the nipple and cannulated with a lacrimal probe. A circumareolar or radial incision on the nipple and areola is made and the duct excised with the probe in situ, the probe guiding the surgeon to the direction of travel of the duct (see Fig. 43.11). The most common reason for this presentation is an intraductal papilloma, although it
may also be due to duct ectasia or breast cancer, either invasive or in situ.

3. A 26-year-old female, who is 12 weeks postpartum and breast feeds her baby, presents with an exquisitely tender lump in the retro-areolar position of her left breast. The skin overlying is hot and erythematous. You suspect a lactational breast abscess.

A. Outline the physiological changes to the breast during pregnancy and lactation and list the responsible major hormones involved in these processes.

The breast undergoes considerable remodelling during pregnancy with formation of further ducts and lobules, secondary and tertiary ductal branching, increased numbers of secretory acini and an increase in the size of existing acini. The proportion of stromal adipose tissue decreases relative to the increased proportion of glandular tissue and the breasts overall significantly enlarge in size. These changes are driven primarily by progesterone and prolactin, and also by oestrogens, lactogen and chorionic gonadotrophin.

Lactation begins a few days postpartum following the sudden drop in placental lactogen and oestrogens that occurs at birth. Lactation is dependent on prolactin from the anterior pituitary for milk production and oxytocin from the posterior pituitary for milk ejection.

B. How should you assess a new patient with a breast lump?

All patients who present to the symptomatic breast clinic should undergo triple assessment, including clinical examination, imaging and pathology. The standard of breast imaging is mammography for all females aged 40 or above. Ultrasound is also used to assess palpable abnormalities and to image the breasts of younger females where mammography is less sensitive because of the increased density of the breast tissue. Core biopsy is taken of any palpable or image-detected lesion.

C. Summarize the treatment plan for this patient.

This patient should undergo clinical examination and breast ultrasound in the first instance. Mammography would not be used because of her young age and the fact she is breast feeding, both of which would reduce the sensitivity of mammography. If a lactational breast abscess is confirmed on clinical examination and ultrasound, aspiration with local anaesthetic should be performed rather than incision and drainage. Samples should be sent for microbiology and she should be commenced on antibiotics. Regular clinical
review and often repeated aspirations are required until the abscess resolves. She should be encouraged to continue to feed or express milk from this breast.
Core Procedures

**Surgical Repair of Aortic Arch**

- Proximal aortic arch (so-called hemiarch)
- Distal aortic arch (so-called reverse hemiarch)
- Total aortic arch (involves at least one epi-aortic vessel)
- Total aortic arch and elephant trunk: conventional elephant trunk; reverse elephant trunk; frozen elephant trunk

**Surgical Repair of Descending Thoracic Aorta (DTA)**

- Type A DTA (proximal third)
- Type B DTA (distal third)
- Type C DTA (entire thoracic portion)

Core operations performed on the thoracic aorta are typically described in terms of the extent replaced because the vessel is a continuous tube. The thoracic aorta is broken up into anatomical segments, originally for the purposes of endovascular intervention and the description of landing zones (Z0–Z4).\(^1\) In this classification, which is increasingly utilized in open surgery, Z0 is the ascending aorta and proximal arch to the brachiocephalic (innominate) artery; Z1 is the segment between the brachiocephalic and left common carotid arteries; Z2 is the segment between the left common carotid...
and left subclavian arteries; Z3 is the segment beyond the left subclavian artery along the curved portion of the distal arch; and Z4 is the straight portion of the descending thoracic aorta, starting at the level of the fourth thoracic vertebra (Fig. 44.1). Zonation has been encouraged by the introduction of complex hybrid surgical Dacron stent grafts with variable sites for the distal aortic anastomoses. In addition to zones, other key anatomical features that help to define the extent of core procedures are the epi-aortic vessels (Video 44.1) (brachiocephalic trunk, BCT; left common carotid artery, LCC; and left subclavian artery, LSA), as well as the visceral vessels (coeliac artery, superior mesenteric artery and renal arteries).

FIG. 44.1  Aortic landing zones for thoracic endovascular aortic repair. The thoracic aorta is divided into five anatomical zones that relate to the landing zone for thoracic endovascular aortic repair. Key: Zone (Z)0, ascending aorta and proximal arch to the brachiocephalic (innominate) artery; Z1, segment between the brachiocephalic and left common carotid arteries; Z2, segment between the left common carotid and left subclavian arteries; Z3, segment beyond the left subclavian artery along the curved portion of the distal arch; Z4, straight portion of the descending thoracic aorta, starting at the level of the fourth thoracic vertebra. (Adapted from A.T. Cheung, S.J. Weiss, Diseases of the aorta. In: D.C. Oxorn (ed.), Intraoperative Echocardiography, Philadelphia: Saunders, 2012, pp. 161–182.)
Preoperative planning

In approaching surgery on the thoracic aorta, the surgeon is informed by a number of sources, including clinical history, physical examination, and investigations such as routine blood tests and more advanced imaging like CT, MRI, positron emission tomography (PET) and echocardiography. A thorough understanding of a patient’s contrast ‘CT whole aorta’ is, however, the most important prerequisite for planning an operation on the aorta. The ability to manipulate multislice contrast CT of the aorta into sagittal and coronal reconstructions and three-dimensional volume-rendered images allows the surgeon to understand the anatomy and pathology and to create an operative plan. Many of the operative approaches described in this chapter are based on analysis of CT of the aorta and these are represented in the images. Every opportunity should be taken to review CT scans of the aorta as patients are referred either electively or urgently. The novice surgeon is in a unique position to marry these images up with intraoperative findings and learn through experience what is important for surgical planning and execution. A report of a CT scan should never be accepted in isolation because it may well be from a radiologist who has had far less exposure to imaging the aorta than a specialist surgeon. An ECG-gated CT of the aorta should always be sought, as it will correct for root motion during the cardiac cycle (Fig. 44.2).
This chapter focuses on the perspective of a cardiac surgeon intervening on the great vessels and, as such, requires a basic understanding of cardiopulmonary bypass, left heart bypass and deep hypothermic circulatory arrest (DHCA), allowing cardiac arrest and interruption of blood flow, without which such operations are impossible. While there are a multitude of configurations, the basics are described here so that it is easier to understand the planning and operative processes laid out in this chapter.
Cardiopulmonary bypass

Venous blood is drained via a large-bore cannula, typically via a central point at the right atrium, although other options include a long femoral venous line with the tip positioned in the right atrium under transoesophageal echocardiography (TOE) guidance. Supplementary drainage may be acquired from the superior vena cava (SVC), either via direct cannulation or percutaneously via the internal jugular vein. Direct cannulation of the pulmonary artery may also be used for additional venous drainage. Arterial return may be via any decent-sized artery that will accept an arterial cannula or a Dacron graft. Often, this would be the ascending aorta or proximal arch, but commonly the axillary artery, brachiocephalic artery or femoral artery may also be used. The bypass configuration will typically also involve a vent into one of the chambers of the heart to help create a bloodless field and prevent cardiac distension, and a centrifugal pump, oxygenator and open reservoir are situated between drainage and return.

Left heart bypass

Left heart bypass is used during surgery on the DTA and thoraco-abdominal aorta. The circuit is essentially a shunt with cardiopulmonary function preserved. A clamp will commonly be placed around the LSA and either the diaphragm or infrarenal aorta. In order to provide distal perfusion to the limbs and visceral vessels, a shunt is created whereby blood is taken from either the left atrium (inferior pulmonary vein) or the aorta proximal to the proximal aortic cross-clamp, and pumped via a closed circuit to beyond the distal clamp. Side arms allow selective perfusion of the coeliac artery, superior mesenteric artery and renal arteries.

Hypothermic circulatory arrest

Very commonly, replacement of the aortic arch requires interruption of blood flow entirely in order to reconstruct epi-aortic arch vessels. Such a manoeuvre obviously exposes the entire body to no-flow ischaemia. The basis of end-organ protection under these circumstances is hypothermia and, depending on surgeon preference, this may be between 28°C and 18°C. Often, this will be accompanied by selective cerebral perfusion either anterogradely or retrogradely, and early body reperfusion. Orchestration of this methodology in terms of perfusion priority for heart, brain and body is discussed later.
Clinical anatomy relevant to aortic arch surgery

The aortic arch is divided historically on an anatomical basis into proximal, tranverse and distal sections (Fig. 44.3). The transverse aortic arch is the main arterial conduit positioned at the very epicentre of the superior mediastinum, channelling and distributing blood and serving as a reference point to juxtaposed structures. There is a surgical art to preparing the aortic arch for resection and the approach depends on the intended extent of surgical resection, anatomical variation and pathology.
The distinction between the distal ascending aorta and the proximal aortic arch is slim but has clinical significance. In effect, the proximal arch is a slither of aorta extending along two tangents from the proximal origin of the BCT – one extending perpendicular to the underside of the arch, the other extending under the epi-aortic vessels – and reaching the apex of the inferior
aortic arch. For the surgeon, establishing cardiopulmonary bypass and applying a cross-clamp on the distal ascending aorta just proximal to the BCT define the resection as ascending. DHCA and removal of the cross-clamp allow the surgeon to choose to restrict the resection to the ascending aorta as an open distal anastomosis or to undercut the epi-aortic vessels resecting the proximal aortic arch.

The transverse aortic arch is defined by the length that gives rise to the epi-aortic vessels. Clinically, resection of the transverse aortic arch is often defined by the site of distal anastomosis and may involve one, two or three of the epi-aortic vessels (BCT, LCC and LSA).

The distal arch, in a similar way to the proximal arch, is a slither of aorta between the proximal DTA, the origin of the LSA and the apex of the underside of the aortic arch. A more contemporary regional definition of the aortic arch is shown in Fig. 44.1; this is based around an arbitrary definition using the epi-aortic vessels and it is certainly more useful clinically to define the extent of treatment, surgical or endovascular, performed.

A number of important nerves traverse the aortic arch (see Fig. 44.3). Knowledge of their course is crucial to the aortic arch surgeon in order to avoid significant postoperative morbidity, such as a hoarse voice from recurrent laryngeal nerve (RLN) injury or a paralysed diaphragm from phrenic nerve injury.

The courses of the right and left phrenic nerves (see Fig. 44.3) are important in relation to the aortic arch, left internal thoracic artery (internal mammary artery) and pericardium, all of which may be mobilized with the inherent risk of injury. Both phrenic nerves originate from C3, 4 and 5. The right phrenic nerve enters the thorax between the subclavian artery and origin of the right brachiocephalic vein. It passes along the lateral aspect of the SVC and along the pericardium over the right side of the heart, anterior to the hilum of the lung, lying close to the right internal thoracic artery and ending distally at the diaphragm. The left phrenic nerve passes lateral to the LCC and LSA, between the LSA and the subclavian vein, over the arch and down the lateral aspect of the pericardium anterior to the hilum of the lung, lying close to the left internal thoracic artery (Video 44.2).

The courses of the right and left vagus nerves are important as waymarkers to the RLNs. The right vagus passes anterior to the subclavian artery and posterior to the right brachiocephalic vein. Importantly, the nerve then usually gives off the RLN, which hooks under the subclavian artery. This is key for those aortic surgeons chasing the origins of the right common carotid
artery and right subclavian artery in aortic arch surgery. Risk of left RLN injury is variable in aortic surgery (0–20%), and knowledge of the course of the right RLN will certainly reduce the risks of bilateral RLN injury and ensuing issues (Chs 17 and 18). The left vagus passes over the transverse arch between the LSA and LCC, giving off the left RLN, which passes under the transverse arch lateral to the ligamentum arteriosum.

**Blood supply to the spinal cord and posterior circulation**

Monitoring and managing the blood supply to the spinal cord and posterior circulation to the brain are crucial to avoiding stroke and paraplegia. Fig. 44.4 outlines the complex network that the aortic surgeon must understand, particularly when managing the LSA.
The left and right subclavian arteries give off vertebral arteries in their proximal portions. Each vertebral artery passes through the foramina in the transverse processes of all of the cervical vertebrae except the seventh, curves medially behind the lateral mass of the atlas, enters the cranium via the foramen magnum, and joins its fellow to form the basilar artery at the lower pontine border (see Fig. 44.4). The largest branch of the vertebral artery is the posterior inferior cerebellar artery. Asymmetry due to arterial hypoplasia, complete absence or unilateral termination of the posterior inferior cerebellar artery is very common. Vertebral arteries are described as left-dominant (approximately 45%), right-dominant (approximately 30%) or co-dominant (approximately 25%). Branches from the basilar artery include the
anterior inferior cerebellar and superior cerebellar arteries. The basilar artery ends by dividing into two posterior cerebral arteries, which are joined by the distal branches of the internal carotid arteries via the posterior communicating arteries, forming the arterial circle of Willis. The blood supply of the spinal cord is derived in part from the anterior and posterior spinal arteries, fed segmentally in the cervical region by branches of the vertebral arteries and subsequently by intercostal arteries and lumbar arteries, forming a so-called paraspinal network. Preoperative imaging of the cerebral circulation before considering aortic arch surgery is critical to understanding the blood supply and planning surgery.
Surgical approaches and procedures

Aortovascular surgeons most often operate relatively consistently via a full sternotomy or thoracotomy. Occasionally, additional access is required and is described below. This chapter will not deal with super-specialized minimal access thoracic aortic surgery.

Sternotomy

Approaching aortic arch surgery begins with planning the sternal incision. The key questions relate to the proximal extent up on to the neck and placement of the incision median or oblique to the left or to the right. The traditional proximal extent of the incision is between the sternal notch and the manubriosternal junction, depending on the surgeon's preference. The decision is informed by the expected operative extent on the epi-aortic vessels. The proximal extent and form of incision should be planned carefully; extending the incision intraoperatively in a fully heparinized patient should be avoided. Extensive exposure is required to chase resection of a dissected epi-aortic vessel; usually a midline incision up to the inferior aspect of the cricothyroid membrane allows dissection to the left and right, aided by an inverted Travers retractor. Care needs to be exercised in undermining the incision up to the proximal trachea, as there is a significant risk that such patients will require tracheostomy, and communication between the mediastinum and potential tracheostomy needs to be avoided with its inherent risk of infection. Familiarity with the anatomy relating to the epi-aortic vessels is essential and is described below. The inferior aspect of the incision is the xiphisternum. The midline is identified by the intercostal spaces. Sternotomy is standard. Traditional anatomy books place a heavy emphasis on relating structures within the superior mediastinum to the manubrium and sternoclavicular joint; this does not apply here because the sternum is split and retracted, and aortic pathology will distort structures (Fig. 44.5).
Axillary artery
A surgeon may choose to use the left or the right axillary artery to gain access for cardiopulmonary bypass. While each has its benefits, the surface anatomy and dissection are the same on the left and on the right. The relevant landmarks are the mid third of the clavicle, the deltoid groove and the infraclavicular fossa (see Fig. 44.5).

Left ventricular apex
Exposing the left ventricular apex to allow a vent cannula requires planning because the position is variable. The CT scan should be studied, intraoperative ultrasound used and the apex palpated through the chest wall. The level of the xiphisternum, and therefore the central tendon of the diaphragm on which the heart is positioned, should be established. The anterior extent of the intercostal space should be known, as should the position of the nipple. The standard incision will be 4–5 cm, running laterally on top of the rib just above the xiphisternum, and starting about 2 cm lateral
to the anterior extent of the intercostal space. The lateral extent will run just under the nipple in a slim patient (see Fig. 44.5).

**Posterolateral thoracotomy**

In planning a thoracotomy, the surgeon needs to understand the CT scan and the intended operation because these will determine the intercostal space used (either fourth, fifth, sixth or seventh), and hence the relevant landmarks required. The patient is placed in a lateral position. Landmarks include the tip of the scapula, the spinous processes of the thoracic vertebrae and the costal margin. The elevation of the rib should be palpated to allow the incision to follow along a chosen rib until it reaches the chosen point on the costal margin (see Fig. 44.5).

**Thoracolaparotomy**

The thoracotomy portion of this incision is typically low, on the seventh rib extending over the costal margin. The landmarks then become the distal extent of the thoracotomy, the umbilicus and the lateral aspect of the rectus sheath, along which the incision will pass.

**Anterior approach to the aortic arch**

The skin incision is described above and is the initial key to planning surgery on the aortic arch. The sternotomy is standard, extending from the transverse ligament at the suprasternal notch, through the midline to the xiphisternum, and is largely independent of the intended surgery on the aorta.

Dissection into the arch before entering the pericardium is often useful, as it keeps the area free of pericardial fluid and blood oozing from pericardial and pleural edges. In the adult population, the amount of thymic fat is variable. Usually, the midline of the two thymic lobes is easily identified and may be divided and swept to the left and right (Ch. 48). The left brachiocephalic (innominate) vein can be identified and dissected free, as below, and the epi-aortic vessels can be dissected and encircled, as below. The pericardium may then be opened along the midline. The reflection at the superior margin lies over the distal ascending aorta. On the left side, the reflection may be divided, allowing access to the transverse arch and epi-aortic vessels. By reflecting the left brachiocephalic vein superiorly and opening the lateral pericardial reflection, access is gained to a plane
containing loose tissue and the epi-aortic vessels and RLN. The reflection may be divided on the right side near the BCT and down on to the SVC.

The left brachiocephalic vein is a waymarker for the aortic arch surgeon (see Fig. 44.3). It crosses anterior to the transverse arch; the underside of the arch is inferior and the epi-aortic vessels are superior. The vein often needs mobilization; it is contained within a sheath of fibrous tissue that must be divided to allow the sternum to be opened without tension. The vein is best encircled and taped to allow retraction inferiorly and superiorly. The pretracheal fascia lies posterior to the left brachiocephalic vein and can often be felt as a tight band; its division removes tension in the dissection. The inferior thyroid vein is superior to the main body of the left brachiocephalic vein and the thymic veins are inferior, and both may be divided as necessary with impunity. The left side needs mobilization to allow access to the underside of the arch. The distal end is formed by the left internal jugular vein and left subclavian vein. The left internal thoracic vein may run quite distally. The right side needs mobilization across to the junction of the SVC and right brachiocephalic vein (the distal end of the latter is formed by the right internal jugular vein and right subclavian vein). The vein may be divided in cases of redo surgery where the sternum cannot be opened due to adhesions and access to the arch is difficult. Aortic surgeons have not documented any physiological sequelae to this manoeuvre and for some this is routine practice. The only consequences are limitations in the postoperative availability of access for venous lines and pacemakers.

Lateral approach to the aortic arch and descending thoracic aorta

Performing aortic arch surgery via the left hemithorax is challenging and often involves an entirely different set of points to consider, including difficult access, complex practical issues in cerebral protection, and consideration of spinal cord injury because a variable part of the DTA will often be replaced (Fig. 44.6). Isolated DTA surgery will involve DHCA or left heart bypass with its particular nuances (see later), as well as complex management of the spinal cord to avoid risks of paraplegia. For the aortovascular surgeon, there is definitely a different ‘feel’ to operating through the left chest, and certainly with left heart bypass, an element of unfamiliarity and vulnerability around the lack of complete cardiopulmonary bypass. Knowledge of key aspects of the anatomy of the distal aortic arch and
related nerves and lymphatic vessels is important in avoiding complications. A particular knowledge of the blood supply to the spinal cord, especially the importance of the LSA (see Fig. 44.4), is vital in avoiding paraplegia.

**FIG. 44.6** The left posterolateral thoracotomy approach to the aortic arch/descending thoracic aorta. (From R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray's Anatomy for Students, Elsevier. Copyright 2015, Fig. 3.88.)

The thoracotomy required for access for aortic surgery will often be more
extensive than that required for pulmonary surgery. The patient is placed in the left lateral position and, depending on local protocols, will have double-lumen tube, spinal drain and motor-evoked potential. The surface landmarks are as described above and are the tip of the scapula, the point of preferred incision across the costal margin in case of extension onto the abdomen and retroperitoneal space, and the spinous processes of the thoracic vertebrae.

The layers include skin, subcutaneous fat, latissimus dorsi and serratus anterior. Once the ribs are reached, a hand can be swept up to feel the first rib and count down. Typically, the rib chosen is based on its projection over the costal margin, which is often divided. The posterior extent of the resection is to the longitudinal spinal ligaments. With single-lung ventilation, diathermy is applied to the superior aspect of the rib, dividing the external and internal intercostal muscles. The rib may then be divided, allowing free retraction. A hook levered against a cross-bar allows good access to the aortic arch. A standard retractor is then used to spread the ribs further (see Fig. 44.6).

The inferior pulmonary vein is required in the event of left heart bypass as a source of drainage. Retraction of the left lower lobe reveals the reflection of the visceral and parietal pleura and the connective tissue extending from the inferior aspect of the hilum of the lung to the mediastinum. Lymph nodes and the inferior pulmonary vein will be found within this loose tissue. It is important to identify the pericardial reflection along the vein because inadvertent bleeding from the veinotomy into the pericardium during a case may lead to tamponade.

Retraction of the left upper lobe reveals the superior aspect of the hilum and the aortic arch. The visceral pleural membrane is reflected over the hilum and the left main pulmonary artery passes through the so-called aortopulmonary window. Entering the pleural reflection reveals a space of loose tissue, into which the surgeon may dissect to encircle the aortic arch near the LSA.

The transverse and distal aortic arches are seen from the left side. The LSA may be seen coursing to the apex of the hemithorax and often the LCC is easily palpated. Surgery on the DTA may require a clamp proximal to the LSA. This space is entered as described above, staying above the pulmonary artery, and avoiding the RLN if possible. In cases involving DHCA, the LCC and BCT may often be visualized from inside and allow cannulation for anterograde cerebral perfusion.

The distal DTA passes through the diaphragm at the crus at the level of the
twelfth thoracic vertebra. Intercostal arteries branch from the aorta at each costal level. There will often be a need to encircle the distal DTA to allow for a cross-clamp. Awareness of the intercostal arteries is useful in avoiding difficult bleeding. Care is also required, as the oesophagus, lymphatic circulation and right pleura are in close proximity; a TOE probe or bougie will often help to identify the oesophagus.

The left vagus passes anterior to the LSA and over the distal aortic arch, with the RLN looping under the arch. Injury to the RLN is more common from this approach (see Fig. 44.6).

Knowledge of the course of the lymphatic drainage is important in avoiding injury and postoperative chyle leak, which carries significant morbidity and inconvenience. The thoracic duct is intimately applied to the DTA on the medial side. Often, breach of the system is obvious only when opaque fluid is seen during dissection. Feeding the patient cream before surgery will help the surgeon identify the system (see Fig. 44.6).

Resection of the aortic arch and descending aorta

There are an enormous numbers of approaches to replacing the aortic arch, including entirely open and hybrid procedures. Surgeons will, of course, have a preference, based on experience and teaching, but underlying the different innovative methodologies is a desire to avoid or reduce the duration of hypothermic circulatory arrest, and particularly the interruption of cerebral blood flow. In the interests of simplicity, this chapter will focus on ‘entry-level’ anatomical reconstruction of the aortic arch (Video 44.3).

In general, there are three surgical extents to resection, and classifications vary, depending on centre. The so-called hemiarch involves an open distal anastomosis under hypothermic circulatory arrest, and a resection that extends from the origin of the BCT to the apex of the underside of the arch. A total arch replacement involves a much longer period of hypothermic circulatory arrest and resection and reimplantation of at least one, and up to three, epi-aortic vessels. Placement of one of the newer stent–graft hybrids, or frozen ‘elephant trunk’, allows the treatment to extend into the proximal DTA.

Hemiarch surgery

Preparing to resect the distal ascending aorta and proximal aortic arch requires a familiarity with the anatomy of juxtapositioned vessels. The key is
to perform as much of the required dissection as possible before hypothermic circulatory arrest to minimize this time. The pericardial reflection is divided on the outer greater curvature of the distal ascending aorta down to the SVC. The pericardial reflection anterior to the arch is divided, allowing access to the transverse arch and epi-aortic vessels. The purpose is to sloop the BCT and LCC for anterograde cerebral perfusion and, depending on strategy, an arterial line for cardiopulmonary bypass. The pulmonary artery needs to be carefully dissected off the underside of the arch (see Fig. 44.3). Once hypothermic circulatory arrest is established, there is little further dissection to perform and the anastomosis may typically be constructed within 20 minutes. The left RLN rarely comes into sight. Cannulae may be placed directly into the left and right common carotid arteries to supplement cerebral perfusion during DHCA, or on occasion into the SVC to allow so-called retrograde cerebral perfusion. Following construction of the anastomosis, the circulation is restarted, preferably via a side arm of the graft or alternatively at a site of peripheral cannulation (Fig. 44.7A).
Total arch surgery

Preparing to resect the total arch is an entirely different proposition to a hemiarch and requires planning to cover a long period of circulatory arrest, a strategy for multiorgan protection and commitment to strategies for unexpected issues. The arch needs to be mobilized as much as possible and this typically requires a higher than normal sternal incision and mobilization of the left brachiocephalic vein, as described above (see Fig. 44.3). In principle, as much dissection as possible should be performed before heparinization but mobilization of the LSA often requires the luxury of cardiopulmonary bypass, allowing transient depressurization of the arterial system. The BCT, LCC and LSA are mobilized and taped with snares. The
RLN is mobilized and swept away from the operative field. The arch is mobilized off the pulmonary artery in the aortopulmonary window. Once DHCA is achieved and the aorta has been opened, the surgeon needs to assess the position of the epi-aortic vessels, particularly the LSA and the distance between them; this should not come as a surprise, since the CT has already been interrogated. Any pathology, such as intimal tears and atheroma, needs to be reviewed and assessed. A brief period of reflection, requiring calm and attention to detail, will help the surgeon to establish a plan. The surgeon will have an overwhelming urge ‘just to get on with it’ but time should be allowed to establish effective cerebral oxygenation, effective myocardial protection and distal organ preservation. The epi-aortic vessels may be reimplanted individually (Fig. 44.7B) or as a so-called ‘Carrel patch or island’. This may be useful in atherosclerotic pathologies. Thought needs to be given to a dominant left vertebral artery originating from the aortic arch. This can be reimplanted using an island technique with the other branches or reimplanted separately.

**Total arch and conventional/frozen elephant trunk surgery**

An ‘elephant trunk’ in the context of aortic arch surgery refers to a form of extension of prosthetic material beyond the distal anastomosis. Placement of an elephant trunk graft either facilitates second-stage surgery (‘conventional elephant trunk’) in supplying a clampable graft for DTA/thoraco-abdominal aortic aneurysm (TAAA) surgery under left heart bypass, or acts to treat the proximal DTA with an endovascular stent (‘frozen elephant trunk’) (see Fig. 44.7B). Frozen elephant trunks may have particular utility in the acute setting of dissection to modify the size of the true lumen acutely and alter the natural history of the distal aorta in the long term. The device may also act to exclude proximal DTA aneurysms, effectively treating two-stage disease in a single intervention.

**Left subclavian artery**

The LSA is a key vessel in the surgical management of the aortic arch. As described above, the transverse aortic arch passes posterolaterally in the superior mediastinum. Depending on the native variability and pathology, the origin of the LSA may lie posterior and far from the surgeon's access point. Access may be even more limited in cases of redo surgery where there is little tissue compliance. In addition, mobilization may be required up into the carotid sheath parallel to the trachea in order to place a clamp on the
vessel and allow sufficient room to suture an 8 mm graft. This makes the LSA one of the most challenging elements of total aortic arch surgery. There are various solutions to the problem of the distal nature of the origin of the vessel from the arch.

The simplest approach is to avoid a traditional zone 3 distal anastomosis beyond the LSA. The distal anastomosis can be brought forward to zone 2, avoiding reimplantation of the LSA (see Fig. 44.1). Several issues may arise, such as leaving some unresected aneurysmal tissue, and a conventional elephant trunk may partially occlude the LSA. A frozen elephant trunk may be susceptible to endoleak and the LSA may need oversewing or rerouting.

In cases where access is especially difficult, it may be easier to use a separate 8 mm graft first and before the distal anastomosis of the multibranched graft.

With preparation and forward planning, the left axillary artery may be exposed via a subclavian incision and an 8 mm graft anastomosis prior to full heparinization (Fig. 44.8). This may be used to establish bypass but may be delivered into the superior mediastinum tunnelled though the second intercostal space and anastomosed to the main graft.
In difficult circumstances and as a ‘bailout’ option, it is possible to oversew the LSA or tie it off. The left arm will receive blood from the collateral network around the shoulder and will not become acutely ischaemic. However, for the reasons outlined below, there is a risk of stroke and paraplegia, and there may be long-term claudication in the arm.

**Dominance of the left vertebral artery**

Imaging of the vertebral system and cerebral circulation is ideal before embarking on a total aortic arch replacement because it will determine the
management of adjunctive perfusion of the LSA intraoperatively and options for reconstruction.

The contribution from the vertebral arteries to the supply of the spinal cord and posterior brain is not always equal; in patients with a left-dominant vertebral system, care is required to respect this bias intraoperatively because compromise may lead to reduced basilar artery flow to the brainstem and cerebellum, potentially causing posterior circulation stroke. This information is important in planning antegrade cerebral perfusion and in deciding how to manage the LSA; improper consideration may lead to stroke and/or posterior circulation stroke.

**Paraspinal network**

The blood supply to the spinal cord is best described as a paraspinal network (see Fig. 44.4). The spinal cord and its roots and nerves are supplied with blood by both longitudinal and segmental vessels. Three major longitudinal vessels, a single anterior and two posterior spinal arteries (each of which is sometimes doubled to pass on either side of the dorsal rootlets), originate intracranially from the vertebral artery and terminate in a plexus around the conus medullaris. The anterior spinal artery forms from the fused anterior spinal branches of the vertebral artery and descends in the ventral median fissure of the cord. Each posterior spinal artery originates either directly from the ipsilateral vertebral artery or from its posterior inferior cerebellar branch, and descends in a posterolateral sulcus of the cord. The segmental arteries are derived in craniocaudal sequence from spinal branches of the vertebral, deep cervical, intercostal and lumbar arteries.

Management of the LSA during periods of circulatory arrest and in the final reconstruction is crucial to outcome. Without due care, a frozen elephant trunk may interfere with vertebral and intercostal supplies.

**Recurrent laryngeal nerves (RLN)**

Injury to a RLN during aortic arch surgery has a significant negative effect on patient satisfaction as a result of a temporary or permanent hoarse voice. The surgeon must be aware of the course of the RLN when it is approached via a median sternotomy and thoracotomy. In the course of redo surgery, the risk of injury is significantly higher.

Injury to the right RLN is infrequent because the course of this nerve means that it is a rare appearance in surgery. It is important to understand that the right RLN is at risk with high resection to the bifurcation of the BCT.
into the right subclavian and right common carotid arteries, and it is vital to be aware of the risks and consequences of bilateral RLN injury. Maintain vigilance and do not rush to proceed with surgery; do not consider the RLN as dispensable. Stay close to the wall of the aorta and sweep loose tissue away. Try to avoid direct instrumentation or taping.

By bringing the distal anastomosis forward to zone 0, it is possible to avoid the RLN. This comes at the expense of reducing distal coverage below 15 cm. Be especially wary in redo surgery, when the RLN will be fibrosed.

**Important perioperative issues**

One of the emerging issues with aortic arch and frozen elephant trunk surgery is the report of paraplegia in some series. An understanding of the relevant anatomy and physiology is vital to reduce these risks.

Generally, it is true to say that the lower the temperature, the better for neurological protection during DHCA. There has been a tendency to perform aortic arch surgery under moderate hypothermia and up to 28°C. Evidence is emerging that this approach appears to be associated with a higher paraplegia rate. Most surgeons are now lowering the temperature of arrest to around 20°C, although a temperature much below 20°C is associated with prolonged bypass time and coagulopathy, and the risk/benefit balance therefore tips.

Perfusion to LSA throughout the operation may help avoid the risk of ischaemia of the vertebral system. Typically, surgeons rely on monitoring of the cerebral circulation using near infra-red spectroscopy (NIRS) on the forehead but this will not reflect compromise of the posterior cerebral circulation; patients with left vertebral-dominant systems should therefore have mandatory perfusion of their LSA.

A proximal anastomosis may be used; bringing the distal anastomosis to zone 0 may reduce the risk of paraplegia by covering fewer intercostals but the trade-off is less coverage of the DTA.

Treat these patients as if they had undergone thoraco-abdominal aortic surgery, where the postoperative blood pressure is kept high for spinal cord perfusion. Aim for COPS (CSF drain status/Oxygen delivery/ Patient Status) protocol\(^2\) with a mean arterial pressure (MAP) over 90 mmHg.

To manage cerebrospinal fluid pressure (CSFP), consider a CSF drain and follow the COPS protocol with a cerebrospinal perfusion pressure below 10 mmHg. Remember SCPP (spinal cord perfusion pressure) = MAP−CSFP.

Regarding the length of frozen elephant trunk coverage, consider the
balance between the risk of paraplegia and less coverage and treatment of DTA with possible endoleaks.

**Surgery on the aortic arch approached via a left thoracotomy**

The approach to the arch from the left thoracotomy is key to the thoracic aortic surgeon but unfamiliar to all but the experienced surgeon (see Fig. 44.6; Fig. 44.9). There are some aspects that simply entail a different approach to the anatomy from usual; however, the nature and extent of the aortic resection have consequences that require aspects of management that are not necessary in a sternotomy aortic arch replacement. The typical operation is either replacement of the DTA, with or without a clamp, or a reverse hemiarch of the distal arch under DHCA.

Unique to this approach is the option to use left heart bypass rather than cardiopulmonary bypass and DHCA. If a ‘clamped anastomosis’ and single-lung ventilation are performed, the distal arch/proximal DTA may be replaced relatively more quickly than with cardiopulmonary bypass and DHCA, also avoiding significant coagulopathy.

**Surgery on the aortic arch and DTA**

Surgery on the arch from the left side rarely involves a total aortic arch but
more typically entails a reverse hemiarch (Video 44.4). In addition, surgery rarely involves just the distal arch but typically extends to the DTA and TAAA, which means that spinal cord protection becomes an important factor.

Arch surgery involves DHCA, as in proximal hemiarch surgery described above (see Fig. 44.7), and again, doing as much dissection and preparation before DHCA will shorten the period of no flow. Distal body flow, including intercostal perfusion, may be achieved during DHCA by femoral arterial cannulation (Fig. 44.10) and a mid-DTA cross-clamp (sequential clamping). The RLN is more obvious in the lateral approach to arch surgery and care is needed to avoid injury. Anterograde cerebral protection may be achieved under DHCA; however, some persistence is required to cannulate the vessels. A reverse elephant trunk should be considered to facilitate second-stage proximal surgery.

![Femoral vessel access](image)

**FIG. 44.10** Femoral vessel access. (From M. Ragosta, Vascular access and hemostasis. In: Cardiac Catheterization. Copyright © 2010 by Saunders, an imprint of Elsevier Inc., Fig. 2.1, pp. 8–20.)

Surgery to replace the DTA may involve a clamp distal or proximal to the LSA, as well as at the level of the diaphragm (Fig. 44.11). Provided that safe clamps can be applied, then DHCA can be avoided and distal perfusion maintained with left heart bypass. As described above, care needs to be exercised to avoid injury to the oesophagus, thoracic duct and intercostal
arteries. Anastomosis of Dacron graft is standard.

During aortic arch surgery under DHCA, the LSA may be managed by occlusion or perfusion, depending on the factors discussed above for sternotomy arch surgery and the cerebral circulation. When clamping for left heart bypass, it is important to have access to imaging of the cerebral circulation to understand the risks of paraplegia and posterior circulation stroke.

The vagus nerve is much more obvious when approached from the left chest. The nerve passes down the carotid sheath and crosses over the arch at the origin of the LSA, then follows down the underside of the arch and DTA. The left RLN takes off at the ligamentum arteriosum and passes lateral to it and under the arch: this is the exact point surgeons typically want to encircle,
clamp and anastomose. At this point, the left superior intercostal vein crosses the arch transversely and the vagus at right angles. Ideally, the vein should be transected and the nerve mobilized to allow a clamp to underlie it. In cases of DHCA and an open distal anastomosis, this extent of mobilization is not necessary.

A postoperative chyle leak can be a very significant problem, and as with the RLN, the lymphatic system should not be relegated intraoperatively to lesser importance. Patients can lose litres of chyle per day and be plagued for weeks with total parenteral nutrition, octreotide and nil by mouth status. The thoracic duct lies on T12 as the aorta passes into the thorax through the diaphragm, usually arising from the cysterna chyli and passing superiorly on the medial side of the aorta. At T4, it crosses over to the left and finds its way into the venous system, most commonly at the junction of the left internal jugular and left subclavian veins (Ch. 45). Blind spots for injuring the thoracic duct are when encircling the aorta for clamping and transection, around the distal DTA at the level of the diaphragm, and at the LSA, which is commonly encircled and which is around the transition at T4. Giving patients cream before surgery may help surgeons identify any injuries. The oesophagus is also at risk in these manoeuvres but may be avoided by palpation of the TOE probe commonly in place.

Postoperative paraplegia is a recognized complication of DTA and TAAA surgery. It is a consequence of interruption of the segmental blood supply to the spinal cord from the intercostal arteries and therefore relates to the length of aorta resected, previous surgery and cerebral perfusion pressure. Much of the orchestration of the surgery described in this chapter is about reducing this risk. Once the aorta is opened, either between clamps or at circulatory arrest, management of the intercostal arteries seen within the splayed open aorta becomes crucial. When the patient is warm and using left heart bypass, the process can be guided by MEP measurement. The general consensus is that back-bleeding intercostals are thought to have a source of blood outside the aorta: these can and should be oversewn to help maintain pressure in the network. For intercostal arteries between T8 and L1, the presumed area of the artery of Adamkiewicz, these may be temporarily occluded pending the end of the surgery and the status of the MEPs. When MEPs are lost on opening the aorta, priority should be given to anastomosing a 12 mm graft end to side to allow immediate perfusion. Spinal catheters are important in optimizing spinal cord blood flow and a source of analgesia.
Tips and Anatomical Hazards: General Considerations

Competency is an important aspect of the surgeon's armamentarium. In approaching surgery on the great vessels, as described above, general consideration needs to be given to native anatomy and variants, pathology and peripheral access options. Congenital variants of the great vessels are infrequent but have a significant impact on the orchestration of an operation and the nature of any repair. These include a bovine arch, aberrant subclavian arteries, right-sided arch and left-sided SVC.

The pathology for which surgery is indicated may have a significant effect on the approach to that surgery. Important considerations include connective tissue disorders, dissection, infection, acute aortic syndromes and end-stage degenerative disease.

Peripheral access becomes very important in emergency scenarios and redo surgery. The axillary artery is distal to the subclavian artery arising from the bifurcation of the BCT to the LCC on the left and directly from the arch on the left (see Fig. 44.8). For the cardiovascular surgeon, the artery is exposed through an incision 1 cm below the clavicle, parallel to the clavicle and extending from the deltopectoral groove. Once through the skin and subcutaneous fat, the dissection is extended on to pectoralis major, which may be divided with diathermy or a muscle-sparing blunt dissection. Once through pectoralis major, the surgeon is faced with variable anatomy that includes the closely interposed axillary vein and brachial plexus, covered in adipose tissue. Often, pectoralis minor needs dividing to allow a sufficient length of exposure of the axillary artery, which is identified by careful palpation. The axillary artery and vessels are slooped. After heparin, the artery is clamped and incised. An 8 mm Dacron graft is anastomosed with a 5/0 Prolene.

The left ventricular apex is typically required for venting of the chamber in cases where the patient is placed on bypass peripherally and cooled down before opening. The anatomy is described above. The dissection and exposure should be anticipated and performed prior to heparinization (see Fig. 44.9).
The femoral vessels are a key access point for aortic surgery (see Fig. 44.10). It may be necessary to expose the femoral artery and vein, especially in unstable acute patients and those undergoing redo surgery when there is close proximity to the sternum and risk of a re-entry injury to the heart or great vessels. Ideally, this should be anticipated and performed prior to heparinization.

**Thoracic Aortic Arch Surgery**

Study the CT and understand the anatomy and pathology. Anticipate the challenges and have options. Give yourself time by cooling the patient liberally. Do not rush and attend to multiorgan protection, including:
- Myocardial protection
- Cerebral protection
- Distal body protection
Take time to avoid traction or transection of the RLN.

Management of the LSA may include:
- Anatomical reconstruction
- Left axillary bypass
- Anastomosis proximal to the LSA
- Ligation of the LSA

Perfuse the epi-aortic vessels (BCT and LCC) anterogradely. Consider spinal cord protection, especially with frozen elephant trunk surgery:
- LSA perfusion
- Cooling
- MAP
- CSF drainage

Plan the priorities and orchestration of reperfusion: that is, ‘heart, body, head’.

Maintain post-surgical vigilance and have protocols for:
- Correction of coagulopathy
- Spinal cord protection
- Arch-specific intensive treatment unit care

**Descending Thoracic Aorta Surgery**
Study the CT and understand the anatomy and pathology.  
Anticipate the challenges and have options.  
Try to stage the procedure.  
Try to use left heart bypass.  
Ensure distal perfusion.  
Have a strategy for spinal arteries.  
Have MEP technology.  
Have a CSF drain.  
Be flexible intraoperatively.  
Maintain vigilance through the intensive treatment unit stay.
References


Single Best Answers

1. Which one of the following statements about dividing the left brachiocephalic vein is true?
   A. It causes cerebral oedema
   B. It causes myocardial oedema
   C. It has no physiological consequence
   D. It has no consequence for central venous access
   E. It reduces venous return on cardiopulmonary bypass

   **Answer:** C. Dividing the brachiocephalic vein has no functional consequence. Although routine practice by some surgeons, it is mostly performed in difficult reoperations. The practice has consequences for pacing access in the postoperative phase.

2. Which one of the following statements about oversewing of the left subclavian artery is true?
   A. It causes acute arm ischaemia
   B. It may cause posterior circulation stroke
   C. It should never be performed without immediate revascularization
   D. It has no consequences for patients who have had previous left internal thoracic artery (internal mammary artery) graft to the left anterior descending artery
   E. It has effects independent of vertebral artery dominance

   **Answer:** B. As a bailout, the left subclavian artery may be oversewn and this will not cause acute arm ischaemia. The practice may result in long-term claudication. In patients with a dominant left vertebral system, the manoeuvre may result in posterior circulation stroke.
3. Which one of the following statements about anterograde cerebral perfusion is true?
   
   A. Near infra-red spectroscopy (NIRS) on the forehead reflects cerebral oxygenation throughout the brain
   B. It may be performed by unilateral perfusion in the majority of patients
   C. Cerebral imaging is never required and is a waste of resource
   D. It should always include selective perfusion of the left subclavian artery
   E. It may be run concurrently with retrograde cerebral perfusion

   **Answer:** B. NIRS does not measure the posterior circulation and would give a false sense of security about cerebral blood flow. Unilateral perfusion is commonly performed by perfusing the right axillary artery and clamping the brachiocephalic trunk. The safest approach in the absence of cerebral imaging would be to perfuse all three vessels.

4. Which one of the following statements about spinal cord protection during descending thoracic aorta (DTA) surgery is true?
   
   A. DTA surgery should never be performed without measuring motor evoked potentials
   B. During surgery on the DTA, a spinal drain should be inserted and placed on free drainage
   C. Large intercostal arteries with poor back flow should be re-implanted at the time of surgery
   D. Sequential clamping of the aorta is dangerous and should never be performed
   E. Distal perfusion using left heart bypass is unnecessary and a clamp and sew technique is an adequate form of spinal cord protection
Answer: C. Large intercostals not back-bleeding during surgery should be reimplanted and perfused, as they are not in contact with the paraspinal network. Sequential clamping and distal perfusion are recognized as reducing the risks of paraplegia. In emergency situations, motor evoked potentials and cerebrospinal fluid drain may not be possible.

5. Which one of the following statements about frozen elephant trunks is true?
   A. Deploying a frozen elephant trunk does not increase the risk of paraplegia
   B. Patients should always have a spinal drain inserted
   C. Using shorter devices lowers the risk of paraplegia
   D. Revascularization of the left subclavian artery is less important when employing a frozen elephant trunk
   E. Deploying a frozen elephant trunk allows the temperature of hypothermic circulatory arrest to be modest

Answer: C. Generally, the less a frozen elephant trunk covers the aorta, the lower the risks of paraplegia will be. Current thinking is that perfusion of the left subclavian artery during the case and deep hypothermic circulatory arrest are more important with these devices. In addition, maintaining high blood pressure in the postoperative phase is important.
Clinical Cases

1. A 67-year-old male presents with chest pain over the last 24 hours. On questioning, he admits to having been generally unwell for 2 weeks with lethargy, malaise and rigors. The ECG is unremarkable. Chest X-ray shows a left pleural effusion. Routine blood tests reveal anaemia, as well as renal impairment and a C-reactive protein of 206 mg/L. White cells are raised at $22 \times 10^9$/L. Examination of the patient is unremarkable, apart from a pyrexia of 38.6°C. CT reveals a contained rupture of the arch anteriorly. Echocardiography is unremarkable.

A. What is the likely diagnosis?

The history is suggestive of a mycotic, contained rupture of the aortic arch. The aetiology of such acute aortic syndromes is often uncertain. Blood cultures are important to identify a causative organism. In the West, the original pathology is often thought to be a penetrating atherosclerotic plaque that has subsequently become infected.

B. What are the treatment options?

The first-line therapy is broad-spectrum intravenous antibiotics until cultures reveal a specific organism. In addition, the patient needs resuscitation according to local protocols for treatment of sepsis. The main issue then is the timing of intervention. In this scenario, there will be no easy endovascular solution and the patient faces surgery to replace the aortic arch. Ideally, a course of antibiotic therapy is required to treat sepsis and reduce the burden of infection; however, this needs to be balanced against the risk of overwhelming infection or complete rupture and death. This decision is complex and should be guided by patient-related factors on presentation.

C. What anatomical aspects of the CT scan will be of interest?

The aorta needs careful examination on the CT scan. The native anatomy should be noted, including the position of the epi-aortic vessels – in particular, the left subclavian artery – and also any congenital variations such as aberrant left vertebral artery, aberrant right subclavian artery or bovine arch. The extent of the pathology then needs to be assessed with respect to possible aortic arch reconstruction. Elements that will be important are the involvement of epi-aortic vessels, distal extent of disease, and degree of containment of the rupture. This last aspect will determine the strategy for safe opening of the chest and cannulation for cardiopulmonary bypass.
Peripheral cardiopulmonary bypass prior to sternotomy should be considered if the risk of rupture is deemed to be high; however, quite often, the anterior mediastinum is indurated and the rupture contained.

D. What intraoperative anatomy and pathology findings are key?

Once deep hypothermic circulatory arrest is established and the distal ascending aorta opened, several decisions need to be made. Prior to deciding the nature of the reconstruction, the surgeon should have established cerebral protection (either antegrade or retrograde cerebral perfusion) and ensured myocardial preservation and early body reperfusion. The arch then needs to be assessed. The key questions are: firstly, is the left subclavian artery supplying a left-dominant vertebral artery? If so, attention needs to be given to supplementing the left subclavian artery with antegrade cerebral perfusion. In addition, the left subclavian artery needs to be reimplanted; secondly, what is the accessibility of the left subclavian artery? This should be known from the CT scan. Options will include anatomical reconstruction, extra-anatomical bypass or separate reimplantation; thirdly, is there a suitable area to perform a distal anastomosis in zone 3? If the rupture is extensive, there may be no site for a safe anatomical distal anastomosis for a Dacron graft. Typically, if this is possible, surgeons will use a multibranched premanufactured graft with three branches for the epi-aortic vessels and a side arm for reperfusion; fourthly, is it possible to avoid the recurrent laryngeal nerve? Often in this scenario, the area is a mass of inflammatory tissue and the only way to avoid the nerve is a proximal anastomosis into zone 0.

E. What key elements of surgery are important?

Once the assessments described above have been made, the only remaining questions are in which zone to construct the distal anastomosis and how to manage the rupture. A novel approach to this scenario, enabled by the availability of multibranched hybrid stent surgical grafts (see Fig. 44.7B), is to deploy the stent across the ruptured aortic arch to exclude the aneurysm and construct the distal anastomosis in zone 0. The branches are then brought up from the anatomical position of the ascending aorta to anastomose to the left subclavian artery, left common carotid artery and brachiocephalic trunk. Often, the proximal anastomosis is at the sinutubular junction, as the root and valve are preserved.

F. How would the patient be managed postoperatively?

Immediate postoperative management would include maintaining the mean arterial pressure at 90 mmHg, bearing in mind the risk to the spinal
cord from the frozen elephant trunk. Prolonged intravenous antibiotics are then indicated, given that the infected arch has not been entirely resected and the stent portion of the graft remains in a potentially infected field.

2. A 59-year-old male is undergoing surgery on the descending thoracic aorta (DTA) for an expanding, chronically dissected type A aortic dissection. As there is normal-sized aorta distal to the left subclavian artery (LSA) and the dissection stops at the diaphragm, the operation has been planned using left heart bypass and clamps at the LSA and distal aorta at the diaphragm. As soon as the aorta is opened, the motor evoked potential (MEP) signals are lost.

A. What anatomical features on the CT scan will be worth remembering?

Close examination of the CT scan preoperatively is important in order to examine the number of sizeable intercostal arteries in the thorax that may require reimplanting intraoperatively. In addition, the dominance of the left vertebral artery is crucial to note because the artery may be important in supplying the paraspinal network. The endoluminal nature should also be examined for potential clamp sites. Provided there is no endoluminal clot, a clamp may initially be applied at the LSA and then proximal DTA, thus allowing perfusion of the distal DTA intercostals while the proximal anastomosis is being constructed. The clamp may then be moved to the diaphragm to construct the distal anastomosis.

B. What is worth checking to ensure the effect is real?

Ensure that the MEP signals are preserved to the arms and that the fall in signal is specific to the legs. In addition, check that the MEP drop is not unilateral; often, a cannula in the left femoral artery (for return of distal blood on left heart bypass) may cause ischaemia and a loss of MEP signal.

C. What are the surgical options?

The option of a sequential clamp should be considered, as described above, to allow perfusion of more intercostal arteries while the proximal anastomosis is constructed. Distal flow on left heart bypass should be improved, if possible. To provide haemodynamic stability, the priority should switch from constructing the surgical replacement of the DTA to intercostal reperfusion. The approach is to look at the intercostals available; large intercostals not back-bleeding are important. Choose several in close proximity in the distal DTA, anastomose a 12 mm graft side-on and then perfuse from a side of the left heart bypass circuit. Other intercostal arteries
deemed suitable can be blocked with small catheters while a decision is made to reimplant. Other back-bleeding intercostals near to the proximal and distal anastomoses may be oversewn. At the end of the main surgical reconstruction of the DTA, the intercostal graft may be anastomosed to the main graft.

D. What are the medical options?

Adopt the COPS protocol and elevate proximal and distal mean arterial pressure, as well as draining cerebrospinal fluid to a pressure of less than 10 mmHg. Maintain the haemoglobin over 100 g/L.

E. What management should be followed if no MEP signals return?

This is a difficult scenario for the team. MEP signals should be measured on the intensive care unit, and for this to happen, the anaesthetist will have to omit muscle relaxants. The COPS protocol needs to be followed aggressively. Wake the patient up early for clinical assessment. Arrange for an urgent CT of the spine to ensure that there are no other correctable causes, such as spinal haematoma from cerebrospinal fluid drain insertion.
Oesophagus, thoracic duct and lymphatics

Claire L Donohoe, S Michael Griffin

Core Procedures

- Transthoracic oesophagectomy
- Minimally invasive oesophagectomy (MIO)
- Thoracic lymphadenectomy
Embryology

The oesophagus develops from the primitive foregut, a ventral diverticulum caudal to the fifth pharyngeal pouch in the third week of gestation. It is initially a single common gastrointestinal (oesophagus) and respiratory (trachea) tube, which later develops a respiratory bud from which the tracheobronchial tree develops. Failure of division results in congenital problems, such as oesophageal atresia and tracheo-oesophageal fistula, which are beyond the scope of the present chapter. In adults, foregut duplication cysts include cystic or tubular duplications of the oesophagus or bronchus. They are usually located in the posterior mediastinum, and although they commonly share a common wall with the oesophagus, are rarely in continuity with it.\textsuperscript{1} Treatment is required only if the cyst is causing respiratory, gastrointestinal or cardiac effects due to its size.
Surgical surface anatomy

The anatomy of the chest wall has already been discussed in detail in Chapter 42 and the anatomical location of the intercostal neurovascular bundle should be reviewed.

The oesophagus is usually approached via a right-sided thoracotomy with the patient placed in a left lateral position (right side up). For MIO procedures, patients may be positioned prone or in a left lateral position with the table rotated so the patient lies almost prone. For open thoracotomy, the surface landmarks of the nipple and tip of the scapula are used to site the incision. The skin, subcutaneous fat and muscles of the chest walls are divided using diathermy. Superficial arteries running within the subcuticular adipose tissue and muscle should be ligated.

The scapula is mobilized by developing the space beneath the scapula using blunt dissection of areolar tissue to lift the scapula from the chest wall. The second rib will be palpable at the upper level of the thorax; the ribs can then be counted and a thoracotomy via the fourth intercostal space is recommended to allow easy access to both the infra- and supra-azygos oesophagus. Ligation and excision of the intercostal neurovascular bundle inferior to the thoracotomy wound may reduce the incidence of postoperative pain.
Clinical anatomy

The oesophagus enters the thoracic cavity from the neck posterior to the trachea and anterior to the vertebral column. It passes inferiorly behind the aortic arch and at the level of the T4/5 vertebral body is said to occupy the posterior mediastinum along the right side of the descending thoracic aorta. (The posterior mediastinum is defined as the area bounded anteriorly by the tracheal bifurcation, pericardium and pulmonary vessels, and posteriorly by the bodies of the fifth to the twelfth thoracic vertebrae. The arched posterior third of the central portion of the diaphragm constitutes the anteroinferior limit of the posterior mediastinum laterally as the mediastinal pleurae come close together). Below, as it inclines left, the oesophagus crosses anterior to the aorta and enters the abdomen through the diaphragm at the level of the tenth thoracic vertebra. From above downwards, the trachea, right pulmonary artery, left principal bronchus, pericardium (separating the oesophagus from the left atrium) and diaphragm are anterior. The vertebral column, longus colli, right posterior intercostal arteries, thoracic duct, azygos vein, terminal parts of the hemiazygos and accessory hemiazygos veins, and, near the diaphragm, the aorta, are all posterior relations (Video 45.1).

The thoracic duct originates from the condensation of the right and left lumbar trunks with the intestinal trunk, forming the cisterna chyli at the level of L2, and enters the thorax through the aortic diaphragmatic hiatus. The duct traverses the hiatus alongside the aortic opening and ascends between the aorta and the azygos vein, running posterolateral to the oesophagus. At the T4/T5 vertebral level, it curves posterior to the left carotid artery and left internal jugular vein, and drains into the venous system at the angle of the left subclavian and internal jugular vein.2
Surgical approaches and considerations

Oesophagectomy is the key surgical procedure for oesophagogastric surgeons with respect to the thoracic oesophagus. This section summarizes the key evidence underpinning the choice of approach to oesophagectomy. Discussion of the anatomical principles of treatment of paediatric oesophageal atresia and tracheo-oesophageal fistulae is beyond the scope of the present chapter.

The oesophagus may be removed using a transthoracic approach: i.e. using a midline laparotomy to mobilize the gastric conduit and resect the draining abdominal lymph node stations, followed by a right-sided posterolateral thoracotomy to resect the thoracic oesophagus and perform an intrathoracic anastomosis. Alternative approaches for oesophagectomy include the transhiatal approach, whereby the gastric conduit preparation and lymphadenectomy proceed as per the first phase of the two-phase transthoracic approach but the oesophagus is mobilized via the hiatus under vision as far as the inferior pulmonary ligament and then bluntly dissected blindly by developing the peri-oesophageal plane alongside the oesophagus. A left-sided cervical incision exposes the oesophagus and allows blunt dissection of the oesophagus into the superior mediastinum. The gastric conduit is anastomosed to the remnant oesophagus in the neck. The left anterolateral thoracoabdominal approach utilizes extension of the midline laparotomy incision across the left side of the chest to enter the chest at the level of the sixth costal cartilage, and the diaphragm is opened to expose the oesophagus, with formation of the intrathoracic anastomosis below the aortic arch. A three-phase oesophagectomy involves the same first two stages as a transthoracic approach with a third incision in the neck, generally used to remove high (usually squamous cell) oesophageal tumours. In Eastern locations, where squamous cell tumours are most prevalent, resection of the draining lymph nodes within the supra-azygos compartment, as well as in the neck, is standard practice during resection of tumours of the oesophagus, but this practice is infrequent in Western centres.

Choice of approach partly depends on the location and histology of the tumour, carefully assessed endoscopically, as well as using CT of the chest and abdomen. The principles of surgical resection involve removal of the primary tumour with negative margins (denoted an R0 resection), along with removal of the draining lymph nodes and creation of a healthy, well-perfused gastric conduit that can be anastomosed in a tension-free manner to the
remnant oesophagus. Creation of the gastric conduit, as well as alternate conduits in cases where tumour involvement of the stomach precludes use of the gastric tube, is discussed in more detail in Chapter 58.

Adenocarcinomas tend to develop in the lower oesophagus and at the oesophagogastric junction, meaning that three-phase surgery with three-field lymphadenectomy is not standard treatment, as most lymph node spread is in a caudal distribution.\textsuperscript{3–5} Junctional tumours are defined as those arising within 5 cm of the oesophagogastric junction (OGJ), defined anatomically as where the oesophagus meets the proximal gastric rugal folds. Originally classified by Siewert et al,\textsuperscript{6} tumours of the junction with their centre or more than two-thirds of the tumour more than 1 cm above the OGJ are denoted Siewert type 1. Siewert type 2 tumours lie within 1 cm proximally or within 2 cm distally of the junction. Siewert type 3 tumours have their centre or more than two-thirds of the visible tumour within 2–5 cm of the OGJ. Since 2010, tumours of the oesophagogastric junction have been staged in the American Joint Committee on Cancer–Union for International Cancer Control (AJCC–UICC) TNM staging system (7th edition) as oesophageal cancers rather than gastric cancers, since their biological behaviour more closely resembles that of oesophageal tumours.\textsuperscript{7}

Although ongoing application of Siewert grading is recommended, there is a lack of evidence regarding its suitability to guide treatment decisions, particularly with respect to selection of operative approach: i.e. whether type 3 tumours are adequately treated by a total gastrectomy with abdominal lymphadenectomy only rather than a two-phase, two-field lymphadenectomy. Squamous cell tumours tend to develop higher in the oesophagus and are associated with a higher risk of developing nodal metastases in the draining nodes of the neck, as well as the possibility of developing ‘skip’ metastases, whereby involvement of lymph nodes is not contiguous and may occur at an earlier stage in the tumour development.\textsuperscript{8}

A proximal margin of 5 cm is generally considered standard and the location of the anastomosis is partly determined by location of the tumour. To allow adequate proximal margins, as well as choice of anastomotic technique, a hand-sewn anastomosis is generally placed at the level of the azygos arch, versus a stapled approach which allows placement of the anastomosis higher in the apex of the thoracic cavity. Barbour et al have reported that an \textit{ex vivo} proximal margin of more than 3.8 cm of normal oesophagus (which equates to 5 cm \textit{in vivo}) is associated with a minimal risk of anastomotic recurrence and is an independent predictor of survival.\textsuperscript{9}
The extent of the thoracic lymphadenectomy is considered in more detail below. Other considerations for operative approach depend on the background surgical training and experience of the operator; presence of background Barrett’s metaplasia; presence of suspicious lymph nodes within the operative field versus lymphadenectomy guided by primary tumour location; and patient comorbidities and preferences.

**Open versus minimally invasive approach**

Minimally invasive oesophagectomy (MIO) strategies include minimally invasive Ivor Lewis oesophagogastrectomy (laparoscopy and limited thoracotomy or thoracoscopy) and minimally invasive McKeown oesophagogastrectomy (thoracoscopy, limited laparotomy or laparoscopy, and cervical incision). MIO strategies may be associated with decreased morbidity and shorter recovery times. In a study of MIO (mainly using thoracoscopic mobilization) in over 1000 patients, mortality rate was only 1.7% and hospital stay was only 8 days, which is less than most open procedures; only 4.5% required conversion to an open procedure.\(^\text{10}\) However, it is important to note that the volume of cases reported in the literature exceeds that of other centres reporting MIO and may not be generalizable. The prospectively maintained Esophagectomy Complications Consensus Group (ECCG) database reports outcomes from 24 high-volume centres internationally and is the largest database comprehensively reporting complication outcomes.\(^\text{11}\) These data indicate no significant differences in terms of length of stay or complications between open and MIO approaches and may be more reflective of current practice than trial data.

No randomized trials have assessed whether MIO improves oncological outcomes when compared with open procedures. At meta-analysis of 16 case control studies, there were fewer lymph nodes resected in the MIO group,\(^\text{12}\) but it is not clear whether this has an impact on overall survival. A randomized controlled trial of MIO (n=59) versus open oesophagectomy (n=56), powered on pulmonary complications as a primary endpoint, reported fewer postoperative respiratory tract infections in the MIO group (12% versus 34%, \(p=0.005\)).\(^\text{13}\) A prospective cohort study using validated measures of health-related quality of life (HRQL) shows that following minimal access oesophagectomy, the impact on HRQL may be less severe than standard open surgery.\(^\text{14}\) However, the risk of observer bias in these trials is high because non-blinded observers, and not the patients
themselves, performed the assessments.

A prospective phase II multicentre feasibility trial enrolled 104 patients over a 6-year period and reported broadly satisfactory outcomes for a totally minimally invasive approach with a 2.9% 30-day mortality rate, 8.6% anastomotic leak rate, a median of 19 (range 2–55) lymph nodes harvested and survival outcomes broadly similar to international norms. The caveat remains that 45 patients in this study came from one centre and the median number of cases was 4 cases per centre (IQR: 3–5) in the 17 centres participating. This indicates that minimally invasive approaches, while feasible, require extensive experience and developed expertise.

Results of the French MIRO trial report a reduced postoperative morbidity in the hybrid minimally invasive arm (laparoscopic gastric mobilization and open thoracotomy, n=103) versus open controls (n=104) at 35.9% versus 64.4% (p=0.0001) and similar mortality rate (4.9%).

Robotic approaches to minimally invasive oesophagectomy are in development at present, although early series report a relatively large proportion of anastomotic leaks, reoperations and airway injuries. Whether these issues are due to the learning curve associated with the development of newer approaches or are inherent to the decreased haptic feedback of the technique will need careful scrutiny within controlled environments. Larger single-centre series report fewer complications as experience increases and a randomized controlled trial comparing robotic to open surgery is under way.

**Extent of thoracic lymphadenectomy**

**Transthoracic versus transhiatal approach**

Although the transhiatal approach has been associated with less morbidity, the adequacy of lymph node resection has been questioned; whether this has a bearing on long-term survival is not certain. Additionally, whether a transthoracic en bloc oesophagectomy results in improved local disease control or long-term cancer-related outcomes is not clear. A meta-analysis of 59 studies which compared transthoracic with transhiatal oesophagectomy concluded that there was no difference in 5-year survival between the approaches. However, there was significant heterogeneity in the results, and the quality of the included studies was suboptimal, in both groups. The best-quality trial addressing this question is reported by Hulscher et al.
updated by Omloo et al. A total of 220 patients with oesophageal adenocarcinoma and oesophagogastric junctional cancers were randomized to transhiatal or transthoracic oesophagectomy. There was no significant difference in either the in-hospital mortality rate (2% versus 4%, p=0.45) or 5-year survival (34% versus 36%, p=0.71). The rate of pulmonary complications was reduced using the transhiatal approach. However, for the subset of patients with Siewert type 1 tumours (n=90), there was a non-significant increase of 14% in survival, and in patients with node-positive disease there was improved locoregional disease-free survival (64% versus 23% for transhiatal) with the transthoracic approach. Analysis of the Chemoradiotherapy in Oesophageal Cancer and Surgery Study (CROSS) trial data revealed improved survival in surgery-only patients who underwent a transthoracic oesophagectomy compared to those who had a transhiatal resection, but the addition of neoadjuvant chemoradiation obviated this effect.

Two-field versus three-field lymphadenectomy

The standard transthoracic oesophagectomy includes a ‘two-field’ lymphadenectomy, i.e. all lymph nodes in standard D2 lymphadenectomy during the abdominal phase (incorporating nodal stations according to the Japanese classification system (Table 45.1) denoted 1–7, 8a, 9p, 11p, 11d, 12a, 19 and 20), as well as the para-oesophageal lymph nodes below the infra-azygos oesophagus (stations 107, 108, 109, 110, 111, 112; Fig. 45.1). Whether there is any benefit from resection of nodes from the supra-azygos portion of the oesophagus (stations 105 and 106) or from lymph node stations within the neck (stations 101 and 104) is unclear. In the 6th edition of the AJCC–UICC TNM staging for oesophageal cancer, nodes within the neck or beyond the coeliac axis were denoted metastatic disease. However, this method of staging nodal metastases was withdrawn from the 7th edition, where the number of involved nodes and not their location was the determinant of nodal stage. This leaves an unanswered question – should patients with clinically suspicious nodes within the supra-azygos field or neck undergo an extended ‘three-field’ lymphadenectomy?
### TABLE 45.1
Japanese classification of lymph node stations draining the oesophagus (displayed in Fig. 45.1)

<table>
<thead>
<tr>
<th>Field</th>
<th>Number</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical lymph node stations</td>
<td>101R</td>
<td>Right cervical para-oesophageal</td>
</tr>
<tr>
<td></td>
<td>101L</td>
<td>Left cervical para-oesophageal</td>
</tr>
<tr>
<td></td>
<td>104R</td>
<td>Right supraclavicular</td>
</tr>
<tr>
<td></td>
<td>104L</td>
<td>Left supraclavicular</td>
</tr>
<tr>
<td>Thoracic lymph node stations</td>
<td>105</td>
<td>Upper thoracic para-oesophageal</td>
</tr>
<tr>
<td></td>
<td>106 recR</td>
<td>Right recurrent laryngeal</td>
</tr>
<tr>
<td></td>
<td>106 recL</td>
<td>Left recurrent laryngeal</td>
</tr>
<tr>
<td></td>
<td>106 pre</td>
<td>Pretracheal</td>
</tr>
<tr>
<td></td>
<td>106 tbR</td>
<td>Right tracheobronchial</td>
</tr>
<tr>
<td></td>
<td>106 tbL</td>
<td>Left tracheobronchial</td>
</tr>
<tr>
<td></td>
<td>107</td>
<td>Subcarinal</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>Middle thoracic para-oesophageal</td>
</tr>
<tr>
<td></td>
<td>109R</td>
<td>Right main bronchus</td>
</tr>
<tr>
<td></td>
<td>109L</td>
<td>Left main bronchus</td>
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<td>110</td>
<td>Lower thoracic para-oesophageal</td>
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<td>Supradiaphragmatic</td>
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<td>112</td>
<td>Posterior mediastinal/thoracic duct</td>
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<td>Abdominal nodal stations</td>
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<td>Right cardial</td>
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<td></td>
<td>2</td>
<td>Left cardial</td>
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<td>3</td>
<td>Lesser curvature</td>
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<td>7</td>
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<td>8</td>
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<td>9</td>
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<td>11</td>
<td>Splenic artery</td>
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<td>19</td>
<td>Infradiaphragmatic</td>
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<td></td>
<td>20</td>
<td>Hiatal</td>
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Key questions involve the risk of lymph node metastases in these fields and whether this differs between squamous tumours and adenocarcinomas. In a large cohort (n=1580) of Chinese patients undergoing three-field lymphadenectomy for thoracic squamous cell tumours without neoadjuvant treatment, the rate of neck nodal metastases was 49.5%, 35% and 17.2% for
upper, middle and lower oesophageal tumours, respectively, and that of upper mediastinal (supra-azygos) nodal metastases was 28.7%, 22.4% and 10%, respectively. Based on these and similar data, the treatment of oesophageal squamous cell carcinoma in Eastern centres includes a standard three-field lymphadenectomy.

Even in squamous cell tumours, involvement of cervical nodes is highly correlated with nodes in the thoracic cavity, and isolated nodal metastases in the neck are unusual. In a series of 1715 patients with thoracic squamous cell carcinoma, patients with three-field nodal involvement had the poorest long-term survival, but when these patients were stratified according to the number of involved lymph nodes, the greater the number of involved nodes, the worse the prognosis; their relative location did not make any difference. In summary, patients with involved nodes in three fields had a heavy burden of lymph node involvement and it was the burden that determined overall survival.

There are sparse data concerning adenocarcinomas but these tumours seem to display a similar pattern concerning the importance of number versus location of nodal metastases. In a series of 196 patients with adenocarcinoma undergoing neoadjuvant chemoradiotherapy followed by surgery with a two-field lymphadenectomy, the location of involved lymph nodes did not result in a difference in long-term survival.

Data from Western centres on three-field resections are few: in a prospective study of 174 patients, 96 of whom had adenocarcinoma (which did not include any patients with an American Society of Anesthesiologists (ASA) score of 3 or more), the overall rate of positive cervical nodes was 23.6% (41/174) and the rate of involved nodes increased as T stage increased. In 31/41 cases, the involved cervical nodes were not foreseen, with clinical staging (comprising CT and endoscopic ultrasound); in 26/41 cases, the cervical nodes were the only involved lymph nodes. Patients with involved cervical lymph nodes had a median survival of 14.6 months compared to those with negative cervical lymph nodes (median survival 48.8 months, p=0.032) – the equivalent 5-year survival rate to patients with metastatic disease (i.e. 5-year survival less than 10%).

There has only been one randomized study of three- versus two-field (including a supra-azygos) lymphadenectomy comparing 32 versus 30 patients with squamous cell carcinoma. Importantly for analysis, there was only a 3.2% rate of positive cervical lymph nodes included (one patient), limiting conclusions that can be drawn from the trial, although a difference
in 5-year survival of 66.2% versus 48% (p=0.192) was reported for those undergoing cervical dissection. This study was underpowered to detect a significant difference attributable to a neck dissection.33

To summarize, there are no high-quality data to inform choice of extent of lymphadenectomy. The accuracy of current staging modalities, including endoscopic ultrasound and positron emission tomography–computed tomography (PET-CT), has a suboptimal positive predictive value for lymph nodes with nodal metastases.34,35 Extensive nodal resection may make no difference to survival and there are unlikely to be any randomized trial data to support decision-making in this setting. There is increased morbidity from three-field resections, although the relative burden is poorly defined: the surgery is longer and there may be increased risk of anastomotic leaks, conduit necrosis and subsequent anastomotic strictures, since the anastomosis is formed in the neck. The risk of recurrent laryngeal nerve palsy, which may be temporary or permanent, leads to increased prolonged ventilation, increased respiratory failure and aspiration, and decreased exercise tolerance.36 In the author’s experience, three-field nodal dissection is used in fit patients with supra-azygos nodal disease in both squamous cell carcinoma and adenocarcinoma.

Two-phase transthoracic oesophagectomy

Infra-azygos dissection

A suggested approach to the infra-azygos dissection via a right-sided thoracotomy (or thoracoscopically with the patient rotated from full posterolateral position into a near-prone position3) with single lung ventilation is as follows. The dissection begins with division of the inferior pulmonary ligament as far superiorly as the inferior pulmonary vein, which allows retraction of the lung away from the oesophagus. This plane is developed to remove any nodes between the inferior pulmonary vein and the oesophagus en bloc as far inferiorly as the diaphragmatic hiatus and superiorly on to the fibrous pericardium (station 111). The azygos arch is then ligated and divided.

Images in this chapter are taken from a thoracoscopy MIO but display key anatomical portions of the dissection relevant to the open approach.3

There is often an intercostal artery underneath the arch, which should be preserved; if present, a small venous tributary emptying into the arch may
need to be ligated separately. Care should be taken not to twist the end of the vein under the suture material, resulting in a loose ligature that could untwist, resulting in torrential bleeding at a later point. Division of the azygos arch allows identification of the oesophagus as it runs from the thoracic inlet to the diaphragmatic hiatus (Fig. 45.2). The thoracic duct should be identifiable in most cases at this point, running lateral to the azygos vein and posterolateral to the retracted oesophagus (Fig. 45.3). The pleural sac should be opened to allow development of the plane between the azygos vein and oesophagus as far inferiorly as the diaphragmatic hiatus, without opening into the abdomen (to prevent reflux of fluid from the abdominal compartment and the gastric conduit, which is usually created during the first phase of the operation). Small venous tributaries of the azygos arch draining into the oesophagus should be ligated in continuity.

FIG. 45.2 Contents of the posterior mediastinum. Following division of the azygos arch, the structures of the posterior mediastinum can be dissected by opening the pleura overlying the azygos vein in order to develop the plane between it and the oesophagus. The aorta forms the posterior boundary of this dissection.
FIG. 45.3  The position of the thoracic duct in the posterior mediastinum. The thoracic duct is identified running lateral to the azygos vein and posterolateral to the retracted oesophagus. It should be ligated 3–5 cm superior to the hiatus.

The thoracic duct is rolled medially off the aorta with the oesophagus and removed *en bloc* as part of the radical lymphadenectomy. The inferior end of the thoracic duct should be ligated 3–5 cm superior to the diaphragmatic hiatus (Fig. 45.4). Care should be taken to identify any side-branch (radical) lymphatics draining into the main duct from behind the T12 vertebral body: failure to ligate the larger vessels may result in a chylothorax postoperatively. It should be noted that the thoracic duct system may comprise up to three ducts rather than a single main duct (in approximately 65% of the population) and all larger lymphatics should be ligated. The duct is usually 2–3 mm wide at the hiatus and may be difficult to identify without careful examination. Ligation more proximally in the chest may allow easier identification of the duct more inferiorly.
FIG. 45.4  Ligation of the thoracic duct. The thoracic duct is carefully ligated above the hiatus and the proximal duct rolled medially and taken en bloc with the paraoesophageal lymph nodes (wide arrow). In this image, the thoracic duct has been ligated with polymer ligating clips because the procedure was performed thoracoscopically. In the open approach, the duct is ligated in continuity using 3.0 sutures. The aorta lies immediately posterior to the plane of dissection of the thoracic duct.

The posterior plane of dissection between the azygos vein and oesophagus is the aorta (Fig. 45.5). Care should be taken not to develop this plane too far laterally behind the vertebral bodies because ligation of aortic lumbar branches is more challenging in this position and lateral resection at this point is not required for oncological purposes. Development of this plane brings the peri-oesophageal nodes lying lateral to the oesophagus medially en bloc with the oesophagus and opens the plane on to the posterior aspect of the oesophagus, with the most posterior margin being the left-sided pleura. A variable number of small branches of the aorta supply the oesophagus within this plane of dissection, which should be ligated in continuity and divided.
At the inferior aspect of the dissection, the oesophagus will become fully mobile as the plane between the pleura and draining nodal tissue thins laterally on to the already mobilized inferior pulmonary ligament plane/pericardium. The oesophagus may be slung at this point with a nylon tape to allow countertraction to complete the lateral dissection plane and to develop the medial dissection plane on to the pericardium.

At this time it is useful to mobilize the proximal oesophagus to prepare it for anastomosis high in the thoracic cavity (22–25 cm from the incisors, as measured endoscopically). This should be done first by extending the plane created laterally during the division of the azygos arch and then medially. The vagus nerves are identified above the level of the azygos arch and divided.

The final plane of dissection is removal of the peribronchial and subcarinal nodes en bloc (Figs 45.6, 45.7). Care must be taken to protect the membranous trachea or bronchus from thermal injury. The variable small vessels supplying these nodes should be identified and ligated individually to prevent bleeding. It should be borne in mind that this area is adjacent to the membranous portions of the airways and therefore the use of diathermy for control of bleeding is unsuitable.
FIG. 45.6 Dissection of the station 107 subcarinal nodes. A bronchial vessel is visible within the nodal package and may need to be ligated to avoid bleeding.
FIG. 45.7  The carina after removal of stage 107 nodes. The plane between the subcarinal nodes and the membranous walls of the bronchi is thin and care must be taken with the use of thermal dissection. The edges of the rings of the right main bronchus are clearly visible (arrows).

**Supra-azygos dissection**

Development of the supra-azygos plane is aided by mobilization of the oesophagus inferiorly. After division of the azygos arch, the plane between the oesophagus and trachea can be developed by parallel blunt dissection between the two structures, aided by lateral retraction of the oesophagus. The posterior plane of resection is the left-sided mediastinal pleura. The left recurrent laryngeal nerve runs in the tracheo-oesophageal groove and should be identified and preserved. The right recurrent laryngeal nerve is usually seen at the thoracic inlet, curving around the right subclavian artery and adjacent to the right brachiocephalic vein; rarely, the right recurrent laryngeal nerve does not recur around the right subclavian artery (non-recurrent recurrent laryngeal nerve).

**Left thoraco-abdominal approach**
The left thoraco-abdominal approach allows access to the left upper quadrant of the abdomen, as well as the left thoracic cavity and the oesophagus and peri-oesophageal lymph nodes as far superiorly as the aortic arch. The patient lies in a right lateral decubitus position (left side up); the left neck may also be prepared if the anastomosis required is to be higher than the level of the aortic arch. An oblique incision is made approximately two fingers’ breadths below the scapular tip and runs parallel to the ribs, crossing the costal cartilages at the level of the sixth rib and entering the sixth intercostal space. The incision is carried to the midline of the abdomen and is curved along the midline. Latissimus dorsi and serratus anterior are divided and the sixth intercostal space entered. The sixth costal cartilage is divided carefully, ligating the musculophrenic terminal branches of the internal thoracic artery as they run posterior to the cartilage. The anterior and posterior layers of the rectus sheath are divided to enter the abdomen. Stay sutures are placed in the diaphragm to facilitate its retraction and closure, and the diaphragm is divided approximately 3 cm from the chest wall to create a T-shaped opening with the incision in the rectus sheath. The diaphragm is divided circumferentially 2–3 cm from the lateral chest wall in order not to denervate the muscular component.

Transhiatal approach
The transhiatal approach is discussed in more detail in Chapter 58.

Anastomotic considerations
The key outcomes determining choice of anastomotic technique are the anastomotic leak rate and the stricture rate. For all anastomoses, the key surgical principles include a well-vascularized oesophageal wall and gastric conduit, resection of any ischaemic portions and creation of a tension-free anastomosis. Patient-related factors, including previous neoadjuvant therapy, nutritional status, immunocompromised status (diabetes and so on), smoking and respiratory or cardiovascular comorbidity, may also influence outcome.

Oesophagogastric anastomoses can be broadly divided into hand-sewn or mechanical types. Hand-sewn anastomoses may be end-to-side or end-to-end, with either a single or double layer of sutures. Mechanical stapling devices permit circular end-to-end anastomoses; intraluminal stapling devices and
linear staplers may be used to construct side-to-side anastomoses. The site of anastomosis may be intrathoracic or cervical. Twelve randomized controlled trials, including 1407 patients analysed at meta-analysis, reported no significant difference in anastomotic leak rate between circular versus hand-sewn anastomoses. Subgroup analyses of differences in site, diameter or configuration were underpowered, due to the large number of different techniques and small numbers of patients included, but showed no obvious differences in outcomes. Alternative techniques, including the modified Collard (linear side-to-side) anastomosis, delta anastomosis and others, were not represented in this meta-analysis. A meta-analysis of 12 comparative studies and 3 randomized controlled trials of the linear anastomotic versus hand-sewn techniques reported a significant decrease in anastomotic leaks (RR 0.51, 95% CI 0.41–0.65, p<0.001), as well as strictures (RR 0.56, 95% CI 0.49–0.64, p<0.001). Exclusion of non-randomized studies would not provide adequate power to differentiate between these outcomes. Wrapping the anastomosis with omentum from the gastroepiploic pedicles seems to reduce both the incidence and the severity of anastomotic leaks.

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**Tips and Anatomical Hazards**

The key anatomical hazards during the thoracic phase of an oesophagectomy are:

- Recognition of the thoracic duct and ensuring its secure ligation. The surgeon should carefully assess for duplications of the main duct, as well as large draining branches requiring ligation, and ensure that delicate branches are not torn during ligation.
- Identification and ligation of aortic branches, without injury to the aorta or excessive bleeding.
- Prevention of tracheobronchial injury during resection of subcarinal and bronchial nodes (stations 107 and 109 right and left), along with mobilization of the oesophagus from the posterior wall of the trachea.
- Identification of the recurrent laryngeal nerves and recognition of RLN palsy as a consequence of iatrogenic injury, especially during supra-azygos lymph node dissection and/or lymphadenectomy in the neck.
References


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27. Noordman BJ, van Klaveren D, van Berge Henegouwen MI,


Single best answers

1. Of which one of the following operations is resection of thoracic duct NOT a standard part?
   A. Two-phase two-field transthoracic oesophagectomy
   B. Three-phase two-field oesophagectomy
   C. Thoracoabdominal oesophagectomy
   D. Transhiatal oesophagectomy

   **Answer: D.** Since the thoracic oesophagus is mobilized blindly using blunt dissection during a transhiatal oesophagectomy, the thoracic duct is not ligated.

2. Which one of the following describes the course of the thoracic duct in the chest?
   A. Posterolateral to the oesophagus
   B. Anterior to the oesophagus
   C. Posteromedial to the oesophagus
   D. No relationship to the oesophagus

   **Answer: A.** The thoracic duct lies posterolateral to the oesophagus.

3. At which one of the following levels does the thoracic duct system begin, as a condensation of the right and left lumbar trunks with the intestinal trunk?
   A. T12
   B. L1
   C. T11
   D. L3
Answer: B. The thoracic duct system may comprise up to three ducts rather than a single main duct (in approximately 65% of the population) and arises anterior to L1 or L2.

4. Which one of the following describes where the thoracic duct enters the thorax?
   A. Through the aortic diaphragmatic hiatus
   B. Alongside the oesophagus at the level of T10
   C. Adjacent to the inferior vena cava at the level of T8
   D. The thoracic duct forms within the thoracic cavity

Answer: A. The thoracic duct traverses the hiatus alongside the aortic opening and ascends between the aorta and the azygos vein, running posterolateral to the oesophagus.

5. Which one of the following describes where the thoracic duct usually drains into the venous system?
   A. At the angle of the right subclavian and internal jugular veins
   B. Directly into the superior vena cava
   C. Into the left brachiocephalic vein
   D. At the angle of the left subclavian and internal jugular veins

Answer: D. The thoracic duct usually drains into the venous system at the angle of the left subclavian and internal jugular veins.

6. Resection of which one of the following lymph node stations is NOT involved in a standard two-phase two-field lymphadenectomy for a distal oesophageal tumour?
   A. Station 107 subcarinal
   B. Station 106 recR right recurrent laryngeal nerve
   C. Station 109R right main bronchus
D. Station 111 supradiaphragmatic

**Answer: B.** The nodes lying alongside the recurrent laryngeal nodes are not routinely resected during a two-field lymphadenectomy for a distal oesophageal tumour. For mid- and proximal oesophageal tumours, resection of the nodes in the supra-azygos compartment is considered on an individual basis in Western centres but with potentially increased morbidity and no proven survival advantage.

7. Resection of which one of the following lymph node stations is NOT involved in a standard two-phase two-field lymphadenectomy for a distal oesophageal tumour?
   A. Station 2 left cardial
   B. Station 9 coeliac artery
   C. Station 10 splenic hilum
   D. Station 19 infradiaphragmatic

**Answer: C:** Lymph node stations resected during the abdominal phase of a two-field oesophagectomy include stations 1–7, 8a, 9p, 11p, 11d, 12a, 19 and 20. Removal of nodes in the splenic hilum increases the risk of bleeding, blood transfusions and splenectomy, and is not a standard step in lymphadenectomy for oesophageal cancer.
Clinical cases

1. A previously fit and well 66-year-old male presents with an 8-week history of progressive dysphagia. An endoscopy shows a mass extending 28–32 cm from the incisors, partly occupying the oesophageal lumen. Biopsies from the mass show a poorly differentiated squamous cell carcinoma. A positron emission tomography–computed tomography (PET-CT) scan shows an $^{18}$fluoro-deoxyglucose ($^{18}$FDG)-avid primary tumour with no evidence of distant metastases. Endoscopic ultrasound (EUS) reveals invasion of the muscularis propria without invasion of the aorta or pleura, and two peri-oesophageal round lymph nodes which are suspicious for nodal metastases. The clinical stage of the tumour is thus T3N1M0.

A. What are the treatment options for this patient?
This locally advanced high squamous tumour of the oesophagus may be treated with either definitive chemoradiotherapy alone or neoadjuvant chemoradiotherapy followed by a three-phase oesophagectomy with a cervical anastomosis. The most recent Cochrane review (L.M. Best, M. Mughal, K.S. Gurusamy, Non-surgical versus surgical treatment for oesophageal cancer, Cochrane Database Syst. Rev. 2016) and meta-analysis (K.M. Sjoquist, B.H. Burmeister, B.M. Smithers, et al., Survival after neoadjuvant chemotherapy or chemoradiotherapy for resectable oesophageal carcinoma: an updated meta-analysis, Lancet Oncol. 12 (2011) 681–692) comparing the two approaches report equivalent oncological outcomes with lesser morbidity in the non-operative group. However, the current standard of care is based on the Dutch Chemoradiotherapy in Oesophageal Cancer and Surgery Study (CROSS) trial (P. van Hagen, M.C.C.M. Hulshof, J.J.B. van Lanschot, et al., Preoperative chemoradiotherapy for esophageal or junctional cancer, New Engl. J. Med. 366 (2012) 2074–2084), which demonstrates superior outcomes from this regimen for squamous cell carcinoma than the current evidence base for definitive chemoradiotherapy, highlighting a need to revisit such a comparison with definitive chemoradiation within future randomized clinical trials.

2. A 76-year-old male with a history of coronary artery disease, congestive cardiac failure and type II diabetes mellitus is found to
have a bulky stenosing distal oesophageal adenocarcinoma extending from 36 to 42 cm across the gastro-oesophageal junction. At EUS, at least seven nodes suspicious for nodal metastases are noted within the posterior mediastinum (level 110) and in the gastrohepatic ligament (level 7). There is invasion of the muscularis propria. A PET-CT shows an FDG-avid primary lesion, as well as uptake within the nodes seen at EUS at levels 110 and 7. In addition, there is uptake within a node in the supraclavicular level (104R).

**A. What further staging investigations are required?**
The next step would be to arrange a neck ultrasound and fine needle aspiration of the node within the neck. If this confirms tumour, then the clinical stage is T3N3M0. Patients with this clinical stage and nodes that are outside the usual field of resection are often considered only for treatment with palliative intent. As discussed in this chapter, there are few data to support a three-field lymphadenectomy for oesophageal adenocarcinoma, and the prognosis for patients with large numbers of metastatic lymph nodes is equivalent to that for patients with metastatic disease.

If the node is biopsied and a benign process (e.g. sarcoidosis) or a low-grade lymphoma is found to be the cause of the lymphadenopathy, then further staging with a diagnostic laparoscopy and peritoneal washings is indicated for this tumour, which spans the gastro-oesophageal junction (a Siewert type II lesion) (J. Findlay, K. Bradley, E. Maile, et al., Pragmatic staging of oesophageal cancer using decision theory involving selective endoscopic ultrasonography, PET and laparoscopy, Br. J. Surg. 102 (2015) 1488–1499). If no distant metastases are found and cytology of the washings shows no malignant cells, then neoadjuvant treatment with chemotherapy or chemoradiotherapy should be considered, followed by restaging with a PET-CT scan at the completion of treatment.

3. A 68-year-old female undergoes a two-phase transthoracic oesophagectomy with two-field lymphadenectomy and placement of a feeding jejunostomy tube for treatment of a T3N0M0 oesophageal adenocarcinoma. On the second postoperative day, enteral nutrition is commenced through the feeding jejunostomy. The output of her right-sided chest drain is noted to increase and to change in appearance to a milky colour.

**A. What is the cause?**
The suspicion is that the patient has developed a chylothorax. Enteral feeding results in the absorption of fats in the form of chylomicrons via the lymphatic system of the small bowel, which condenses as the cisterna chyli and becomes the thoracic duct in the upper abdomen. The thoracic duct is often ligated *en bloc* during oesophagectomy, but if injured or incompletely ligated, or if branches are not recognized and ligated, a chylothorax may develop. The diagnosis may be confirmed by testing the pleural fluid for triglycerides.

**B. What is the treatment?**

Pleura and thoracic sympathetic trunk

May Al-Sahaf, Herbert J Witzke, David A Waller

Core procedures

- Pleural biopsy, pleural drainage, pleural debridement
- Spontaneous pneumothorax surgery, parietal pleurectomy
- Decortication of empyema
- Pleurectomy/decortication (extended) for mesothelioma
- Excision of solitary pleural tumour
- Thoracic sympathectomy, facial flushing, axillary and palmar hyperhidrosis, angina, splanchnicectomy
Surgical surface anatomy of the pleura

The surface marking of the lung represents the markings of the visceral pleura. The apex of the lung extends convexly upwards to a distance of approximately 2.5 cm above the junction of the medial and intermediate thirds of the clavicle. The anterior border of the right lung descends from the posterior aspect of the sternoclavicular joint, behind the sternal angle, to the level of the xiphisternal joint. The left lung has a similar course until it reaches the level of the fourth or fifth intercostal space, where it curves laterally beyond the lateral margin of the sternum to accommodate the cardiac notch. After this, the anterior border of the left lung turns sharply to the level of the xiphisternal joint. The lower lung border extends in mid-inspiration to the sixth rib in the mid-clavicular line, the eighth rib in the mid-axillary line and the tenth rib adjacent to the vertebra posteriorly.

The surface marking of the parietal pleura closely follows that of the lung. The apical extension of the parietal pleura is almost identical to that of the visceral pleura because only a thin film of fluid separates them. The anteromedial border of the parietal pleura on the right is similar to that of the visceral pleura. The left parietal pleura takes a course similar to the visceral pleura, except at the level of the fourth costal cartilage, where the deviation of the parietal pleura extends up to, but not beyond, the lateral sternal edge and then turns sharply to the xiphisternal joint. The lower parietal pleural border is similar on both sides, crossing the eighth rib at the mid-clavicular line, the tenth rib at the mid-axillary line and the twelfth rib just adjacent to the vertebra posteriorly.

To avoid iatrogenic injuries during percutaneous entry into the pleural cavity, an understanding of the anatomy of an intercostal space, the position of the subcostal neurovascular bundle and the position of the hemidiaphragm (which may be elevated in the presence of adhesions) is essential. The correct point of chest wall penetration for drainage of an uncomplicated pleural collection is usually between the mid-axillary and posterior axillary line at the level of the sixth intercostal space. For simple thoracocentesis, the needle is advanced on to the rib and ‘walked’ to the superior border of the rib. For tube thoracostomy, a small 1–2 cm skin incision is made parallel to the intercostal space, and a channel is created through the subcutaneous tissue and intercostal muscle layer on to the upper border of the lower rib: this reduces the risk of injury to the neurovascular bundle.
Clinical anatomy of the pleurae

The pleurae consist of two serous membranes: the visceral and parietal pleurae. The visceral pleura is adherent to the lung surface and extends into the interlobar fissures. The parietal pleura lines the corresponding thoracic wall and extends over the diaphragm and the lateral aspect of the mediastinum in what are often described as costal, diaphragmatic and mediastinal parietal pleural segments. The transition between each of the parietal pleural segments is referred to as a pleural sinus and includes the mediastinoophrenic sinus, the costophrenic sinus and the costomediastinal sinuses (anterior and posterior). The surfaces of the parietal pleura at the level of the sinuses are in contact at the end of expiration.

The parietal pleura is continuous with the visceral pleura at the hilum. In a radical pleurectomy for malignant tumour, the tissue plane between the underlying lung parenchyma and the overlying visceral pleura may be entered at this pleural reflection over the rigid structure of the left or right main bronchus. Once this plane has been developed, the entire visceral pleural layer can be dissected off the lung surface. At the inferior hilum, the reflection of the pleura extends towards the diaphragm as the inferior pulmonary ligament. The endothoracic fascia between the parietal pleura and the chest wall forms the dissection plane for parietal pleurectomy.

The pleural cavity is the space between the two pleural layers. It contains a thin film of between 0.1 and 0.2 mL/kg of glycoprotein-rich lubricating fluid which eases gliding of the two pleural surfaces during the various phases of respiration by facilitating the synchronous movements of thoracic wall and lung expansion. Fluid volume is maintained by a balance between fluid filtration and absorption, which in turn are controlled by a balance between lymphatic drainage and the hydrostatic and oncotic pressures of pleura and plasma. Any imbalance in this mechanism may lead to development of pleural effusion. The outward pull of the chest wall and inward elastic recoil of the lung generate a negative intrapleural pressure. Changes in the elasticity of these structures or the accumulation of fluid or air within the pleural cavity will therefore alter respiratory activity. Pleural effusion, the abnormal collection of fluid in the pleural cavity, may result from an imbalance in filtration or absorption, or from a change in the composition of the pleural fluid. Pleurodesis is carried out to obliterate the pleural space and prevent recurrent fluid accumulation. Failure of lung expansion following drainage of pleural effusion may be due to an underlying malignant process causing
excessive visceral pleural thickening or due to the formation of an inflammatory cortex covering the visceral pleura.

**Visceral pleura**

The arterial supply and venous drainage of the visceral pleura are provided by the bronchial vessels. The bronchial arteries at the hilum form a circle surrounding the principal bronchus, and branches from this ring supply the mediastinal interlobar and apical visceral pleura and part of the diaphragmatic visceral pleura. Pulmonary veins drain the visceral pleura, apart from an area around the hilum which drains into bronchial veins. The lymphatic drainage of the visceral pleura is to the deep pulmonary plexus within the interlobar and peribronchial spaces. Visceral afferents from the visceral pleura travel along the bronchial vessels with the autonomic fibres.

Solitary fibrous tumours usually arise as a solitary pedunculated mass from the submesothelial layer of the visceral pleura. Multiple tumour sites have been reported.

**Parietal pleura**

The costovertebral parietal pleura is supplied by the intercostal and internal thoracic arteries; the mediastinal pleura by branches from the bronchial, upper diaphragmatic, internal thoracic and mediastinal arteries; the cervical pleura by branches from the subclavian artery; and the diaphragmatic pleura by the superficial part of the diaphragmatic microcirculation. The veins join the thoracic wall veins, eventually draining into the superior vena cava. Lymph from the costovertebral pleura drains into the internal thoracic chain anteriorly and intercostal chains posteriorly, while that from the diaphragmatic pleura drains into the mediastinal, retrosternal and coeliac axis nodes. The importance of the difference in lymphatic drainage of the pleurae and the lungs has been recognized in the latest (eighth) TNM revision of malignant mesothelioma: there is no demarcation between hilar (N1) and mediastinal (N2) lymph node metastases as per lung cancer, just N1 for all ipsilateral nodal metastasis. Less than a quarter of all solitary fibrous tumours originate from the diaphragmatic or mediastinal surface of the parietal pleura.

The costal and peripheral diaphragmatic parietal pleurae are innervated by intercostal nerves; irritation results in pain that is referred to the appropriate
part of the thoracic or abdominal wall. The mediastinal and central diaphragmatic parietal pleurae are innervated by the phrenic nerves; irritation of the central diaphragmatic pleura causes pain that is referred to the lower neck and shoulder tip, i.e. to the C3 and 4 dermatomes.

When a parietal pleurectomy is performed to achieve pleurodesis, the pleura is usually a thin membrane. Dissection is begun from a port site and extended into the extrapleural space. The parietal pleura is separated from the underlying endo​thoracic fascia from the parasternal internal thoracic artery anteriorly to the vertebral bodies posteriorly. The pleurectomy is then extended across the dome of the thoracic cavity. The subclavian artery and vein are subpleural apical structures at risk of injury during this procedure (Fig. 46.1).

![FIG. 46.1](image)

**FIG. 46.1** An anterior view of the subclavian artery, the internal thoracic artery and vein, and the phrenic nerve.

During decortication for empyema, a plane of dissection is developed between the fibrotic, thickened parietal pleura and the endothoracic fascia. With a combination of sharp and blunt dissection, the parietal pleura is mobilized off the aorta, left subclavian artery, left common carotid artery, phrenic and vagus nerves on the left and subclavian vessels, azygos vein, superior vena cava and phrenic nerve on the right.

Malignant solitary fibrous tumours arising from the parietal pleura tend to be sessile tumours with a broad base. Their complete removal requires a wide surgical excision margin: resection of the underlying chest wall is necessary if tumour invasion beyond the endothoracic fascia is suspected or apparent. In resection of diffuse primary malignant disease of the pleura it is possible to dissect the potential plane between the parietal pleura and the diaphragmatic muscle fibres and between the pericardium and mediastinal
pleura. If there is direct invasion, then an en bloc resection is required.

**Pleural fissures**

Pleural fissures divide the lung into lobes. A fissure is defined as the space between two layers of adjacent lobar visceral pleura.

The right lung is partitioned into upper, middle and lower lobes by the oblique and the transverse (or horizontal) fissures. A single fissure, the oblique fissure, divides the left lung into upper and lower lobes. The surface anatomy of the fissures can vary significantly depending on pulmonary pathology, such as emphysema, fibrosis, malignancy or inflammation, as well as scarring or previous surgery.

The right oblique fissure courses from the level of the transverse process of the fourth thoracic vertebra posteriorly (at the height of the spinous process of the fifth thoracic vertebra). From here, the fissure can be followed across the posterior and lateral chest wall, along the course of the fifth rib. Its projection then crosses the anterior axillary line, descending further across the sixth rib to reach its end point just behind the costochondral junction of the sixth rib. This anterior segment of the oblique fissure separates the middle and lower lobes; the posterior and lateral segments separate the upper and lower lobes. The transverse fissure divides the upper and middle lobes and runs laterally from the fourth sternochondral junction on the anterior chest wall to meet the oblique fissure at the level of the anterior axillary line in the fifth intercostal space.

On the left, the surface projection of the oblique fissure starts at the height of the third or fourth vertebra posteriorly, and then courses across the curvature of the chest wall obliquely in a downward direction, crossing the fifth rib in the mid-axillary line and reaching the sixth or seventh sternocostal junction anteriorly.

Fissural development varies greatly, from complete (lung surface to lung hilum) to total absence. High-resolution CT scan series have reported a prevalence of incomplete or total absence of the oblique fissure as 64–87% (right) and 50–70% (left).\(^5\)–\(^7\)

Areas of incomplete fissures show fusion of the pulmonary parenchyma of the two adjacent lobes. Incompleteness of fissures may complicate anatomical lung resection, such as lobectomy, because a neofissure must be developed and carefully sealed to avoid postoperative air leak with its risk of associated complications. Lobar fusion can have therapeutic significance.
Indirect alveolar interlobar connections, enabling so-called collateral ventilation through the pores of Kohn or canals of Lambert,\textsuperscript{8} significantly limit the effectiveness of lung volume reduction therapy by preventing lobar collapse from endobronchial obstruction.\textsuperscript{9}
Clinical anatomy of the mediastinal nerves

A thorough knowledge of the anatomy of the mediastinal elements of the phrenic, vagus, recurrent laryngeal and thoracic spinal nerves and of the thoracic sympathetic trunk is essential to prevent their iatrogenic injury during surgery involving the pleura (Fig. 46.2).

**FIG. 46.2** A view of the thoracic sympathetic trunk (arrow) in the right posterior hemithorax.

Phrenic nerve

The phrenic nerve originates from C3, 4, 5. It enters the superior mediastinum anterior to scalenus anterior and the subclavian artery, and posterior to the origin of the brachiocephalic vein. As it descends, it crosses the internal thoracic artery from lateral to medial. The pericardiophrenic arteries and veins run along the phrenic nerve throughout its course in the chest (Fig. 46.3). On the right, the phrenic nerve travels posterolateral to the right brachiocephalic vein and the superior vena cava, and then passes anterior to the hilum of the right lung on the right side of the pericardium, descending along the inferior vena cava. Once the nerve reaches the
The right vagus descends posterior to the internal jugular vein in the neck and crosses the first part of the subclavian artery to enter the thorax posterior to the right sternoclavicular joint. At this point, it usually gives off the right recurrent laryngeal nerve (RRLN), which loops around the subclavian artery and ascends in the tracheo-oesophageal groove posterior to the common carotid artery; the RRLN is rarely damaged during thoracic surgical procedures but may be torn in a malignant decortication. The right vagus descends through the superior mediastinum, at first posterior to the right brachiocephalic vein, and then to the right of the trachea and posteromedial to the superior vena cava. Superiorly, the right pleura and lung are lateral; inferiorly, the azygos vein and its arching terminal portion separate the right vagus from the right lung and pleura. The nerve next passes posterior to the right main bronchus, lying on the posterior aspect of the right pulmonary hilum, where it gives off posterior bronchial branches that unite with rami from the second to fifth or sixth thoracic sympathetic ganglia to form the
right posterior pulmonary plexus. Two or three branches descend from the inferior part of this plexus on the posterior aspect of the oesophagus to join a left vagal branch and form the posterior oesophageal plexus. A vagal trunk, containing fibres from both vagal nerves, branches from the plexus and runs in caudal direction along the posterior surface of the oesophagus. The vagal trunk enters the abdomen by passing through the diaphragmatic oesophageal aperture.

The left vagus enters the thorax posterior to the left brachiocephalic vein, between the left common carotid (anterior) and the subclavian arteries (posterior). It descends through the superior mediastinum and crosses the left side of the aortic arch, passing posterior to the left pulmonary hilum. Superior to the aortic arch, it is crossed anterolaterally by the left phrenic nerve; on the arch, it is crossed by the left superior intercostal vein. The left recurrent laryngeal nerve originates from the left vagus as it curves medially, passes below the arch, lateral to the ligamentum arteriosum, and ascends in the tracheo-oesophageal groove towards the larynx. Posterior to the left hilum, the left vagus divides into posterior bronchial branches, which unite with postganglionic rami from the second to fourth thoracic sympathetic ganglia to form the left posterior pulmonary plexus. Two or three branches descend anteriorly on the oesophagus and join with a ramus from the right posterior pulmonary plexus to form the anterior oesophageal plexus. The parasympathetic axons that relay in the ganglia of the pulmonary plexuses are motor (bronchoconstrictor) to the circular non-striated muscle fibres of the bronchi and bronchioles, and secretomotor to the mucous glands of the respiratory epithelium.

**Thoracic sympathetic trunk**

The thoracic sympathetic trunk contains ganglia that are almost equal in number to those of the thoracic spinal nerves (usually 11, occasionally 12, rarely 10 or 13). Almost always, the first thoracic ganglion is fused with the inferior cervical ganglion, forming the cervicothoracic (stellate) ganglion (**Fig. 46.4**); occasionally, the second thoracic ganglion is included in this fusion. The succeeding ganglia are counted in order to make them correspond numerically with the correlative segmental structures. Except for the second and lowest two or three, the thoracic ganglia lie against the costal heads, posterior to the costal pleura. The second thoracic sympathetic ganglion is commonly located in the second intercostal space, and the lowest two or
three ganglia lie laterally to the bodies of the corresponding vertebrae. Inferiorly, the thoracic sympathetic trunk passes posterior to the medial arcuate ligament or through the diaphragmatic crus to become the lumbar sympathetic trunk.

An inconstant intrathoracic ramus may join the second intercostal nerve to the ventral ramus of the first thoracic nerve proximal to the point where the latter issues a large branch to the brachial plexus. This intrathoracic nerve of Kuntz is considered to carry sympathetic fibres to the brachial plexus without passing through the sympathetic trunk and has been held responsible for the recurrence of symptoms following sympathectomy. The anatomical variation exhibited by the communicating rami and the location
of the second sympathetic ganglion may also contribute to surgical failure and symptom recurrence.

Interruption of the thoracic sympathetic fibres by division (sympathicotomy) or excision (sympathectomy) is a therapy of choice for regional hyperhidrosis not responding to medical treatment and may also be indicated to treat vasomotor disease of the upper limbs, such as Raynaud's disease.\textsuperscript{11–14} Interruption of visceral afferent fibres travelling through the sympathetic trunk has been reported in the management of angina (T3, 4), pancreatic pain (T5–8) and chronic regional pain syndrome of the upper extremities\textsuperscript{15} (although sympathectomy is generally considered only when alternative treatment options have failed\textsuperscript{16} or in chronic chest wall pain.\textsuperscript{17}
Thoracic duct

The thoracic duct is the largest lymphatic vessel in the body. It conveys the lymph from the entire body, except the right part of the head, neck and heart, right upper limb, right lung and part of the convex surface of the liver, back to the venous circulation, with an hourly flow of lymph estimated at 1.38 mL/kg of body weight. The thoracic duct usually originates anterior to the first or second lumbar vertebra, where the intestinal and two lumbar lymph trunks join to form the cisterna chyli. (Both the thoracic duct and the cisterna chyli are variable in their origin, course and length; the latter is even more variable in width and shape than the thoracic duct.) From the superior aspect of the cisterna chyli, the thoracic duct passes through the aortic hiatus in the diaphragm and enters the posterior mediastinum, lying to the right between the aorta and the azygos vein up to the level of the body of the fifth thoracic vertebra, where it typically crosses over the vertebral column posterior to the oesophagus: lymphatic injury or obstruction above or below this level results in a left- or right-sided pleural effusion, respectively.

The thoracic duct continues upwards, first posterior to the aortic arch adjacent to the left posterolateral margin of the oesophagus, and then posterior to the left subclavian artery in the superior mediastinum. It next arches over the subclavian artery and descends anteriorly to empty into the venous circulation in the region of the left jugular and subclavian veins, either at or close to their confluence, sometimes into the left brachiocephalic vein. In the space between longus colli, scalenus anterior and the pleural dome, the duct usually arches 3 or 4 cm superior to the clavicle, crossing anterior to the vertebral vessels, the left sympathetic trunk, the thyrocervical trunk and the left phrenic nerve. Drainage into the left-sided central neck veins is seen in more than 90% of patients, with the remaining cases draining into a right-sided central vein or having a bilateral central drainage. Multiple variations of thoracic duct anatomy have been described (Ch. 15) (Fig. 46.5).
**FIG. 46.5**  
A, The termination of the right lymphatic trunk and the thoracic duct.  
B, Variations in the terminal lymphatic trunk nodes of the right side.  

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**Tips and Anatomical Hazards**

**Parietal Pleural Biopsy**

To avoid injury to the intercostal vessels during all percutaneous attempts to enter the thoracic cavity (insertion of a chest drain, thoracoscopy, parietal pleural biopsy), the subcostal groove should be avoided.

The upper border of each rib is the area of safety.

**Parietal Pleurectomy**

The main structures at risk of traction injury during an apical parietal pleurectomy include the lower trunk of the brachial plexus and the stellate ganglion at the upper border of the first rib.

Injury to the former may cause sensory loss in the C8/T1 dermatomes and, rarely, muscular weakness of the small muscles of the hand.

Injury to the stellate ganglion and disruption of adjacent preganglionic sympathetic fibres containing the oculosympathetic pathway may result in the typical clinical triad of ipsilateral miosis, ptosis and enophthalmos, as well as anhidrosis of the ipsilateral face (Horner's syndrome).

**Decortication of Thickened Pleura in Empyema or Tumour**

During decortication of thickened parietal pleura off the costophrenic recess, the surgeon must be careful not to interrupt the costal connections of the diaphragm inadvertently, which will result in entry into the retroperitoneal space. Decortication must extend into the...
fissures to ensure full expansion of the lung. Care should also be taken in a malignant decortication in the interlobar fissure because the visceral pleura is closely applied to the underlying pulmonary artery branches. Parenchymal injury, resulting in bleeding and air leak, is a common complication if the correct plane over intact visceral pleura is not dissected in empyema.
Within the right hemithorax, the structures at risk during parietal pleurectomy include the phrenic nerve as it passes under the mediastinal pleura over the superior vena cava; the azygos/hemiazygos veins and their tributaries ascending through the aortic opening in the diaphragm and crossing over to the hilum of the right lung at the level of the fifth thoracic vertebra; the inferior vena cava, which is enveloped by pleura at its junction with the hepatic venous system; and the oesophagus because it has no serosal layer. The thoracic duct may be damaged in the costophrenic recess posteriorly (a potential blind spot).
Within the left hemithorax, the left subclavian artery may be damaged in the apex because it is surrounded by a pleural sheet. The vagus nerve may be damaged as it descends and the left recurrent laryngeal nerve must be identified when removing pleura from the aortic arch. The thoracic duct may be injured at the level of T5 in the supra-aortic notch adjacent to the left posterolateral margin of the oesophagus.

**Thoracic Sympathectomy/Sympathicotomy**

Stay below the first rib to avoid damage to the stellate ganglion. Preserve the T1 ramus because it contains preganglionic sympathetic fibres that constitute the oculosympathetic pathway\(^\text{21}\): their disruption will cause a temporary or permanent ipsilateral preganglionic Horner's syndrome.\(^\text{22}\) In most patients, the first rib cannot be seen during thoracoscopy; the second rib is the most proximal rib that can be visualized. This can easily be confirmed by identifying the second intercostal artery, a branch of the subclavian artery, as it descends vertically over the second rib to continue horizontally within the neurovascular subcostal sheet. Ganglionectomy will be effective in reducing hyperhidrosis but it may cause compensatory sweating postoperatively. Division of the rami
communicantes and the nerve of Kuntz only may reduce this well-known complication of compensatory sweating, as will T2 clipping, but the counterargument is a higher risk of primary recurrence. The debate with regard to the optimal surgical strategy is ongoing. Recent studies have shown that clipping of the sympathetic chain not only is as effective as transection but also offers the advantage of potential reversal, should this become indicated. Successful reversibility following clip removal in up to 77% of cases has been reported. Other groups, however, have reported superior results following sympathectomy. Denervation at T4 level appears to be associated with a lower incidence of compensatory sweating and more patient satisfaction compared to outcomes following T3 or T2 sympathectomy.
References


Single Best Answers

1. The clinical course of solitary fibrous tumours is unpredictable, probably due to variable histological and morphological characteristics. Which of the following statements about solitary fibrous tumours is TRUE?
   A. They arise from the endothoracic fascia
   B. Malignant solitary fibrous tumours arising from the parietal pleura tend to be sessile tumours with a broad base
   C. Around 75% of these tumours are malignant
   D. The majority of all solitary fibrous tumours originate from the diaphragmatic or mediastinal surface of the parietal pleura

   **Answer:** B. Malignant solitary fibrous tumours arising from the parietal pleura tend to be sessile tumours with a broad base. Solitary fibrous tumours usually arise as a solitary pedunculated mass from the submesothelial layer of the visceral pleura. Multiple tumour sites have also been reported. Less than a quarter arise from the diaphragmatic or mediastinal surface and the majority are benign.

2. A 47-year-old male attends hospital with perforation of the oesophagus. He undergoes a right thoracotomy for repair of the injury. Postoperatively, he is noted to have some milky fluid in the chest drain: the diagnosis of a chylothorax is made. Regarding the course of the thoracic duct, which of the following statements is TRUE?
   A. It enters the chest through the oesophageal hiatus
   B. It terminates at the cisterna chyli
   C. It terminates posterior to the junction of the left internal jugular and subclavian veins
   D. It originates anterior to the first and second lumbar vertebrae

   **Answer:** D. The thoracic duct usually arises anterior to the first and second lumbar vertebrae, where it is joined by the intestinal lymph trunk to form the cisterna chyli. It ascends through the aortic hiatus in the diaphragm and enters the posterior mediastinum, lying to the right between the aorta and
the azygos vein up to the level of the body of the fifth thoracic vertebra, where it typically crosses over the vertebral column posterior to the oesophagus. The thoracic duct continues upwards, first posterior to the aortic arch and then posterior to the left subclavian artery in the superior mediastinum. It next arches over the subclavian artery and descends anteriorly to empty into the venous circulation in the region of the left jugular and subclavian veins, either at or close to their confluence.

3. Which of the following is the most common complication following thoracoscopic sympathectomy for palmar hyperhidrosis?
   A. Horner's syndrome
   B. Recurrent hyperhidrosis
   C. Compensatory sweating in the lower body
   D. Gustatory sweating
   **Answer:** C. Visualization of the sympathetic chain is excellent using a thoracoscopic approach. The most frequent complication of sympathectomy for palmar hyperhidrosis is compensatory sweating in the lower extremities, which may be more pronounced when more extensive resection is performed. Recurrence of symptoms is rarely seen after incomplete resection. Horner's syndrome is a serious complication which could result from injury to the stellate ganglion. Gustatory sweating is not related to thoracic sympathectomy; it is a complication seen post parotidectomy.

4. A patient underwent coronary artery bypass grafting where the left internal thoracic artery was harvested to graft the left anterior descending coronary artery. In the intensive care unit, the patient is found to have a raised left hemidiaphragm and basal atelectasis on chest X-ray. Which one of the following is the most likely cause?
   A. Phrenic nerve trauma
   B. Severe chronic obstructive pulmonary disease
   C. Early postoperative pneumonia
   D. Normal appearance in the immediate postoperative period following such a procedure
Answer: A. Phrenic nerve paralysis may result from injury due to traction on the sternum during internal thoracic artery harvest. The phrenic nerve must be identified and preserved throughout its course during this procedure. If unilateral injury is sustained, most patients have only minimal symptoms and can be managed conservatively. If, however, due to other pre-existing lung disease, the patient is unable to be weaned off the ventilator after such injury, diaphragmatic plication must be considered.
Clinical Cases

1. A patient awakes from a right radical pleurectomy/decortication; he is unable to cough effectively and has also lost his voice.

   **A. What is the most likely cause?**
   Damage to the left recurrent laryngeal nerve during extrapleural dissection around the trachea in the superior mediastinum is a possibility but the cause is most probably damage to the right recurrent laryngeal nerve in the apex of the right hemithorax in the tracheo-oesophageal groove.

2. Two weeks after a successful, uncomplicated thoracic sympathectomy, a patient complains that the back of her head is soaking wet during the daytime.

   **A. How can you explain this?**
   This is compensatory sweating to maintain thermoregulation: sweat glands in the skin of the head and neck have not been denervated.

3. During his inpatient recovery from a difficult right decortication for pleural empyema, a patient's chest drainage increases once he begins to eat again.

   **A. Can you explain why?**
   This is caused by chylothorax due to trauma to the thoracic duct.
   **B. What action would you suggest?**
   A postoperative chylothorax is always managed conservatively initially (total parenteral nutrition, no enteral intake, octreotide). Failure of medical treatment with persistence of chylous leak may indicate surgical reintervention for thoracic duct ligation.

4. After draining a malignant pleural effusion with a small-bore catheter, a junior doctor notices collapse of the underlying lung on the post-procedure chest X-ray. He is sure that he has damaged the lung, leading to a pneumothorax.
A. What else could be an explanation of the appearances?
Visceral pleural thickening may be causing an entrapped lower lobe.

5. Having undergone a left parietal pleurectomy to prevent recurrent spontaneous pneumothorax, a young man visits the optician complaining of ‘something not right with his left eye’.

A. What might the optician find and why?
The optician might find a Horner's syndrome due to damage to the stellate ganglion causing miosis.

6. Why is it not possible to stage the nodal spread of a diffuse malignant pleural mesothelioma accurately before surgery?

   Lymphatic drainage of the pleura is widespread and to nodes inaccessible to clinical staging (internal thoracic, intercostal, pericardial, diaphragmatic). The close application of the pleura to mediastinal lymph nodes makes differentiation on imaging difficult.

7. A junior cardiac surgeon expresses surprise when he sees a patient with intractable angina pectoris and apparently untreatable coronary artery disease listed for a thoracic sympathectomy. ‘Surely sweaty palms are the least of his problems?’ he asks.

A. Can you educate him?
   Interruption of visceral afferent fibres travelling with the sympathetic nerves may reduce pain sensation. Interruption of efferent fibres may cause vasodilation of coronary vasculature.
Core Procedures

- Tracheal resection: segmental resection
- Bronchoscopy: assessment
- Mediastinoscopy: assessment
- Wedge resection: non-anatomical wedge
- Segmentectomy: segment or multiple segments
- Lobectomy: lobe
- Sleeve lobectomy: lobe with segment of bronchus or pulmonary artery
- Pneumonectomy: whole lung
Trachea

Clinical anatomy

The adult trachea averages 11.8 cm in length (range 10–13 cm). Typically, there are 18–22 cartilaginous rings. The larynx and the origin of the oesophagus are intimately related at the level of cricopharyngeus. Below this level, the posterior membranous wall of the trachea is closely related to the oesophagus. This proximity means that diseases such as cancer affecting either structure can involve the other, and that damage of both structures can result in a tracheo-oesophageal fistula, a life-threatening complication.

The structure of the trachea is designed to allow the normal variations in length that occur when the neck is flexed and extended. In flexion, the trachea is almost completely within the mediastinum, with the cricoid cartilage descending to the level of the thoracic inlet. The C-shaped cartilages provide mechanical support that prevents collapse of the trachea on expiration. The fibromuscular tissue between these cartilages allows the trachea to stretch to some degree on extension of the neck. These characteristics mean that surgeons can resect part of the trachea and join the ends together without excessive tension on the anastomosis.

The blood supply is extremely important in the healing process after resection. The blood supply of the trachea enters either laterally or just posterolaterally from branches of the subclavian artery (mainly the inferior thyroid artery) for the upper trachea and from the bronchial arteries for the lower trachea. These arteries connect with each other to a variable extent, providing a vascular anastomosis on the lateral wall of the trachea (Fig. 47.1).
**Fig. 47.1** Tracheal blood supply. A, Left anterior view. B, Right anterior view. Note the essentially segmental nature of distribution. (From D.J. Minnich, D.J. Mathisen, Anatomy of the trachea, carina and bronchi, Thoracic Surg. Clin. 17 (2007) 571–585. Copyright © 2007, Elsevier Inc., Fig. 3.)

**Important anatomical relationships**

The thyroid isthmus lies anteriorly over the region of the second tracheal
ring. The two lobes of the thyroid gland are closely applied to the lateral aspect of the trachea and share a common blood supply from the inferior thyroid artery (Ch. 18). The brachiocehalic (innominate) artery crosses over the mid-trachea obliquely and can be found at a higher level in children and some adults. The recurrent laryngeal nerves lie in the tracheo-oesophageal groove. The left has a longer course than the right, entering the tracheo-oesophageal groove after looping around the aorta. The right enters the tracheo-oesophageal groove after looping round the right subclavian artery (although occasionally it may be given off directly from the right vagus). At the level of the carina, the left main bronchus passes under the aortic arch and the right main bronchus passes beneath the azygos vein. The pulmonary artery lies anterior to the carina. For further reading about the surgical anatomy of the trachea, see reference 1.

**Surgical approaches and considerations**

**Tracheal resection**

**Approach**

The upper half of the trachea lies mostly in the neck and can be approached via a collar incision. If further access is needed, it may be necessary to split the sternum to below the angle of Louis. For the cervical approach, platysma is divided in the line of the incision, the strap muscles are separated in the midline, and the pretracheal plane is entered. Dissection of the trachea is performed circumferentially at the site of the resection. Dissection above and below the site of resection should be limited to the anterior and posterior trachea, preserving the blood supply that enters the trachea laterally. It is important to remember that the recurrent laryngeal nerves lie in the tracheo-oesophageal groove and are at risk of damage. Unilateral damage will result in hoarse voice but bilateral damage can result in severe breathing difficulty and may even require a tracheostomy (Ch. 17). For benign tracheal stenosis, the dissection at the level of the stenosis should take place as close as possible to the trachea to avoid damage to the nerve.

The lower trachea can be approached through a high (fourth intercostal space) right thoracotomy.

It can also be approached by median sternotomy transpericardially with dissection between the superior vena cava and the aorta; however, this provides limited access. This approach has been used to gain access to the
bronchial stump after pneumonectomy when the stump has failed to heal.

**Extent of resection**

The aim of a tracheal resection is to resect the abnormal trachea and reapproximate the ends with sutures. Tension at this anastomosis must not be excessive; otherwise, there is a significant risk of dehiscence. A number of manoeuvres can be performed to reduce this tension. Flexion of the neck when the anastomotic sutures are tied and maintaining flexion for a week after the operation (sutures placed between the chin and the skin of the chest wall to avoid extension) are used in nearly all resections. Tension can also be reduced by performing a suprahypoid laryngeal release (dividing mylohyoid, geniohyoid, genioglossus and the hyoid bone), which allows the larynx to drop down. In the chest, a hilar release can be performed by freeing the hilum of the lung, dividing the inferior pulmonary ligament and dividing the pericardium around the right inferior pulmonary vein, so allowing the hilum of the lung to ascend. Rarely, reimplantation of the left main bronchus into the bronchus intermedius may be required. The length of trachea that can be resected varies with age, posture, extent of disease and previous tracheal surgery. Approximately half the length of the trachea can be resected in most adults and one-third of the more fragile juvenile trachea.

### Tips and Anatomical Hazards

The brachiocephalic (innominate) artery lies anterior to the mid-trachea and this should be borne in mind when placing a tracheostomy; there is a risk of erosion of this vessel by the tracheostomy if it is placed adjacent to it.

The membranous trachea is thin and can be damaged by instrumentation. Percutaneous minitracheostomy or tracheostomy using the Seldinger technique can result in perforation of the back of the trachea. The trachea can also be damaged by excessive inflation of the balloon cuff of an endotracheal tube or tracheostomy; because the trachea is intimately related to the oesophagus posteriorly, a tracheo-oesophageal fistula can result. This anatomical relationship should also be borne in mind when stenting tumours of the oesophagus. Rarely, placement of a stent in a bulky tumour of the oesophagus can
result in compression of the trachea and respiratory compromise. The recurrent laryngeal nerve lies posterolaterally and can be damaged during mobilization of the trachea; dissection of benign lesions should be close to the wall of the trachea to avoid iatrogenic injury to the nerve.

Excessive circumferential mobilization of the trachea can devascularize the trachea, resulting in poor healing. The brachiocephalic (innominate) artery crosses the mid-trachea anteriorly and there is a risk of erosion when a tracheostomy is placed close to the vessel. To counter this, avoid placing the tracheostomy low in the trachea.

The posterior wall of the trachea is thin and can be easily damaged by instrumentation, which can lead to a tracheo-oesophageal fistula. Placement of a minitracheostomy and tracheostomy using the Seldinger technique should therefore be done with bronchoscopic guidance. Care should be taken to avoid over-inflation of the balloon cuff of an endotracheal tube or tracheostomy tube.

The close relationship between the trachea and oesophagus means that there is a risk of compression with oesophageal stenting in the palliative setting; similarly, a tracheal stent can compromise the oesophagus. In this situation, it is therefore important to consider whether such stenting is appropriate if there is a risk of compressing the non-stented structure. Placement of stents in both trachea and oesophagus may be necessary but risks a tracheo-oesophageal fistula.

The lateral blood supply of the trachea means that there is a risk of devascularization if there is excessive circumferential mobilization during resection. Circumferential dissection should take place only at the level of the lesion, and further dissection only in the anterior and posterior planes.

During mobilization of the trachea, there is a risk of damage to the recurrent laryngeal nerves as they lie in the tracheo-oesophageal groove. Dissection should be kept close to the trachea for benign lesions. Formal identification of the recurrent laryngeal nerve is mandatory in malignant lesions.
Bronchial tree

Clinical anatomy

The trachea usually bifurcates at the level of the upper half of the sixth thoracic vertebra into the right main bronchus and left main bronchus (Fig. 47.2).

**FIG. 47.2** The cartilages of the larynx, trachea and bronchi, anterior aspect. The bronchopulmonary segments are shown in brackets. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 54.7. Redrawn from an original figure drawn from a metal cast made by the late Lord Russell Brock, GKT School of Medicine, London.)

Right bronchial tree
The right main bronchus is shorter than the left, starting at the trachea and finishing where the right upper lobe bronchus arises on its lateral wall about 1.2 cm from its origin. The right upper lobe bronchus gives off three segmental bronchi (apical, posterior and anterior segmental bronchus). Although usually a trifurcation, various combinations of branching can occur. The finding of just two orifices should prompt a search to make sure a tracheal bronchus is not present.

The intermediate bronchus then continues and lies posterior to the right pulmonary artery as it courses down the fissure. After 1.7–2 cm, the middle lobe bronchus arises and gives off a medial and a lateral segmental bronchus. The superior segmental bronchus of the lower lobe is usually given off posteriorly, slightly distal to the origin of the middle lobe bronchus; it may sometimes arise at the same level or above. Further distally, the basal stem bronchus gives off segmental bronchi to the medial, anterior, lateral and posterior basal segments.

Numerous anomalies of this typical arrangement occur. A tracheal bronchus arising from the lateral wall of the trachea can occur in up to 2% of individuals. This may supply the apical segment of the right upper lobe or actually represent a misplaced right upper lobe bronchus. More rarely, a bronchus can arise from the medial aspect of the bronchus intermedius; this is usually blind-ending but can be associated with some branching and a small amount of pulmonary parenchyma.

As the right main bronchus is more vertically orientated than the left main bronchus and is more in line with the trachea, it is more common for inhaled foreign bodies to be lodged in the right airway. However, it is uncommon for any foreign body to be lodged in the right upper lobe bronchus because this usually comes off the right main bronchus at an acute angle.

**Left bronchial tree**

The left main bronchus is longer than the right, being 4–6 cm in length. The left upper lobe bronchus divides into superior and lingular branches. The superior branch divides into apicoposterior and anterior segmental branches. Occasionally, the superior branch may trifurcate into apical, posterior and anterior segmental branches. The lingular branch divides into superior and inferior segmental branches. Approximately 0.5 cm distal to the upper lobe take-off, the lower lobe stem bronchus gives off the superior segmental bronchus of the lower lobe. The basal trunk continues for 1.5 cm before dividing into two branches, an anterior basal segmental branch and a
common stem for the lateral and posterior basal segmental branches. Variations occur in the way the upper and lingular divisions divide into their segments. A subsuperior bronchus can arise from the lower lobe bronchus. Very rarely, the right lower lobe (and sometimes a portion of the middle lobe) can be supplied by a bronchus arising from the left main stem bronchus that crosses the mediastinum (so-called bridging bronchus). Bronchial isomerism can occur with identical branching in both lungs and is frequently associated with other congenital abnormalities. Very rarely, a lobar bronchus may be absent.

**Bronchoscopic anatomy**

A knowledge of bronchoscopic anatomy is essential for the surgeon to plan surgical resection. It is also relevant for the anaesthetist who needs to provide selective lung ventilation so that the lung that is to be operated on is collapsed during surgery. This is usually achieved by using a double-lumen endotracheal tube with a bronchial lumen that is passed down into one main bronchus and a tracheal lumen that sits above the carina and ventilates the other lung. The anatomical differences between the right and left main bronchi are very important. Because the left main bronchus is long before it branches, it is possible to place the bronchial lumen of the double-lumen tube in the main bronchus so that ventilating both the upper and lower lobes is straightforward. A left-sided double-lumen tube is used for most thoracic procedures but is generally avoided for any left-sided resection that could involve the main bronchus. In this situation, a right-sided double-lumen tube is used. The major challenge with a right-sided tube is maintaining ventilation of the right upper lobe because of its early take-off from the right main bronchus. This is managed by having a hole in the lateral aspect of the bronchial lumen of the double-lumen tube that allows ventilation of the right upper lobe if the hole is aligned with the origin of the right upper lobe. If there are issues with a right-sided tube placement, it is still possible to use a left-sided tube for left-sided lung isolation when the resection involves the distal left main bronchus. In this scenario, it is important to withdraw the double lumen tube as far proximally as possible beyond the planned resection margin just before it is divided. The alternative approach is to use a bronchial blocker to isolate the lung. This is a balloon catheter that is passed through a single-lumen tube and placed in the main bronchus to block ventilation of that side. Since the right main bronchus is short, it can be
difficult to place this on the right without compromising the right upper lobe bronchus. In an emergency situation where a right thoracotomy is needed, a small single-lumen tube can be passed into the left main bronchus for the duration of the procedure and pulled back into the trachea to ventilate both lungs at the end of the procedure.

**Bronchoscopy**

Bronchoscopy is a useful diagnostic and therapeutic procedure for airway conditions. For the surgeon, it is also an important preoperative tool for assessing the extent of resection required for lung tumours. While peripheral tumours may not be visible at bronchoscopy, more central tumours arising in the lobar bronchi will be visible. The surgeon decides whether the tumour and associated lobe can be resected with a margin of normal tissue or whether it involves another branch of the bronchial tree, meaning that either a sleeve resection, a bilobectomy or a pneumonectomy needs to be performed.

Bronchoscopy can be performed using fiberoptic bronchoscopy or rigid bronchoscopy. Fiberoptic bronchoscopy is normally carried out under local anaesthetic with light sedation (if the patient can tolerate the procedure) or under general anaesthetic with airway protection (for example, laryngeal mask, single-lumen intubation or rigid bronchoscopy). When bronchoscopy is performed under local anaesthetic, the bronchoscope is usually passed through the nose and then under direct vision through the vocal cords into the trachea. Alternatively, this can be performed through the mouth with a mouth guard protecting the teeth and the bronchoscope. The fiberoptic bronchoscope is a useful tool for initial diagnosis and assessment of airway pathology. It has an operating channel through which endoluminal biopsies and therapeutic procedures such as airway cautery/laserering can be performed. It is also a useful tool for airway toileting and secretion clearance, and recently has been used for placement of endobronchial valves and coils. Using a specialized fiberoptic bronchoscope with an ultrasound probe at its tip, it is now possible to perform endobronchial ultrasound (EBUS), which is particularly useful for endobronchial biopsies and sampling of lymph nodes close to the airway.

In situations where a larger endoluminal operating field is needed and a secure airway is required during intervention, rigid bronchoscopy should be used. Such situations include airway foreign body, airway bleeding and endoluminal tumour debulking/stenting. Rigid bronchoscopy is performed
under general anaesthesia. The surgeon inserts the bronchoscope into the mouth and, while protecting the teeth with his/her fingers, passes the bronchoscope over the tongue until the epiglottis is seen. The bronchoscope is then pushed anteriorly behind the epiglottis, allowing the vocal cords to come into view; the bronchoscope is next rotated and the beak of the instrument is passed through the cords into the trachea. Usually, the surgeon then passes a straight telescope or flexible bronchoscope through the rigid bronchoscope to complete the examination.
Lungs

Clinical anatomy

Lobes and fissures

The right lung has three lobes (upper, middle and lower) and two fissures (oblique and horizontal). The oblique fissure separates the lower lobe from the middle and upper lobes; it begins posteriorly at the level of the fifth rib and runs forward along the course of the sixth rib to the diaphragm. The horizontal fissure separates the middle from the upper lobe; it begins in the oblique fissure in the mid-axillary line at the level of the sixth rib and runs anteriorly to the costochondral junction of the fourth rib. The fissures may be complete so that the lobes are completely separate, or incomplete where the lobes are not easily separable. In more than 50% of cases, the horizontal fissure is incomplete and the middle lobe is fused to the anterior part of the upper lobe.

The left lung has two lobes (upper and lower) separated by the oblique fissure, which runs obliquely downward from between the third and fifth ribs to end at the level of the sixth or seventh costochondral junction.

Additional fissures may delineate accessory lobes, the most common being the posterior accessory, inferior accessory, middle lobe of left lung (lingual) and azygos lobes.

When planning resection, surgeons look carefully for the fissures on CT scans; they are usually visible and will indicate which lobe contains a lesion and whether more than one lobe is involved.

For further reading about pulmonary lobes and fissures, see reference 2.

Bronchopulmonary segments

Each lobe of the lung is divided into a number of bronchopulmonary segments, which can be regarded as individual functional units (Fig. 47.3). Each segment is served by a segmental bronchus lying centrally within the segment; the veins are situated at the junction between adjacent segments.
Historically, the nomenclature of some of the bronchopulmonary segments has been the subject of debate. It was not clear whether the upper lobe should be regarded as three segments or two (an apicoposterior and an anterior segment). The medial basal bronchus on the left was absent in one classification and part of the anteromedial basal bronchus in another. In 1950, the Thoracic Society appointed a subcommittee to review the terminology and agree an international terminology, which is still widely adopted today.\(^3\) The apical segment of the lower lobe is now more usually called the superior segment of the lower lobe.

Prediction of postoperative lung function, which is important for deciding on the extent of resection, can be estimated by establishing the number of segments that are non-functional as a consequence of the tumour and the number of functioning segments that would need to be resected to clear the tumour. Knowing the existing lung function of the patient, it is possible to calculate the percentage loss of lung function (making the assumption that
the segments of the lung have equal volume) and therefore to decide whether
the patient will be left with enough functioning lung to survive the operation
and have a reasonable quality of life.

**Pulmonary arterial system**
The main pulmonary artery arises from the pulmonary anulus surrounding
the subpulmonary infundibulum at the base of the right ventricle, and slopes
posterosuperiorly, at first anterior to the ascending aorta and then to its left;
at the level of the fifth thoracic vertebra, inferior to the aortic arch at the left
of the midline, and lying above the left main bronchus, it divides into right
and left pulmonary arteries. The right main pulmonary artery is longer than
the left but the segment lying outside the pericardium before the first branch
is given off is shorter than its counterpart on the left. The branches of the
pulmonary artery are more variable than those of the bronchi. They tend to
lie close to the segmental bronchi and their branches ([Figs 47.4, 47.5](#)). For
further reading about the pulmonary vascular system, see reference 4.
FIG. 47.4  A, A lateral view of the right pulmonary artery. B, A lateral view of the left pulmonary artery. (From F. Tronc, J. Gregoire, J. Deslauriers, Bronchoplasty. In: G. Patterson, J. Cooper, J. Deslauriers, et al. (eds), Pearson's Thoracic and Esophageal Surgery, third ed. © 2008, Churchill Livingstone, an imprint of Elsevier Inc., Fig. 74.5, pp. 894–908.)

Right pulmonary artery

The right pulmonary artery, after it leaves the pericardium, lies anterior and inferior to the right main bronchus and posterior and superior to the superior pulmonary vein. Its first branch is the truncus anterior, which divides into two branches: the apical segmental artery and the anterior segmental artery. In about 10% of individuals, the truncus anterior provides the entire pulmonary arterial blood supply to the upper lobe. The interlobar portion of the pulmonary artery then arches over the bronchus intermedius and usually gives off the posterior ascending artery to supply the posterior segment of the upper lobe. The posterior segment can also be supplied by a branch from either the apical segmental artery or the truncus anterior. At a similar level to the posterior ascending artery, the middle lobe artery is given off anteromedially (at the junction of the horizontal and oblique fissures)
and then bifurcates to supply the medial and lateral segments. The artery to the superior segment of the lower lobe arises posteriorly opposite the middle lobe artery (or slightly distal). The pulmonary artery then becomes the common basal trunk. The medial basal artery subsequently arises on its own or in association with the anterior basal branch. The common basal trunk terminates by dividing into the lateral and posterior segmental branches.

Variations occur with all the branchings of the pulmonary arterial system. In 20% of individuals, two arteries arise from the anterior trunk (the truncus anterosuperior and truncus anteroinferior). The recurrent posterior branch is a branch of the truncus anterosuperior. More than one ascending branch to the upper lobe can occur, the more proximal branch going to the anterior segment. Sometimes the posterior ascending branch arises from the superior segmental artery, or rarely from the middle lobe artery. The middle lobe artery, although usually single, may be two or three separate vessels. A subsuperior or accessory subsuperior artery may arise from either the common stem or the posterior basal branch.

**Left pulmonary artery**

The left pulmonary artery has a longer segment extrapericardially than its counterpart on the right before it gives off its first branch to the left upper lobe. Usually, four branches arise from the left pulmonary artery; there can be two to seven branches. The first branch is the anterior trunk, which is short and gives off branches that supply the anterior segment, the apical segment, the lingula (less frequently) and the posterior segment (uncommonly). A second branch from the main artery gives off a branch to the apicoposterior segment. As the left pulmonary artery passes into the interlobar fissure, it gives off a branch to the superior segment of the lower lobe. The lingular artery leaves the pulmonary artery distal to the superior segmental artery. The common basal trunk then divides into two branches: the more anterior branch supplies the anteromedial basal segment, and the posterior branch supplies the lateral basal and posterior basal segments.

Major variations may occur in all the segmental branches of the left pulmonary artery. The first anterior branch uncommonly provides all the blood supply to the lingula. It may supply the apical segment alone, with the anterior segment receiving a branch from the interlobar pulmonary artery. Usually, the apical segmental artery arises proximal to the lingular artery, but the latter can sometimes arise proximal to the apical segmental artery. In one-third of individuals, a branch of the lingular artery or a separate artery from
the interlobar pulmonary artery may supply the anterior segment.

In a rare congenital anomaly called vascular or pulmonary artery sling, the left main pulmonary artery arises from the right main pulmonary artery, and usually passes between the trachea and oesophagus. This can potentially cause breathlessness or dysphagia due to compression of the trachea or oesophagus, respectively.

**Pulmonary venous system**

**Right pulmonary veins**

The right superior pulmonary vein lies anterior and inferior to the right pulmonary artery (**Fig. 47.6**). It has four major tributaries draining the upper and middle lobes. The first three branches are the apical anterior, anteroinferior and posterior branches. The fourth and most inferior branch drains the middle lobe and usually has two branches. The middle lobe vein can, on occasion, drain separately into the atrium and, rarely, may drain into the inferior pulmonary vein. The inferior pulmonary vein is inferior and posterior to the superior vein and is formed by two major trunks that drain the lower lobe: a vein draining the apical lower lobe segment and the common basal vein draining the basal segments of the lung.
Left pulmonary veins
The left superior pulmonary vein has three to four tributaries that drain the entire upper lobe (Fig. 47.7). The first branch is the apicoposterior vein, the second is the anterior vein, and the third and fourth are the superior and inferior lingular veins, respectively. In about 50% of individuals, the lingular vein is a single trunk. Like the middle lobe on the right, these veins can drain into the inferior pulmonary vein. The inferior pulmonary vein is located inferior and posterior to the superior vein; apical segmental and common basal veins drain into it.
Abnormal venous drainage

A number of variations in venous drainage can occur. The posterior segment of the right upper lobe can drain into the atrium through a vein that courses posterior to the bronchus intermedius; other upper lobe veins have been described taking this route. The right upper lobe vein may drain into the azygos vein or into the confluence of the azygos vein and superior vena cava. The superior and inferior left pulmonary veins may sometimes form a single trunk draining into the left atrium.

Surgical approaches and considerations in lung resection
The extent of lung resection is dependent on a number of factors. These include the size and location of the tumour and the fitness of the patient for resection. The aims of surgery are to remove the tumour and draining lymph nodes. There are a number of procedures that can be performed, with progressively more lung tissue being resected: non-anatomical wedge resection; anatomical segmentectomy, lobectomy, bilobectomy (on the right side upper and middle lobectomy or middle and lower lobectomy) and pneumonectomy (the whole lung). If a tumour is involving the origin of a lobar bronchus, a sleeve lobectomy may be performed.

Lung resection can be approached either through an open approach (thoracotomy) or through a video-assisted thoracoscopic surgery (VATS) approach. The open approach can be either a posterolateral thoracotomy, muscle-sparing thoracotomy, anterior thoracotomy or, rarely, a clamshell incision or median sternotomy. There are two main VATS approaches: a posterior approach with anatomical considerations similar to those of open thoracotomy and the more common anterior approach. More recently, robotically controlled instruments have been used to facilitate VATS resection.

**Segmentectomy**

Each segment of the lung is a functional unit with its own segmental bronchus and artery situated centrally within the segment, and venous drainage via veins located in the zone abutting adjacent segments; these structures should all be identified during a segmentectomy. Segmentectomy is considered for small lesions confined to one segment in patients with borderline lung function, or in those having resection for metastases, or where the diagnosis has not been made preoperatively. Sometimes, more than one segment is resected. Common segmental resections include apical segmentectomy of the right upper lobe; superior segmentectomy of the lower lobe; upper trisegmentectomy on the left; and lingulectomy on the left.

**Lobectomy**

As with segmental resection, it is important to identify the correct bronchus and the branches of the pulmonary artery and vein supplying/draining the lobe to be resected. Although we describe the common approaches used for lobectomy via open posterolateral thoracotomy and VATS via the anterior approach, the most important consideration is to appreciate the three-
dimensional anatomical relationships between the vein, artery and bronchus for each lobe.

**Right upper lobectomy**

**Open right upper lobectomy**
The pleura around the hilum of the lung is incised. The phrenic nerve, as it courses anterior to the hilum on the superior vena cava, must be carefully avoided. The superior pulmonary vein is then encountered; it has two or three branches. The middle lobe vein commonly arises from the superior pulmonary vein and this must be identified and preserved. The main pulmonary artery lies posterior and slightly above this vein and its first branch, the truncus anterior, is encountered. This usually divides into apical and anterior segmental arteries. The right main pulmonary artery courses behind the superior vena cava beneath the azygos vein; if the dissection is judged to be difficult (or as a routine), the pulmonary artery is dissected and a tape placed round it in case there is difficulty later and a clamp needs to be applied. The truncus anterior and apical and anterior segmental branches are carefully dissected. If access is difficult, it may be necessary to divide the apical segmental branch of the vein. The dissection then continues posteriorly and the upper lobe bronchus take-off can be seen just below the azygos vein. At this point, the constant lymph node at the junction of the upper lobe bronchus and bronchus intermedius is identified and removed. The pulmonary artery lies medial to this. It may be possible to identify the apical segmental artery from behind, and once this is identified, the fissure can be stapled posteriorly. Further dissection in the fissure allows identification of the posterior segmental (recurrent) artery. The middle lobe artery take-off can then be identified just opposite the superior segmental branch. The transverse fissure is often fused and a stapler may be used to develop this. It is important to identify the middle lobe artery and bronchus so that they are not inadvertently stapled. Once all the structures are exposed, they are either stapled or ligated and divided; the bronchus is usually stapled.

**VATS right upper lobectomy**
The first step is to dissect the tributaries of the superior pulmonary vein draining the right upper lobe. Care must be taken during the dissection of its posterior wall because it is closely associated with the pulmonary artery. The
right upper lobe vein is stapled and divided, followed by the anterior trunk of the pulmonary artery and the right upper lobe bronchus, which can usually be found posterior to the artery. To facilitate the identification of the posterior ascending artery, it is usually better to divide the transverse fissure. This will facilitate the dissection and division of the posterior ascending artery; then the right upper lobe bronchus and remainder of the fissure can be divided. Rarely, the posterior ascending artery may share a common trunk with the artery for the superior segment of the lower lobe, so the superior segmental artery should be clearly identified and preserved. Sometimes, it is easier to take the bronchus first.

**Right middle lobectomy**

**Open right middle lobectomy**

The relationship between the middle lobe artery, the posterior segmental artery to the upper lobe, and the superior segmental artery of the lower lobe must be appreciated during middle lobectomy.

After dissection of the hilum anteriorly and posteriorly, the middle lobe vein is identified. This commonly drains into the superior pulmonary vein but can drain directly into the left atrium or the inferior pulmonary vein. Other anomalies include an accessory middle lobe artery posterior and inferior to the bronchus (20%), and venous drainage to both the superior and the inferior pulmonary veins (5%). When the oblique fissure is well developed, the middle lobe artery can be identified in the fissure. The middle lobe bronchus lies posteriorly and slightly inferior to the middle lobe artery. If the fissure is not well developed, then division of the vein is performed, followed by division of the bronchus and artery, and the fissure is then stapled.

**VATS right middle lobectomy**

As in the open right middle lobectomy, it is important to make sure that the middle lobe vein is correctly identified before stapling and dividing it. In the anterior VATS approach, it will be helpful to retract the right middle lobe upwards, so that the right middle lobe bronchus and its arterial supply are straightened and orientated in a vertical position in the operative view. The middle lobe vein usually drains into the superior pulmonary vein but can drain separately into the atrium or, rarely, into the inferior pulmonary vein. Other anomalies include an accessory middle lobe artery posterior and
inferior to the bronchus (20%), and venous drainage to both the superior and the inferior pulmonary veins (5%). The bronchus sits posterior to the vein, and the middle lobe pulmonary arteries are either posterior to the bronchus or slightly above. This means that, once the middle lobe vein has been divided, the next step is to divide the middle lobe bronchus. The pulmonary artery is at risk when passing instruments around the bronchus.

**Right lower lobectomy**

**Open right lower lobectomy**

There are two important considerations in right lower lobectomy. Where the superior segmental artery comes off the pulmonary artery is important. If the basilar artery is long – that is, if the superior segmental artery comes off higher on the pulmonary artery – then it may be necessary to take this vessel separately to the basilar segmental trunk. If the basilar artery is short, then it may be possible to take the entire lower lobe arterial supply by ligating/stapling to include the superior segmental artery and the basilar artery together. The middle lobe artery must be clearly identified and preserved. The bronchial anatomy is also important. In dividing the lower lobe bronchus, the surgeon must be careful not to compromise the bronchus to the middle lobe. While it may be necessary to take the superior segmental bronchus separately, it is usually possible to divide the lower lobe bronchus obliquely so that the superior segmental bronchus is included. It is usually possible to identify the pulmonary artery in the fissure first and divide the lower lobe pulmonary artery; the bronchus is then identified posteriorly. The inferior pulmonary vein is usually straightforward to dissect and staple or ligate.

**VATS right lower lobectomy**

Inferior pulmonary vein dissection is usually straightforward, after the inferior pulmonary ligament is freed. The phrenic nerve is close to the inferior border of the inferior pulmonary vein and should be seen and protected. The lower lobe bronchus and basilar pulmonary artery lie immediately superior to the superior border of the inferior pulmonary vein. Dissecting close to the bronchus is important to avoid damage to the underlying pulmonary artery. It is important to identify the superior segmental artery and to avoid kinking the middle lobe bronchus when dividing the lower lobe bronchus. The right middle lobe vessels or bronchi
must not be compromised when stapling lower lobe structures; the surgeon should check that the right middle lobe vein does not drain into the inferior pulmonary vein before dividing it.

**Left upper lobectomy**

**Open left upper lobectomy**
The hilar pleura overlying the pulmonary artery and superior pulmonary vein is divided and the pulmonary artery is found at the upper part of the hilum. Care must be taken when retracting the upper lobe since the first branch of the artery, the truncus anterior, is short and easily torn. If there is a centrally placed tumour close to this artery, proximal control of the left pulmonary artery should be obtained. It may be necessary to open the pericardium and divide the ligamentum arteriosum to get more length on the pulmonary artery; care should be taken when doing this because the left recurrent laryngeal nerve and vagus nerve are in close proximity. The lingular vein usually drains into the superior pulmonary vein. The apical segmental branch of the superior pulmonary vein lies anterior to the apical posterior branch of the artery and it may be necessary to divide the vein to expose the artery. The artery is then dissected into the fissure. An anterior segmental branch is next encountered, and continued dissection reveals the superior segmental artery of the lower lobe. Once this has been identified, the fissure can be stapled. Further dissection in the fissure reveals one or two lingular arteries. The branches of the pulmonary artery to the upper lobe and lingula can then be divided, as can the superior pulmonary vein, including the lingular branch. The bronchus is then identified; it is important to identify the bifurcation and the origin of the lingular bronchus so that this is included in the division.

**VATS left upper lobectomy**
VATS left upper lobectomy can be the most challenging because there may be variations in the pulmonary arterial supply. Most of the arterial branches are closely related to the left upper lobe bronchus, which means that dissection and isolation of the left upper lobe can be a dangerous manoeuvre. If proximal control is needed for any bleeding, this can be difficult in the VATS anterior approach. The same precautions for open left upper lobectomy should be taken in VATS, avoiding injury to the vagus nerve and recurrent laryngeal nerve (during dissection of the aortic arch and the subaortic lymph
nodes) and oesophagus (when dissecting posteriorly). After the superior pulmonary vein is identified and divided, the left upper lobe bronchus will be visible. This is usually surrounded superiorly by the first two branches (anterior and apicoposterior) of the left main pulmonary artery and by the lingular branch inferiorly. Behind the upper lobe bronchus is the continuation of the left main pulmonary artery and some additional branches (which vary in number) to the left upper lobe. Usually, to make dissection of the left upper lobe bronchus safer, any visible branches of the pulmonary artery around the bronchus should be divided first. To facilitate safe division, it is important to free the posterior aspect of the left upper lobe bronchus from the main pulmonary artery and its branches. Once the left upper lobe bronchus is divided, any remaining pulmonary artery branches to the left upper lobe will be exposed and can then be divided to complete the lobectomy. If the fissure is relatively well developed, it may sometimes be easier and safer to look for the pulmonary artery and these branches by dissecting into the fissures.

**Left lower lobectomy**

**Open left lower lobectomy**

If the fissure is complete, the pulmonary artery can be identified in the fissure. If the fissure is incomplete, then dissection starts at hilar level on the main pulmonary artery and progresses into the fissure until the superior segmental artery is identified. Once this is seen, it is possible to divide the posterior fissure with a stapler. It is important to identify the superior segmental artery and establish its relationship to the anterior segmental and lingular branches. Usually, the superior segmental branch comes off opposite the lingular branches. The basilar trunk is mobilized and can then be ligated or stapled. It may be necessary to divide the superior segmental branch separate to the basilar trunk. The inferior pulmonary ligament is divided and the inferior pulmonary vein dissected. The lower lobe bronchus is just posterior to the inferior pulmonary vein. Once all the structures have been identified, they are divided in turn.

**VATS left lower lobectomy**

The inferior pulmonary ligament is freed to facilitate dissection of the inferior pulmonary vein. The oesophagus can be adherent inferior and posterior to the vein so care must be taken during dissection. The inferior
pulmonary vein and then the lower part of the fissure are divided to facilitate dissection and identification of the branches of the pulmonary artery, which are next divided, and finally the bronchus is divided. The alternative approach after dividing the inferior pulmonary vein is to reflect the base of the lower lobe upwards so as to explore the left lower lobe bronchus. Using this approach, it is possible to dissect the bronchus first and then the basal trunk of the pulmonary artery, which lies behind the bronchus; care must be taken to dissect close to the bronchus to avoid injury to the artery. The order in which the structures are divided depends on the patient’s anatomy, as well as the surgeon’s preference.

**Sleeve resection**

Following resection and removal of a segment of bronchus (or pulmonary artery), anatomical continuity is restored by anastomosing the cut ends, a procedure termed a sleeve resection. Bronchial sleeve resection can be performed in isolation for a tumour confined to the bronchus (usually benign or slow-growing tumours such as carcinoid or adenoid cystic carcinoma), or more commonly, in association with lobectomy. Rarely, a tracheal sleeve pneumonectomy may be performed for a tumour of the main bronchus lying very close to the carina.

If a tumour involves the main pulmonary artery, it may be possible to avoid pneumonectomy by performing a sleeve resection of the pulmonary artery.

**Pneumonectomy**

Pneumonectomy is performed for central tumours and involves ligating or stapling the pulmonary artery, ligating or stapling the inferior and superior pulmonary veins, and stapling or suturing the main bronchus. If the tumour is very central, it may be necessary to open the pericardium and ligate, staple or suture the vessel within the pericardium. Occasionally, it may be appropriate to resect pericardium or some of the atrium to achieve clearance.

**Right pneumonectomy**

The hilar pleura is incised, the superior and inferior pulmonary veins are dissected and ties are placed around them. The right main pulmonary artery courses posterior to the superior vena cava and can be encircled at this point. It may be necessary to open up the pericardium and isolate the vessels within the pericardium (intrapericardial pneumonectomy). The right main
bronchus is encircled as it lies behind the azygos vein.

**Left pneumonectomy**

On the left side, the left main bronchus is closely related to the oesophagus, and dissection around the posterior aspect of the bronchus needs to be careful to avoid damaging the oesophagus. The subaortic lymph nodes should be dissected. They are related intimately to the left recurrent laryngeal nerve; the vagal branches to the lung should therefore be divided close to the lung to avoid damaging the recurrent laryngeal nerve during resection.

**Intrapericardial anatomy**

For some centrally placed tumours, it may be necessary to open the pericardium to access the pulmonary artery and veins intrapericardially. The left pulmonary artery and veins can be accessed through a pericardial incision ([Fig. 47.8](#)). The right pulmonary artery can be accessed with retraction of the superior vena cava to achieve better access to the vessels ([Fig. 47.9](#)). Occasionally, the pulmonary artery can be accessed by entering the pericardium anteriorly and incising the posterior pericardium ([Fig. 47.10](#)). The aorta and vena cava can then be retracted to provide access to the pulmonary artery. This route can also be used to gain access to the distal trachea and bronchial bifurcation.
FIG. 47.8 Intrapericardial dissection of the left inferior pulmonary vein. (Adapted from Thoracic anatomy Part I, Thorac. Surg. Clin. 17 (2007) 616. Copyright © 2007, Elsevier Inc., Fig. 12.)

FIG. 47.9 Intrapericardial dissection of the right main pulmonary artery. (Adapted from Thoracic anatomy Part I, Thorac. Surg. Clin. 17 (2007) 607. Copyright © 2007, Elsevier Inc., Fig. 5.)
**Tips and Anatomical Hazards**

When the venous drainage of the lung is via a single pulmonary vein, there is a risk of dividing the venous drainage of the whole lung during lobectomy. Always check there are superior and inferior pulmonary veins and confirm where they drain.

The left recurrent laryngeal nerve branches off the vagus and hooks around the aortic arch; left vocal cord palsy can result if either the left vagus nerve above the arch or the left recurrent laryngeal nerve as it loops round the aorta is damaged. Lymph node dissection above and beneath the arch should be undertaken with caution. Patients should be made aware of possible recurrent nerve injury and consequential postoperative hoarse voice after left-sided resections that involve dissection in this area.

If a middle lobe bronchus comes off the bronchus intermedius...
anteriorly opposite the apical segmental bronchus of the right lower lobe, there is a risk of damage to the middle lobe bronchus in lower lobectomy. Consider taking the apical segmental bronchus separately or divide the bronchus obliquely. Before division, check that the middle lobe reinflates after clamping the bronchus.

As the oesophagus lies posterior to the left main bronchus, there is a risk that the oesophagus may be damaged during dissection in this area. Identify the oesophagus and formally dissect away from the bronchus, avoiding the use of diathermy.

The posterior segment of the right upper lobe may be drained directly to the atrium by a vein crossing behind the bronchus intermedius. If this anomalous vein is not identified and is damaged, there is a risk of bleeding, particularly when developing the fissure posteriorly. Check for this anomalous venous drainage.

Lymphatic drainage of the lungs

A network of lymphatic vessels lies beneath the visceral pleura, in the interlobular septa and in the peribronchial vascular sheaths. These lymphatic vessels drain proximally towards the hilum. As they get larger, the channels (lymphatic collectors) contain smooth muscle and valves that direct the flow towards the hilum. Along their course, many of these lymphatic collectors flow into lymph nodes in the lung and mediastinum. On occasion, the lymphatic collectors can bypass lymph nodes to enter lymph nodes higher up the mediastinum. This explains how ‘skip metastases’, where lymph nodes along a chain are bypassed, can occur. Bronchial lymphatics from both lungs, while they usually remain ipsilateral, can also on occasion cross to the contralateral mediastinum in front of the lower trachea and carina. This feature is of importance when considering the lymphatic spread of lung cancers.

Intrapulmonary lymph nodes are most often located underneath the visceral pleura but can also occur within the substance of the lung. The bronchopulmonary lymph nodes are found at the bifurcations of segmental and lobar bronchi and also at the bifurcation of branches of the pulmonary artery. These lymph nodes are connected to the lobar lymph nodes, which in turn are connected to the mediastinal lymph nodes. The lobar lymph nodes are most commonly found on the right side along the bronchus intermedius between the upper lobe bronchus and middle lobe bronchus (the right
lymphatic sump), and just below the middle lobe bronchus. A constant lymph node lies at the junction of the right upper lobe bronchus and bronchus intermedius with a branch of the bronchial artery leading to it. In cases where the fissure is completely fused, it can be very helpful to dissect out this node because the pulmonary artery can be found lying behind it. The other lobar lymph nodes on the right can be grouped into nodes related to the upper, middle and lower lobe bronchi. In the left lung, these nodes are commonly found at the angle of the upper lobe bronchus and lower lobe bronchus (left lymphatic sump). As on the right, there is a constant node in the bifurcation between the left upper and lower lobe bronchi with a bronchial arterial branch leading to it.

On the right side, the lymph nodes lateral to the right main bronchus within the visceral pleura are hilar lymph nodes but form part of a chain of nodes that extend upwards to the right tracheobronchial mediastinal lymph nodes lying lateral to the trachea. Similarly, the hilar lymph nodes medial to the bronchus are contiguous with the subcarinal mediastinal lymph nodes. On the left side, the distinction between hilar and mediastinal lymph nodes is based on an imaginary plane at the level of the lateral surfaces of the ascending and descending thoracic aorta. Medial to this plane, nodes are deemed mediastinal, and lateral to it they are considered hilar. The nodes on the anterior surface of the left main bronchus drain into the subaortic mediastinal lymph nodes. Those lying medial to the left main bronchus drain into the subcarinal lymph nodes.

Mediastinal lymph nodes

Mediastinal lymph nodes consist of anterior (prevascular), tracheobronchial, paratracheal and posterior nodes in the posterior mediastinum. For lung cancer staging, these are grouped into zones based on a modification of lymph node mapping originally proposed by Naruke and the Mountain–Dresler modification of the American Thoracic Society map.

Routes of spread for lung cancer

Numerous studies have mapped the lymph node drainage of the various segments and lobes of the lung. Right upper lobe tumours usually drain to the right paratracheal lymph nodes; left upper lobe tumours drain to the periaortic and subaortic lymph nodes; and middle and lower lobe tumours drain to the subcarinal and right paratracheal lymph nodes. So-called ‘skip
metastases’, where there is direct drainage to the mediastinal lymph nodes without involvement of the hilar and interlobar lymph nodes, occur in up to 25% of cases\textsuperscript{13} (Figs 47.11, 47.12).
Lymph node maps

Staging of lung cancers is important for treatment planning, prognostication and comparison of results between different centres. The international TNM system is used. A number of lymph node maps have been developed to assist with nodal staging of lung cancer. The International Association for the Study of Lung Cancer (IASLC) proposed a map that reconciled features of previous maps into one that is internationally agreed, and grouped lymph node stations together into ‘zones’ for the purposes of prognostic analyses\textsuperscript{13} (Fig. 47.13).
A map of regional lymph nodes for the determination of the N descriptor during tumour, node and metastasis staging of lung cancer, published by the International Association for the Study of Lung Cancer. Abbreviations: Ao, aorta; AP,
Depending on the lymph node stations involved, nodal staging (N) is divided into Nx (not assessed); N0 (no regional involvement); N1 (ipsilateral hilar to intrapulmonary nodes involved); N2 (ipsilateral mediastinal nodes involved); and N3 (supraclavicular nodes or contralateral nodes involved). Defining mediastinal lymph nodes using this staging system is a key concept; any lung tumour with mediastinal nodal involvement would have at least N2 disease. Mediastinal lymph nodes are usually single-digit stations (that is, stations 2–9); station 1 is part of the supraclavicular nodes (N3). The letters L and R denote left-sided and right-sided lymph nodes, respectively. Mediastinal lymph nodes are grouped into zones as follows: upper zones (stations 2L, 2R, 3, 4L, 4R); aortopulmonary window zones (stations 5, 6); subcarinal zone (station 7); and lower zones (stations 8, 9).

Defining what constitutes 2R as opposed to 2L and 4R as opposed to 4L is important. According to the current nomenclature, any paratracheal node to the right of the left border of the trachea is considered a right-sided lymph node (either 2R or 4R). This will affect the decision as to whether mediastinal nodal involvement is ipsilateral (N2) or contralateral (N3). Anatomical borders separate diseases involving stations 4 (N2) and 10 (N1). On the right, only paratracheal lymph nodes above the inferior border of the azygos vein can be considered 4R. On the left, 4L lymph nodes should lie within the superior border of the left main pulmonary artery and the aorta. A group of lymph nodes lying between the proximal pulmonary artery and aorta just lateral to the ligamentum arteriosum is classified as station 5. The subcarinal zone contains lymph nodes extending from the carina to the start of the right bronchus intermedius and left lower lobe bronchus.

Surgical resection is appropriate if a tumour is staged N0 or N1 and the patient is fit. In general, N2 disease (involvement of ipsilateral mediastinal lymph nodes) usually precludes surgery. However, some patients with N2 disease confined to a single zone may benefit from surgical resection. Histological confirmation of N2 involvement is important if imaging assessment raises suspicion; biopsied material is obtained following bronchoscopy using EBUS (endobronchial ultrasound, which in many centres is replacing mediastinoscopy), mediastinoscopy, mediastinotomy or VATS.
**Mediastinoscopy**

Mediastinoscopy is a procedure used to stage the mediastinum (Fig. 47.14). It allows mediastinal or N2 nodes to be sampled from multiple zones and is used to guide treatment. The early stages of the operation are very similar to those of tracheostomy. A skin-crease incision is made a finger's breadth above the jugular notch. Platysma is divided in the line of the incision and sternohyoid and sternothyroid are separated in the midline. The thyroid isthmus is retracted upwards or may need to be divided. The fascia overlying the trachea is incised and the pretracheal plane is entered. After initial blunt dissection a finger is passed into the pretracheal plane, further dissecting this plane down to the carina. This action indicates an essential difference between mediastinoscopy and tracheostomy, where such dissection is undesirable (if this plane is dissected during tracheostomy and the tube falls out, it is more likely that a replacement tube would inadvertently be placed anterior to the trachea). The mediastinoscope is then passed and further dissection performed with suction diathermy. It is possible to sample right-sided lymph nodes 2R and 4R; left-sided lymph nodes 2L and 4L; and subcarinal lymph nodes.
Mediastinoscopy is usually a straightforward procedure but there is a risk of significant bleeding if a major vessel is damaged. The brachiocephalic (innominate) artery is at risk as it crosses the trachea anteriorly; the azygos vein loops over the right main bronchus and is at risk of injury on the right; the aorta is at risk of injury on the left; the pulmonary artery is at risk during dissection of the subcarinal lymph nodes. The recurrent laryngeal nerve on the left is at risk as it ascends in the tracheo-oesophageal groove.

Nodes in the anterior mediastinum, such as aortopulmonary window nodes, can be sampled via an anterior mediastinotomy. This involves making an incision around the second or third intercostal space just lateral to the internal thoracic vessels. It is also possible to perform mediastinal staging via VATS; this will allow access to most of the lymph node stations, 2, 4, 5, 6, 7, 8 and 9 on the operated side, but will not allow biopsy of the contralateral nodes.
12. Mountain CF, Dresler CM. Regional lymph node

Single best answers

1. Which one of the following statements about the trachea is FALSE?
A. The posterior membranous wall of the trachea is closely related to the oesophagus
B. The blood supply of the trachea is derived mainly from the inferior thyroid artery and bronchial arteries
C. The blood supply enters the trachea mainly through its posterior wall
D. The recurrent laryngeal nerve lies within the tracheo-oesophageal groove

Answer C. Statements A, B and D are true. The blood supply of the trachea is derived mainly from the subclavian artery (the inferior thyroid artery is a branch of the thyrocervical trunk) and bronchial arteries. Branches enter the trachea mainly through its lateral wall, and posterolaterally in parts of the upper trachea. These vessels form a vascular anastomosis with each other along the lateral tracheal wall.

2. When a right upper lobectomy is performed via an anterior video-assisted thoracoscopic approach, which one of the following options reflects the order of right upper lobe structures that is expected, progressing in anterior to posterior fashion?
A. Bronchus, artery, vein
B. Bronchus, vein, artery
C. Vein, bronchus, artery
D. Vein, artery, bronchus

Answer: D. In an anterior approach, the first structure encountered is usually the branch of the superior pulmonary
vein to the right upper lobe. Once this is divided, the arterial branches to the right upper lobe will be encountered. The right upper lobe bronchus is the most posterior structure.

3. When a right lower lobectomy is performed via a posterolateral thoracotomy, which one of the following options reflects the normal order of the right lower lobe structures encountered if the lobectomy is approached from the posterior aspect?
   A. Bronchus, artery, vein
   B. Bronchus, vein, artery
   C. Vein, bronchus, artery
   D. Vein, artery, bronchus

   **Answer: A.** In a posterior approach, the most posterior structure is the right bronchus intermedius and lower lobe bronchus. The lower lobe pulmonary artery is closely related in front of this. The inferior pulmonary vein is the most anterior structure. The order is reversed if we perform a VATS resection via an anterior approach.

4. In the majority of cases, which one of the following structures does the right middle lobe vein usually drain into?
   A. Inferior pulmonary vein
   B. Superior pulmonary vein
   C. A single pulmonary vein for both upper and lower lobes
   D. Directly into the left atrium

   **Answer: B.** The right middle lobe vein usually drains into the superior pulmonary vein. It is therefore important for this not to be divided when a right upper lobectomy is performed. Rarely, the middle lobe vein can drain into the inferior pulmonary vein, a common vein for both upper and lower lobes or directly into the
left atrium. During any lung resection, it is therefore important to identify the correct venous drainage pattern for the part of the lung that is to be removed before dividing it.

5. Which one of the following statements about the anatomy of the left lung is true?
A. The left main bronchus is shorter than the right main bronchus
B. The right main pulmonary artery usually has a longer segment extrapericardially than the left
C. The lingular vein usually drains into the inferior pulmonary vein
D. There is more variation in the anatomy of the pulmonary arterial branches to the left upper lobe than in the right upper lobe

Answer: D. There is more variation in the left upper lobe arterial branches, which can range from four to seven branches. The left main bronchus is longer than the right main bronchus, and hence the left main pulmonary artery also has a longer extrapericardial segment. The left lingular vein draining the lingular segment of the left upper lobe usually drains into the superior pulmonary vein, although it can occasionally drain into the inferior pulmonary vein.

6. According to the current lymph node mapping recommendation by the International Association for the Study of Lung Cancer (IASLC), which one of the following options describes the involvement that a right upper lobe tumour with tumour involvement of a lymph node at the origin of the right main bronchus, but just below the lower border of the azygos vein, is considered to have?
A. N0 involvement
B. N1 involvement  
C. N2 involvement  
D. N3 involvement

**Answer: B.** The nodal status is used to define the extent of lymph node involvement by a lung tumour. N0 is used if there is no evidence of lymph node involvement. N1 denotes involvement of hilar lymph nodes. N2 denotes involvement of mediastinal nodes. N3 is used when supraclavicular nodes or any contralateral nodes are involved. The lower border of the azygos vein is used as the landmark on the right to define whether a lymph node should be considered a station 4R (N2 lymph nodes) or station 10 (N1 lymph node). Any nodes involved above this border should be considered N2 lymph nodes.

7. According to the current lymph node mapping recommendation by the International Association for the Study of Lung Cancer (IASLC), which one of the following options describes the position of paratracheal lymph nodes that are considered left-sided lymph nodes?
   A. They lie to the left of the right border of the trachea  
   B. They lie to the left of the mid-trachea  
   C. They lie to the left of the left border of the trachea  
   D. They lie to the left of the left border of the superior vena cava

**Answer: C.** Under current recommendations, the left border of the trachea is used to determine whether paratracheal lymph nodes are classified as left- or right-sided lymph nodes. An involved node to the left of this border is considered to be a left-sided lymph node, and an involved node to the right is considered to be a right-sided lymph node. This is important because a left-sided tumour with a paratracheal lymph node that
is lying anterior to the trachea is considered to have N3 disease if this lymph node is involved.
Clinical cases

1. A 55-year-old smoker is found to have an endobronchial tumour completely blocking the bronchus intermedius.
   A. Describe the relationships of the right middle and lower lobe bronchi.
   The bronchus intermedius terminates when the airway divides into the middle lobe bronchus anteriorly, with the basal segmental bronchi of the lower lobe between it and the superior segmental bronchus of the lower lobe arising posteriorly.
   B. Why is this relevant when resecting this tumour?
   Most tumours of bronchus intermedius are likely to involve both middle and lower lobe. In this case when there is complete obstruction of bronchus intermedius, there will be little ventilation to both middle and lower lobe, resulting in bilobar collapse. If the tumour is at the proximal bronchus intermedius, the right upper lobe orifice can be involved.
   C. What lobes will need to be resected?
   This depends on the location and extent of bronchus intermedius tumour. Careful pre-resection bronchoscopy is vital for operative planning. To achieve adequate resection margin, both middle and lower lobe usually need to be resected. If the upper lobe bronchial orifice is involved, the whole right lung may need to be resected. Lung preservation sleeve resection can also be considered if it is feasible to resect the tumour with clear margin and sufficient airway for re-anastomosis.

2. A 70-year-old female with a tumour in the superior segment of the left lower lobe is taken to theatre. Lymph nodes are found on the pulmonary artery in the fissure at the origin of the superior segmental artery.
   A. Describe the relationship between the superior segmental artery of the left lower lobe and the lingular artery.
   The superior segmental artery of the left lower lobe arises opposite or just proximal to the origin of the lingular artery.
   B. If the lingular artery is involved with tumour, what resection is likely to be necessary?
   If the lingular artery is involved, then resection of the lower lobe and
lingular segment, sparing the upper three segments, may be required. However, it is likely that both lobes will need to be resected: that is, the whole lung will need to be removed.

3. A mediastinoscopy is performed to stage a tumour of the right upper lobe of the lung.

A. Describe the lymph nodes that can be biopsied at mediastinoscopy.
Classically, the nodes that can be sampled are stations 2 and 4 on the right, stations 2 and 4 on the left, and the subcarinal lymph nodes (station 7) below the carina.

B. The pathologist reports that in this patient 4R and 4L contain tumour. What is the nodal staging of this patient?
The staging is N3 since the 4L nodes are contralateral lymph nodes.

C. There is significant bleeding during a mediastinoscopy. Describe the possible sources of the bleeding.
On the right, the azygos vein arches over the right main bronchus and can be seen at mediastinoscopy. Anteriorly, the brachiocephalic artery, and more distally the aortic arch, lie anterior to the trachea. The pulmonary artery lies anterior to the distal trachea and its bifurcation. Branches of the bronchial artery can be found over the distal trachea and subcarinally.
Thymus

Keng Ang, John P Duffy

Core Procedures

- Thymectomy
Clinical anatomy

The thymus is an encapsulated soft, bilobed organ; the two lobes are joined in the midline by connective tissue that merges with the capsule of each lobe. It is usually located in the anterior mediastinum.\textsuperscript{1} The thymus plays an important role in the immune system from the early part of life until puberty and, as a result, it is usually largest during this time. At birth, it can weigh about 10–15 g, rapidly increasing to about 20 g and remaining this size for the rest of life. Its dimensions are 4–6 cm long, 2.5–5 cm wide and 1 cm thick. In early childhood, it usually assumes a more pyramidal shape and can extend from the suprasternal notch down to the fourth intercostal space (Fig. 48.1). Over time, through the later part of childhood, it lengthens and the cervical portion becomes less noticeable. After puberty, the thymus starts to atrophy and becomes replaced by fibrofatty infiltration. It becomes thinner and greyer compared with the deep red colouration of early life (Fig. 48.2).

\textbf{FIG. 48.1} The neonatal thymus. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 56.8.)
In the adult, the thymus is situated along the midline superior aspect of the anterior mediastinum. Superiorly and anteriorly, the upper poles of the thymus lie behind sternohyoid and sternothyroid (Ch. 18). It can extend up to the inferior poles of the thyroid gland, to which it is connected by the thyrothymic ligament. The left upper pole usually sits slightly more superior than the right. The phrenic and recurrent laryngeal nerves can be closely related laterally to the upper poles of the thymus, particularly if these are enlarged. The rest of the thymus is closely related to the sternum, upper costal cartilages and internal thoracic vessels anteriorly and to the pleura and phrenic nerve laterally. Posterior relations of thymus include the thoracic trachea, the great vessels of the superior mediastinum and the anterior pericardium and heart. While the left brachiocephalic vein usually lies posterior to the thymus, it is not uncommon to find it embedded in, and on occasions encircled by, the thymus.
Vascular supply, lymphatic drainage and innervation

The thymus receives its arterial supply from branches of the internal thoracic and inferior thyroid arteries and occasionally from a branch of the superior thyroid artery; most of the arterial supply enters the thymus via its upper pole. As no definite hilum exists, the arterial branches either travel along the interlobar septa before entering the thymus at the junction of the cortex and medulla, or reach the thymic tissue directly through the capsule. Thymic veins drain to the left brachiocephalic, internal thoracic and inferior thyroid veins, and occasionally directly into the superior vena cava. One or more veins often emerge medially from each lobe of the thymus to form a common trunk opening into the left brachiocephalic vein and require careful ligation during thymectomy.

The thymus has no afferent lymphatics. Efferent lymphatics arise from the medulla and corticomedullary junction, drain through the extravascular spaces, accompany the supplying arteries and veins, and end in the brachiocephalic, tracheobronchial and parasternal nodes.

The thymus is innervated from the sympathetic chains via the cervicothoracic (stellate) ganglia or ansa subclavia and from the vagi. Branches from the phrenic and descending cervical nerves (inferior roots of the ansa cervicalis) are distributed mainly to the capsule.
Classification of thymoma

A thymoma is a slow-growing tumour arising from the epithelial elements of the thymus; it may be benign or malignant, depending on its histological features. Although rare, thymomas are the most frequently diagnosed tumours of the anterior mediastinum. Several classification systems have been developed and described. The most widely used staging system, which combines perioperative and histopathological findings, was defined by Masaoka et al.\textsuperscript{2} The current staging system for thymic malignancy recommended by the International Thymic Interest Group (ITMIG)\textsuperscript{3} is based on Masaoka's original anatomical classification with modifications proposed by Koga et al\textsuperscript{4} and further histological/microscopic confirmation of the structures involved (Table 48.1, Fig. 48.3). The key anatomical considerations are whether the thymoma has spread beyond its capsule (microscopic versus macroscopic), and if so, what near and distant structures are involved.

### TABLE 48.1

#### Masaoka–Koga staging

<table>
<thead>
<tr>
<th>Masaoka staging</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I</td>
<td>Lesion is within capsule; also known as non-invasive thymoma</td>
</tr>
<tr>
<td>Stage II</td>
<td>Invades beyond capsule</td>
</tr>
<tr>
<td>Stage IIA</td>
<td>Microscopic spread to capsule</td>
</tr>
<tr>
<td>Stage IIB</td>
<td>Macroscopic spread beyond capsule to surrounding fat but not breaking through pleura or mediastinum</td>
</tr>
<tr>
<td>Stage III</td>
<td>Involves neighbouring structures, e.g. pericardium, mediastinal vessels, lung</td>
</tr>
<tr>
<td>Stage IVA</td>
<td>Widespread pericardial or pleural involvement</td>
</tr>
<tr>
<td>Stage IVB</td>
<td>Haematogenous or lymphatic dissemination</td>
</tr>
</tbody>
</table>

FIG. 48.3 Masaoka–Koga staging with International Thymic Interest Group (ITMIG) descriptions, illustrating the different staging of thymic malignancy. A, Penetrations
within the fibrous capsule of a thymoma are classified as non-invasive, although they do (partially) invade the capsule. B, Absence of a capsule by itself does not constitute invasion. Transcapsular invasion is included in stage Ila. C, D, Types of invasion included in stage IIb may range from a single area of localized invasion (C) to more extensive involvement of the mediastinal fat without pleural or pericardial involvement (D). E, F, Types of invasion included in stage III may include involvement of the mediastinal pleura or partial involvement of the pericardium, or of vessels (E), or penetration through the pericardium or visceral pleura, or into the phrenic nerve (F). G, H, Separate foci of tumour included in stage IV range from a separate nodule on the pleural or pericardial surfaces, classified as IVa (G), to involvement of nodal sites, extrathoracic sites or parenchymal lung nodules (H). (Modified from F.C. Detterbeck, A.G. Nicholson, K. Kondo, et al: The Masaoka–Koga stage classification for thymic malignancies: clarification and definition of terms, J. Thorac. Oncol. 6 (7 Suppl 3) (2011) S1710–1716.)

Generally, stage I thymic tumours are treated primarily by surgery alone. Stages II and III may be treated with a combination of surgery and radiotherapy or chemotherapy. Stage IV tumours are mainly treated by chemotherapy and radiotherapy. There may be a limited role for surgical debulking for palliation (see Fig. 48.3).
Surgical approaches and Considerations

Surgical resection of the thymus may be required for thymic tumours, the symptomatic management of myasthenia gravis and access to cardiac structures during cardiac surgery. The thymus can be approached by a median sternotomy or video-assisted thoracoscopy, or via a transcervical incision.

Median sternotomy provides comprehensive access to the entire thymus (Fig. 48.4) and is the preferred approach for large thymic tumours or those involving vascular or surrounding tissues. In order to perform complete excision of the thymus, a ‘phrenic to phrenic’ resection of the thymus must be performed. To facilitate the identification of both phrenic nerves, the mediastinal pleura is opened bilaterally. The left brachiocephalic vein can usually be located anteriorly by dissecting the connective tissue between the two lobes of the thymus. A common venous trunk will typically be found draining from both lobes into the left brachiocephalic vein.
Video-assisted thoracoscopy (VATS) is currently a popular approach for removing a small, localized thymic tumour. It usually involves two or three ports. The principle of port placement is to provide access to the upper poles as well as the inferior margins, usually achieved via a right-sided approach in the first instance. The patient is usually positioned in a semi-supine position with the right side up and right arm placed over the head. It is important to
identify the phrenic nerves and the left brachiocephalic vein, the latter by locating its entry into the superior vena cava. One of the problems with this approach is that it can be difficult to achieve vascular control if there is vascular involvement or iatrogenic injury. It can also be difficult sometimes to achieve complete resection on the contralateral side, in which case bilateral VATS may be required. Robot-assisted minimally invasive surgery (RVATS) is a relatively new technique applied for thymectomies.\textsuperscript{5}

The transcervical approach is useful for removing thymus tissue, particularly in the context of thymic hyperplasia, for symptom control in myasthenia gravis. One of the earliest descriptions of thymic resection was performed via a transcervical approach.\textsuperscript{6} This approach provides good access to the upper poles of the thymus. The working area is limited, however, and specialized equipment is required to elevate the sternum in order to increase surgical visualization and the working area.\textsuperscript{7} It is possible to dissect the entire thymus as far as the inferior pole bilaterally. A suprasternal incision is used, as for cervical mediastinoscopy. The resection starts by identifying and dissecting the upper poles of the thymus, which are usually located behind the infrahyoid strap muscles. The anterior surface of the thymus is then dissected away from the back of sternum, allowing introduction of a Cooper's thymectomy retractor in order to elevate the sternum and improve visualization for resection of the remaining thymic tissue (Fig. 48.5).
FIG. 48.5 The transcervical approach. A, The surgical incision is usually made just above the suprasternal notch. B, Surgical exposure.
During dissection of thymic tissue it is important to be particularly vigilant near the phrenic nerves: diathermy and sharp dissection should be avoided. Any bleeding from tissues near the nerves should be either oversewn with sutures or clipped.

As the majority of the blood supply enters the thymus via its upper poles, it is important to look out for any feeding vessels and ensure appropriate haemostasis during dissection of these areas. Enlarged upper poles may be closely related to the phrenic and recurrent laryngeal nerves. When using the transcervical approach, it is usually easier to locate the upper poles of the thymus, as they lie behind sternohyoid.

The brachiocephalic vein can sustain iatrogenic injury because the common feeding vein from the thymus can be avulsed during dissection. The vein can also be injured because direct involvement by the thymic tumour makes its identification difficult. The brachiocephalic vein can usually be found between the two thymic lobes anteriorly by blunt dissection of the adjoining connective tissues, or by tracing it back from its entry to the superior vena cava. The thymus can occasionally encircle the left brachiocephalic vein and so it is important to ensure that the vein is completely dissected on the thymus; if there is a common feeding vein, this should be ligated and divided first.

Choose the surgical approach for thymus resection according to pathology in order to achieve the best results in terms of resection margins and safety.

Warn the patient of the risks of potential major procedure-specific complications, especially injury to the phrenic and recurrent laryngeal nerves. In minimal access approaches, warn the patient of the risk of conversion to an open procedure.

Identify and avoid the phrenic nerves.

Watch for phrenic nerves and recurrent laryngeal nerves during dissection of the upper poles of the thymus.

Remember that in tumours extending into the aortopulmonary window, the recurrent laryngeal nerve is also at risk.

Look out for feeding vessels in the upper poles of the thymus.

Identify and dissect the left brachiocephalic vein early, looking out for the common feeding vein from both thymic lobes.
References

1. Which one of the following statements about the upper pole of thymus is FALSE?
   A. The right upper pole usually sits more superiorly than the left
   B. The recurrent laryngeal nerves can be closely related laterally to the upper pole
   C. The main arterial supply to the thymus usually enters the thymus around the upper pole
   D. The upper pole of the thymus can be connected to the thyroid gland by the thyrothymic ligament

   **Answer:** A. The left upper pole usually sits more superiorly than the right.

2. Which one of the following structures is LEAST likely to be affected by direct invasion of thymic cancer?
   A. Phrenic nerve
   B. Recurrent laryngeal nerve
   C. Superior vena cava
   D. Oesophagus

   **Answer:** D. The oesophagus lies posterior to the trachea and is the structure least likely to be affected by direct invasion of thymic cancer.

3. At the time of surgical resection, a thymic tumour was found to involve the mediastinal fat but did not involve the pleura or other neighbouring structures. Which one of the following is the most likely Masaoka–Koga staging of this tumour, according to current International Thymic Interest Group (ITMIG) definitions?
A. Stage I  
B. Stage II  
C. Stage III  
D. Stage IV  

**Answer:** B. The key anatomical consideration in this staging system is whether the thymic tumour is confined within its capsule (stage I); has extended beyond the surrounding fat (stage II); or spread even further into surrounding structures (stage III).

4. If a patient with thymic malignancy also has separate pleural nodules on CT scan, one of the following is the most likely Masaoka–Koga staging according to current ITMIG definitions?  
A. Stage I  
B. Stage II  
C. Stage III  
D. Stage IV  

**Answer:** D. A thymic tumour with separate pleural nodules is considered to be stage IVA under the current Masaoka–Koga staging.

5. When performing thymic resection, which one of the following structures does NOT require extra precautions to be taken?  
A. Brachiocephalic vein  
B. Inferior vena cava  
C. Phrenic nerve  
D. Upper poles of thymus  

**Answer:** B. The inferior vena cava lies a good distance away from the thymus. The brachiocephalic vein and phrenic nerve are at
risk of injury during thymic resection because of their close anatomical relationships with the thymus. The thymus receives most of its arterial supply via the upper poles and so it is important to look out for feeding vessels and for the phrenic and recurrent laryngeal nerves in this area.
Clinical Case

1. A 40-year-old male was referred for surgery for an asymptomatic, small, well-encapsulated thymic tumour, mainly involving the right thymic lobe.

A. **What surgical approach can be offered to this patient?**

The patient has a small, localized tumour, which is well encapsulated and therefore is likely to be a stage I thymic tumour. The common approaches used are video-assisted thoracic surgery (VATS) and median sternotomy. The transcervical approach can be considered but it requires specialized equipment.

B. **What are the risks that the patient needs to be made aware of?**

The main risks that the patient should be informed about include phrenic nerve injury, hoarse voice (injury to the recurrent laryngeal nerve), and bleeding following injury to the brachiocephalic vein or arterial bleeding at the upper pole of the thymus. If a VATS approach is used, the patient should be warned about the possibility of conversion to an open procedure, such as a median sternotomy.
CHAPTER 49
Core procedures

- Pericardiectomy
- Pericardiocentesis
- Pericardial harvesting, e.g. closure of atrial septal defect
- Thoracoscopic pericardial window creation
- Relief of pericardial tamponade post-cardiotomy
- Pericardial biopsy
The surface projections of an average adult heart are modified by age, sex, stature, ventilation, the position of the diaphragm and posture. The projection of the cardiac borders on to the anterior thoracic wall forms a trapezoid. The upper border slopes from the second left costal cartilage to the third right costal cartilage, and the inferior border runs leftwards from the sixth right costal cartilage to the cardiac apex, located approximately 9 cm lateral to the midline, often in the left fifth intercostal space or level with the fifth or sixth rib. The right border is a curved line, convex to the right, running from the third to the sixth right costal cartilages, usually 1–2 cm lateral to the sternal edge. The left border is convex laterally and extends superomedially from the cardiac apex to meet the second left costal cartilage, approximately 1 cm from the left sternal edge.
Clinical anatomy

The pericardium is a double-walled sac consisting of two components – fibrous and serous pericardia – with a normal combined thickness of 1–2 mm. It contains the heart, juxtacardiac segments of the great vessels and 20–50 ml of serous fluid distributed mostly over the atrioventricular and interventricular grooves.\(^1\) It is located in the middle mediastinum, where it is anchored superiorly by continuity with the adventitia of the aorta, pulmonary trunk, superior vena cava and pretracheal fascia; inferiorly, by attachment to the central tendon of the diaphragm; and anteriorly, by attachment to the posterior surface of the sternum via the superior and inferior sternopericardial ligaments (the extent of these ‘ligaments’ is very variable and the superior is often undetectable).

The outer fibrous pericardium is a tough collagen-rich layer that is used as an autograft in closure of septal defects, osteoplasty valve repairs, intracardiac baffles and suture reinforcement.\(^2\)–\(^5\) The serous pericardium is a closed sac within the fibrous pericardium and has visceral and parietal layers. The visceral serous layer is continuous with the epicardium and covers the heart and great vessels; it is reflected into the parietal layer, which lines the internal surface of the fibrous pericardium. The pericardium serves multiple functions. Anatomically, it provides stabilization for the heart within the chest via its anchor points, maintains cardiac geometry and provides a physical barrier to infection. Physiologically, the pericardial fluid reduces friction during cardiac movement; the lack of compliance of the fibrous layer prevents chamber distension, maintains a constant hydrostatic pressure to all cardiac chambers, and promotes chamber coupling with facilitation of atrial filling due to the resulting negative pericardial pressure during ventricular systole.\(^6\)\(^,\)\(^7\)

As the serous pericardium is reflected around the great vessels it creates two clinically important sinuses – the oblique and transverse sinuses (Fig. 49.1). The oblique sinus lies behind the heart as a cul-de-sac between the inferior vena cava and pulmonary veins, anterior to the oesophagus and posterior to the left atrium. The transverse sinus lies anterior to the superior vena cava but posterior to the aorta and main pulmonary trunk; it is important during cardiac surgery when the aorta is cross-clamped to isolate the heart during delivery of cardioplegia to arrest the heart, and is also used to pass a ligature during surgery. Both sinuses are accessed surgically when creating lines of ablation for atrial fibrillation (see Fig. 49.1).
The phrenic is a mixed nerve that provides the sole motor supply to its hemidiaphragm (Ch. 46). Derived mostly from the fourth cervical ventral ramus, it also receives contributions from the third and fifth cervical ventral rami. Within the thorax, the phrenic nerves descend anterior to the pulmonary hilum between the fibrous pericardium and mediastinal pleura, accompanied by the pericardiacophrenic vessels. They supply sensory branches to the mediastinal pleura, fibrous pericardium and parietal serous pericardium. The phrenic nerves must be identified and preserved during pericardial procedures, especially window creation, pericardial decortication and thymectomy. The right phrenic nerve is shorter and lies more posteriorly,
such that usually only an anterior window is feasible. On the left it is possible to create windows both anterior and posterior to the phrenic nerve.

**Pericardial vascular and lymphatic drainage and innervation**

Most of the pericardial blood supply comes via the pericardiaco-phrenic arteries branching from the internal thoracic (mammary) arteries. Posteriorly, the supply is directly from the aorta or branches of the oesophageal and bronchial arteries, and more inferiorly from small intercostal and superior phrenic arteries. The phrenic, internal thoracic and azygos veins drain the pericardium.

Lymphatic drainage is complex: a ‘double layer’ drains the parietal pericardium and a separate system drains the loose areolar tissue and fat. Most lymph drainage of the pericardium is to either the thoracic or the right lymphatic ducts (Chs 15 and 45); bilateral upper mediastinal and parasternal internal thoracic lymph nodal groups also receive efferents. The sternocostal pericardium either drains laterally towards the phrenic nerves as they enter the diaphragm, or travels along the ventral border of the pericardium to enter the prepericardial nodes located at the pericardio-diaphragmatic junction. Drainage from the lateral pericardium is more variable. Inferiorly, it drains towards the phrenic nerves and the pericardiaco-phrenic vessels as they reach the diaphragm; superiorly, it drains into the tracheobronchial and paratracheal lymph nodes. The posterior pericardium, including the posterior aspect of the cupula and extending as far as the pulmonary veins, drains superiorly to the superior and inferior tracheobronchial lymph nodes. The portion of the pericardium that adheres to the diaphragm drains via short channels to the lymph nodes at the right border of the inferior vena caval opening in the central diaphragmatic tendon. The superior aspect of the diaphragmatic pericardium drains to prepericardial nodes.\(^8\)

Pain from parietal pericardium is mainly transmitted by the phrenic nerves. Pain from serous pericardium is mediated by visceral afferents that mainly travel, without synapsing, through the aortic and cardiac plexuses and ganglia in the sympathetic chain to the dorsal horn of the spinal cord. Pericardial pain is characteristically sharp, severe and substernal, typically exacerbated by lying back or on the left side and relieved by leaning forwards, occasionally radiating to the superior border of trapezius.
Cardiac tamponade

Under normal physiological conditions, the pericardium contains 20–50 ml of pericardial fluid. With larger volumes, especially with rapid accumulation as occurs in trauma, as little as 150 ml can result in cardiac tamponade. As the right atrium is compressed it leads to diminished venous return and loss of cardiac output. Cardiac tamponade with rapid accumulation is a surgical emergency that requires immediate relief, usually with needle pericardiocentesis under echocardiographic guidance and/or surgery, depending on the cause. The subxiphoid approach, drained surgically or by pericardiocentesis under echocardiographic guidance, avoids breach of the pleura. Recently, parasternal and paraxiphoid approaches have been described. More chronic effusions can be managed with pericardial window creation using video-assisted thoracoscopic surgery (VATS); good results are reported even with single-port VATS.

Constrictive pericarditis

Constrictive pericarditis is a chronic inflammatory condition resulting in pericardial scarring, thickening and calcification. Diastolic filling is compromised and cardiac output is impaired, resulting in heart failure. For many, the treatment is surgical with decortication of the pericardial peel. Dissection to elucidate the plane between the epicardium and parietal pericardium can be difficult. Occasionally, calcification may involve the myocardium, making it necessary to leave islands of densely adherent pericardium behind. Where adhesions are especially dense, a ‘waffle procedure’ may be used, where multiple longitudinal and transverse incisions are made, extending into the epicardium. The primary danger in breaching the epicardium is damage to the coronary arteries. The lateral limits for dissection for decortication for constrictive pericarditis extend to the phrenic nerves, which are at risk during the surgery. Take note that the phrenic nerve on the left side lies more anteriorly than the right nerve. The phrenic nerves also serve as boundaries of dissection for thymectomy, especially for clearance of thymic tissue for myasthenia gravis. In recent years, there has been an increase in cardiac ablation techniques. The phrenic nerves are particularly at risk during ablation
for symptomatic atrial fibrillation (Fig. 49.2). The right phrenic nerve is separated from the junction of the superior vena cava and right atrium only by the pericardium, where its distance to ablation landmarks is anything from 0 to 2.3 mm. From this point, the nerve courses posteriorly to lie close to the right pulmonary veins, where again iatrogenic damage during ablation is likely. The left phrenic nerve lies anterior to the left pulmonary veins and along the roof of the left atrium, where it may be injured during ablation.

![Diagram of right phrenic nerve](image)

**FIG. 49.2** An intraoperative image demonstrating the route of the right phrenic nerve (arrows) on the pericardium as it courses over the superior vena cava (SVC) anterior to the lung hilum. Its close proximity to the SVC and pulmonary veins makes the nerve susceptible to iatrogenic damage during cardiac ablation procedures.

Cardiac herniation is a potentially life-threatening complication of excessive pericardial resection: for example, following pneumonectomy, lobectomy with pericardial resection or even a technically inferior repair of a pericardial defect. It can occur if the patient has a coughing fit, with excessive postoperative chest drain suction, posture or positive pressure ventilation. Cardiac herniation on the right side has dramatic haemodynamic consequences, with reduction of inflow as the heart kinks the superior and inferior venae cavae.

**Pericardiocentesis**

With the introduction of standard clinical guidelines such as the use of
ultrasound guidance, pericardiocentesis is now considered a safe procedure with a mortality risk of less than 1% and a morbidity rate of 1–3%. (Previously the complication rates using blind techniques exceeded 20%.16) Pericardiocentesis is now the technique of choice for draining over 80% of pericardial effusions. Three approaches, parasternal, apical and subxiphoid, are used; each has its unique potential complications. The parasternal approach is associated with a higher incidence of pneumothorax and inadvertent damage to the internal thoracic vessels. The apical approach carries the highest risk of ventricular fibrillation, while the subxiphoid approach (Fig. 49.3), usually the safest in an emergency, can cause colonic, hepatic and gastric injuries.16 The incidence of pericardial effusions has risen with the increase in catheter-based interventions: in over 95% of cases, at least one antiplatelet agent was used during the day of the intervention, thereby increasing the risk of bleeding.17
Tips and Anatomical Hazards

With redo cardiac surgery, start the dissection plane at the diaphragmatic reflection inferiorly, where typically there are fewer pericardial adhesions. ‘Skinning’ trauma of the great vessels and epicardium during redo dissection is easily done while looking for the ideal plane. Ensure the pericardium ‘tents’ during pericardial biopsy or window creation. No ‘tenting’ may indicate that the underlying heart is adherent and therefore susceptible to damage.
Small pericardial defects can be repaired with sutures; moderate and large defects require patch repair. Both synthetic and biological patches are acceptable. Take care to fenestrate impermeable patches so that the risk of tamponade is reduced. Pericardial patch repairs should preserve anatomical geometry to prevent tamponade. Pericardial patch harvesting for autologous use is best done from the right side anteriorly, where the quality of the graft is considered to be superior.\textsuperscript{18}

The oblique sinus is blind-ending and may accumulate blood, especially following cardiac surgery; this may result in left atrial tamponade. The phrenic nerves lie very close to the pulmonary veins on both sides and may be damaged during ablation and/or careless dissection. The phrenic nerve may be also injured in its course, especially on the left, where it lies more anteriorly. The anterior approach to pericardial fluid drainage can result in a pneumothorax or internal thoracic vessel injury; the apical approach can result in ventricular arrhythmias; the subxiphoid approach can result in bowel or liver injury.

Ablation for atrial fibrillation often involves isolation of the left atrial posterior wall (box lesion) by ablating around the pulmonary veins. This approach involves traversing pericardial reflections in both transverse and oblique sinuses, with the risk of vascular damage, especially where the pulmonary veins lie close to the superior and inferior venae cavae. Autologous pericardial harvesting in children has a higher incidence of left phrenic nerve palsy, given the need often to obtain large patches and expose the great vessels.\textsuperscript{19} Blalock–Taussig (BT) shunts have a higher incidence of right-sided phrenic nerve palsy.\textsuperscript{19}
References


1. Which one of the following structures does NOT form part of the oblique sinus?
   A. Inferior vena cava
   B. Superior vena cava
   C. Right superior pulmonary vein
   D. Left inferior pulmonary vein
   E. Right superior pulmonary vein

   **Answer: B.** The oblique and transverse sinuses are formed by the pericardial reflections of the visceral and parietal pericardium. The oblique sinus is a blind-ending cul-de-sac bounded by pericardial reflections coming off the pulmonary veins on the left and inferior vena cava and right pulmonary veins on the right.

2. Which one of the following statements is FALSE?
   A. The majority of the pericardial blood supply comes from the phrenic arteries
   B. Venous drainage of the pericardium is into the azygos, phrenic and intercostal veins
   C. The pericardium has a complex ‘double-layered’ lymphatic drainage
   D. Pain transmission pathways for the parietal pericardium are mainly via the phrenic nerve
   E. Lymph from the superior pericardium eventually drains into the brachiocephalic vein

   **Answer: A.** The majority of the blood supply of the pericardium is from the internal thoracic arteries via the pericardiacophrenic arteries. The phrenic arteries supply a small portion together with direct branches from the aorta and bronchial and
oesophageal arteries.

3. Which one of the following statements about the transverse sinus is TRUE?
   A. It is a blind-ending cul-de-sac
   B. It is posterior to the superior vena cava
   C. It connects to the oblique sinus inferiorly
   D. It is located anterior to the great vessels
   E. It is located posterior to the great vessels

**Answer: E.** The transverse sinus is approached anterior to the superior vena cava and posterior to the aorta and pulmonary artery. The oblique and transverse sinuses do not connect with each other.

4. Which one of the following statements about the phrenic nerve is FALSE?
   A. The right phrenic nerve courses more anteriorly than the left phrenic nerve
   B. The phrenic nerves originate from C3–5
   C. The phrenic nerve carries both motor and sensory functions
   D. The phrenic nerve transmits pain fibres from the parietal pericardium
   E. The phrenic nerve is prone to damage during cardiac ablation procedures, especially around the right and left upper pulmonary veins

**Answer: A.** The phrenic nerves are both motor and sensory, and originate from the ventral rami of C3–5. They course on the lateral aspect of the pericardium, with the left phrenic more anterior than the right. On both sides, the nerves are in close proximity to the upper pulmonary veins, which makes them
susceptible to damage during cardiac ablation procedures.

5. Which one of the following approaches is NOT **routinely** used for pericardial effusion drainage?
   A. Video-assisted thoracoscopic surgery (VATS)
   B. Parasternal pericardiocentesis
   C. Subxiphoid pericardiocentesis
   D. Subxiphoid surgical approach
   E. Transoesophageal pericardiocentesis

**Answer: E.** Transoesophageal pericardiocentesis, although recently described for isolated posterior pericardial effusions that are not amenable to conventional approaches, is not routinely practised. The other approaches are well documented and routinely used.
Clinical Cases

1. A 52-year-old male presents to his GP, complaining of increasing shortness of breath over 24 hours. He had undergone aortic root replacement with a mechanical valve conduit 14 days prior and was discharged on warfarin. On examination, he has a well-healed sternal scar, is dyspnoeic and has a blood pressure of 85/45 mmHg with an elevated jugular venous pulse.

A. What is your provisional diagnosis?
This patient most likely has a delayed cardiac tamponade, especially with the history of extensive cardiac surgery with anticoagulation.

B. He is transferred immediately to the nearest cardiac unit, where he undergoes urgent echocardiography. What are the echocardiographic features of cardiac tamponade?
Cardiac tamponade has typical features on echocardiography, including right atrial collapse, as pericardial pressure due to fluid build-up exceeds right atrial pressure. Venous return is diminished, such that cardiac output and blood pressure fall. With the reduction in right atrial filling, the inferior vena cava is dilated with no change in diameter with respiration. Although less sensitive than right atrial collapse, there may be right ventricular free wall collapse during diastole. Other echocardiographic features include exaggerated tricuspid and decreased mitral diastolic inflow on inspiration, pericardial separation of at least 1 cm and pulsus paradoxus, a drop in systolic blood pressure of at least 10 mmHg on inspiration.

C. The echocardiogram shows a ‘floating heart’, along with the typical features of cardiac tamponade. Blood tests demonstrate an INR (international normalized ratio) of 5.7 with elevated liver enzymes. What could explain the blood biochemistry?
The lack of forward flow in the inferior vena cava due to elevated pericardial pressure results in liver engorgement with a concomitant rise in liver enzymes and a reduction in warfarin metabolism.

D. A cardiologist is called for. What options and approaches are available to the cardiologist for the management of the patient’s cardiac tamponade?
The cardiac tamponade in this case would be amenable to pericardial catheter drainage. Unless it was a life-threatening emergency, the INR should be brought to 2–2.5 to prevent bleeding complications. The pericardial fluid
can be approached via the subxiphoid, parasternal or apical route. The catheter is inserted under echocardiographic guidance and usually left for 24 hours.

E. The cardiologist opts for the parasternal approach, following which 1.5 litres of blood-stained fluid is drained. The patient's haemodynamics improve and he is discharged to the ward for overnight observation. Around 6 hours after catheter insertion, he complains of increasing breathlessness. What has most likely happened?

The patient has developed a pneumothorax. The parasternal approach for pericardial drainage is associated with a risk of pleural breach, which may require chest drain placement.

F. What other complications are associated with pericardiocentesis?

Other complications include cardiac perforation, which has a median presentation time of 5 hours post procedure and happens in around 1% of cases. It may also present with catastrophic iatrogenic tamponade. Lacerations to intercostal or internal thoracic vessels, ventricular arrhythmias, pericardial decompression syndrome, vasovagal attacks and pneumopericardium have all been described. Specific to the subxiphoid approach, there may be damage to the inferior vena cava, liver, diaphragm, stomach or colon.

2. A 65-year-old female presents with a 6-month history of increasing shortness of breath, lethargy, and abdominal and leg swelling. The symptoms are of gradual onset. She underwent radiotherapy for breast cancer 12 years prior. On examination, she has an elevated jugular venous pulse, which increases on inspiration. You can hear a pericardial knock.

A. What is your working diagnosis?

There must be a high index of suspicion that the patient has constrictive pericarditis, given the history of radiation. In the developed world, many cases of constrictive pericarditis are idiopathic, although the precipitating cause, such as viral pericarditis, may often go undetected. In developing countries, tuberculosis remains an important cause. An important clinical finding is Kussmaul's sign, where the constricting pericardium over the right heart does not permit increased venous inflow with inspiration and so jugular venous pressure increases with inspiration. The clinical diagnosis of constrictive pericarditis is not easy and is often confused with myocardial
diseases, especially of the restrictive type.

B. The patient proceeds to echocardiography to confirm the diagnosis. What features on echocardiography are pathognomonic of constrictive pericarditis?

With a high clinical index of suspicion, echocardiography may be sufficient for reaching a diagnosis. The important features unique to constrictive pericarditis include an exaggerated respirophasic response with interventricular dependence. The pericardial constriction results in lower filling of the left heart relative to the right, so on inspiration the interventricular septum bulges to the left. With expiration, left heart filling increases and the septum bulges to the right. With advanced tissue Doppler techniques, it is also possible to differentiate constriction from restrictive myocardial disease.

C. What other tests would help in reaching a diagnosis of constrictive pericarditis?

Cardiac CT and MRI are useful tests that also allow measurement of pericardial thickening. Cardiac MRI especially can detect thickening of 4 mm with over 90% accuracy. However, it is important to note that in around 20% of all cases of constrictive pericarditis the pericardium will be of normal thickness. If non-invasive tests remain inconclusive, then cardiac catheterization is undertaken, especially in patients where radiation damage is suspected. Radiation may also result in a certain degree of myocardial damage, with restrictive as well as constrictive pericarditis.

D. Once the diagnosis is confirmed, the patient proceeds to pericardial decortication. What are the principles underpinning this procedure?

Pericardiectomy, or pericardial decortication/stripping, is undertaken to relieve pericardial constriction. During the surgery, great care must be taken to create the correct plane of dissection between the epicardium and parietal pericardium. The epicardium contains the coronary arteries, which are easily damaged. Various dissection techniques are available, ranging from the traditional sharp/blunt dissection to laser dissection. Most cases are undertaken without the need for cardiopulmonary bypass using the median sternotomy approach. The pericardium is stripped from the great vessels superiorly to the diaphragm, taking care to release the inferior vena cava. Laterally, dissection extends to the phrenic nerves.

E. The patient undergoes pericardiectomy and is discharged to the ward. However, she complains of dyspnoea and persistent hiccups. Chest X-ray demonstrates persistent basal atelectasis on the left side with the suggestion
of an elevated hemidiaphragm. What may be the underlying pathology?

It is possible that the patient has a left phrenic nerve palsy. The left phrenic nerve lies more anterior than the right and is prone to damage. Cardiac procedures account for most cases of phrenic nerve palsy, with the underlying pathology ranging from ice-slush damage to complete transection during pericardiectomy or redo surgery.

F. How is the diagnosis of phrenic nerve palsy made and what treatment options are available?

Bedside ultrasonography or fluoroscopy is used to diagnose phrenic nerve palsy. The tests assess for paradoxical movement of the diaphragm on the affected side. Most cases of palsy recover with time. However, complete transections may require diaphragmatic plication with either the open or the minimally invasive approach.
Non-invasive evaluation of the heart is an essential part of the assessment of patients undergoing cardiac surgery. Echocardiography is the commonly used non-invasive imaging modality. Preoperatively, it is an essential part of the decision-making process to identify patients suitable for surgery, guide the type of surgical intervention and predict outcomes. Intra- and postoperatively, it is used to assess anatomy and function, and to detect early complications. This chapter provides a review of the echocardiographic anatomy of the heart from a surgical perspective.
Basic principles of echocardiography

Echocardiography uses ultrasound (US) waves to image tissues of various densities within the body. US is generated when the piezoelectric crystals housed within the transducer are stimulated by an electrical current. They propagate through the tissues as mechanical vibrations; when these strike structures with different acoustic densities, such as myocardium and blood, part of the energy is reflected back. The reflected signal is received by the transducer, converted to electrical energy and used for image creation. The location of the structure within the body is determined by the time taken by the US wave to travel back and forth from the transducer, and the brightness is dependent on its acoustic impedance.

There are several imaging modes – A mode, B mode, M mode, 2D, Doppler and 3D – and a comprehensive examination uses all the appropriate modalities to arrive at a conclusion. M mode echocardiography provides a single-dimensional view using a narrow beam of US across a small section of the heart. The motion of the structures within the US beam is displayed against time at a high temporal resolution. Two-dimensional echocardiography (2DE) uses multiple scan lines across a sector, producing a tomographic view corresponding to an anatomical section of the heart. Doppler echocardiography utilizes the change in frequency shift of a moving object to calculate velocity. Pressure (P) can be derived from velocity (V) using the modified Bernoulli equation\(^1,2\) \(\Delta P = 4 V^2\).

Penetration of the sound wave and resolution of images depend on the frequency of US wave: lower frequencies achieve better penetration at the expense of reduced resolution and vice versa. Echocardiography uses US transducers with frequencies ranging from 2 to 7.5 MHz and the selection of transducer is based on the type of examination.\(^3\)

There are two types of examinations: transthoracic (TTE) and transoesophageal (TOE). The echocardiographic windows and planes (Table 50.1; Figs 50.1 and 50.2) are different for both techniques but the basic principles of assessment remain the same. The choice of examination depends on the information required and the clinical setting. In general, a TOE examination is carried out in situations where the results of TTE are non-diagnostic, and commonly include evaluation of posteriorly located structures, the left atrial appendage, prosthetic valves and cardiac masses. TOE is also increasingly used to guide and monitor specific procedures, such as valve surgery and percutaneous intervention.
## TABLE 50.1

**Key transthoracic (TTE) and transoesophageal (TOE) views for various structures**

<table>
<thead>
<tr>
<th>Structure</th>
<th>TTE views</th>
<th>TOE views</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricle</td>
<td>PS – LAX, SAX</td>
<td>ME – 4C, 2C, 3C</td>
</tr>
<tr>
<td></td>
<td>Apical views – 4C, 2C, 3C</td>
<td>TG – SAX, LAX</td>
</tr>
<tr>
<td></td>
<td>3D echocardiography</td>
<td></td>
</tr>
<tr>
<td>Right ventricle</td>
<td>PS – LAX, SAX</td>
<td>ME – 4C, RV inflow/outflow</td>
</tr>
<tr>
<td></td>
<td>Apical – 4C (RV focused)</td>
<td>TG – SAX</td>
</tr>
<tr>
<td></td>
<td>Subcostal</td>
<td></td>
</tr>
<tr>
<td>Mitral valve</td>
<td>PS – LAX, SAX</td>
<td>ME – 4C, 2C, 3C, BCs</td>
</tr>
<tr>
<td></td>
<td>Apical – 4C, 2C, 3C</td>
<td>TG – SAX, LAX</td>
</tr>
<tr>
<td></td>
<td>3D echocardiography</td>
<td></td>
</tr>
<tr>
<td>Left atrium and pulmonary veins</td>
<td>PS – LAX</td>
<td>ME – 0–120°, BC</td>
</tr>
<tr>
<td></td>
<td>Apical – 4C</td>
<td></td>
</tr>
<tr>
<td>Right atrium</td>
<td>Apical – 4C</td>
<td>ME – 4C, BC</td>
</tr>
<tr>
<td>Tricuspid valve</td>
<td>PS – LAX in flow view, SAX</td>
<td>ME – 4C, inflow/outflow, BC</td>
</tr>
<tr>
<td></td>
<td>Apical 4C</td>
<td>TG – SAX, LAX</td>
</tr>
<tr>
<td></td>
<td>Subcostal</td>
<td></td>
</tr>
<tr>
<td>Aortic valve</td>
<td>PS – LAX, SAX</td>
<td>ME – 4C, 3C</td>
</tr>
<tr>
<td></td>
<td>Apical 3C, 5C</td>
<td>TG – SAX, LAX</td>
</tr>
<tr>
<td>Aorta</td>
<td>PS – LAX</td>
<td>ME – 3C</td>
</tr>
<tr>
<td></td>
<td>Apical – 3C</td>
<td>TG – SAX, LAX</td>
</tr>
<tr>
<td></td>
<td>Suprasternal</td>
<td></td>
</tr>
</tbody>
</table>

BC, bicaval; BCs, bicommissural; C, chamber; LAX, long axis; ME, mid-oesophageal; PS, parasternal; RV, right ventricle; SAX, short axis; TG, transgastric.
FIG. 50.1 Principal transthoracic views. Abbreviations: AL, anterolateral papillary muscle; AML, anterior mitral leaflet; AO, aorta; CS, coronary sinus; DA, descending aorta; IVC, inferior vena cava; L, left coronary cusp; LA, left atrium; LAA, left atrial appendage; LUPV, left upper pulmonary vein; LV, left ventricle; NC, non-coronary cusp; PM, posteromedial papillary muscle; PML, posterior mitral leaflet; R, right coronary cusp; RA, right atrium; RUPV, right upper pulmonary vein; RV, right ventricle; RVOT, right ventricular outflow. (From Clinical Gate: https://clinicalgate.com/echocardiography.)
FIG. 50.2 Principal transoesophageal views. Abbreviations: AL, anterolateral papillary muscle; AML, anterior mitral leaflet; AO, aorta; CS, coronary sinus; L, left coronary cusp; LA, left atrium; LAA, left atrial appendage; LV, left ventricle; LVOT, left ventricular outflow; ME, mid-oesophageal; NC, non-coronary cusp; PM, posteromedial papillary muscle; PML, posterior mitral leaflet; R, right coronary cusp; RA, right atrium; RV, right ventricle; RVOT, right ventricular outflow; TG, transgastric.

(Adapted from Clinical Gate: https://clinicalgate.com/echocardiography.)
**Left ventricle**

**Clinical anatomy relevant to echocardiography**

The left ventricle (LV) has three components without clear anatomical boundaries. These are inlet and outlet portions separated by the mitral valve (MV), and a trabeculated apex.\(^4\) The interventricular septum (IVS) forms the medial wall of the LV and the other walls are referred to as anterior, inferior, inferolateral and anterolateral, based on their relation to the chest wall. In the anatomically normal heart, the LV is ellipsoid in shape; its base is attached to the mitral valve and its apex tapers to a conical cap. Myocardial wall thickness varies between 0.6 and 1.0 cm, being thickest at the base and thin towards the apex.\(^4\) The endocardium is normally irregular and trabeculated towards the apex.

**Echocardiographic anatomy**

Echocardiographic imaging of the LV is usually done by TTE. TOE is rarely used to assess the LV alone, except during surgery or in the early postoperative period. Using 2DE, imaging is performed from long and short axis, apical and subcostal windows (see Table 50.1; Figs 50.1 and 50.2). The echocardiographic planes and the regional anatomy are shown in Fig. 50.3. Comprehensive evaluation of the LV should include assessment of its geometry, size and regional and global function.
Alteration of LV morphology is seen in various disease states. With global dilation, the ventricle becomes more spherical, which results in reduced systolic performance and displacement of papillary muscles, causing functional mitral regurgitation. This is commonly seen in primary myocardial
disease and volume overload conditions, whereas pressure overload states, such as aortic stenosis and hypertension, result in increased wall thickness, leading to concentric LV hypertrophy.

LV size is assessed by linear dimensions from the long axis views or volumes derived from apical views, and values are indexed to body surface area to define normality. Regional function is assessed using a 17-segment model that reflects different coronary artery territories. Each segment is analysed in systole and diastole for regional wall motion abnormality. Depending on the extent and severity of disease, myocardial segments can show reduced thickening, scarring or aneurysm formation. Acute transmural myocardial infarction can also result in rupture of the LV free wall, IVS or papillary muscle, causing cardiac tamponade, ventricular septal defect or acute mitral regurgitation. Rarely, rupture of the free wall can be contained by the pericardium, resulting in the formation of a pseudo-aneurysm. Various echocardiographic features can be used to differentiate between true and pseudo-aneurysm.

Global systolic function is assessed by calculating ejection fraction (EF), the percentage of chamber volume ejected in systole. Although three-dimensional echocardiography (3DE) is a superior technique for calculating volumes, 2DE is still the commonly used modality. Using 2DE, LV volumes are derived in end-systolic volume (ESV) and end-diastolic volume (EDV) by the biplane method of disks summation (modified Simpson's rule) from the apical windows, and EF is calculated by the following formula: EF = EDV − ESV/EDV.

Tips and Anatomical Hazards

Apical foreshortening and geometric assumptions limit the reproducibility of 2D in assessing volumes and function. 3DE is the recommended method for assessment of volume and function. Fibromuscular bands called false tendons can be seen in the apical third of the LV cavity in certain patients. These are anatomical variants and should not be mistaken for thrombus or hypertrophy. Regional dysfunction is a typical feature of coronary artery disease but can also be seen in other conditions.
Right ventricle

Clinical anatomy relevant to echocardiography

Compared to the LV, the right ventricle (RV) has a more complex shape, with three distinct anatomical parts (inlet, apical and outlet) that are wrapped around the LV. The segmental nomenclature and coronary distribution are shown in Fig. 50.4. The RV shares the IVS with the LV, which normally arches into the RV and is an important determinant of its shape. The free wall of the RV is thin compared to that of the LV, and measures 3–5 mm in thickness. Myocardial fibres are oriented predominantly in the longitudinal plane; hence, contraction is primarily longitudinal rather than radial.

Echocardiographic anatomy

Due to its complex anatomy, echo assessment of the RV is carried out using
TTE from multiple imaging planes (see Table 50.1; Fig. 50.1). TOE is rarely required for assessment of the RV alone, except in situations in which access to primary windows is limited, such as in ventilated patients or in those with severe chest deformity. Anatomically, the RV is identified by the following features: an apically displaced trileaflet atrioventricular (tricuspid) valve; heavily trabeculated endocardium; the moderator band; and three or more papillary muscles supporting the tricuspid valve leaflets. Like the LV, full evaluation of the RV should include assessment of its size, morphology and regional and global function.

RV size is usually assessed qualitatively in comparison to LV size and is done from the four-chamber view; the size of the RV is usually not more than two-thirds of the LV cavity in this view. The RV is considered moderately enlarged when its size is equal to that of the LV and severely enlarged if it exceeds that of the LV. With significant dilation, the RV may displace the LV and occupy the apex of the heart. Dilation can occur in volume and pressure overload conditions of the RV and should prompt a search for the aetiology, such as an atrial septal defect, tricuspid regurgitation, pulmonary regurgitation or elevated pulmonary artery pressures.

Volume and pressure overload states can also alter the shape and result in distinct contraction patterns of the IVS. Both conditions can cause flattening and leftward shift of the septum towards the LV. In pressure overload the shift is present throughout the cardiac cycle and is most pronounced at end-systole, whereas in volume overload conditions the shift is seen primarily in diastole with relative sparing in end-systole. A bouncing motion of the IVS during inspiration, referred to as septal bounce, is a sign of ventricular independence and is typically seen in constrictive pericarditis. Abnormal septal motion is also commonly seen in patients after cardiac surgery; the exact mechanism for this is not known.

Hypokinesis of the free wall can be due to global or regional dysfunction. Regional wall motion affecting the free wall can be seen in RV infarction, pulmonary embolism or cardiomyopathies. Global function of the RV is an important predictor of surgical outcome and should be assessed preoperatively. This is done qualitatively by visual assessment or semi-quantitatively using fractional area change (FAC), or by a non-volumetric method such as tricuspid anular plane systolic excursion (TAPSE). FAC is the percentage of area change within the RV between diastole (EDA) and systole (ESA), and is derived by the formula $\text{FAC} = \frac{\text{EDA} - \text{ESA}}{\text{EDA}} \times 100$.5
Simultaneous assessment of all parts of the RV is not possible from any view and therefore quantitative assessment of volume and function is not possible by echocardiography. Abnormal contraction pattern of the IVS can cause difficulty in assessing RV function.
**Left atrium**

**Clinical anatomy relevant to echocardiography**

The left atrium (LA) is posteriorly located at the base of the heart. It has four components: a venous portion that receives four pulmonary veins (PVs); the left atrial appendage (LAA); the vestibule that opens into the mitral valve; and the interatrial septum (IAS) shared with the RA. The LAA is a finger-like projection located anterolaterally and is trabeculated by fine pectinate muscles. The LAA is multilobulated in the majority of hearts. The ridge between the LAA and left upper pulmonary vein is an infolding of the serous pericardium and is variably referred to as the posterolateral ridge, coumadin ridge or ligament of Marshall. The coronary sinus and the great cardiac vein run on the epicardial surface of the LA and occupy the left atrioventricular groove.

**Echocardiographic anatomy**

The LA is assessed using TTE from the parasternal short axis and apical windows (see Fig. 50.1; Table 50.1). These views help to image the walls of the LA, and to assess its size and any gross abnormalities such as a tumour or a large thrombus. The resolution of TTE is usually insufficient to visualize posterior structures (pulmonary veins and left atrial appendage) and this is undertaken using TOE.

The LAA is imaged using TOE by electronically scanning between 0 and 120° in the mid-oesophageal (ME) position (Fig. 50.5). Right-sided PVs are identified in the ME 0° or bicaval views. Left-sided PVs are close to the LAA and are best seen in the LAA views. In addition to identifying the normal pulmonary venous drainage, Doppler assessment of the PV can provide information on LA function and pressure.
Dilation of the LA is common in atrial fibrillation, MV disease and LV dysfunction, and is an important predictor of cardiovascular outcome.\textsuperscript{18,19} Left atrial size is measured using either linear dimensions or volumes obtained from multiple imaging planes. Dilation and remodelling associated with atrial fibrillation can result in stagnation and thrombus formation. Stasis of blood can cause a smoke-like appearance within the LA, termed ‘spontaneous contrast’, while thrombus is identified as a well-circumscribed echogenic structure with uniform consistency.\textsuperscript{20,21} Thrombus formation typically occurs within the region of the LAA. Apart from thrombi, the LA can be a site for intracardiac masses, especially myxoma.

\textit{Tips and Anatomical Hazards}

The LAA has multiple lobes and scanning in multiple planes is important to assess all the lobes. Pectinate muscles within the LAA and the posterolateral ridge can be mistaken for thrombus, and careful evaluation of the LAA from multiple imaging planes using 2D/3D and Doppler echocardiography
is required to identify a true thrombus. LA dilation can be asymmetric and linear measurements should be carried out in multiple planes to assess the size.
Right atrium

Clinical anatomy relevant to echocardiography

The right atrium (RA) is located to the right and anterior to the LA and shares the IAS with the LA. It has a venous component, appendage and a vestibule that opens into the tricuspid valve (TV). The RA is identified by its connection to the superior vena cava (SVC) and the inferior vena cava (IVC), and by the crista terminalis, a prominent ridge separating the smooth venous portion from the trabeculated appendage. The coronary sinus opens into the RA between the IVC and TV, and is guarded by the Thebesian valve.

Echocardiographic anatomy

The RA can be imaged using TTE from the parasternal short axis, apical and subcostal windows (see Fig. 50.1). The four-chamber view is the primary imaging window and is used to assess size and morphology. The size of the RA is assessed using planimetry: an area of more than 18 cm$^2$ is considered abnormal. TOE from the ME bicaval view provides a more detailed evaluation of the RA (see Fig. 50.5). This view is also useful to guide various procedures, including SVC cannulation and trans-septal puncture. The opening of the coronary sinus (CS) can be identified in the ME 0° view by advancing the probe towards the gastro-oesophageal junction and is useful to guide CS cannulation. RA dilation can occur in atrial fibrillation and in conditions affecting the RV and TV. Although less common, RA can be a site for tumour or thrombus.

Tips and Anatomical Hazards

Anatomical variants within the RA should be recognized to avoid misinterpretation and overdiagnosis. The Eustachian valve, Chiari network and crista terminalis are all embryological remnants; when prominent, they can be mistaken for thrombus, vegetation or tumour (see Fig. 50.5).
**Interatrial septum**

**Clinical anatomy relevant to echocardiography**

The IAS separates the RA and LA, and has three components: the septum primum, septum secundum and atrioventricular (AV) canal septum. The foramen ovale is a normal separation between the septum secundum and septum primum, located in the anterosuperior part of the septum, whereas atrial septal defects are true deficiencies of the septum and are classified according to their anatomical location as ostium primum, ostium secundum and sinus venosus defects.

**Echocardiographic anatomy**

TTE is the initial imaging modality for the assessment of the IAS, which can be viewed from the parasternal short axis, apical 4C and subcostal long axis windows. TOE can identify the size, margins and relationship of an atrial septal defect to adjacent structures and should be considered in all patients suitable for closure. TOE should be considered in patients with suspected sinus venosus defects and anomalous pulmonary venous drainage.

Using TOE, the atrial septum is imaged from multiple views (see Fig. 50.2; Table 50.1). Ostium secundum defects are due to deficiency of the septum primum and are in the region of the fossa ovalis. Ostium primum defects (endocardial cushion defects) are located inferiorly and commonly associated with abnormalities of the AV valves. Sinus venosus defects are close to the caval entries. As well as establishing the location and suitability for closure, the pulmonary venous drainage and the haemodynamic impact of the shunt should also be assessed.

⚠️ **Tips and Anatomical Hazards**

The foramen ovale can be functional (patent foramen ovale), allowing intermittent shunting of blood in about 25% of the normal population, and should not be mistaken for an atrial septal defect.\(^{22}\)

Pseudo-dropouts of the septum are not uncommon in the apical views.
Mitral valve

Clinical anatomy relevant to echocardiography

The mitral valve (MV) apparatus consists of leaflets, anulus, chordae, papillary muscles, and the part of the LV wall to which the MV is attached. The anterior mitral leaflet is identified by its attachment to the aortic mitral curtain, and the posterior mitral leaflet by its characteristic indentations dividing the leaflets into three scallops. Leaflets converge at the anterolateral and posteromedial commissures. The mitral valve anulus is a D-shaped structure with a fixed fibrous anterior component and a non-enforced posterior component. Anterolateral and posteromedial papillary muscles supply chordae to the ipsilateral leaflets.

Echocardiographic anatomy

TTE is the primary imaging modality to assess the MV in day-to-day practice. TOE provides higher spatial resolution and has better accuracy in predicting pathology; it is therefore routinely undertaken in patients being considered for surgical intervention. TOE is also used to assess and monitor complications during surgery. A comprehensive evaluation of the structure and function uses multiple modalities.

Using 2D echocardiography, the MV is imaged from multiple planes (see Table 50.1). Views are similar for TTE and TOE, but are displayed in a different format (Fig. 50.6). In each view, leaflets should be assessed for thickness, mobility and coaptation. Coaptation of the leaflets is normally subanular within the ventricle, with a minimum distance of at least 5 mm to maintain adequate valve function.  

23,24
Anular dilation occurs in the anteroposterior dimension and is measured from the parasternal long axis or apical three-chamber views. Measurements are related to body surface area: in general, a diameter of 35 mm or an annulus to anterior mitral leaflet ratio of more than 1.3 is considered abnormal. Intercommissural (measured in the bicommissural view; see Fig. 50.6) and intertrigonal (obtained from 3D multiplanar review) distances can provide additional information to plan MV repair.

The subvalvular apparatus is assessed from the parasternal long and short axis views (TTE) or 90° transgastric view using TOE (see Figs 50.1 and 50.2). The anterolateral papillary muscle is seen attached to the anterior wall, and the posteromedial papillary muscle is attached to the inferior wall of the LV. Assessment of the subvalvular apparatus helps to identify the mechanism of mitral valve dysfunction (chordal rupture, elongation) and is useful to plan surgery.

The haemodynamic impact of MV disease on the cardiac chambers should also be a routine part of the MV evaluation. This includes assessment of the left ventricular size, shape, function, interpapillary distance, left atrial
Mitral regurgitation

Mitral regurgitation is secondary to defective coaptation of the leaflets, resulting in leakage of blood from the LV to LA. This is classified as primary when due to intrinsic disease of the leaflets or secondary when due to dysfunction/dilation of the LV or LA. Common conditions causing primary mitral regurgitation include degenerative disease, rheumatic heart disease and endocarditis. Secondary mitral regurgitation occurs in dilated cardiomyopathy and ischaemic heart disease, or with severe LA dilatation. From a surgical perspective, once mitral regurgitation is established, the severity, mechanism, haemodynamic impact and suitability for repair should be addressed. Severity can be assessed by several echocardiographic parameters. The mechanism of mitral regurgitation is based on the Carpentier classification of leaflet motion. Mitral regurgitation secondary to normal leaflet motion (type I) is due to either perforation, annular dilation, or a change in LV morphology distorting the structure and function of the papillary muscle; this typically results in a central jet of mitral regurgitation (Fig. 50.7). Mitral regurgitation secondary to excess leaflet motion (type II) is due to a spectrum of diseases: billowing refers to prolapse of the leaflets above the annular plane with the coaptation point still below the anulus; prolapse is defined as displacement of the leaflets with the coaptation point above the annular plane; and a flail leaflet describes a free-floating leaflet with its tip pointing to the roof of the atrium. The jet of mitral regurgitation in this situation is usually eccentric and directed away from the prolapsing leaflet (see Fig. 50.7). Mitral regurgitation due to restricted leaflet motion (type III) is commonly caused by a disease process affecting the leaflet motion (rheumatic and calcific MV disease) or tethering of the subvalvular apparatus, as occurs in ischaemic heart disease.
An in-depth assessment of the mechanism provides information on the aetiology. Most diseases can be recognized by specific morphological features. Degenerative disease characteristically causes thickening of leaflets, excessive motion, elongation of chordae and/or rupture leading to mitral regurgitation. Rheumatic heart disease typically causes commissural fusion, resulting in a specific echo appearance where there is doming of the anterior mitral leaflet in diastole with a restricted/fixed posterior mitral leaflet. Ischaemic heart disease almost always causes regional wall motion abnormality of the LV and tethering/tenting of leaflets due to regional dysfunction. Acute myocardial infarction can rarely cause rupture of the papillary muscle, resulting in acute severe mitral regurgitation that is a life-threatening condition.

**Mitral stenosis**

The normal mitral valve area ranges between 4 and 5 cm$^2$ and allows free flow of blood between the LA and LV. As the valve area decreases, a pressure gradient develops between the LA and LV, which results in an elevation of LA pressure that is transmitted to the pulmonary veins and causes symptoms. A haemodynamically significant gradient occurs only when the valve area is less than 1.5 cm$^2$. Mitral stenosis is almost always due to rheumatic heart disease but severe calcification of the anulus extending to the base of the leaflets is increasingly recognized as a cause in elderly patients.
Mitral stenosis is graded based on mitral valve area and mean pressure (Table 50.2). Area is measured by planimetry from a short axis view or pressure half-time method using Doppler. Mitral stenosis due to rheumatic heart disease without significant mitral regurgitation can be treated with balloon valvotomy, and several parameters can guide its suitability and success rate.²,²⁶

### TABLE 50.2
Grading of mitral stenosis and aortic stenosis

<table>
<thead>
<tr>
<th></th>
<th>Mitral stenosis</th>
<th>Aortic stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MILD</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Valve area (cm²)</td>
<td>&gt;1.5</td>
<td>1.0–1.5</td>
</tr>
<tr>
<td>Mean gradient (mmHg)</td>
<td>&lt;5</td>
<td>5–10</td>
</tr>
<tr>
<td>Pulmonary artery pressure (mmHg)</td>
<td>&lt;30</td>
<td>30–50</td>
</tr>
<tr>
<td>Aortic jet velocity (m/s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tips and Anatomical Hazards**

Identification of the leaflet/scallop and the mechanism of mitral regurgitation can be challenging with 2D in certain patients. A good-quality 3D image provides additional information and is routinely recommended.

Quantification of mitral regurgitation is difficult with multiple jets and those confined to mid- or late systole. Multiple parameters should be taken into consideration to assess severity.

In patients with significant mitral regurgitation, left ventricular EF may not truly represent the systolic function, as the ventricle partly empties into the low-pressure LA and the function can be overestimated. End-systolic volume or diameter is considered to be a better indicator of LV function in this situation.

Significant mitral regurgitation and tachycardia can overestimate the gradient across the mitral regurgitation and should be considered in grading severity of mitral stenosis.
Aortic valve

Clinical anatomy relevant to echocardiography

The aortic valve (AV) has three leaflets, each of which has a free margin, body and a basal part that is attached to the aortic wall in a semilunar shape. Leaflets are named after the sinuses as right (RCC), left (LCC) and non-coronary (NCC). LCC and NCC (mainly the NCC) are in close proximity to the aortomitral curtain, and the RCC to the membranous portion of the IVS (see Figs 50.1 and 50.2). The anulus is a virtual ring formed by the nadir of each leaflet and is not always as circular in shape as its name implies. The plane of the anulus is the narrowest area in the connection between the heart and aorta, and its measurement has important clinical implications in planning the type of aortic valve/root surgery.

Echocardiographic anatomy

TTE is primarily used to image the AV; TOE can be used when image quality is suboptimal. The morphology of the valve is assessed using 2D from the short (all three cusps) and long axis planes (NCC and RCC; see Fig. 50.1). Leaflets are identified by their relationship to adjacent structures: hence, the NCC to the IAS, and the RCC to the right ventricular outflow tract (RVOT). Normal leaflets are thin and mobile, and during systole open into the sinuses, allowing free flow of blood from LV to the aorta. During diastole, they coapt along the line of apposition to form an inverted ‘Mercedes Benz’ sign in the short axis view (see Fig. 50.1). Leaflet mobility, thickness, calcification and coaptation are assessed in each view using 2D with and without Doppler echocardiography to evaluate structure and function.

Aortic stenosis

With advancing age, leaflets develop focal thickening, termed aortic sclerosis; haemodynamically significant stenosis develops only when the valve area is reduced to less than 2 cm². Degenerative calcification and a congenitally abnormal valve are the two common causes of aortic stenosis. A congenitally abnormal valve can be unicuspid, bicuspid or quadricuspid, and is commonly associated with ascending aortic dilation. Although 2D helps to assess the morphology and valve area (by planimetry), severity assessment of aortic stenosis is primarily carried out using Doppler echocardiography (see Table
The ascending aorta and LV should be assessed in all patients with aortic stenosis.

**Aortic regurgitation**

Broadly speaking, aortic regurgitation can be primary due to intrinsic leaflet disease or secondary to aortic root dilation. A bicuspid valve is the most common cause for primary valve disease, followed by endocarditis, degenerative disease and rheumatic disease. As with mitral regurgitation, a functional classification has been proposed based on the mechanism of aortic regurgitation.

Type I or functional aortic regurgitation is due to dilation of the aorta with normal leaflets. Dilation can occur at the level of the anulus, sinuses or sinotubular junction and typically results in a central jet of aortic regurgitation. Type II aortic regurgitation may be due to excessive leaflet motion, causing prolapse, or to free-edge fenestration, causing eccentric aortic regurgitation. Prolapse is diagnosed when the leaflet margins extend beyond the level of anulus. There are varying degrees of prolapse (partial, full or flail), depending on the extent of disease. Fenestration is diagnosed when there is eccentric aortic regurgitation with no evidence of prolapse. Type III aortic regurgitation is due to rigid and thickened leaflets with poor tissue quality and commonly occurs in degenerative or rheumatic disease.

The principles of assessment are similar to those for mitral regurgitation and should include determination of severity, mechanism, aetiology and haemodynamic impact. Types I and II are considered potentially suitable for valve-sparing surgery, and additional measurements of the aortic root, coaptation distance and height are useful in predicting the reparability. Several studies have shown the value of TOE in predicting the success of repair and this should be undertaken in all patients considered for valve-sparing surgery.

**Tips and Anatomical Hazards**

Patients with LV dysfunction and a small LV cavity may not satisfy the conventional criteria for severe aortic stenosis due to reduced flow; this is referred to as low-gradient aortic stenosis. Further
investigations, including low-dose dobutamine stress echo and CT calcium score, should be considered in these patients. The aortic anulus is elliptical in a proportion of patients and measurements by 2D can underestimate the size. In these patients, 3D and/or CT are the preferred investigations. Estimation of severity of aortic regurgitation can be challenging and multiple parameters should be taken into consideration.
Aorta

Clinical anatomy relevant to echocardiography

The aorta connects the LV with the systemic circulation and has thoracic and abdominal parts. The thoracic aorta is divided into the aortic root, ascending aorta, aortic arch and descending aorta. The aortic root is the portion that supports the valve leaflets and extends from the sinotubular junction superiorly to the base of the leaflets inferiorly.\textsuperscript{31,32} The coronary arteries arise directly from the aortic sinuses and the arch has three branches (brachiocephalic artery, left subclavian and left common carotid arteries).

Echocardiographic anatomy

TTE can assess only limited segments of the thoracic aorta and is done from parasternal, apical and suprasternal windows (see Fig. 50.1). TOE is the US imaging modality of choice, but in practice, aortic assessment is usually carried out by CT or MRI. Using TOE, the aortic root and ascending aorta are imaged from the ME short and long axis views (see Fig. 50.2). The descending aorta, from the arch to the coeliac trunk, can be seen in 0 and 90° views by advancing and withdrawing the probe. Size and morphology are assessed in different views.

Aortic size is strongly related to body surface area and age; the normal values for different segments are shown in Table 50.3.\textsuperscript{32} Conditions that affect the structural components of the vascular wall can result in aortic dilation; they include genetic syndromes, inflammation, degenerative diseases and mechanical causes. The incidence of dissection or rupture increases with increasing size of the aorta, and prophylactic surgery is recommended when the diameter reaches 5–5.5 body surface area cm.\textsuperscript{33} Aortic dissection is recognized by the intimal flap and true and false lumens.
### TABLE 50.3
Normal measurement values for various segments of the aorta

<table>
<thead>
<tr>
<th>Segment</th>
<th>Position</th>
<th>Size</th>
<th>Size:body surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascending aorta</td>
<td>Anulus</td>
<td>20–31 mm</td>
<td>13±1 mm/m²</td>
</tr>
<tr>
<td></td>
<td>Sinus of Valsalva</td>
<td>29–45 mm</td>
<td>19±1 mm/m²</td>
</tr>
<tr>
<td></td>
<td>Sinotubular ascending aorta</td>
<td>22–36 mm</td>
<td>15±1 mm/m²</td>
</tr>
<tr>
<td>Aortic arch</td>
<td></td>
<td>22–36 mm</td>
<td></td>
</tr>
<tr>
<td>Descending aorta</td>
<td></td>
<td>20–30 mm</td>
<td></td>
</tr>
</tbody>
</table>

#### Tips and Anatomical Hazards

Overestimation of aortic size can occur if measurements are made obliquely.
TTE can access only limited segments of the aorta and a normal TTE does not exclude aortic dissection.
A thickened aortic wall can cause reverberation artefact that can mimic aortic dissection.\(^{32}\)
There are several variations of aortic arch anatomy.
Tricuspid valve

Clinical anatomy relevant to echocardiography

The tricuspid valve (TV) is the largest valve with a valve area of 7–9 cm$^2$, and is located between the RA and RV.\textsuperscript{34} The valve unit has three leaflets – namely, anterior, posterior and septal – attached to an anulus. Leaflets are normally supported by three papillary muscles and chordae but the subvalvular apparatus can be characteristically variable in size and shape. The anulus has minimal fibrous tissue and is susceptible to dilation.\textsuperscript{24}

Echocardiographic anatomy

Despite its retrosternal location, the TV is assessed in most patients using TTE and is imaged from the same views as the RA and RV (see Fig. 50.4). The valve can be visualized in multiple planes using TOE, but the incremental value of routine TOE is limited and is reserved for specific situations, such as in patients with inaccessible windows, endocarditis assessment or the monitoring of interventional procedures.

Valve morphology is commonly assessed by 2D echocardiography and leaflets are identified as shown in Figure 50.1. The valve is typically placed closer to the apex compared to the MV and the septal leaflet is characteristically ≤8 mm/m$^2$ of body surface area compared to the anterior mitral leaflet.\textsuperscript{35} In each view, leaflets should be assessed for thickness, mobility and coaptation.\textsuperscript{29,34} The anulus is commonly measured from the four-chamber view and a distance of more than 35 mm is considered abnormal.\textsuperscript{24} The subvalvular apparatus can be visualised in the four-chamber and subcostal views or the long axis transgastric view in a TOE examination.

Tricuspid regurgitation is commonly secondary or functional, and is due to raised pulmonary artery pressures, dilatation or dysfunction of the RV or RA that typically produce distortion and dilatation of the anulus, causing defective coaptation and a central jet of tricuspid regurgitation, with or without raised RV systolic pressure. Assessment of the tricuspid regurgitation velocity and associated structures will provide information regarding the aetiology and mechanism in most cases.

Primary tricuspid regurgitation can be due to Ebstein's anomaly, carcinoid heart disease, infective endocarditis or trauma, or may be iatrogenic, secondary to pacemaker lead placement. Ebstein's anomaly\textsuperscript{35} is a congenital
condition with excessive apical displacement of the septal leaflet of the valve with the anterior mitral leaflet of more than 8 mm/m². This may be associated with other abnormalities of the leaflets and dilation of the RA and RV. Carcinoid heart disease is an infiltrative condition due to high levels of serotonin in the blood causing valve fibrosis. A fibrous reaction can extend to the subvalvular region and can result in the characteristic appearance of thickened and fixed leaflets with defective coaptation. Degenerative or rheumatic disease of the TV alone is uncommon and is usually associated with left-sided heart disease. Iatrogenic damage during pacemaker lead placement can result in either septal perforation or prolapse secondary to damage to the leaflets or subvalvular apparatus.

Tricuspid stenosis is commonly due to carcinoid or rheumatic heart disease. Clinically significant tricuspid stenosis typically causes an increased gradient across the TV of more than 5 mmHg and can be diagnosed by using a combination of 2D and Doppler echocardiography.

**Tips and Anatomical Hazards**

None of the two-dimensional views provides simultaneous visualization of all leaflets.

Leaflets are identified as per Figure 50.4 but a minor tilt in the US beam can result in a different leaflet being displayed.

**Acknowledgement**

Dr. Thomas Mathew would like to acknowledge Sheela Thomas for her help in preparing this article.


Single Best Answers

1. Which of the following indicates severe aortic stenosis?
   A. Mean valvular gradient >40 mmHg
   B. Transvalvular jet velocity >3 m/s
   C. Peak valvular gradient >40 mmHg
   D. Valve area <1.2 cm²

   Answer: A.

2. Which of the following is not a complication of acute myocardial infarction?
   A. Ventricular septal defect
   B. Mitral regurgitation
   C. Left ventricular hypertrophy
   D. Pericarditis

   Answer: C.

3. Pitfalls in the assessment of the right atrium: which of the following is not a normal variant in the right atrium?
   A. Chiari network
   B. Crista terminalis
   C. Eustachian valve
   D. Secundum atrial septal defect

   Answer: D.

4. Which of the following does not cause an abnormal motion of the interventricular septum?
   A. Left bundle branch block
   B. Mitral regurgitation
C. Constrictive pericarditis
D. Postoperative cardiac surgery

Answer: B.
Mitral and tricuspid valves

Adam Szafranek, David Richens

Core Procedures

- Mitral valve repair/replacement
The fibrous skeleton of the heart

The aortic, mitral and tricuspid valves form one continuous structure, with each valve in close approximation to the other and connected by the fibrous skeleton of the heart. They are arranged as a triangle at the base of the heart; the pulmonary valve is separate and placed anteriorly (Fig. 51.1). The fibrous skeleton of the heart surrounds the aortic valves and partially surrounds the mitral and tricuspid valves (Fig. 51.2). The anulus of each valve is therefore not homogenous, but is made of a combination of fibrous tissue for some of its diameter and muscular tissue for the remainder, which results in asymmetrical dilation of each valve under pressure and/or volume loading.

![Diagram of the heart showing the fibrous skeleton and valve arrangement](image)

**FIG. 51.1** The base of the ventricles, after removal of the atria and the pericardium, exposing the coronary arteries and cardiac veins. Contrast the planes and positions of the aortic and pulmonary valves, and with Fig. 51.2. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)
Ultimately, the effect of valvular and ventricular disease processes is to lead to pathological changes in the structures of the tricuspid and mitral valves. Pressure and/or volume overload of the chambers of the heart will lead to chamber enlargement and then to anular dilation. The normal shape of the valve anulus becomes distorted and enlarged, and these changes, which are initially reversible, become progressive and irreversible. Valve disease is common in the UK, where it occurs in 2–5% of the population; the prevalence
increases with age. There are a variety of causes but the most common mitral condition is known as degenerative disease, which causes mitral valve prolapse. It is thought that 10% of patients with degenerative mitral valve disease will go on to develop regurgitation (leaking) through the valve that is sufficiently severe to warrant surgical intervention.

There is strong evidence that surgical mitral valve repair in degenerative disease has better outcomes than mitral valve replacement. These include early postoperative survival, freedom from stroke after surgery, long-term survival and freedom from reoperation in all patient categories. Mitral valve repair can be technically challenging and requires surgical experience and judgement. The principles of mitral valve repair are restoration of anular geometry and normal leaflet motion, and creation of a large surface area of coaptation. An understanding of the surgical anatomy of the mitral valve is key to performing a successful repair.

The mitral valve is located centrally within the thorax, posterior to the greater mass of the heart and great vessels. The entire cardiac output flows through it. These factors make surgical access challenging. Adequate access requires cardiopulmonary bypass, exclusion of the heart from the circulation, retraction of adjacent structures and incision through the walls of the cardiac chambers. Surgical access should provide adequate exposure of all anatomical components of the valve (leaflets, anulus and subvalvular apparatus) both in the relaxed, empty and motionless heart and under dynamic pressure testing of the valve post repair. Visualization must occur without distortion of the valve and without damage to adjacent structures in order for the function of the valve to be able to be assessed properly.

The standard approach to the valve is through the right atrium and through the interatrial septum, requiring knowledge of the anatomy of these structures. The anatomy of the valve, the interatrial septum and the fibrous skeleton of the heart, together with the various surgical approaches to the mitral valve.
Surgical anatomy of the mitral valve

The dynamic functional unit of the mitral valve is created by the leaflets and commissures, anulus, chordae tendineae and papillary muscles. The function of the mitral valve during the heart cycle is complex and dynamic, and involves the atrium, left ventricle and aortic valve. Optimal function and coaptation of the mitral valve depend on the correct functioning and precise geometrical relationship of the atrioventricular apparatus. In diastole, the anterior and posterior leaflets open and there is high-velocity blood flow through the mitral valve orifice. Just before the contraction of the atrium, the mitral valve leaflets are moving back to their semi-open position and are then pushed widely open by the flow of blood during the atrial systole. At the beginning of left ventricular systole, the papillary muscles contract and position the leaflets of the mitral valve opposite to each other to create the position for competent closure. The pressure of blood in the left ventricle will close the mitral valve by pushing both leaflets towards each other. The large surface area of the coapting leaflets contributes to the competency of the valve during systole, regardless of the physiological variation of the volume and the pressure in the left ventricle. Both leaflets play a role in organizing the flow of blood, first by directing the flow towards the apex of the heart during diastole and then by creating the tunnel of the left ventricular outflow tract for the blood to be pushed towards the aorta during systole.²,³

Leaflets and commissures

The mitral valve is described as having two leaflets, anterior and posterior, which are each attached to the anulus of the valve. On the ventricular aspect of the leaflets a variable number of fibrous chordae tendineae connect the leaflets to the wall of the left ventricle, principally to the papillary muscles. Although the surface area of each leaflet is the same, the anterior leaflet is attached to one-third of the anulus while the posterior leaflet is attached to two-thirds of the anulus (Fig. 51.3). As a result, the anterior leaflet is narrower and longer, while the posterior leaflet is wider and shorter. The narrow anular attachment of the anterior leaflet means that it can swing on a single hinge mechanism off the anulus. In contrast, the wider attachment of the posterior leaflet means that multiple scallops separated by partial clefts or folds in the valve are required to enable it to open fully on its hinge without presenting an obstruction to the forward flow of blood through the
valve during diastole.

![Image of the mitral valve](image)

**FIG. 51.3** The closed mitral valve (as in systole) in a postmortem heart, viewed from the inflow, atrial aspect. The anterior leaflet of the valve hangs from the anulus in a simple hinge mechanism. The posterior leaflet is attached around two-thirds of the anulus and is made of multiple scallops.

Each leaflet is divided into two separate zones that can be clearly defined: an atrial zone, which is thin and smooth, and a coaptation zone, which is rough and thicker. The coaptation zones of each leaflet contact each other directly during systole and are responsible for valve competency. The posterior leaflet is divided by indentations resulting in scallops, usually three in number and termed P1, P2 and P3, respectively. The corresponding adjacent areas on the anterior leaflet are called A1, A2 and A3; they are rarely seen as individual scallops in a healthy valve. Anterolateral and posteromedial commissures separate the anterior and posterior leaflets of the mitral valve. The commissures do not reach the hinges of the valves directly and therefore a competent continuity between both leaflets is formed.

**Anulus**

The mitral anulus has a three-dimensional, saddle-shaped configuration, in which the lowest points are situated in the zone of the trigones and the highest lie towards the A2 and P2 parts of the anulus. The orifice of the mitral valve and the anulus change shape during the heart cycle, becoming
rounder and almost circular during diastole, and flat and square during systole. The two fibrous trigones are condensations of fibrous tissue and are part of the fibrous skeleton of the heart; they lie just adjacent to and beyond the anular attachments of the commissures, posteromedially and anterolaterally. Between them, the aortomitral curtain extends from the middle hinge of the anterior leaflet of the mitral valve to the anulus of the aortic valve, just below the non-coronary cusp.

The structure of the healthy anulus is not uniform and anular enlargement as a result of disease is not uniform. The fibrous portion of the anulus will not stretch to the same degree as the muscular and elastic portions, which means that the mitral valve changes shape during systole from that of a ‘D’ ring on its side to an oval shape, where the attachment of the posterior leaflet enlarges as it dilates. The attachment of the anterior leaflet remains constant. This is shown in Fig. 51.4.
The subvalvular apparatus connects the leaflets of the mitral valve with the walls of the left ventricle and consists of the papillary muscles and chordae tendineae. These structures allow the leaflets to open actively during diastole and level the leaflet in position to create perfect coaptation during systole.

The papillary muscles are organized in two groups lying directly under the commissures and located in the apical half of the left ventricle. Both groups can vary in number and shape, from one single bulky papillary muscle with multiple heads to several thinner muscles from which multiple chordae arise.

The anterolateral papillary muscle is situated superiorly on the anterior wall of the left ventricle and usually has a single head. Chordae from the anterolateral papillary muscle supply the A1, A2, P1 and P2 parts of the mitral leaflets. The posteromedial papillary muscle group is situated between the posterior wall and the intraventricular septum, and usually has three separate heads: anterior, which supplies chordae to the A2 and A3 parts of
the anterior leaflet; posterior, which supplies chordae to the P2 and P3 parts of the posterior leaflet; and a third commissural head, which supplies the corresponding posteromedial commissure of the mitral leaflets. The middle part of the posterior leaflet (P2) is attached equally to both papillary muscles by chordae arranged in a fan-like disposition. The chordae from different groups of papillary muscles never cross the midline of the valve, in either transverse or vertical diameter. The anterolateral papillary muscle is supplied with blood by both the anterior descending coronary artery and its branches and the circumflex artery. The posteromedial papillary muscle is supplied by either the circumflex or the right coronary artery in isolation and is therefore more prone to ischaemia.

Chordae tendineae are fibroelastic bands connecting the tips of the papillary muscles with the leaflets; the distance between the tip of a papillary muscle and the edge of a leaflet is usually around 2 cm. There are three types of chordae. Primary chordae are attached to the margins of the leaflets and are arranged like a fan, encircling the open valve orifice. Secondary chordae are attached to the ventricular underside of the leaflets. Tertiary chordae usually originate from the papillary muscle but very often originate from the ventricular wall; they are attached to the base of the posterior or commissural leaflets and very often to the anulus itself.

The function of the chordae is to position both anterior and posterior leaflets to create a competent line of coaptation; they do not function to oppose the pressure within the left ventricle during systole. The domed shape of the leaflets and the wide coaptation zone are responsible for both resisting prolapse during systole and maintaining forward flow from the ventricle through the ventricular outflow tract. During diastole, the chordal function is to open the mitral valve widely and facilitate laminar blood flow from the left atrium towards the apex of the left ventricle.
Surgical anatomy of the tricuspid valve

Leaflets

Like the mitral valve, the leaflets of the tricuspid valve have two zones: a smooth, thin and translucent atrial zone, and an irregular, roughened coaptation zone towards the free margin of the leaflet. The tricuspid valve apparatus is based on three leaflets: anterior, posterior and septal. The anterior leaflet is the largest. The posterior leaflet, which is attached to one-third of the anulus, is attached to the right ventricular wall and bears two indentations that facilitate opening during diastole. The septal leaflet is the smallest and is attached to the septum. Small accessory commissural leaflets are often present in the angles between the major leaflets; their chordae are disposed in a fan shape. The splits between the leaflets never reach the hinge of the valve, an arrangement that allows competent closure during systole.

Anulus

Like the mitral valve, the non-uniform structure of the tricuspid valve dictates that it dilates in an asymmetrical manner under pressure or volume loading⁶ (see Fig. 51.2). As the anulus dilates, it expands in the manner illustrated in Fig. 51.5.
FIG. 51.5  Progressive dilation of the tricuspid anulus. Red arrows indicate direction of anulus dilation.
Surgical anatomy of the interatrial septum

A depression in the middle of the septum represents the site of the fetal fossa ovalis. The Eustachian valve (valve of the inferior vena cava) guards the entrance of the inferior cava into the atrium. The coronary sinus is guarded by a valve-like structure, the Thebesian valve, which is located between the fossa ovalis and the tricuspid valve. The Eustachian and Thebesian valves vary in size and shape, and may be absent. The tendon of Todaro, a fibrous structure extending towards the anteroseptal commissure of the tricuspid valve, is located between these valves. The hinge of the septal leaflet, the tendon of Todaro and the coronary sinus create an anatomical triangle (the triangle of Koch) (Fig. 51.6); the atrioventricular node lies at the apex of triangle.
FIG. 51.6 The interatrial septum as displayed surgically during operation. A, Depicted as a diagram. B, Intraoperative photograph. Abbreviations: A, anterior leaflet, tricuspid valve; a, line of coaptation of the anterior leaflet; AO, aorta; AVN, atrioventricular node; CS, coronary sinus; FO, fossa ovalis; IVC, inferior vena cava; P, posterior leaflet, tricuspid valve; p, line of coaptation of the posterior leaflet; RAA, right atrial appendage; RV, right ventricle; S, septal leaflet, tricuspid valve; s, line of coaptation of the septal leaflet.

**Tips and Anatomical Hazards**

Important structures for the surgeon to be aware of during a mitral valve operation are located around the anulus and cannot be seen directly.\(^4\)

The circumflex artery runs between the base of the left atrial appendage and the anterolateral commissure, around 5 mm away from the hinge of the mitral valve.

The coronary sinus, starting at the level of P1, surrounds the posterior leaflet to the middle part of P3 and is approximately 5 mm away from the hinge of the mitral valve.

The anulus and the non-coronary and left coronary leaflets of the aortic valve are very closely related to the hinge of the anterior leaflet of the mitral valve, usually 1 cm above the anterolateral commissure and the A1 part of the leaflet itself. The aortomitral curtain extends up to the aortic anulus between the anterolateral and posteromedial trigones, above the hinge of the anterior leaflet.
The atrioventricular node and the bundle of His extend through the central fibrous body into the ventricles under the membranous part of the interventricular septum. The bundle of His is located outside the mitral anulus and almost directly attached to the posteromedial trigone.\textsuperscript{5}
References


Single Best Answers

1. The coronary sinus is used to insert the retrograde cardioplegic cannula during surgery. Which one of the following numbers marks this anatomical structure on Fig. 51.7?

A. 1  
B. 2  
C. 3  
D. 4  
E. 5  

**Answer: B.** The coronary sinus, which is surrounded by the Thebesian valve (semilunar valve), is located between the fossa ovalis and the postero-septal commissure of the tricuspid valve. The coronary sinus is used during surgery to introduce a cannula that allows delivery of retrograde cardioplegia for protection of the heart during the operation. In mitral surgery, direct insertion is a very useful manoeuvre because it allows delivery of cardioplegia without interrupting work on the mitral and tricuspid valves.

2. Which one of the following numbers marks the Eustachian valve on Fig. 51.7?

A. 1  
B. 2  
C. 3  
D. 4  
E. 5  

**Answer: D.** The Eustachian valve is a delicate semilunar valve, which guards the junction between the atrium and inferior vena cava. During inferior vena cava cannulation for bypass, the
surgeon needs to be aware of this structure because it can obstruct passage of the cannula.

3. Which one of the following sets of numbers indicates the borders of the triangle of Koch on Fig. 51.7?

A. 1,2,3  
B. 2,3,4  
C. 1,2,5  
D. 2,3,5

**Answer:** A. The triangle of Koch is bordered by the tendon of Todaro (3), the hinge of the septal leaflet of the tricuspid valve (1) and the coronary sinus (2). The importance of the triangle of Koch is that it contains elements of the conduction system: the atrioventricular node and the bundle of His.

4. Which one of the following pairs do the secondary chordae tendineae connect?

A. Papillary muscle with the edge of the mitral leaflet  
B. Papillary muscle with the ventricular side of the leaflet  
C. Papillary muscle with the left ventricle  
D. Papillary muscle with the atrioventricular junction

**Answer:** B. There are three types of chordae that stabilize the leaflets of the mitral and tricuspid valves. Primary chordae are attached to the margin of the leaflets, secondary chordae are attached to the ventricular side of the leaflet, and tertiary chordae are attached to the base of the posterior and commissural leaflets.
FIG. 51.7  Single Best Answer Questions 1, 2 and 3.
Short Answer Questions

1. What is the importance of mitral valve coaptation?

The depth of the coaptation zone on each leaflet is one of the most important factors in predicting the success of repair. The surface area of the coaptation determines the competency of the valve and also the durability of the repair and the long-term results. The greater the area of coaptation, the stronger the repair, because there is less stress on the valve. At least 0.6 cm depth of coaptation between leaflets should be demonstrable on transoesophageal echo postoperatively.

2. Describe the possible complications after ring anuloplasty of the mitral valve associated with the misplacement of sutures around the anulus.

This life-threatening complication will be related to damage to the circumflex artery, which lies very close to the anterolateral commissure and 0.5–1 cm away from the P1 and P2 scallops of the posterior mitral leaflet. Misplacement of the suture and damage to the coronary artery can lead to significant ischaemia postoperatively and can be fatal. The surgeon should suspect this complication if the heart has been properly de-aired, there is no other explanation for ischaemia in the lateral/inferior left ventricular wall, and contractility is severely impaired postoperatively. If there is no possibility of carrying out an urgent angiogram, a bypass graft to the circumflex territory should be performed to supply the muscle with blood.

Misplaced sutures between the anterolateral commissure and the hinge of the anterior leaflet may cause damage to the aortic valve leaflet. The distance between the mitral valve and aortic anulus is very short and the aortomitral curtain is a very thin structure. A misplaced suture can penetrate the sinuses of the aortic root and damage the aortic leaflet or stitch it to the wall. The first possible sign of trouble could be a distending left ventricle and significant aortic regurgitation on the echo after coming off bypass. In all such situations, the aortic valve needs to be inspected. The relevant mitral valve anular suture needs to be removed, and if the valve is rendered incompetent, another mitral valve procedure needs to be performed. If the aortic valve leaflets are damaged beyond repair, the aortic valve will also need
to be replaced.
Clinical Case

1. A 67-year-old patient attends for a standard mitral valve repair through a median sternotomy. The pathology of the mitral valve is degenerative disease with P2 prolapse. After bicaval cannulation, antegrade cardioplegia is used to protect the heart.

A. Describe the possible surgical approaches to the mitral valve.
A direct approach through the left atrium through the interatrial groove anterior to the right pulmonary veins. This is a simple approach that allows good exposure in patients with an enlarged atrium. If there is difficulty with exposure of the mitral valve through this incision, it can be extended down behind the inferior vena cava, on the posterior wall of the left atrium. The advantage of this incision is quick access to the mitral valve, as well as short and quick closure of the atrium.

A second approach is through the right atrium: this exposure gives the opportunity to assess and repair the tricuspid valve if necessary under direct vision. There are two possible incisions starting from the middle of the fossa ovalis. The first is a trans-septal longitudinal incision up to the superior vena cava until the incision line approaches the roof of the left atrium. This exposure gives better access to the anterior part of the mitral anulus than that through the interatrial groove. The second is a trans-septal oblique incision through the atrial septum starting from the fossa ovalis and going to the mid point between the aortic valve and the superior vena cava, extending along the roof of the left atrium and behind the aorta. It is a long incision and both atria are widely open. This incision provides the best access to the mitral valve. Every mitral surgeon should be familiar with this approach; it is the one that can help in difficult reoperations and in small atria and ischaemic mitral regurgitation scenarios, and allows unparalleled vision of both leaflets, the entire anulus, all primary chordae and both papillary muscles.
Aortic valve, aortic root, left ventricular outflow tract and pulmonary valve

Julie A Mundy, Jordan DW Ross

Core Procedures

- Aortic valve replacement
- Transcatheter aortic valve replacement/implantation (TAVR/TAVI)
- Aortic root replacement
- Aortic root enlargement
Embryology

Septation of the initially single outflow tract begins in the fourth week of gestation (26–32 days post fertilization), occurring in the conotruncal region of the primitive heart tube, which extends from the primitive right ventricle to the boundaries of the pericardial cavity. Development of the arterial valve orifices occurs in the region of the truncus arteriosus, the most distal point of the outflow tract, between the conus arteriosus (precursor of the subpulmonary infundibulum on the right, which regresses on the left) and the aortic sac. Formation of the arterial septum and arterial valves occurs largely through the appearance and migration of two main truncal cushions, the dextrosuperior and sinistro-inferior endocardial cushions, which merge to form the truncal septum and spiral caudally in an anticlockwise fashion to separate the future aorta and pulmonary artery. The spiralling of the truncal septum is responsible for the relationship the great vessels share and for the position of the valve orifices. These main truncal cushions also form the right and left cusps of both the aortic and pulmonary valves. Two other intercalated truncal cushions appear parietally within the truncus arteriosus, the right going on to form the non-coronary aortic cusp, and the left forming the anterior pulmonary valve cusp.

Two endocardial cushions appear in the conus arteriosus, named the dextrodorsal and the sinistroventral cushions, which persist as the infundibulum of the right ventricle. On the left side, the conal tissue resorbs, with the fibrous aortomitral curtain instead forming part of the left ventricular outflow tract.
Surgical surface anatomy

The pulmonary valve has the most superior surface projection, lying horizontally behind the intersection of the left third costal cartilage with the sternum. The aortic valve is located inferomedial to the pulmonary valve, projecting inferiorly and to the right from the most medial end of the left third intercostal space (Fig. 52.1). The aortic valve is directed upwards and to the right. The optimal site of auscultation of heart valve sounds depends on the direction of blood flow, rather than the surface projection of the heart valve. The aortic and pulmonary valves are best auscultated in the second intercostal space, just to the right and left of the sternum, respectively. The murmur of aortic stenosis may radiate to the carotid arteries in the neck, while the murmur of aortic regurgitation is usually best heard in the left parasternal region between the second and fourth intercostal spaces, which marks the location of the regurgitant stream of blood as it courses back into the left ventricle.
FIG. 52.1 Surface anatomy of the heart valves and projection of the associated murmur. The right heart is blue, the blue arrow denotes the inflow and outflow channels of the right ventricle; the left heart is treated similarly in red. The positions, planes and relative sizes of the cardiac valves are shown. The position of the letters A, P, T and M indicate the aortic, pulmonary, tricuspid and mitral auscultation areas of clinical practice, respectively. Note that, for the purpose of illustration, the orifices of the aortic, mitral and tricuspid valves are shown with some separation between them, whereas, in reality, the leaflets of the three valves are in fibrous continuity. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 57.19.)
**Clinical anatomy**

When viewing the heart from the base, with the atria removed (see Fig. 51.1), it is apparent that the aortic valve occupies a central position within the fibrous skeleton of the heart and is intimately related to all of the cardiac chambers. A thorough understanding of the structures which surround the root of the aorta is essential.

The aortic semilunar valve forms both the anatomical and haemodynamic boundary between the left ventricle and the aorta, relying on the surrounding structures of the aortic root to maintain correct apposition during diastole and thus preventing regurgitation of ejected blood into the ventricle. The nomenclature of the aortic valve and the surrounding structures is variable and often confusing. The aortic valve proper is best considered as consisting of the leaflets and their basal attachments. The aortic root is best considered as the area surrounding the proximal and most distal attachments of the aortic valve leaflets. The limits of the aortic root are the sinutubular junction (commissural ring) distally and the basal ring proximally. Within this continuity are the sinuses of Valsalva, the coronary artery orifices, the commissures of the valve and the interleaflet triangles (Fig. 52.2).
Aortic valve

The normal aortic root consists of three sinuses of Valsalva, giving rise to two coronary arteries. The latter arise from the two sinuses which face the pulmonary trunk, the so-named left- and right-facing sinuses, with the reference point being the third (non-pulmonary-facing) sinus; in most cases, this is conveniently the position from which a cardiac surgeon examines the aortic valve (Fig. 52.3; see Fig. 51.1).
The aortic valve leaflets are named left, right and non-coronary leaflets. Each is described as consisting of a hinge, a belly, a coaptation surface and a lunule/nodule of Arantius.\(^7\)\(^-\)\(^9\) The nodule of Arantius marks the middle of the free edge, and is continued laterally along the free edge as a thin supporting layer (the lunule), to the attachment at the wall of the aortic root. The bulk of each leaflet is referred to as the belly of the leaflet and consists of three distinct histological layers (Fig. 52.4).
The inflow or ventricular layer, the ventricularis, consists of a dense sheet of elastic fibres which provide flexibility to the leaflet. The outflow or arterial layer, the fibrosa, features a high density of collagen fibres, which provide structure and strength. The middle spongiosa layer consists of proteoglycans and glycosaminoglycans, which provide durability to the valve and resistance to compression.\textsuperscript{10–13} The average thickness of the leaflet is 1.5–1.75 μm, though there is variability in the thickness of each section of the valve leaflet.\textsuperscript{13,14} The hinge describes the point at which the leaflet attaches to the anulus in a semilunar fashion.

**Aortic root**

The aortic anulus has traditionally been described as the fibrous ‘crown’ which provides attachment for the valve leaflets and marks the haemodynamic junction between ventricle and aorta (see Fig. 52.2).\textsuperscript{6,8,9,15} This terminology is often confused with the basal ring, the virtual circle formed by the most basal attachments of the valve leaflets, which is the usual point of echocardiographic measurement. It is best to consider the so-called anulus as the hinge of attachment of the valve leaflets to a line crossing the anatomical ventriculoarterial junction in a semilunar fashion.

When viewed from above and when closed, the valve resembles a three-point star, the so-called ‘Mercedes Benz sign’ (see Figs 51.1, 52.3). Each leaflet...
can be considered to attach basally in three semilunar ‘cusps’. The zone of continuity between the attachment of one cusp to the next is referred to as a commissure. The commissures are named according to the neighbouring leaflets and are thus referred to as ‘left–right, right–non and left–non’ commissures. It is important to understand that the valve leaflets are not attached in a circular fashion, instead joining each other at the three commissures – the peaks of the so-called crown – with the nadir of the attachment at the bases of the sinuses of Valsalva (see Fig. 52.2). The ventriculoarterial junction is the anatomical zone where the ventricular structures join the wall of the aortic root, while the virtual basal ring is defined as the plane through the nadir of the valve cusp attachment. The aortic root is not a perfectly circumferential structure. The ventriculoarterial junction lies at the basal ring at the non and left coronary sinuses and their intervening commissure, while it is several millimetres above the basal ring at the right sinus, the left–right and right–non commissures. The left–non commissure is thus higher than the other two by a matter of several millimetres.

The sinuses of Valsalva begin proximally at a virtual basal ring and extend significantly above the commissural attachment of the valve, as well as the free edge of the leaflets. In most hearts, the left coronary artery arises from the left-facing sinus, and the right coronary artery from the right-facing sinus. There is significant variability in the location and number of coronary ostia within the sinuses. The coronary ostium usually lies approximately 1 cm from each commissure and 13–14 mm from the base of the sinus. The third sinus is conventionally named the non-coronary sinus of Valsalva. At the mid-sinus level, the aortic wall is considerably thinner than at the sinutubular junction and the ascending aorta. The dimensions of the aortic root correlate well to body surface area, and are known to be greater in older age and in men. The luminal diameter at the mid-sinus level is approximately 5 mm greater than at the sinutubular junction, and 7–8 mm greater than at the basal ring. Several algorithms exist which predict the risk of complications from increasing aortic root dilation (rupture, dissection), when indexed to body surface area.

The interleaflet triangles occur immediately proximal to the commissures, forming between the leaflet cusp attachments (see Fig. 52.2B). It is important to note that the histological ventriculoarterial junction lies distal to the most proximal attachments of the valve leaflets. The interleaflet
triangles are thus considered ‘ventricular’ structures. By convention, the interleaflet triangles describe only that tissue distal to the ventriculoarterial junction. The left–right interleaflet triangle is muscular, forming a relationship with the subpulmonary infundibulum and the muscular septum. The other two interleaflet triangles are fibrous structures. The right–non interleaflet triangle is in continuity with the membranous portion of the ventricular septum. It is crossed basally by the attachment of the septal leaflet of the tricuspid valve, dividing the interleaflet triangle into atrioventricular and interventricular parts. The left–non interleaflet triangle forms the distal portion of the aortomitral continuity (Fig. 52.5; see Fig. 52.2C).

**FIG. 52.5** The left ventricular outflow tract in section. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed. © Elsevier, Urban & Fischer, 2013.)
Left ventricular outflow tract

The left ventricular outflow tract, unlike its morphological right ventricular counterpart, is not a complete muscular tube.\textsuperscript{5,28} This is largely due to its central position between the orifices of the atrioventricular valves (see Fig. 51.1). When viewing the aortic valve from above, the muscular septum occupies the position under the right coronary cusp, with the membranous portion at the right–non commissure and the muscular portion extending around to the left–right commissure. The left ventricular free wall occupies the position under the left coronary cusp. The aortomitral curtain occupies the position under the left–non commissure. This fibrous continuity is bordered at the aortic end by the left and right fibrous trigones of the fibrous skeleton of the heart; the right contributes to the central fibrous body adjacent to the membranous septum. These structures, through which the atrioventricular conduction tissue (the bundle of His) penetrates, are adjacent to the right–non commissure \textbf{(Fig. 52.6)}.\textsuperscript{29}
**FIG. 52.6** The conduction tissue (represented in purple). **A,** From the right side. **B,** From the left side. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 57.36.)

**Pulmonary valve**

The pulmonary valve guards the outflow of the morphological right ventricle.
and is more isolated than the other three valves (which share a close relationship), being some distance from the central fibrous components of the fibrous skeleton of the heart (see Fig. 51.1). The pulmonary valve is the most superior and anterior of the cardiac valves, facing superiorly with a slightly posterior and leftward-facing plane. Terminologia Anatomica defines the three leaflets of the pulmonary valve as being anterior, posterior and septal, based on their position in the fetus; in adult life, however, the leaflets are widely referred to as anterior (non-facing), right and left, respectively.\textsuperscript{7,30–32} They are similarly described as consisting of a hinge, a belly and a coaptation surface, and also feature the nodule of Arantius (Fig. 52.7). The pulmonary wall also features sinuses which contain the valve leaflets, though these are not as pronounced as they are on the left side.\textsuperscript{31,32}

\textbf{FIG. 52.7} The pulmonary valve viewed from a posterior aspect. (From R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray’s Anatomy for Students, third ed., Fig. 3.65, 2015.)

The valve leaflets are semilunar in shape, similar to the aortic valve, and
attach to the wall of the pulmonary trunk and the infundibular muscle of the
right ventricle in a similar ‘crown-like’ fashion. The curved attachment of
each leaflet rises to meet the zone of apposition at three commissures, which
lie at the level of the sinutubular ridge of the pulmonary trunk. The deepest
attachment of the valve leaflets within the sinuses of the pulmonary trunk is
walled by a small amount of infundibular muscle. Three triangular sections
of arterial wall are continuous with the right ventricle beneath the
commissural attachments of the valve leaflets.

The right ventricular outflow tract is an entirely muscular tube, the
infundibulum, and is a rather simpler structure than the left-sided
counterpart (see Fig. 52.6A). It can be removed from the outflow portion of
the right ventricle without disturbing the fibrous skeleton of the heart or any
of the valves, as is performed in the Ross procedure. It is thus incorrect to
suggest that the fibrous skeleton of the heart provides structural support to
all of the cardiac valves. The tendon of the infundibulum, previously
described as connecting the aorta and pulmonary aorta, should no longer be
considered as a discrete structure, that area being filled largely by thin fascial
connective tissue bands which are easily separated by blunt dissection or
electrocautery.
Valve replacement

Aortic valve replacement is performed primarily to treat diseases of the aortic valve or surrounding structures which lead to regurgitation or stenosis of the valve, or in cases of infection of the valve or root (infective endocarditis). The procedure involves excision of the existing aortic valve (native or prosthetic); debridement of the surrounding structures of calcium deposits, plaques or infection; patching of any defects in the continuity of the tract; and replacement of the valve. Options include using a xenograft, allograft or homograft; an autograft; or a mechanical valve. ‘Bioprosthetic’ xenografts may be porcine or bovine pericardial valves. They are the most commonly employed valves worldwide, and have the advantage of no requirement for lifelong anticoagulation but the disadvantage of a limited ‘lifespan’ (usually due to structural valve deterioration, historically quoted as 12–15 years). Allografts or homografts are usually obtained from a cadaveric donor and implanted as part of an aortic root replacement. They are often implanted in the setting of infective endocarditis, though limited by institutional preference and availability of grafts. Autografting (Ross procedure) involves the use of the pulmonary valve as an aortic root autograft. The obvious advantages are the lack of a requirement for prosthetic material and the potential for growth in children; the disadvantages are the significant additional complexity of the operation (see aortic root replacement) and the ongoing need for revision of the reconstructed pulmonary root. Mechanical valves have the advantage of extended durability and the disadvantage of a requirement for lifelong anticoagulation.

Transcatheter aortic valve replacement/implantation (TAVR/TAVI) involves catheter-based delivery of a self- or balloon-expanding bioprosthetic valve, usually via the femoral artery or the apex of the left ventricle. It has the advantage of being a significantly less invasive procedure than a standard aortic valve replacement with a comparable risk of mortality and stroke, though data are lacking on the long-term durability of the implanted valves. TAVR/TAVI is currently reserved in most centres for those patients not suitable for undergoing traditional surgical aortic valve replacement, though it is becoming adopted as a reasonable alternative for high- and intermediate-risk surgical patients in many centres.

Aortic root replacement is performed to treat dilation of the aortic root, to reduce the risk of rupture and/or dissection, often occurring in combination
with aortic valve regurgitation. The procedure involves excision of the diseased aortic wall and replacement with a prosthetic graft, xenograft or homograft, with implantation of the coronary ostia into the wall of the neoroot. Excision of the native aortic valve and replacement with a prosthetic valve (usually as a valve/graft composite) carries the eponym Bentall procedure.\textsuperscript{37} Excision of only the aortic wall with preservation of the native aortic valve is also feasible. The David procedure\textsuperscript{38} and the Yacoub procedure\textsuperscript{39} are variations of this concept.

Aortic root enlargement is performed in combination with surgery to the aortic valve to facilitate implantation of a larger prosthesis. Several variations have been described. They include the Nicks procedure, where an aortotomy is progressed into the non-coronary sinus to the base of the anterior mitral valve leaflet\textsuperscript{40}, the Manouguian–Seybold-Epting procedure, where the aortotomy is extended into the left–non commissure and to the anterior mitral valve leaflet,\textsuperscript{41} and the Otaki\textsuperscript{42} and Yamaguchi\textsuperscript{43} procedures, where a two-sided aortotomy is performed, both anteriorly and posteriorly. Konno aortoventriculoplasty is performed most often in children with subaortic stenosis and a small aortic anulus, requiring incision into the ventricular septum.\textsuperscript{44}

All of these operations have traditionally been performed via a midline incision, full median sternotomy and the use of central cardiopulmonary bypass. Increasingly, aortic valve replacement is being performed using a number of purportedly less invasive ‘sternum-sparing’ techniques, including hemisternotomy and variations of anterior thoracotomy, with the use of peripheral cardiopulmonary bypass.\textsuperscript{45,46}

\section*{Tips and Anatomical Hazards}

\subsection*{Ross–Konno Procedure}

The anatomy of the area described in this chapter is well highlighted by considering the important pitfalls, danger areas and blind spots requiring vigilance in the successful and uncomplicated performance of the Ross pulmonary autograft root replacement and Konno aortoventriculoplasty.\textsuperscript{28,47,48}
The left coronary system lies behind the proximal pulmonary artery, with the large first septal perforating branch artery of the left anterior descending artery lying adjacent to the posterior surface of the pulmonary valve. This artery supplies blood to the right bundle branch of the bundle of His. The ventricular septal incision of the Konno procedure (and septal myomectomy for hypertrophic obstructive cardiomyopathy in an adult) must be to the left of the ostium of the right coronary artery, to avoid the atrioventricular conduction axis, which penetrates through the central fibrous body and membranous ventricular septum, under the right–non commissure of the aortic valve. Knowledge of the variable height and location of the coronary ostia within the aortic sinuses is essential when performing any operation requiring excision and reimplantation of coronary arteries.

**Aortic Root Abscess**

Aortic valve perianular abscess is a severe complication of infective endocarditis, the complications of which serve to highlight important anatomical landmarks surrounding the aortic root and emphasize the central location of the aortic valve. These complications result from the direction of extension of the infection. If the infection is located in the region of the left and right coronary cusps, it may extend out of the aortic root to the pulmonary valve and pulmonary artery. The transverse sinus (outside the heart) lies outside the left coronary cusp, and the muscular septum is under the right coronary cusp. The conduction system is at risk if the infection extends adjacent to the right–non-coronary commissure, the location of the membranous portion of the septum: this may lead to heart block. The tricuspid valve is also at risk, the septal leaflet being located behind the right–non interleaflet triangle, with the ventriculoventricular septum being below (right ventricle), and the atroventricular septum being above (the right atrium). Infection can spread to the left atrium and mitral valve via the aortomitral curtain if it occurs at the junction of the left and non-coronary cusps.

**Bicuspid Aortic Valve**
The incidence of bicuspid valve in the general population is 0.5–2%, with a 3 : 1 male predominance.\textsuperscript{52–56} Individuals with a bicuspid aortic valve are more likely to suffer degenerative aortic valve pathology, occurring at a younger age than in those patients with a tricuspid aortic valve. The Sievers classification describes bicuspid aortic valves as those with no raphe (‘true bicuspid’, type 0) and those with one or two raphes (types 1 and 2, respectively). Type 1 is the most common, with the single raphe most frequently being positioned between the left and right coronary sinuses.\textsuperscript{57}

Three-Dimensional Characterization of the Aortic Root for Transcatheter Aortic Valve Replacement (TAVR)

Modern techniques for non-invasively imaging the aortic root have advanced in concert with transcatheter valve technology, which has significantly increased our understanding of the three-dimensional and dynamic nature of the aortic root. The virtual basal ring is not a circular structure, and is variously described as ‘ovoid’ or ‘elliptical’, with a difference of 5 mm between the short and long axis measurements.\textsuperscript{58–66} It is known that the area and circumference of the aortic valve both increase during systole, and that the valve shows a greater degree of eccentricity during diastole due to a proportionally greater reduction in area than circumference,\textsuperscript{67} thought to be due to flattening of the aortomitral continuity. These findings are essential when considering the optimal TAVR prosthesis size for a patient.

Thorough knowledge of the three-dimensional spatial anatomy of a patient's aortic root should provide the operator with the best chance of reducing the risk of complications from the procedure, by ensuring the valve is seated below the ostia of the coronary arteries, and by optimally sizing the prosthesis to reduce the risk of valve migration and/or paravalvular aortic regurgitation.
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Single Best Answers

1. Which one of the following statements regarding the surface projection of the heart valves is correct?
   A. The aortic valve has the most superior surface projection 
   B. The pulmonary valve projects at the right third chondrosternal junction
   C. Cardiac murmurs are best auscultated at the surface projection of the valve from which they arise
   D. The aortic valve projects at the medial end of the left third intercostal space
   E. The murmur of aortic stenosis is usually best heard at the left second intercostal space

   **Answer: D.** The aortic valve projects at the medial end of the left third intercostal space. The pulmonary valve has the most superior surface projection. The pulmonary valve projects at the left third chondrosternal junction. Cardiac murmurs are best auscultated at points vastly different from the surface projection of the valve from which they arise, as the optimal site of auscultation is related to the direction of blood flow. The murmur of aortic stenosis is usually best heard at the right second intercostal space and commonly radiates to the carotid arteries.

2. Which one of the following statements regarding the aortic valve leaflets is correct?
   A. The non-coronary cusp is usually considered to be the largest leaflet
   B. The prevalence of bicuspid aortic valve in the general population is approximately 5%
   C. The inflow layer of the aortic valve is named spongiosa.  
   D. The hinges of the leaflets attach to the anulus in a circular
fashion.
E. The average thickness of the leaflets is 1.5–1.75 µm.

**Answer: E.** The average thickness of the leaflets is 1.5–1.75 µm. The left cusp is usually considered to be the largest leaflet. The prevalence of bicuspid aortic valve in the general population is 0.5–2%. The inflow layer of the aortic valve is named ventricularis. The hinges of the leaflets attach to the anulus in a semilunar fashion.

3. Which of the coronary sinuses face the pulmonary artery?
   A. The left and right
   B. The left and non-coronary
   C. The right and non-coronary
   D. The left only
   E. The right only

**Answer: A.** The left and right.

4. Which one of the following statements is most accurate?
   A. The conduction system lies at the left–right coronary commissure
   B. The membranous septum lies under the right–non commissure
   C. Sinus node dysfunction will occur if the membranous septum is incised
   D. The left–right interleaflet triangle is primarily a fibrous structure
   E. The mitral valve is most at risk when suturing at the right–non commissure

**Answer: B.** The membranous septum lies under the right–non
commissure. The conduction system lies at the right–non coronary commissure. Heart block may occur if the membranous septum is incised. The left–right interleaflet triangle is primarily a muscular structure. The mitral valve is most at risk when suturing at the left–non commissure.

5. Which one of the following statements regarding embryology of the heart is correct?

A. Septation begins in the sixth week of gestation
B. The left ventricular outflow tract is formed by persistence of the endocardial cushions of the conus arteriosus
C. The truncal septum is formed in a linear fashion
D. The formation of the arterial valves occurs due to the appearance and migration of truncal cushions
E. Two truncal cushions are responsible for the formation of all of the aortic valve leaflets

**Answer: D.** The formation of the arterial valves occurs due to the appearance and migration of truncal cushions. Septation begins in the fourth week of gestation. The right ventricular outflow tract is formed by persistence of the endocardial cushions of the conus arteriosus. The truncal septum is formed in a spiral fashion. Two main truncal cushions are responsible for the formation of some of the aortic valve leaflets (the right and left cusps).
Clinical Cases

1. A 35-year-old male with a history of Marfan's syndrome presents to the Outpatient clinic with a history of increasing breathlessness. A chest X-ray has shown a large cardiac silhouette and prominent ascending aorta.

   A. Describe the surface projection of the aortic valve.
   The aortic valve is located at the medial end of the left third intercostal space, projecting inferiorly and to the right.

   B. Where is the most likely place that a murmur might be heard in this patient?
   Marfan's syndrome is most commonly associated with aortic regurgitation in the setting of a dilated aortic root. The murmur of aortic regurgitation is best heard at the left sternal border between the second and fourth intercostal spaces during diastole.

   C. Describe the three-dimensional anatomy of the anulus of the aortic valve.
   The anulus of the aortic valve describes the hinge of attachment of the aortic valve leaflets to the wall of the aortic root, in part to the wall of the artery and in part to the ventricle itself (crossing the ventriculoarterial junction). The attachments peak at three commissures between the cusps of the valve leaflets and form nadirs at the bases of the coronary sinuses.

   D. Why might a patient require a permanent pacemaker after aortic root replacement?
   The primary atrioventricular conduction pathway penetrates through the membranous septum, located under the right–non commissure of the aortic valve. Damage to this structure due to stitches placed too deeply in the aortic anulus may cause a bundle branch block or complete atrioventricular block.

2. A 55-year-old male presents to the Cardiac Surgery Outpatient clinic with severe calcific aortic stenosis.

   A. Describe the histology of a normal aortic valve leaflet.
   The aortic valve leaflets consist of three distinct histological layers: ventricularis, spongiosa and fibrosa. Ventricularis lies on the ventricular side of the leaflet and consists of a dense sheet of elastic fibres. Fibrosa lies on the
aortic side of the leaflet and is primarily composed of high-density collagen fibres. Spongiosa is the middle layer, which consists of proteoglycans and glycosaminoglycans.

B. How many leaflets does a normal aortic valve have? Describe their usual orientation.

The aortic valve usually consists of three leaflets, called left, right and non-coronary. The left and right coronary cusps face the pulmonary artery and are named according to their position when viewed from the non-coronary cusp.

C. What is the most common congenital abnormality of the aortic valve?

A bicuspid aortic valve occurs in 0.5–2% of the population. Patients with a bicuspid aortic valve present with aortic stenosis at a younger age than those with trileaflet aortic valves.

D. Describe the most common classification system of this abnormality.

The Sievers classification describes bicuspid aortic valves as those with no raphe (‘true bicuspid’, type 0) and those with one or two raphes (types 1 and 2, respectively). Type 1 is most common, with the single raphe most frequently being positioned between the left and right coronary sinuses.
Ventricles, coronary vessels and access to conduits for grafting

Arvind Singh, David Richens

Core Procedures

- Sternotomy
- Redo sternotomy
- Right ventricular outflow tract operations
- Left ventricular vent insertion
- Left ventricular aneurysm repair
- Left ventricular rupture repair
- Post-infarct ventricular septal defect repair
- Long saphenous vein harvest
- Radial artery harvest
- Internal thoracic (mammary) artery harvest
- Coronary artery bypass grafts
Ventricles

Right ventricle

In the normal state, the right and left ventricles pump the same amount of blood in the pulmonary artery and aorta, respectively. The difference in the pressures in the pulmonary and systemic circulation influences the musculature of the ventricles, the right ventricular wall being thinner than the left in a ratio of $1:3$. The left ventricular cavity is circular in cross-section with a thicker wall, whereas the right ventricular cavity is crescentic and to its right (Fig. 53.1).
Surgical surface anatomy

The right ventricle forms most of the anterior surface of the heart, which is related to the posterior aspect of the sternum and ribs on the left side. The left ventricle contributes only a small portion to the anterior surface towards the left side, lateral to the interventricular groove. The external surface, as well as the cavity of the right ventricle, is roughly triangular in shape, the three sides of this being the inferior border of the heart related to the diaphragm, the anterior interventricular groove on the left and the atrioventricular groove on the right. The atrioventricular groove, which runs along the line from the right hypochondrium to the left shoulder, separates it from the right atrium.²

Clinical anatomy
The cavity of the right ventricle consists of three parts: the inlet, the trabecular part and the outlet or infundibulum. The inlet surrounds the tricuspid valve with its chordae extending on to the trabecular part; the latter has irregular muscle ridges protruding into the cavity from its inner surface. Three sets of papillary muscles project from this part into the cavity. The posterior and anterior papillary muscles are large and divide into several smaller projections; the septal muscles arise directly from the interventricular septum (and are sometimes only chordae), and insert into anterior and septal cusps. The trabecular part extends towards the apex of the heart and superiorly leads to the funnel-shaped outflow (hence it is called the infundibulum). This part is smooth-walled and ends at the pulmonary valve. The right ventricular wall is thin at the apex and a common site of perforation from catheters and pacemakers inserted within the ventricle via peripheral venous access.3

Contrary to the arrangement in the left ventricle, the inlet (tricuspid valve) and outlet (pulmonary valve) are not adjacent to each other but are separated by a prominent muscular shelf, the supraventricular crest. A prominent trabecula crosses the cavity of the right ventricle from septum to anterior papillary muscle; it carries the right crus of the atrioventricular bundle of the conducting tissue and is also called the moderator band.4

After the pericardium is opened, correlating haemodynamics with the fullness of the right ventricle and the position of its inferior margin in relation to the diaphragmatic surface are useful observations that will guide the surgeon and anaesthetist while weaning the patient off cardiopulmonary bypass.

Tips and Anatomical Hazards

The right ventricle is the most anterior part of the heart; injuries at sternotomy are known to happen, especially with right ventricular hypertrophy in the paediatric age group and at reoperations where this chamber may be stuck to the posterior aspect of the sternum.5 Preoperative imaging with lateral chest X-ray and CT allows detailed assessment of cardiac anatomy posterior to the sternum and changes in operative strategy to mitigate this risk by either adopting a thoracotomy approach or establishing cardiopulmonary bypass using
peripheral cannulation, most often femoral vessels, prior to sternotomy. At redo operations, sternotomy is performed using an oscillating saw, lifting up the sternum off the underlying structures (anterior surface of right ventricle, aorta or bypass grafts) either by inserting retractors with small blades under the suprasternal notch and xiphoid process or by taking deep sutures going through the muscles and periosteum on either side of the midline. Following sternotomy, sternal retraction should be minimal to allow division of adhesions on either side before full retraction. Forceful retraction of the sternum right at the beginning may induce a right ventricular tear because of the pull of adhesions between the sternum and the anterior surface. If a right ventricular tear happens despite all precautions, either caused by the saw or during retraction, gentle digital pressure using the pulp of a finger is used to control the bleeding. This may not be possible if bleeding is caused by a sternal saw right at the beginning: in such situations, some control can be achieved by pressing the two halves of the sternum together using one hand in each axilla pressing the chest. While temporary control is obtained, expeditious cardiopulmonary bypass is established peripherally using femoral vessels by a second surgeon. Similar injury from a saw is possible at first sternotomy in patients with right ventricular hypertrophy. An assistant’s finger placed longitudinally on the tear controls the bleeding long enough for the surgeon to repair the tear using continuous over-and-over polypropylene suture.

In desperate situations, use of a Foley catheter or even an endotracheal tube inserted though the tear may rescue the surgeon. Once inside the lumen, the balloon is inflated and gentle traction of the balloon against the wall of the chamber can seal the leak while cardiopulmonary bypass is established. An endotracheal tube can be connected to the venous drainage to the bypass machine, understanding that alternative drainage will be required once the situation has been defused.

Tetralogy of Fallot (TOF) is a very common congenital cardiac defect and corrective surgery is performed in early life. Right ventricular hypertrophy is quite prominent with very pronounced trabeculae in the cavity. The supraventricular crest forms the posterior rim of the perimembranous ventricular septal defect. There is a risk of injury to
the right coronary artery if deep sutures are taken to repair the defect in this part, with the needle going into the right atrioventricular groove.\(^9\)

**Left ventricle**

**Surgical surface anatomy**

The left ventricle forms the left heart border as seen from the front and projected on a chest X-ray (posteroanterior view). It forms a small strip of the anterior surface of the heart lateral to the left anterior descending artery running in the interventricular groove. Normally, the apex of the heart is formed by the apex of the left ventricle. On a chest X-ray, this forms an obtuse angle with the left dome of the diaphragm. In patients with right ventricular hypertrophy, the apex is displaced and the cardiac silhouette forms an acute angle with the left dome of the diaphragm.\(^10\)

**Clinical anatomy**

Although the left ventricle has a thicker wall as compared to the right ventricle, both chambers have a thin-walled apex as compared to the rest of the cavity. The left ventricular cavity consists of an inlet formed by the mitral valve; the trabecular part; and an outlet, the left ventricular outflow tract, which is formed by the anterior mitral leaflet and the interventricular septum. The trabeculae in the left ventricle are finer, more numerous and situated more towards the apex than they are in the right ventricle. The septal surface and adjacent anterior surface are smooth and, unlike the right ventricle, these surfaces do not have any papillary muscle attachments. The cavity itself is long and circular in cross-section and the interventricular septum bulges into the right ventricle, rendering its cavity crescentic.\(^11\)

The papillary muscles are large and are attached to the anterolateral and posteromedial walls of the left ventricle. The apex is therefore free of any major attachments on the inside and is also thinner than the rest of the walls. On the external surface of the heart, the apex is the tip of the heart where the lateral and inferior margins meet, between the distal end of the left anterior descending artery and its last diagonal branch. This is one of the possible sites for insertion of a left ventricular vent. A left ventricular vent can also be inserted from the right superior pulmonary vein across the mitral valve. In redo situations where peripheral cardiopulmonary bypass is established
prior to sternotomy, a left ventricular vent can be inserted via a left anterolateral thoracotomy to prevent dilation of the left ventricle. This will mainly be in situations with significant aortic regurgitation or when cooling is commenced in complex circumstances where total circulatory arrest may be necessary prior to sternotomy.

### Tips and Anatomical Hazards

Lateral chest X-ray and chest CT scan are extremely useful to assess anatomy prior to redo operations.

A strategy to lift the sternum during sternotomy is useful to minimize the risk of injury to the right ventricle in these situations.

Gradual step-by-step sternal retraction is recommended to avoid right ventricular tears due to stretch from adhesions in a redo operation.

The right ventricle is the most anterior structure of the heart and is therefore prone to injury when hypertrophied and in redo sternotomy settings.

Deep sutures through the supraventricular crest at perimembranous ventricular septal defect closure may cause injury to the right coronary artery.

Left ventricular aneurysms are most often anterolateral (85%). They follow myocardial infarction in left anterior descending artery territory, as a part of either multivessel coronary disease or single-vessel disease (**Fig. 53.2**).

Posterior aneurysms make up 5–10% (**Fig. 53.3**). The rest are either inferior or lateral aneurysms, of which more than 50% are pseudoaneurysms, caused by leak of blood contained within the pericardium. Anterolateral aneurysms are located next to the apex of the ventricle. During repair, they are opened longitudinally along the long axis of the heart, allowing linear closure. Aneurysms should be opened carefully to avoid injury to the papillary muscles, especially posterior or inferior aneurysms. True aneurysms in these areas most often require a circular patch to close the mouth and avoid distortion of papillary muscles, which may cause mitral regurgitation.12
In patients with ventricular septal defects (Fig. 53.4) following myocardial infarction, the left ventricle is incised in the infarcted region. It is most commonly associated with anterolateral infarct and approached via a longitudinal incision just lateral to the interventricular groove. Ventricular septal defect in the posterior septum is usually approached by lifting the apex upwards to expose the posterior surface of the heart and incising the left ventricle in the infarcted area parallel to the posterior interventricular groove. The infarction can be associated with mitral regurgitation from involvement of posterior papillary muscle, requiring concomitant mitral valve surgery. Right atrial and right ventricular surgical approaches, as well as percutaneous device closure, have been reported with successful outcomes; however, they are not routinely applied.
Left ventricular rupture due to myocardial infarction is most often fatal and a postmortem finding. Rarely, it may be manifest as a slow and contained leak forming a pseudoaneurysm, which has to be treated on an urgent or emergent basis due to the high risk of rupture. In these situations, the pseudoaneurysms almost always originate from the posterolateral wall (Fig. 53.5). However, they may track around the lateral aspect and reach under the sternum anteriorly, making sternotomy or sternal retraction dangerous. Establishing peripheral cardiopulmonary bypass using femoral vessels prior to sternotomy may be the only possible approach in such anatomy.15

**FIG. 53.4**  
A, A transthoracic echocardiogram showing an anteroapical ventricular septal defect. B, Colour Doppler reveals flow across this defect with right-to-left shunt. Abbreviations: IVS, interventricular septum; LV, left ventricle; RV, right ventricle; VSD, ventricular septal defect.
Left ventricular free wall rupture as a complication of surgery in case of mitral operations occurs most often in the subanular region. Lifting the heart to localize this area with a rigid prosthesis in situ in the mitral anulus is not recommended for fear of extending this tear. The only way to approach this would be to stop the heart again with cardioplegia, remove the prosthesis and then repair the rupture. In both of these situations, localizing and defining the actual tear may be impossible due to the haematoma in the left ventricular myocardium, which makes it oedematous and extremely friable. Various glues have become very useful in these cases, to cover the area widely and then cover this with a wider patch sutured on to the normal myocardium away from the area of rupture. In patients with a pseudoaneurysm with a small mouth, where the patient is haemodynamically stable, the possibility of percutaneous device closure should be explored.
FIG. 53.2 A transthoracic echocardiogram showing a dilated left ventricle (LV) and an anteroapical aneurysm with apical thrombus. Other abbreviations: LA, left atrium; RA, right atrium; RV, right ventricle.

**Tips and Anatomical Hazards**

Do not attempt direct closure of post-infarct or intraoperative left ventricular tears; use sealants, haemostatic adjuncts with a wide patch sutured to normal myocardium.

Insert a left ventricular vent at the apex between the left anterior descending and diagonal arteries.

Close the vent site at the end before coming off cardiopulmonary bypass between two adequately sized Teflon pledgets using 3-0 or 4-0 polypropylene sutures.

In redo operations, an apical vent may be inserted prior to sternotomy via a small left anterior thoracotomy.

Assess pseudoaneurysms with a CT scan prior to repair; establish peripheral cardiopulmonary bypass prior to sternotomy if this is tracking under the sternum.

Avoid injury to papillary muscles at vent insertion, repair of aneurysms and ventricular septal defects by proper siting of incisions.

Use information obtained on preoperative imaging, especially intraoperative transoesophageal echocardiogram.

Papillary muscles may be injured if a left ventricular vent inserted via
the apex is not sited carefully.
Opening posterior or lateral aneurysms may damage the papillary muscles, especially posteromedial ones.
Sternotomy in pseudoaneurysm repair may be catastrophic if this has tracked around the heart to reach under the sternum.
Posteromedial papillary muscle is prone to injury during posterior post-infarct VSD repair.
A left ventricular apical vent site, if not secured properly, can lead to catastrophic and uncontrollable bleeding.
Coronary vessels

Surgical surface anatomy
The two coronary arteries – namely, left and right – arise from the corresponding aortic sinuses that face the pulmonary trunk. Although named left and right, they are more posterior and anterior in disposition, respectively. The aortic valve occupies an oblique plane and, hence, the posterior left sinus is superior to the anterior right sinus. Therefore, when analysing sequential cardiac cross-sectional imaging such as a CT scan from the head towards the toe, the left coronary origin is encountered first.

Right coronary artery
The right coronary artery, after its origin, almost immediately enters the right atrioventricular groove to encircle the tricuspid valve. Traversing around the acute margin of heart, it reaches the beginning of the posterior interventricular groove. At this point, in 85–90% of hearts, it continues in this groove as one of the terminal branches, the posterior descending artery. Here, it also gives rise to a small branch to the atrioventricular node of the conduction tissue and a posterior left ventricular branch. This left ventricular branch has a typical C-shaped appearance on angiogram in its initial course.

In its proximal part, the right coronary artery gives an infundibular branch towards the right ventricular outflow tract, and the sinus node artery, which traverses on to the right side to reach the sinus node at the junction of the superior vena cava and right atrium. As it courses in the atrioventricular groove anteriorly, it gives off 2–4 right ventricular branches. The lowest of these branches is usually the largest and longest, reaching the apex along the inferior margin of the heart.

Left coronary artery
The left coronary artery runs a short course as a main stem, usually 1–2 cm, as it goes left after its origin, behind the pulmonary artery, before bifurcating into the left anterior descending artery, which courses into the anterior interventricular groove, and the left circumflex artery, which encircles the mitral valve in the atrioventricular groove between the left atrial appendage and pulmonary artery. Together with the right coronary artery, it encircles the heart in the atrioventricular groove. In 10–15% of hearts, it gives rise to the posterior descending artery. This is termed as a left-dominant circulation; a
right-dominant circulation, when the posterior descending artery arises from
the right coronary artery, is more common.

The left anterior descending artery gives lateral branches, the diagonal
arteries, to the anterolateral part of the left ventricle. The left circumflex
artery gives the obtuse marginal branches to the lateral wall of the left
ventricle.

The interventricular septum lies in the plane between the anterior and
posterior interventricular groove, between the left anterior descending artery
and posterior descending artery, which meet each other at the apex, the left
anterior descending most often going around the apex. These two arteries
give off perpendicular septal branches; the anterior two-thirds of the septum
is supplied by the left anterior descending and the posterior one-third by the
posterior descending artery. These characteristics allow their identification
on coronary angiogram.

**Clinical anatomy**

**Variations of orifice in aortic sinuses**

The left coronary orifice is usually quite central in location on the sinus, with
the initial segment of the artery directed posteriorly, leftwards and slightly
inferiorly.

The left coronary orifice is usually single; rarely, left anterior descending
and left circumflex arteries may arise from two different orifices. In contrast,
the right coronary may have two, or rarely three, orifices: one for the main
artery, which is bigger; one for the infundibular artery, which is smaller and
to the left; and rarely, a third one for the sinuatrial node artery on the right. It
is important to be mindful of these while fashioning the right coronary
button during aortic root operations.

The right coronary orifice is usually located more towards the right and the
non-coronary sinus commissure, bringing it too close to the stent of a
bioprosthesi during aortic valve replacement if stents are aligned to the
commissures as usual. One-stitch rotation of the prosthesis towards the non-
coronary sinus will be enough to keep this orifice free without causing any
obstruction to the left coronary orifice, which is usually located centrally on
the left coronary sinus, as mentioned above.

Apart from the distance of the orifice from the commissures, its height
from the anulus is of significance in aortic valve replacements and
transcatheter aortic valve implantation (TAVI). A low or high take-off is based
on the cut-off distance of 6.3 mm from the anulus to the orifice. For the purposes of TAVI, high-risk anatomy was considered to be <10 mm from ventriculo-aortic junction, which is the plane of deployment of this valve. Hence, TAVI valve height has been designed to be up to 7 mm.

Orifices are also found to be closer to the anulus in small aortic roots. Intra-anular placement of the artificial valve is a useful method to avoid coronary occlusion in these cases and may require aortic root enlargement procedures to allow valve placement. These abnormalities of coronary orifices are better identified at CT than catheter-based coronary angiogram (Table 53.1).16

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<tbody>
<tr>
<td><strong>Multiple orifices at origin</strong></td>
<td>Aortic root operations</td>
<td>At aortic root replacement, it is important to create coronary buttons with care to include all the orifices During preparation of the root and dissection down to the aortoventricular plane, identify and clip the smaller branches carefully if they are difficult to preserve If divided flush, eventually these will cause bleeding from the button; any attempt to repair these may distort or further damage the button</td>
</tr>
<tr>
<td>Most often seen with right coronary origin There may be two or three orifices: one major, leading to the main artery; the second orifice is most often to the left, giving rise to an infundibular branch; rarely, a third orifice may give rise to the sinuatrial node artery (50–55%) The left anterior descending and circumflex arteries may have separate origins in the left coronary sinus</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High origin of coronary arteries</strong></td>
<td>Aortic valve and ascending aortic operations</td>
<td>During aortic valve replacement, aortotomy should be performed after looking carefully for a right coronary origin; otherwise this may be too close to the orifice, making closure difficult Care should be taken at the posterior wall to delineate the origin of the left coronary artery while transecting the aorta during ascending aortic replacement Always remember that, due to the oblique plane of the aortoventricular junction, the left coronary orifice is normally higher than the right</td>
</tr>
<tr>
<td>Most often seen with the right coronary artery but can affect the origin of the left coronary artery Associated with aneurysmal dilation, bicuspid aortic valves or post-stenotic dilation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low orifices of coronary arteries</strong></td>
<td>Surgical aortic valve replacement</td>
<td>There is a risk of occlusion of the orifice due to the prosthesis Surgical implantation should be intra-</td>
</tr>
<tr>
<td>The cut-off to ascertain whether high or low is a distance of 6.3 mm from the anulus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
and transcatheter aortic valve implantation (TAVI) rather than supra-anular, so that the sewing ring does not abut the orifice. More common with small aortic roots; an aortic root enlargement procedure may be required. An orifice height of <10 mm from the ventriculo-aortic junction is considered a high risk for TAVI (the ventriculo-aortic junction is the plane of TAVI valve implantation); hence TAVI valves are designed with a height of 7 mm.

<table>
<thead>
<tr>
<th>Orifices close to commissure</th>
<th>Surgical aortic valve replacement</th>
<th>Replacement with a stented biological prosthesis can cause obstruction of the orifice by the stent. One-stitch rotation towards the non-coronary sinus will move the stent position enough to prevent this obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most often, the right coronary orifice is close to the right and non-coronary commissures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcified orifices</td>
<td>Aortic valve and ascending aortic operations</td>
<td>Aortotomy should be well clear of this calcification to allow good closure. Coronary buttons may have to be large so as not to disturb the calcific plaques. Direct coronary cannulation for cardioplegia delivery has to be very gentle, either with a soft balloon-tipped cannula going inside the orifice or a cannula with a soft cup-like end to be applied around the orifice. Dissection of this calcified orifice or dislodgement of calcium into the coronary may necessitate bypass grafts.</td>
</tr>
</tbody>
</table>

Coronary arteries and specific anatomical relevance during operations

In their normal arrangement, the coronary arteries are prone to injury due to their proximity to certain areas where a specific operative step is to be carried out in some operations. These are described in detail in Table 53.2.

**TABLE 53.2**

Possible coronary artery damage in specific operations

<table>
<thead>
<tr>
<th>Surgical anatomy</th>
<th>Operation</th>
<th>Tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior wall of coronary artery</td>
<td>Coronary artery bypass grafts on cardiopulmonary bypass</td>
<td>Prone to injury at arteriotomy. Lift the artery on either side with fine forceps on the epicardium to lift off the anterior wall. Decrease suction at the aortic root vent so that the coronary walls are not sucked in to collapse on each other.</td>
</tr>
</tbody>
</table>
Approach the artery at a 45° angle with a sharp blade: this may be difficult in a deep chest with the artery in the horizontal plane, most often with posterior descending artery. Use repeated strokes at the same site with the ball of a no. 15 blade instead. If injury is seen, extend the arteriotomy generously; repair the posterior wall with multiple 8-0 sutures, two ends going on either side and tied outside. Perform a long anastomosis with a doming roof of the conduit opposite the repair and the toe and heel of the graft well clear of this area.

<p>| Difficult-to-locate coronaries in adhesions | Redo coronary artery bypass grafts or at times in primary operations with adhesions | Delineate and follow previous grafts Palpate atheromatous coronaries and locate relatively soft segments Follow branch coronaries from their distal ends (if seen) |
| Invisible coronary arteries: myocardial bridging/intramyocardial/subepicardial coronaries | Coronary artery bypass grafts | Follow the branch coronaries or the distal ends proximally: this technique works well for the left anterior descending artery There may be a need to open the most distal end and probe to feel deep in the muscle, opening it at an appropriate spot Palpate the atheromatous vessel to locate it In obtuse marginal territory, where the epicardial fat may not be as abundant, the coronary artery can be seen as a whitish pale line under the myocardium |
| Left circumflex artery close to the mitral valve anulus(^\text{17}) (\text{Fig. 53.6}) | Mitral valve repair or replacement | Beware of this, especially in a left-dominant circulation where the artery runs very close to the anulus Preoperative assessment with coronary CT angiogram is used in our unit for assessment in high-risk anatomy Be prepared to use incomplete rings/bands for anuloplasty in these situations Intraoperative transoesophageal echocardiography should be used to demonstrate flow in the left circumflex artery on coming off cardiopulmonary bypass If any doubt, an invasive coronary angiogram should be performed after coming off cardiopulmonary bypass; hybrid theatre facilitates this significantly Corrective measure may involve taking out the complete ring and replacing it with an incomplete ring/band, stenting or grafting the circumflex territory Heightened awareness of this complication is the most important approach |
| Right coronary artery close to the tricuspid valve anulus(^\text{18}) | Tricuspid valve repair or replacement | The right coronary artery runs in the atrioventricular groove and the distal vessels are close to the tricuspid anulus in the region of the posterior leaflet |</p>
<table>
<thead>
<tr>
<th>Condition</th>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinking or obstruction may need percutaneous stenting or a bypass graft</td>
<td>Mitral valve repair</td>
<td>Involved of this artery in myocardial infarction causes acute and severe mitral regurgitation into a normal undilated left atrium, causing flash pulmonary oedema. Emergency mitral valve surgery will be required in this situation.</td>
</tr>
<tr>
<td>Terminal single-vessel supply to the posteromedial papillary muscle of the</td>
<td></td>
<td>Mitral valve repair</td>
</tr>
<tr>
<td>mitral valve</td>
<td></td>
<td>Involvement of this artery in myocardial infarction causes acute and severe mitral regurgitation into a normal undilated left atrium, causing flash pulmonary oedema. Emergency mitral valve surgery will be required in this situation.</td>
</tr>
<tr>
<td>Left main stem posterior to the pulmonary trunk</td>
<td>Ross procedure</td>
<td>After transecting the pulmonary artery at bifurcation, it is lifted off by dissection from the aorta. It is important to delineate the left main coronary artery with meticulous slow dissection posteriorly.</td>
</tr>
<tr>
<td>Large and proximal first septal branch of the left anterior descending</td>
<td>Ross procedure</td>
<td>A high take-off of the first septal branch is at great risk of injury during pulmonary autograft harvest and right ventricular outflow tract reconstruction. Enucleation technique following the plane of the pulmonary artery into the right ventricular outflow tract muscle on the septal aspect is useful to avoid this complication.</td>
</tr>
<tr>
<td>artery: injury can lead to septal myocardial infarction and significant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bleeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aberrant left anterior descending artery across the right ventricular</td>
<td>Repair of tetralogy of</td>
<td>Encountered in 2–9% of cases. Thinning and coring of endocardium from the inside are required, with the use of separate right ventricular and pulmonary artery patches without disturbing the native coronary anatomy. A right ventricle to pulmonary artery conduit may be the most appropriate option in some cases.</td>
</tr>
<tr>
<td>outflow tract</td>
<td>Fallot</td>
<td></td>
</tr>
</tbody>
</table>
Coronary anomalies

Coronary anomalies have been classified by the Center for Coronary Artery Anomalies at the Texas Heart Institute on the basis of: anomalies of origin and course; anomalies of intrinsic coronary arterial anatomy; anomalies of coronary termination; and anomalous collateral vessels. Some 66 different variations are described; however, only one of them, the anomalous origin of the coronary artery from an opposite sinus of Valsalva with an intramural course (in the aortic wall), is considered to increase the risk of ischaemia. This is thought to be primarily due to intermittent compression in the intramural oblique course of the artery from its slit-like origin.\(^{23}\)

In a large review of more than 125,000 patients undergoing coronary angiograms, the incidence of coronary anomalies was found to be 1.3%. Most of them, 81%, were classed as ‘benign’ incidental findings that did not cause any symptoms. These conditions included a separate origin of the left anterior descending and circumflex arteries from the left sinus of Valsalva; an ectopic origin of the circumflex from the right sinus of Valsalva; an anomalous coronary origin from the ascending aorta; an absent circumflex; intercoronary communications; and small coronary arterial fistulae.\(^{24}\) Others
were deemed ‘potentially serious’, needing surgical correction. These are described in more detail in Table 53.3.

### TABLE 53.3
Potentially serious coronary anomalies

<table>
<thead>
<tr>
<th>Anomaly</th>
<th>Surgical anatomy</th>
<th>Manifestations and mechanisms</th>
<th>Management/Tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary artery arising from the pulmonary artery</td>
<td>Anomalous origin of the left coronary artery from the pulmonary artery (Bland–White–Garland syndrome) is the most common type. A right coronary originating from the pulmonary artery is rare. A left anterior descending arising from the pulmonary artery is the rarest.</td>
<td>Blood flows from the normal coronary artery via collaterals into the anomalous coronary artery, eventually draining into the pulmonary artery. This is essentially a left-to-right shunt. Survival beyond infancy depends on the presence of adequate collaterals from the normal to the anomalous coronary. 90% of ALCAPA patients die in infancy. Presentation is with a continuous murmur, angina pectoris, myocardial infarction, heart failure, syncope, sudden death.</td>
<td>The principle of the operation is to obliterate the connection to the pulmonary artery and reconnect the anomalous artery to the arterial side of the circulation. If adequate collaterals are seen, ligation of the left main coronary artery can be performed. This may need supplementation with a bypass graft. A connection is established to the aorta or subclavian artery by reimplantation on the aorta, anastomosis with the left subclavian artery, baffle or tunnelling from the left coronary artery to ascending aorta. The type of repair has to be individualized according to the anatomy and age of the patient.</td>
</tr>
<tr>
<td>Coronary origin from the opposite aortic sinus</td>
<td>Left coronary origin in the right aortic sinus is more common. Classified into five anatomical subtypes based on the relationship to the aorta and pulmonary artery: anterior, between, septal, posterior and combined. The ‘between’ subtype is the most dangerous. A right coronary artery (RCA) origin in the left aortic sinus most often has an anomalous origin anterior to the left coronary orifice, the artery coursing anteriorly between the aorta.</td>
<td>This can cause angina pectoris, syncope, myocardial infarction, ventricular tachycardia or sudden death in the absence of coronary artery disease. Symptoms occur in young.</td>
<td>Diagnosis and a clear understanding of the anatomy are not easy on an angiogram. Cardiac CT has improved anatomical delineation. Cautious imaging may be required, with an exercise test to implicate a cause of the symptoms due to the absence of atheromatous coronary.</td>
</tr>
</tbody>
</table>
and pulmonary artery individuals during physical exercise. Exercise probably results in expansion of the aorta, occluding the angulated slit-like origin of the left coronary artery. If the RCA orifice is located posterior to the left coronary orifice, it courses posterior to the aorta: this may be symptomatic.

### Single coronary artery

**Classification** is based on three anatomical criteria:
(a) **Sinus of origin:** left (L) or right (R)
(b) **Groups I, II or III:** if it follows the anatomical course of either the right or left coronary artery (I); if it arises from the proximal part of either the right or left coronary artery (II); if the left anterior descending and circumflex arteries arise separately from a normal proximal right coronary artery (III)
(c) **Relationship to the aorta and pulmonary artery:** anterior (A), between (B), posterior (P), septal (S) and combined (C)

There is no consensus about whether this is potentially serious: there are reports of the need for bypass grafts in those patients with symptoms. The proposed mechanism is compression of the initial segment of the artery after origin, which is often slit-like, with an intramuscular course in the aortic wall.

Evidence of ischaemia with exercise tests and imaging may be necessary before surgical intervention. Coronary artery bypass grafts have been found most appropriate in reports, given the nature of the branching. Discrete stenosis in one of the major branches may be suitable for percutaneous stent insertion.

### Multiple or large fistulae

Most (60%) arise from the right coronary artery. ‘True’ fistulae are from the normal branching pattern of the coronary artery (7%). Most are from an abnormal coronary artery branching pattern. 90% terminate on the right side of the heart, 40% in the right ventricle, 25% in the right atrium and 20% in the pulmonary artery. Rarely, they terminate on the left side, mostly in the left atrium.

When they terminate on the right side of the heart, they are essentially left-to-right shunts. They present with a continuous murmur, exertional dyspnoea and heart failure.

The symptoms and risk of endocarditis and rupture favour closure of large fistulae. A fistula is closed as near as possible to the entry in the cardiac chamber so as not to compromise the coronary circulation. Device closure should be considered, based on individual anatomy.

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**ALCAPA**, anomalous origin of the left coronary artery from the pulmonary artery.
Venous drainage of the heart

Surgical anatomy
Cardiac venous drainage is divided in two parts. The greater system consists of large veins that are subepicardial, with larger veins present in interventricular grooves eventually draining into the coronary sinus. The coronary sinus lies in the posterior atrioventricular groove; it is 2–3 cm long and drains into the right atrium between the inferior vena cava and tricuspid valve orifice. The main tributaries of the coronary sinus are the great cardiac vein in the anterior interventricular groove, the middle cardiac vein in the posterior interventricular groove, the small cardiac vein, the oblique veins, and the posterior vein of the left ventricle. The coronary sinus can be seen on cardiopulmonary bypass by lifting the heart upwards and to the right, and following the atrioventricular groove posteriorly from the acute angle of the heart. The smaller system is comprised of Thebesian veins and returns blood from subendocardial cells draining directly into cardiac chambers.

Tips and Anatomical Hazards
If any resistance is encountered, insertion should be abandoned. The cannula can be guided by the fingers posteriorly in the atrioventricular groove, as well as by transoesophageal echocardiography. Cannulation is facilitated by insertion when the right atrium is full and under positive venous pressure. The tip of the cannula should be directed towards the patient's left shoulder, following the orientation of the posterior atrioventricular groove. If a purse string is to be used for direct cannulation, it should be placed on the inside of the sinus to avoid injury to conduction tissue. The coronary sinus does not drain some parts of the right and left ventricles. The coronary sinus opening is guarded by a Thebesian valve, which can cover it variably. It is thin-walled and easily damaged. Access to the sinus requires lifting the heart to the right side and may
not be easy.
The coronary sinus receives the venous return from all parts of heart except the anterior region of the right ventricle, and some parts of both atria and the left ventricle, mainly the inferior aspect. Therefore, retrograde cardioplegia, which is delivered into the coronary sinus, can only be used as an adjunct to antegrade cardioplegia in various cardiac operations.

Cannulation of the coronary sinus may not be easy due to a variable Thebesian valve that guards the opening into the right atrium. When insertion is carried out without opening the right atrium, using a purse string on its free wall, digital palpation in the posterior atrioventricular groove and transoesophageal echocardiography can guide the entry of the cannula into the sinus. If insertion is attempted despite some resistance, there is a likelihood of perforation of the coronary sinus and the cannula will be felt outside the heart. The perforation is closed by bringing together neighbouring epicardial fat with a suture or using a pericardial patch.

Direct cannulation of the coronary sinus is possible when the right atrium can be opened; this can be done with or without a purse string in the sinus.

Pressure in the coronary sinus is always monitored during cardioplegia delivery and limited to less than 50 mmHg.²⁸
Access to conduits for grafting

Internal thoracic artery

The left internal thoracic (mammary) artery to the left anterior descending artery is the most reliable bypass graft with excellent long-term patency (Fig. 53.7). Although most cardiothoracic surgeons refer to the artery as the internal mammary artery, internal ‘thoracic’ artery is considered the most appropriate given its localization, its distribution mainly in the interior of the thorax, and the fact that the term is compliant with Terminologia Anatomica.

![Internal thoracic artery](image)

**FIG. 53.7** The left internal thoracic artery harvested in a pedicled fashion together with adjoining veins.

Surgical surface anatomy

The internal thoracic artery descends on the inner surface of the chest wall about 1 cm lateral to the sternal edge, passing behind the first to the sixth ribs. As it courses inferiorly, it follows a slightly oblique course, moving slightly away from the sternal edge.

Clinical anatomy

The internal thoracic artery arises most commonly from the first part of the subclavian artery. It descends behind the medial third of the clavicle and is crossed on its anterior aspect by the subclavian vein before it reaches the first rib. The phrenic nerve crosses the artery in its initial course, usually anteriorly and most often up to 2 cm from the origin, although crossing may happen as much as 4.5 cm from its origin.
The lateral costal branch is a large artery that arises from the internal thoracic artery in 15% of cases, more often on the left side and usually within 3.8 cm of the initial part of the artery. It may give off pericardiacoephrenic branches in its upper medial part.

The internal thoracic artery terminates at the level of the sixth rib, usually by bifurcating into the superior epigastric artery medially and the musculophrenic arteries laterally. Occasionally, it may trifurcate, giving off an additional diaphragmatic branch.

Throughout its course, the internal thoracic artery gives off several sternal branches and, in each intercostal space, perforator branches that supply the anterior chest wall. These branches supply the pectoral and intercostal muscles, breast tissue, subcutaneous tissue and skin. The first intercostal artery is a large branch of the internal thoracic artery.

After median sternotomy, the sternal half on the side to be harvested is lifted up to access the posterior aspect of the thoracic region of the chest wall from inside. The internal thoracic artery is approached from its medial aspect through this incision. In patients undergoing minimally invasive direct coronary artery bypass operation, where the left internal thoracic artery is grafted to the left anterior descending artery via a left anterior thoracotomy, the artery is approached from its lateral aspect, with some difficulty in reaching the desired upper limit of the harvest, which extends up to the division of the first intercostal perforator branch.

The internal thoracic artery can be harvested from either the left or the right side for grafting. Bilateral arteries have been used to achieve total arterial revascularization. The right internal thoracic artery has been used to graft the left anterior descending artery going across the midline. It has also been passed posterior to the aorta and pulmonary artery via the transverse sinus to graft the obtuse marginal artery. As a free graft, it has been used to construct a composite graft with the left internal thoracic artery in a Y-configuration to graft all targets, the left going to the anterior descending artery and the right sequentially to targets on the lateral aspect, often right up to the posterior descending artery.

Skeletonizing the internal thoracic artery can provide 2–3 cm of extra length as compared to the pedicled method; it also preserves the venous supply of the sternum and is believed to cause less devascularization of the sternum. However, the procedure takes longer and there is more likelihood of injury during harvest.
Tips and Anatomical Hazards

Sternal retraction for thoracic artery harvest produces some traction on the vessel due to its origin from subclavian artery, making it easier to develop the plane for its dissection at its proximal end.

In fat-laden tissues and in elderly patients, developing the plane for dissection of the thoracic artery is easier.

Make sure there is enough space between the clip applied to the branches and chest wall.

Apply diathermy close to the chest wall to avoid contact with the clip and hence thermal damage.

If the space is cramped, divide the branch first and apply clips later to avoid thermal injury.

The upper limit of dissection is the subclavian vein, with definite division of the first intercostal artery to avoid a steal phenomenon.

If diaphragmatic contractions are noted during dissection in the proximal part, use fine scissor dissection. Most often, by this time, the artery is harvested well above the first intercostal branch.

While making a pericardial window to obtain a better lie of the artery, clearly visualize the phrenic nerve posteriorly on the pulmonary aspect of the mediastinal pleura close to the pulmonary hilum.

Beware of a large lateral intercostal branch in its proximal part; this is most often the only significant lateral branch of the artery.

If the artery is found to be short after pedicled harvest, further centimetre length can be obtained by partial skeletonization with multiple transverse incisions on the pleural aspect.

If the artery is still short for use, it can be employed as a free graft with proximal anastomosis on the ascending aorta.

The internal thoracic artery in its proximal course can be hanging off the chest wall in the mediastinal pleura, and so is prone to injury while the pleura is opened.

A bony prominence may be encountered on the posterior aspect of the manubrium, with the artery coursing lateral to it. This makes access to the artery difficult and renders the vessel prone to injury.

Chest wall deformities, especially pectus excavatum, may pose a significant obstruction to accessing the artery.
The phrenic nerve is closely related to the proximal course of the internal thoracic artery and may be injured directly or due to thermal energy from diathermy. Trainees in their early learning phase have traditionally been taught to start harvesting the internal thoracic artery from its lower end. However, the retraction of the sternum upwards pulls the artery off the relatively fixed subclavian artery and helps develop the plane for harvesting the internal thoracic artery in its proximal part quite well. Harvesting the artery without clipping its branches provides an opportunity to divide them as close as possible to the chest wall without the diathermy inadvertently contacting the clip, which would cause thermal injury to the vessel. Clips can be applied easily after the internal thoracic artery is off the chest wall. Sometimes, the artery comes off the chest wall so that a considerable part of the proximal vessel is hanging in the mediastinal pleura and in danger of injury while the pleura is opened. Occasionally, the artery can be stuck to the chest wall and is therefore difficult to dissect, especially in lean and young individuals, where tissues are firm and there is less fatty tissue between the various layers. A bony prominence may be encountered on the posterior aspect of manubrium, with the artery coursing lateral to it. This makes access to the artery difficult and renders the vessel prone to injury. Injury to the phrenic nerve can be caused by diathermy during the harvesting of the internal thoracic artery in its proximal part close to the subclavian vein. The nerve may also be injured if the surgeon does not take care to visualize it on the pleural aspect of the pericardium posteriorly towards the lung hilum, and to avoid it while creating a pericardial cut/window for the nerve to lie on the medial aspect of the lung to obtain a satisfactory lie. Use of ice for myocardial preservation has also been implicated in causing cryogenic injury to the nerve, leading to a temporary phrenic palsy.

**Long saphenous vein**

The long saphenous vein is widely used as a conduit for coronary artery bypass grafts. It is the longest vein in the body and is superficially located. Its removal is well tolerated because of the presence of the deep venous system of the lower limbs.
Surgical surface anatomy
The long saphenous vein arises from the inner part of the dorsal venous arch of the foot. It courses upwards anterior to the medial malleolus and along the tibial aspect of the medial calf, to the posteromedial aspect of the knee joint, one hand's breadth posterior to the patella. It then ascends superiorly, in the medial aspect of the thigh, to the fossa ovalis (saphenous opening) in the upper thigh, 4 cm below and lateral to the pubic tubercle. The vein terminates here by draining into the femoral vein. Most often, it is initially exposed at or just above the medial malleolus to start the open harvest (Fig. 53.8).

Clinical anatomy
The long saphenous vein receives two major tributaries in the leg: the anterior vein of the leg and the posterior arch vein (Leonardo's vein) just below the knee joint. In the upper thigh, it receives anterolateral and posteromedial veins, and as it drains into the femoral vein at the fossa ovalis, it receives three tributaries: the external pudendal, inferior epigastric and circumflex iliac veins. Anatomical variations in terms of size, the presence or absence in certain segments of the lower limb, and the distribution of tributaries have all been described. It is essential for the surgeon to assess ultrasonically the calibre of the vessel and to identify parts of its course where it is absent, so that incisions can be planned to avoid these areas, leaving the skin intact (see Fig. 53.8).

Ultrasound assessment of the long saphenous vein most often allows quite
accurate mapping of the vein. The vein is easily localized in the proximal and mid thigh, where it lies within the saphenous compartment outlined by the superficial and aponeurotic deep fasciae of the thigh, producing an appearance in transverse section known as the ‘saphenous eye’ or ‘Egyptian eye’. This arrangement disappears in the upper part of the leg around the knee joint, where the vein is located within a triangle bordered by the tibia, medial gastrocnemius and the fascial sheet between the distal third of the thigh and the proximal third of the calf: the ‘tibio-gastrocnemius angle’ sign. The development of a minimally invasive technique enables harvesting of the long saphenous vein via two or three small incisions along its course. Mapping with ultrasound is very useful with this technique in localizing the vein medial to the knee joint. A small skin incision is made here to expose and encircle the vein; further dissection of the vein is carried out under endoscopic vision after carbon dioxide insufflation.

**Tips and Anatomical Hazards**

Use ultrasound to map the long saphenous vein preoperatively in theatre.

Practise identifying the ‘saphenous/Egyptian eye’ and ‘tibio-gastrocnemius’ signs on ultrasound.

Do not harvest the long saphenous vein from a lower limb affected by peripheral vascular disease, significant oedema or any local skin condition that will impair healing.

If the long saphenous vein has to be used in the presence of significant peripheral vascular disease, harvest the vein from the thigh, preferably with skip incisions.

Double control of tributaries is recommended, with any preferred combination of ties and clips; both have been known to slip, leading to re-exploration for postoperative bleeding.

Endothelial injury can cause thrombosis in these veins, so avoid overdistension, stretching and traction on the vein during harvest.

Gentle handling of the vein is essential, as with any other conduit. Remember that this is the future ‘coronary artery’ of the patient.

When subcutaneous tissue is lacking, the skin incision may inadvertently damage the long saphenous vein. This is especially
important when it is a precious conduit: for example, for redo operations, where the vein may be the only available conduit. Impaired healing and chronic infection leading to limb amputation have been reported after harvesting the long saphenous vein from patients with significant peripheral vascular disease. Although the long saphenous vein is easier to find at the ankle, in patients with scarce subcutaneous tissue, peripheral vascular disease, significant oedema or small varicosities, healing of the skin in the lower third of leg may be impaired, causing wound complications. Locating the long saphenous vein in the thigh can be challenging, especially in overweight patients with abundant subcutaneous fat, where it may be difficult to feel the pubic tubercle, which is the bony landmark. In these situations, vascular ultrasound can be extremely useful in localizing and marking the course of the vein, ensuring correct placement of the surgical incision. In the author's experience, the use of ultrasound enables a decision to be made about where to harvest the vein from the lower limb. Accurate placement of the skin incision prevents undermining the skin and subcutaneous tissue, creating flaps and increasing the chance of poor wound healing and infection.

The long saphenous vein is closely related to the saphenous nerve, a cutaneous sensory branch of the femoral nerve; its branches cross the vein in places. Injury to this nerve or its branches may cause sensory symptoms such as tingling and numbness postoperatively. These symptoms are not limiting in any way but some patients are troubled by them (Fig. 53.9).

FIG. 53.9 The long saphenous vein harvested by the open technique. The saphenous nerve crosses the vein.

Radial artery
The radial artery located in the forearm is a frequently used arterial conduit after the left internal thoracic artery. Its superficial location, good length and the opportunity to harvest it simultaneously with the internal thoracic artery and long saphenous vein make it a useful artery for coronary artery bypass grafts. It is a muscular artery that is easy to handle and it resists kinking. However, being a muscular artery, it is very prone to spasms that can cause significant postoperative problems with ischaemia. Harvesting it as a pedicled graft with its venae comitantes, the use of a harmonic scalpel with gentle handling, and the postoperative prescription of arterial dilators like calcium channel blockers have all made it a more acceptable graft when compared to initial experience with this conduit (Fig. 53.10).

**FIG. 53.10** Radial artery harvest. **A**, The left hand is gently retracting the ‘mobile wad of three’. **B**, The radial artery with its venae comitantes is being dissected using a harmonic scalpel. **C**, The radial artery is ready for division at both ends. (Courtesy of Mr V. Aronica, Surgical Care Practitioner and Mr S.K. Naik, Consultant Cardiac Surgeon, Trent Cardiac Centre, Nottingham, UK.)

**Surgical surface anatomy**

The radial artery starts just medial to the tendon of biceps brachii. It runs almost in a straight line, from the medial side of the neck of the radius to the wrist, with a gentle curve along the medial border of the upper part of brachioradialis. At the wrist joint it crosses the scaphoid bone and trapezium (in the anatomical snuff-box), where its pulsation may be palpated. It
terminates by dividing into branches that will ultimately anastomose with branches of the ulnar artery and complete the superficial and deep palmar arches.

There are two important landmarks on the flexor aspect of the proximal part of forearm: the prominent tendon of biceps brachii and a lateral, mobile muscular prominence that can be pinched between thumb and fingers, the ‘mobile wad of three’, consisting of brachioradialis, flexor carpi radialis longus and flexor carpi radialis brevis. The landmarks for incision for radial artery harvest are the tendon of biceps brachii, the mobile wad of three and the radial styloid. The incision starts a finger's breadth lateral to the insertion of the tendon of biceps brachii and follows the gentle curve of the prominence of the mobile wad in the upper forearm. It then straightens out in mid-forearm to reach just above the wrist medial to the styloid process of the radius, where the radial pulse can usually be palpated.33

The endoscopic approach to harvesting radial artery is now available, using either a single incision above the wrist or the addition of another incision in the antecubital fossa (to gain proximal control).

Clinical anatomy

The most important factor in harvesting the radial artery is to make sure that the ulnar collateralization across the superficial and deep palmar arches is adequate to prevent any ischaemic complications following removal of the radial artery. This is assessed by Allen's test preoperatively, where return of colour to the hands and fingers within 5 seconds of releasing the ulnar artery is considered normal.34 The reliability of this test has been questioned: a negative test is considered safe to proceed, whereas a positive test should prompt further assessment with other tests such as Doppler ultrasound and digital plethysmography.35

The upper extent of the dissection is the radial recurrent artery, which is given off by the radial artery just distal to the elbow joint, approximately 1 cm distal to the bicipital aponeurosis; it turns upwards and supplies muscles on the radial side of the forearm. The distal limit is the superficial palmar artery, which arises from the radial artery just before it curves round the carpus at the wrist and which usually anastomoses with the end of the ulnar artery to complete the superficial palmar arch.

The two important nerves in close relation to the radial artery are the lateral antebrachial cutaneous nerve in the proximal and middle parts of the
forearm and the superficial branch of the radial nerve in the middle part of the forearm.

**Tips and Anatomical Hazards**

Perform Allen's test preoperatively using a saturation probe, which is more objective than return of colour.

Lateral retraction of the ‘mobile wad of three’ will expose the proximal part of the radial artery. This retraction should not be vigorous to avoid stretching the lateral antebrachial cutaneous nerve.

Dissection of the radial artery as a pedicle with its venae comitantes ensures maintenance of a safe distance from the artery to mitigate the risk of spasm.

Stay close to the venae comitantes, especially in the mid part of the artery, where the superficial branch of the radial artery is in close proximity.

Limit the extent of the proximal dissection to the radial recurrent branch, and that of the distal dissection to just proximal to the superficial palmar branch.

Meticulous haemostasis should be performed at the end, without closure of the fascial layer.

Put in place a protocol to observe perfusion of the hand postoperatively. Do not hesitate to open the incision in an emergency if compartment syndrome is suspected.

Harvesting the radial artery with an inadequate collateral supply from the ulnar artery will lead to disastrous ischaemia of the hand.

Division of the proximal branch of the radial recurrent artery may cause ischaemia in the extensor compartment and around the elbow.

Dissection very close to the radial artery may induce severe spasm, making it unsuitable for grafting.

Closure of the fascia of the flexor compartment is a recipe for compartment syndrome.

Dissection of the radial artery should always be outside its venae comitantes. The artery is very prone to spasm because it is a muscular blood vessel and so a low-energy source should be used to harvest the vessel. One of the most satisfactory instruments is a harmonic scalpel,
which uses ultrasound.
Harvesting the radial artery proximal to the origin of the radial recurrent artery or injury to the radial recurrent artery can cause significant ischaemia in the extensor compartment.
The self-retaining retractor used to retract brachioradialis laterally should not overstretch the tissues because this can damage the lateral antebrachial nerve with neurological sequelae (loss of sensations and tingling) on the lateral aspect of forearm. The superficial branch of the radial nerve is closely related to the artery in the mid part of the forearm, where it may be damaged by scissors, diathermy or the harmonic scalpel during dissection, resulting in tingling and numbness on the radial aspect of the dorsum of the hand.
Meticulous haemostasis is extremely important to prevent compartment syndrome caused by haematoma after closure of the incision. To avoid this complication, closure should be limited to the subcutaneous tissue and skin without involving the fascia.
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Single Best Answers

1. A 72-year-old male had undergone coronary artery bypass grafts using the left internal thoracic artery 3 months ago for angina on exertion on walking uphill and climbing a flight of stairs. He had no other symptoms. Following his recovery with excellent wound healing, he has developed shortness of breath. He does not experience any angina on exertion, but exertion is always associated with dyspnoea. A postoperative echocardiogram has shown preserved good left ventricular function. What is the probable cause of his shortness of breath?
   A. He has developed obstructive lung disease
   B. His left hemidiaphragm is likely to be high on chest X-ray
   C. He may be in heart failure
   D. He is exerting himself too much

Answer: B. His exertion level is the same as in the pre-symptomatic stage without any angina and therefore his revascularization is satisfactory. Left ventricular function is good on echocardiogram, suggesting he does not have heart failure. It is very unlikely that this patient suddenly developed obstructive lung disease. The left internal thoracic artery has been harvested as a conduit and there is a likelihood of left phrenic nerve palsy due to phrenic nerve injury. This will show a raised left hemidiaphragm on chest X-ray.

2. A 78-year-old male with diabetes and osteoporosis was undergoing a coronary artery bypass graft operation with three-vessel disease requiring triple bypass grafts. He did not have any varicose veins and Allen's test was positive on both sides. He had undergone right above-knee amputation in the past after a road accident. While harvesting the left long saphenous vein, it was noted that the calibre of the vein suddenly decreased after an
initial 5 cm working up from the ankle. The surgeon was taking the left internal thoracic artery with minimum sternal retraction. What should the intraoperative strategy be in this situation?

A. Continue to extend the incision upwards, even if the vein does not look usable in the leg
B. Use the available vein, even if it is small in calibre
C. Assess the vein in the thigh with ultrasound
D. Leave the two other target vessels and accept incomplete revascularization

**Answer: C.** Although the incision can be extended without knowing the vein calibre or anatomy, it is not desirable, and will cause pointless surgical trauma in a diabetic patient. Using a poor-quality vein should be avoided as much as possible, especially here when the upper segments of the vein have not been explored. The patient does not have any varicosities, so there is a likelihood of a good-quality vein. Segments of the long saphenous vein can be underdeveloped or absent, with reformation upstream, and therefore the possibility of full revascularization should not be dismissed until the vein is fully assessed. Ultrasound in the upper thigh, starting at the fossa ovalis, 4 cm below and lateral to pubic tubercle, will help delineate and assess the vein before deciding on incomplete revascularization.

3. A 47-year-old non-diabetic, non-smoking female had undergone coronary artery bypass grafts using the left internal thoracic and left radial arteries after ensuring a satisfactory Allen's test. She was being seen in follow-up clinic at 8 weeks postoperatively. Her exercise tolerance had improved significantly. However, she had noticed tingling and numbness on the lateral aspect of her left forearm. The surgical care practitioner who had harvested the radial artery was very experienced and an expert in this
procedure. The only difficulty encountered was a slightly bulky brachioradialis muscle near the elbow. What do you think is the cause of this sensory symptom?
A. Forceful application of the retractor on brachioradialis
B. Loss of blood supply to the area due to radial artery harvest
C. Median nerve injury
D. Radial nerve injury at the wrist

**Answer: A.** Direct injury to the radial and median nerves is very unlikely during radial artery harvest because these nerves are not immediately related to the artery. This is especially so with an experienced expert operator who is likely to adhere to the correct planes of dissection with good handling of tissues. Allen's test was satisfactory preoperatively, so inadequate blood supply is unlikely. In this patient, brachioradialis had to be retracted with more force than usual and this can cause stretching of the lateral antebrachial cutaneous nerve, which can lead to sensory symptoms.

4. A 70-year-old female with short stature was undergoing mitral valve repair in theatre for severe mitral regurgitation with good left ventricular function. A ring anuloplasty was done after repairing the valve with creation of neo-chordae without any difficulty. On weaning the patient off cardiopulmonary bypass, the valve repair looked satisfactory on transoesophageal echocardiogram and there was no major bleeding. However, left ventricular function had deteriorated significantly, despite diligent myocardial preservation, and did not respond to an increase in inotropes. What should be the foremost thought in the surgeon's mind as to the cause of this dysfunction?
A. Post-cardioplegia stunning of heart
B. Inadequate inotropic support while weaning off cardiopulmonary bypass
C. Injury to the left ventricle
D. Kinking or occlusion of the left circumflex artery

**Answer: D.** The mitral valve repair seems to have gone smoothly without any problems and with good myocardial protection. The dysfunction is therefore less likely to be due to stunning of the myocardium, inadequate inotropes or injury to the left ventricle, especially since there was no bleeding. The left circumflex artery runs close to the mitral anulus and is prone to distortion or occlusion. This is a remediable cause and should be foremost in the surgeon's mind in planning the next steps to confirm this as the cause and to treat it.

5. An angiogram was being performed in a 64-year-old female with exertional angina with good left ventricular function. Right coronary injection had revealed a non-dominant small coronary artery. Left coronary injection with the catheter just at the left main stem ostium only revealed the left anterior descending artery with minor coronary artery disease, which did not explain the patient's symptoms. The left circumflex artery was not seen on left coronary injection. What should the operator suspect as a cause of this finding?

A. The left circumflex artery must be congenitally absent
B. The left anterior descending and circumflex arteries may have separate orifices
C. The left circumflex artery must be occluded at the orifice flush with the left main stem lumen
D. The catheter must have occluded the artery so that the dye only went into the left anterior descending artery

**Answer: B.** The catheter was engaging only the ostium and was not advanced too far into the left main stem. Therefore it is unlikely to go selectively into the left anterior descending artery,
bypassing or obstructing the ostium of the left circumflex artery. Given the smooth lumen of the left main stem, ischaemic heart disease causing complete cut-off is very unlikely. There is good left ventricular function and the right coronary artery is non-dominant. There has to be some blood supply to the circumflex and right coronary arterial territories. Two separate orifices of the left anterior descending and circumflex arteries are known; hence, efforts should be made to locate and cannulate the circumflex orifice.
Clinical Case

1. A 78-year-old female with severe aortic stenosis was undergoing a minimally invasive aortic valve replacement. Preoperative assessment had shown moderate coronary artery disease in the mid right coronary artery, which was deemed non-critical and hence not destined for bypass graft. The rest of the coronary arteries showed minor irregularities only. Left ventricular function was normal with hypertrophy. Pulmonary function and carotid Doppler were normal. She had a normal build with an upper-normal body mass index and a body surface area of 1.6 m\(^2\). A preoperative CT aortogram had shown calcification on the aortic valve as expected but no other major abnormality. The vena cavae were normal.

An upper mini-sternotomy was performed into the third right intercostal space with good ascending aortic exposure. After heparinization, satisfactory cardiopulmonary bypass was established using ascending aortic cannulation and transoesophageal echocardiogram (TOE)-guided venous cannulation via the right femoral vein, with a two-stage cannula advanced into the superior vena cava. A main pulmonary artery vent was inserted. The ascending aorta was soft on palpation; TOE confirmed significant aortic valve calcification extending into the anulus. There was no aortic regurgitation. An aortic cross-clamp was applied and aortotomy was performed to expose the valve after achieving rapid diastolic arrest of the heart by delivering aortic root cardioplegia. There was significant atheroma surrounding both the left and the right coronary orifices with overhanging shelf-like calcification.

The aortic valve was extremely difficult to excise due to the calcification. The aortic anulus was very hard with calcification and required debridement. There was significant calcification in the subvalvular plane in the mid portion of each sinus. The aortic anulus could accommodate only a size 21 mm bioprosthesis, which was implanted using pledgeted sutures in supra-anular position.

Throughout the procedure, care was taken that the atheroma around the coronary orifices was not damaged, with careful delivery of ostial cardioplegia for maintenance dose using soft balloon-tipped ostial cannulae.

After closure of the aortotomy, the patient was weaned successfully off cardiopulmonary bypass without any problems. TOE revealed good left and
right ventricular function. However, significant para-valvular leak was noted on the non-coronary sinus aspect. Therefore, an aortic cross-clamp was applied again and the aortotomy was reopened after stopping the heart with antegrade aortic root cardioplegia. The para-valvular leak site was identified and repaired. The aortotomy was closed again. At this point, it was noted that the prominent shelf of atheroma above the left coronary orifice was no longer there. Washing with saline was repeated and the aortotomy was closed.

The patient was weaned off cardiopulmonary bypass again. However, a few minutes later, inotropid support had to be commenced and increased. It was evident on TOE that, although the para-valvular leak had been corrected, left ventricular function was depressed in the anterior and lateral territory.

These changes, in the context of the atheroma above the left coronary orifice that had disappeared, prompted a decision to perform bypass grafting. Cardiopulmonary bypass was re-established. The incision was extended to full sternotomy and the long saphenous vein was harvested. Bypass grafts were performed to all the three territories of the left anterior descending, left circumflex and right coronary arteries.

Cardiopulmonary bypass was weaned off successfully with good ventricular functions after this and the patient recovered well on intensive care and later on the ward. Postoperative sternal instability was managed with vacuum dressings. The patient has been seen in follow-up with good recovery and normal biventricular function.

An appreciation of the anatomy around the aortic valve and at the coronary orifices, and the presence of moderate disease in the right coronary artery, allowed a logical thought process and decision-making intraoperatively.
SECTION 7
Abdomen

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CHAPTER 54
Overview of the abdomen

Jennifer Li, Sam M Wiseman

This chapter is an overview of the surgical anatomy of the abdomen, the region of the body that is located between the thoracic diaphragm and the pelvic inlet. It is bounded by muscular layers of the abdominal wall and by the peritoneum, and contains the majority of the hollow organs of the gastrointestinal tract, as well as several solid organs. These organs play critical roles in digestion, metabolism and endocrine regulation, and are potential sites of significant pathology that causes clinical disease. Good knowledge and understanding of abdominal anatomy is important in aiding surgeons and other healthcare professionals in the diagnosis and treatment of a vast array of medical conditions.
Anterior abdominal wall and inguinal canal

Anterior abdominal wall

Nine layers make up the anterior abdominal wall: skin, subcutaneous tissue, superficial fascia (Camper's anteriorly and Scarpa's posteriorly – their approximation aids with skin alignment during closure of surgical incisions in the lower abdomen), external oblique, internal oblique, transversus abdominis, transversalis fascia, preperitoneal fat and peritoneum (Fig. 54.1). Of the three aforementioned flat abdominal wall muscles, external oblique is the largest and transversus abdominis is the smallest. In the midline, the anterior abdominal wall is composed of the rectus abdominis and pyramidalis. Formed by the bilaminar aponeuroses of the three flat muscles, the rectus sheath envelops the rectus abdominis anteriorly and posteriorly superior to the arcuate line (linea semicircularis of Douglas). Inferiorly, the aponeuroses of internal oblique and transversus abdominis pass anterior to rectus abdominis, which is therefore bordered posteriorly only by the transversalis fascia. Spigelian hernias and arcuate line hernias may develop at the intersection of these fascial layers, which is a potential weak spot in the abdominal wall. The decussation of the rectus sheath in the midline forms the linea alba, where the most common surgical incision, the midline incision, is created. When present, pyramidalis may serve as an accurate intraoperative landmark for the linea alba (the muscle is absent in 10–20% of people on one or both sides). In patients with complex ventral hernias who have insufficient abdominal wall for adequate abdominal closure, incision of the external oblique fascia parallel and just lateral to the edge of rectus abdominis (component separation) facilitates repair.¹
The arterial supply of the anterolateral abdominal wall arises from the last six intercostal and four lumbar arteries, superior and inferior epigastric arteries, and deep circumflex iliac arteries. Branches of the superior epigastric artery penetrate the anterior rectus sheath to supply the overlying skin. They are located in close proximity to the lateral borders of the rectus abdominis and may bleed if incisions are placed off the midline. When possible, old incisions should be reused in order to avoid necrosis from ischaemia to specific abdominal wall segments. The abdominal wall venous drainage follows its arterial supply.

**Inguinal canal**

The lower portion of the external oblique aponeurosis rolls posteriorly and superiorly to form a groove that extends from the anterior superior iliac spine to the pubic tubercle, and is referred to as Poupart's ligament or the
inguinal ligament. The femoral artery, vein and nerve pass posterior to the inguinal ligament (Fig. 54.2). Femoral hernias are located inferior to the inguinal ligament, and inguinal hernias are located superiorly. The external oblique also serves as the anterior boundary of the inguinal canal, which is about 4 cm in length and extends between the deep (internal) and superficial (external) inguinal rings. Superiorly, the inguinal canal is bounded by the musculo-aponeuroses of the internal oblique and transversus abdominis, and inferiorly by the inguinal and lacunar ligaments. Occasionally, the obturator artery arises from the inferior epigastric artery and travels along the posterior aspect of the lacunar ligament; care must be taken during femoral hernia repair to avoid division of the lacunar ligament to facilitate reduction, as haemorrhage will result. The floor of the canal (often considered the most anatomically and clinically important) is composed of the aponeurosis of transversus abdominis and the transversalis fascia. The region bounded between the rectus sheath medially, the inferior epigastric vessels superolaterally and the inguinal ligament inferiorly is referred to as Hesselbach’s triangle, within which direct inguinal hernias occur. Indirect inguinal hernias arise lateral to this triangle. The inguinal canal contains the spermatic cord in men and the round ligament of the uterus in women. Important sensory nerves in the inguinal region include the ilioinguinal and iliohypogastric nerves, and the genital branch of the genitofemoral nerve. Entrapment or damage to these nerves during hernia repair may contribute to the development of postoperative chronic pain. For patients with intractable chronic pain after hernia repair, triple neurectomy, or excision of all three major nerves, has been reported to have a success rate of 80% to 95%.3–4
FIG. 54.2 The structures of the inguinal canal. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 61.16.)
Posterior abdominal wall and retroperitoneum

Posterior abdominal wall

The posterior abdominal wall is muscular and supports the retroperitoneal organs, as well as the abdominal aorta and the inferior vena cava (IVC). Its principal muscles include the psoas (major and minor) medially, quadratus lumborum laterally, the diaphragm superiorly and iliacus inferiorly (Fig. 54.3). Lumbar hernias may occur in areas where the lumbodorsal fascia is weak: they are not prone to strangulation. The posterior abdominal wall contains the lumbar plexus, including the iliohypogastric, ilioinguinal, genitofemoral, femoral and obturator nerves, the lateral cutaneous nerve of the thigh, and the lumbosacral trunk.
Retroperitoneum

The retroperitoneal space lies between the peritoneum and the posterior parietal wall of the abdominal cavity. Structures that lie behind the peritoneum are described as being retroperitoneal and include the adrenal glands, kidneys, ascending and descending colon, duodenum (except for the proximal portion, which is intraperitoneal) and pancreas. The retroperitoneum is also traversed by the ureter, renal and gonadal vessels,
aorta and IVC. The abdominal aorta emerges from an opening in the diaphragm in the midline at the level of T12 and it divides into the right and left common iliac arteries at the level of L4. Its branches include the unpaired, anterior midline coeliac trunk, superior mesenteric artery (SMA) and inferior mesentery artery (IMA), and the paired middle adrenal arteries, renal arteries and the testicular or ovarian arteries, which branch laterally from the aorta. Posteriorly, it also gives off the inferior phrenic, lumbar and median sacral arteries. Bowel ischaemia is a rare but serious complication that may occur after abdominal aortic aneurysm repair and can be caused by both occlusive and non-occlusive mechanisms. The duodenum passes between the SMA anteriorly and the aorta posteriorly, a relationship that may lead to abdominal pain, as seen in SMA syndrome. The IVC is longer and larger in calibre than the abdominal aorta. Its main tributaries include the common iliac veins, lumbar veins, right testicular or ovarian vein (versus the left-sided equivalent veins that drain into the left renal vein), renal veins, right adrenal vein, inferior phrenic veins and hepatic veins. The left renal vein is located in close proximity to the splenic vein and may be used to construct a splenorenal shunt for treatment of portal hypertension.
**Peritoneum, mesenteries and peritoneal cavity**

The abdominal cavity is lined with the peritoneum, which is composed of a layer of mesothelium supported by a thin layer of connective tissue stroma, and is divided into parietal and visceral components. The parietal peritoneum covers the abdominal wall surfaces and the inferior diaphragm and the pelvis, whereas the visceral peritoneum covers the intra-abdominal organs (stomach, jejunum, ileum, transverse colon, liver and spleen) and serves as a conduit for their blood vessels, lymphatics and nerves. It also covers the anterior surface of the retroperitoneal organs. The double-layered extensions of peritoneum passing from the stomach and proximal part of the duodenum towards adjacent organs form the greater and lesser omenta. The greater omentum includes the gastrocolic, gastrosplenic and gastrophrenic ligaments, and the lesser omentum is composed of the hepatoduodenal and hepatogastric ligaments. The greater omentum is supplied by the right and left gastroepiploic arteries, which are branches of the coeliac trunk.

The peritoneal ligaments and mesenteric reflections in adults further divide the abdomen into nine potential spaces, including the right and left subphrenic, subhepatic, supramesenteric and inframesenteric, right and left paracolic gutters, pelvis and lesser sac (omental bursa), which is connected to the greater sac through the omental (epiploic) foramen. The direction of fluid flow within the different peritoneal ligaments and spaces has important clinical significance, as it predicts the direction of the spread of infectious and malignant disease within the abdomen. Recent work has challenged this traditional surgical anatomical multiple ‘mesenteries’ perspective, is evidence-based, and is based upon the mesentery being a single and continuous organ.
Abdominal oesophagus and stomach

Abdominal oesophagus

The oesophagus is a bilayered muscular tube, usually 25–30 cm long, which may be divided into cervical, thoracic and abdominal portions. The abdominal portion emerges from the oesophageal hiatus of the diaphragm at approximately the T11 level and ranges in length from 0.5 cm to 2.5 cm. It is surrounded anteriorly by the posterior surface of the left lobe of the liver, the left vagal trunk and the oesophageal plexus, and posteriorly by one or both crura of the diaphragm, the left inferior phrenic artery and the aorta. To its right side is the caudate lobe of the liver, and to its left side is the fundus of the stomach. The arterial supply of the abdominal oesophagus primarily arises from branches of the left gastric and left inferior phrenic arteries. Venous drainage occurs through the left gastric and left inferior phrenic veins. The oesophagus enters the abdomen at the site of the lower oesophageal sphincter, a specialized distal oesophageal segment with a circular muscular layer that accounts for 90% of the basal pressure at the gastro-oesophageal junction. The histological junction between the oesophagus and stomach is referred to as the squamocolumnar junction (z line), where the stratified squamous epithelium of the oesophagus transitions into the simple columnar epithelium of the stomach. Endoscopically, the transition from smooth oesophageal lining into prominent gastric rugae may also be used to identify the gastro-oesophageal junction. This is where the premalignant change of Barrett's oesophagus, which develops due to gastro-oesophageal reflux, occurs.

Stomach

The stomach lies within the upper abdomen. It is bounded superiorly by the diaphragm, laterally by the spleen and anteriorly by the left lateral segment of the liver. Inferiorly, the stomach is attached to the colon, spleen and caudate lobe of the liver. The cardia, the most proximal portion of the stomach, is the site where the oesophagus empties into the stomach and lies immediately below the z line of the gastro-oesophageal junction. The fundus is the most superior portion of the stomach. The body is the main central portion of the stomach and is delineated by the lesser and greater curvatures. Distally, the pylorus connects the antrum of the stomach to the proximal duodenum. From a surgical standpoint, the stomach may be divided into the
proximal gastric unit, which includes the distal oesophagus and proximal stomach, and the distal gastric unit, which includes the gastric antrum, pylorus and first part of the duodenum. Malignancies arising within these two different units require different types of operative procedure.

The four main arteries that supply the stomach are the left and right gastric arteries running along the lesser curvature, and the left and right gastroepiploic arteries running along the greater curvature (Fig. 54.4). All four arteries arise from the coeliac trunk. The left gastric artery is the largest; in 15–20% of people it gives rise to an aberrant left hepatic artery. Additional blood supply is provided by the inferior phrenic and short gastric arteries (the latter are branches of the splenic artery). The stomach can survive after ligation of all but one of its four main arteries. Venous drainage follows the arterial supply. Lymphatic drainage includes nodes located within the inferior gastric, splenic, superior gastric and hepatic zones.

FIG. 54.4  The arterial blood supply of the stomach. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 64.9.)
Small intestine

The small intestine extends between the pylorus and the caecum. It measures from 270 cm to 300 cm in length and consists of the duodenum, jejunum and ileum. From external surface to lumen, the walls of the small intestine consist of serosa, longitudinal and circular muscle, submucosa and mucosa. The submucosa, a highly vascularized layer of connective tissue, is the strength layer of the small intestinal wall, holding sutures and staples; inclusion of this layer is therefore important when constructing an intestinal anastomosis.

The duodenum is divided into four portions. The first/ascending portion passes upward from the pylorus toward the gallbladder and becomes retroperitoneal distally. The second/descending portion is located posterior to the transverse mesocolon, and its left border is attached to the head of the pancreas. The common bile duct and pancreatic duct drain into this portion of the duodenum. The third portion turns left, passes upward and crosses posteriorly to the SMA and superior mesenteric vein (SMV). The fourth/ascending portion passes upward and ends at the duodenojejunal flexure, which is supported by a peritoneal fold (the ligament of Treitz), which serves as an important landmark separating the upper and lower gastrointestinal tracts (Fig. 54.5).
The remainder of the small intestine consists of the jejunum (proximal two-fifths) and the ileum (distal three-fifths). Although no clear anatomical landmark separates them, the jejunum is slightly larger in calibre and its mesentery has fewer vascular arcades with long, straight vasa recta, whereas the ileum has numerous vascular arcades with shorter vasa recta. The wall of the small intestine is seen to possess transverse folds, plicae circulares, which may be appreciated on imaging, and help to distinguish it from the colon. The vascular, neural and lymphatic supply of the small intestine travels through its mesentery. Except for the proximal duodenum, which is supplied by branches of the coeliac trunk, the small intestine is entirely supplied by the SMA. Its branches give rise to arcades that give off the vasa recta, which directly penetrate the intestinal wall. Because there are no collaterals between the vasa recta at the surface of the intestine, the best supply of blood is along its mesenteric border, and the poorest blood supply is along its antimesenteric border. For this reason, small intestinal anastomoses are usually constructed on the antimesenteric side in order to preserve the blood supply of that segment of intestine maximally and so promote anastomotic viability. Venous drainage of the small intestine follows the arterial supply: typically, the SMV joins the splenic vein to form the portal...
vein.
Colon and rectum

The colon connects the terminal ileum to the rectum and is about 150 cm in length. The colonic wall is composed of the same layers as the small intestine, except that the longitudinal muscular layer in the colon exists in three discrete bands (taeniae coli). At areas of weakness in the wall, where small arterioles penetrate the muscular layers, an abnormal outpouching of the wall may occur, with protrusion of the mucosa and submucosa between the layers of muscle. This is referred to as a pseudodiverticulum (false diverticulum) because it does not involve all the layers of the colonic wall. Diverticulitis occurs when pseudodiverticuli become inflamed and perforate.

The most proximal portion of the colon is the caecum, a sac-like segment that has an average diameter of 7.5 cm and a length of 5–10 cm. At the caecal base, the appendix originates approximately 3 cm below the ileocaecal valve and appears as a blind-ending tube. Even though its origin is fairly constant, the distal end of the appendix may be found in a variety of positions. Intraoperatively, it can be found at the convergence of the taeniae coli, or by identifying the bloodless fold of Treves, which marks the junction of the ileum and caecum. The remainder of the colon is separated into the ascending colon, transverse colon, descending colon and sigmoid colon. The ascending colon and descending colon are attached to the retroperitoneum posteriorly and covered with peritoneum anteriorly. In the event of incomplete fusion and persistent mesocolon, a volvulus may occur. Volvulus accounts for up to 30% of large bowel obstructions; the sigmoid colon is affected more frequently than the right colon. The fusion of the mesentery with the posterior peritoneum leads to the development of the white line of Toldt, an important landmark that is commonly exploited by the surgeon when mobilizing the colon from the retroperitoneum during colectomy. The transverse colon is the colonic segment that begins at the hepatic flexure, just beneath the right lobe of the liver, and ends at the splenic flexure; it often exhibits a sharp upward then downward bend adjacent to the spleen. The descending colon is smaller in diameter than the ascending colon; it transitions into the thicker and more mobile sigmoid colon, which is attached to a longer and more redundant mesentery. During sigmoid and left colectomy, the left ureter must be carefully identified and preserved. One important landmark that facilitates the identification of the ureter is the intersigmoid fossa, a small recess in the mesentery that is formed by the attachment of the mesosigmoid to the left pelvic side wall.
The rectum is 12–15 cm in length and passes through the levator ani to become the anal canal. The transition between the sigmoid colon and rectum has been described in several ways. In general, it occurs at the level of the sacral promontory, though the point at which the taeniae coli converge has also been used to identify the transition.

The ileocolic and right colic arteries, branches of the SMA, supply the caecum and ascending colon. The middle colic artery, also a branch of the SMA, supplies the transverse colon. The splenic flexure is supplied by the middle colic artery in approximately one-third of cases; more commonly, it is supplied by the left colic artery, which is a branch of the IMA. The left colic artery also supplies the descending colon. The IMA branches into the sigmoid arteries to supply the sigmoid colon, before terminating as the superior haemorrhoidal (rectal) artery of the rectum. The remainder of the rectal blood supply comes from the middle rectal artery, a branch of the internal iliac artery, and the inferior rectal artery, a branch of the pudendal artery. The venous and lymphatic drainage follows the arterial anatomy. Of note, the superior rectal veins drain into the portal venous system, and the middle and inferior rectal veins drain into the systemic venous circulation. This bidirectional drainage explains observed differences in the pattern of metastatic spread of anorectal cancer based on the specific location of the primary tumour: cancers of the proximal rectum will initially metastasize to the liver, whereas pulmonary metastases are more commonly diagnosed in the setting of cancers that are located within the distal rectum or anal canal.
Liver

The liver is located in the right upper quadrant beneath the diaphragm, and the thoracic cage protects much of its surface. It is invested in peritoneum, except for the gallbladder fossa, porta hepatis and the bare area on the posterior surface adjacent to the IVC. The liver is attached to the anterior abdominal wall and the inferior surface of the diaphragm by the falciform and coronary ligaments. The ligamentum teres (obliterated umbilical vein) runs along the free edge of the falciform ligament. The latter has historically been used as a landmark to divide the liver into the left and right lobes. On the left side, the two leaves of the coronary ligament join to form the left triangular ligament, and on the right side, they form the right triangular ligament. At the porta hepatis, the lesser omentum is divided into the hepatogastric and hepatoduodenal ligaments. The portal triad of the hepatic artery, portal vein and common bile duct is contained within the right margin of the lesser omentum. The posterior surface of the liver straddles the IVC; to its left is the caudate lobe, which is bounded on its other side by a fissure that contains the ligamentum venosum (remnant of the ductus venosus of the fetal circulation). In relation to other organs, the right lobe of the liver is closer to the hepatic flexure of the colon and to the right transverse colon. The bare area of the liver is in contact with the right adrenal gland. The gallbladder fossa is located just beneath the anterior inferior border of the liver; the fossa of the IVC is posterior to the gallbladder fossa. The first and second parts of the duodenum are also located in close proximity to the gallbladder. On the left side, the stomach is in contact with the left lobe of the liver. The liver may also be separated into the right and left lobes, based on the portal and hepatic vein branches (Fig. 54.7). Cantlie’s line (portal fissure), which runs from the middle of the gallbladder fossa to the IVC, divides the liver into the right and left lobes. The right lobe may be further divided into anterior and posterior segments, and the left lobe divided into the left medial and the left lateral segments. Each segment of the right and left lobes may be further divided into superior and inferior subsegments.
The liver is supplied by both the hepatic artery (25% hepatic blood supply) and the portal vein (75% hepatic blood supply). The common hepatic artery arises from the coeliac trunk; after giving off the gastroduodenal artery, it becomes the hepatic artery proper, subsequently dividing into the left and right hepatic arteries prior to entering the porta. The arteries follow the
course of the bile ducts within the liver. Hepatic artery ligation is usually well tolerated, as ligation of either the right or the left hepatic artery generally results in the development of a collateral circulation within 24 hours. The SMV and splenic vein typically join to form the portal vein, which receives the left gastric and smaller veins prior to dividing into left and right branches at the porta hepatis. Interestingly, reduction in portal blood flow increases hepatic arterial blood flow, but the opposite does not occur. Unlike the hepatic arteries and portal veins, the hepatic veins lie within the planes between hepatic lobes and segments, and drain portions of the adjacent segments.
Pancreas, gallbladder and biliary tree

Pancreas

The pancreas is located within the retroperitoneum between the duodenum and the spleen, and posterior to the transverse mesocolon. It is anatomically divided into five parts: head, uncinate process, neck, body and tail. The pancreatic head lies within the C loop of the duodenum just anterior to the IVC (Fig. 54.8). The uncinate process extends from the head of the pancreas, passes downwards and towards the left side, and continues behind the superior mesenteric vessels and in front of the aorta and IVC. The neck ranges in size from 1.5 to 2 cm and immediately overlies the SMV. The body and tail of the pancreas continue towards the left side; the tail reaches the splenic hilum in approximately half of individuals. Tumours of the pancreas are potentially resectable if there is no evidence of distortion of the important surrounding vasculature, such as the SMV, portal vein, coeliac axis, hepatic artery and SMA.

![Diagram of the pancreas and adjacent organs](https://via.placeholder.com/150)

**FIG. 54.8** The relations of the pancreas to adjacent organs. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 69.1.)

The arterial supply of the pancreas arises from the coeliac trunk and SMA. The anterior and posterior pancreaticoduodenal arteries supply the head and uncinate process, while branches from the splenic artery supply the neck, body and tail. The venous drainage of the pancreas parallels its arterial supply.

Gallbladder and biliary tree
The gallbladder is located on the visceral surface of the liver in a fossa that divides the left and right lobes of the liver. It is separated from the liver by Glisson's capsule. The body of the gallbladder is adjacent to the transverse colon and the first and second parts of the duodenum. The infundibulum of the gallbladder is the angulated portion located between its neck and the entrance point of the cystic artery (Fig. 54.9), and is often referred to as Hartmann's pouch when it is dilated. The neck of the gallbladder is located within the free border of the hepatoduodenal ligament. In 2–6% of cases, a Phrygian cap deformity may be present; it is a normal anatomical variant, readily appreciated by ultrasound.\(^{10}\) (A Phrygian cap is a close-fitting conical hat made of wool or felt and characterized by a pointed crown that curls forward; it originated in the ancient country of Phrygia in Anatolia – hence the name.)

The left and right hepatic ducts join together soon after emerging from the liver to form the common hepatic duct. On average, the left duct is longer than the right duct. The cystic duct is about 3 mm in diameter and ranges from 2 to 4 cm in length. It connects the gallbladder to the common hepatic duct and forms the common bile duct (CBD). Very rarely, the cystic duct may be absent and the gallbladder drains directly into the CBD. Awareness of the many different anatomical variations in the anatomy of the cystic duct is
important for the operating surgeon in order to avoid complications when performing a cholecystectomy. The CBD begins at the union of the cystic duct and the common hepatic duct, and ends at the papilla of Vater in the second part of the duodenum, passing through the sphincter of Oddi. The most inferior portion of the CBD is enveloped by the head of the pancreas. Calot's triangle is defined by the area bounded by the cystic artery, cystic duct and the common hepatic duct. During laparoscopic cholecystectomy, Calot's triangle must be cleared of fat, lymphatics and inflammatory tissue in order to achieve the ‘critical view of safety’.\textsuperscript{11} The hepatocystic triangle is the area located between the cystic duct, common hepatic duct and the inferior margin of the right lobe of the liver. The gallbladder is supplied by the cystic artery, which usually arises from the right hepatic artery but may also arise from the left hepatic artery, hepatic artery proper, common hepatic artery, gastroduodenal arteries or the SMA. The cystic artery often passes posterior to Calot's (cystic) node. In contrast, the majority of the venous drainage of the gallbladder occurs through the gallbladder bed and passes into the quadrate lobe of the liver.
Spleen

The spleen is located in the left uppermost aspect of the abdomen, below the diaphragm and adjacent to the greater curvature of the stomach, splenic flexure of the colon, tail of the pancreas and the apex of the left kidney. It is a solid organ that normally weighs 80–300 g. It is covered by a double layer of peritoneum, except at its hilum. The splenic pedicle is formed by the gastroplenic and splenorenal ligaments. The gastrosplenic ligament contains the short gastric arteries and the left gastroepiploic vessels. The splenorenal ligament envelops the splenic vessels and the tail of the pancreas. The tail of the pancreas abuts the splenic hilum in 30% of cases, and is located within 1 cm of the hilum in 70% of cases. Injury to the pancreatic tail during splenectomy may lead to a pancreatic duct leak. The spleen has several minor ligaments: namely, the splenophrenic, splenocolic, pancreaticosplenic, pancreaticocolic and phrenicocolic ligaments.

The splenic artery is a branch of the coeliac trunk and it gives off multiple branches to the pancreas. The presence of an available collateral circulation through the short gastric arteries means that the splenic artery may be ligated and the spleen will still survive. The splenic vein travels along with the splenic artery (Fig. 54.10). During splenectomy for treatment of splenomegaly early division of the splenic artery may be helpful because it leads to autotransfusion and spleen shrinkage.
FIG. 54.10 The visceral surface of the spleen. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 70.2.)
Adrenal glands

The adrenal glands are positioned superior and slightly medial to the kidneys within the retroperitoneum. Each adrenal gland is enclosed in a capsule, in addition to Gerota's fascia. The right adrenal is bounded by the right kidney inferolaterally, diaphragm posteriorly and the bare area of the liver anterosuperiorly. The left adrenal is located between the left kidney and the aorta, and is bounded by the diaphragm posteriorly and the tail of the pancreas and the splenic hilum anteriorly. The adrenal glands are supplied by the superior adrenal arteries (arising from the inferior phrenic arteries), the middle adrenal arteries (arising from the juxtacoeliac aorta) and the inferior adrenal arteries (arising from the renal arteries). In contrast, the venous drainage of each adrenal gland is solitary: the left adrenal vein drains into the left renal vein after joining the inferior phrenic vein, and the right adrenal vein drains directly into the IVC.
Development of the gastrointestinal tract: overview

The regions of the primitive embryonic gut are formed very early in development as a consequence of the morphogenetic movements of neurulation, lateral folding of the initially flat embryonic disc and restriction of the connection with the yolk sac. By 28–29 days post fertilization, the primitive foregut is present as a deep tube of endodermal epithelium. It is subjacent to the notochord and neural tube dorsally and in contact with the pericardial cavity ventrally; it interacts with these epithelial structures. The hindgut and cloacal region are formed when the connecting stalk from the embryonic body to the developing placenta, containing the allantois (a blind-ending tube of endoderm), moves into the body. Between the tubular foregut and hindgut, the midgut remains connected to the yolk sac.

The most cranial portions of foregut, closely related to the pericardial cavity, form bilateral pharyngeal pouches and later, in the midline, the respiratory diverticulum. More caudally, the foregut is flanked by two lateral pericardioperitoneal canals, parts of the intraembryonic coelom. The epithelial walls of the coelom are proliferative and generate extensive mesenchymal cell populations, which surround the foregut (as splanchnopleuric mesenchyme) and, more laterally, contribute to the body wall (as somatopleuric mesenchyme). The splanchnopleuric mesenchyme patterns the development of local regions of the gut. It eventually becomes mesothelium, the laminae propriae which support the mucosal (and submucosal) endodermal epithelia, the smooth muscle in the gut wall, and the lamina propria of the serosa. The epithelial wall of the intraembryonic coelom facing the peritoneal cavity eventually becomes a mesothelium, the epithelial portion of the serosa.

The position and expansion of the caudal portions of the pericardioperitoneal canals (termed pleuroperitoneal after lung development starts and until the formation of the diaphragm) lead to the formation of foregut ventral and dorsal mesenteries. Evaginations of enteric endodermal epithelium into these mesenteries and into the septum transversum give rise to the ducts and epithelial cells of the liver and pancreas. Following formation of the diaphragm, the medial walls of the lowest portions of the canals, now part of the peritoneal cavity, form the falciform ligament between the ventral body wall and the liver; the lesser omentum between the liver and developing stomach; and the greater omentum between the stomach and
dorsally developing structures.

The freedom of movement of the lower foregut, provided by ventral and dorsal mesenteries, is associated with rotational changes of the region destined to become the stomach. The dorsal border of the putative stomach grows longer than the ventral; at the same time, the orientation of dorsal and ventral borders changes to become left and right borders, respectively – a rotation of its original position – and the stomach is displaced to the left of the median plane. The relative movements of the developing stomach are best summarized as two rotations occurring during stages 15–17 (35–41 days post fertilization). The first is 90° clockwise along the longitudinal axis, when viewed from the top/above. This results in the right pleuroperitoneal canal becoming dorsal to the stomach (forming the lesser sac). A second rotation of the stomach 90° clockwise, along the ventral/dorsal axis, when viewed from the front, results in the pylorus facing to the right and limits the entry to the lesser sac from the general peritoneal cavity to a narrower opening, the epiploic foramen.

With growth, the original wide connection of the midgut to the yolk sac becomes reduced to the opening of an elongating vitelline duct (stage 13; 31–33 days post fertilization). By stage 14 (32–34 days post fertilization), the midgut has increased in length more than the axial length of the embryonic body, and its dorsal mesentery has elongated. During stages 15–22 (35–55 days post fertilization), the midgut moves out of the limits of the body wall and remains in the extraembryonic coelom within the forming umbilical cord. At this time, the abdomen in the embryo contains a precocious and relatively large liver (the main centre for haemopoiesis throughout development).

While outside the body, variation of regional growth of the midgut wall results in its overall rotation. This can be noted by changes in the position of the caecum. The rotation can be described as greater than 270° anticlockwise, along the ventral/dorsal axis, when viewed from the front. The midgut returns to the peritoneal cavity continuing to rotate as it does, from approximately 10 weeks post fertilization. At this time, the peritoneal cavity has enlarged and the relative size of the liver and mesonephros has decreased. The proximal loop returns first, with the jejunum mainly on the left and the ileum mainly on the right. They displace the descending colon to the left. The transverse colon passes superiorly to the origin of the dorsal mesentery. The caecum re-enters last. The serosa (peritoneum) of the descending colon and ascending colon become sessile during the fourth and
fifth months. In the neonate, the transverse colon is relatively long; the descending colon is short but is twice the length of the ascending colon.

Only the midgut protrudes into the extraembryonic coelom. The hindgut, similar to the foregut, is adjacent to a number of ventrally developing structures. The early hindgut consists of a dorsal tubular region extending to the cloacal membrane, and a ventral, blind-ending allantois extending from the cloacal region into the connecting stalk. These endodermal structures are close to the wall of the intraembryonic peritoneal coelom and surrounded by splanchnopleuric mesenchyme. At their junction, the mesenchyme proliferates to form the urorectal septum. This pushes the endodermal epithelium towards the cloacal membrane, where it fuses centrally, separating the dorsal enteric hindgut structures, rectum and upper anal canal, from the ventral allantoic structures, the allantoic duct, urinary bladder and urogenital sinus. The allantoic duct later narrows to become the urachus; it finally becomes the median umbilical ligament. Subsequent midline expansion of the peritoneal cavity adjacent to these structures forms the rectovesical pouch in the male and the recto-uterine pouch in the female.

The umbilical cord is formed by and contains umbilical vessels, which develop close to the allantoic duct within the connecting stalk allantoic mesenchyme; vitelline vessels and the vitelline duct, associated with splanchnopleuric intra- and extraembryonic coverings; and amniotic membrane, formed from intra- and extrasomatopleuric tissues, which extend as the umbilical cord lengthens. The various mesenchymal compartments fuse and gradually transform into the loose connective tissue known as Wharton’s jelly.

The vitelline vessels involute, as does the right umbilical vein; thus, the mature umbilical cord contains the left umbilical vein, right and left umbilical arteries, the vitelline duct and, proximally, the allantoic duct. The vessels and ducts usually become twisted into a right- or left-handed cylindrical helix.

The developing gut is supplied by ventral splanchnic arteries arising from the aorta. These become limited to the coeliac trunk supplying the enteric foregut caudally to the proximal part of the duodenum; the superior mesenteric artery supplying the midgut from the distal duodenum to two-thirds of the proximal transverse colon; and the inferior mesenteric artery supplying the hindgut from the remainder of the transverse colon to the upper part of the anal canal.

The venous and lymphatic drainage of the gut is initially related to the
formation of anastomoses between the umbilical and vitelline veins as they approach the septum transversum and developing heart. Rotational movements of the lower foregut and upper midgut occur at the same time as expansion and invasion of venous channels by hepatic tissue. This results in a portal vein formed from venous anastomoses around the duodenum, and the main blood flow from the placenta flowing along the left umbilical vein and bypassing the liver sinusoids through the ductus venosus.

The enteric nervous system is formed by cranial neural crest cells (from somites 1–7) and sacral neural crest (from somite 28 downwards) that migrate from their original levels and invade the gut via the dorsal mesentery, giving rise to both neural and glial cell populations. They are patterned locally by the surrounding splanchnopleuric mesenchyme. The myenteric plexus matures in a craniocaudal progression. The submucosal plexus arises from cells of the myenteric plexus migrating centripetally 2–3 days later. Interstitial cells of Cajal are derived from the local splanchnopleuric mesenchyme.

Errors during any stage of embryonic gut development may result in a broad range of congenital abnormalities of varying clinical significance, that range from being completely inconsequential to life-threatening.
References

Anterior abdominal wall and inguinal region
Despite the significant advances that have occurred in minimally invasive surgery over the past several decades, an understanding of the anatomy of the anterior abdominal wall has remained of critical importance to surgeons because it forms the basis not only for the creation and closure of abdominal wall incisions, but also for hernia repair.
Embryology and congenital anomalies

The anterior body wall is formed by ectodermal epithelium, which becomes the epidermis of the skin, and the underlying somatopleuric mesenchyme, which differentiates into (from superficial to deep) the tissues within the dermis, the layers of connective tissues that form the aponeuroses of the anterior abdominal wall musculature, and the lamina propria of the parietal peritoneum. Muscles of the anterior abdominal wall arise from extension of the somite dermomyotomes into the lateral and ventral body walls. This hypaxial population gives rise to a premuscle mass, which, through interaction with local somatopleuric mesenchyme, splits into the muscle populations for the oblique muscles, transversus abdominis and rectus abdominis.\textsuperscript{1,2} The right and left recti approximate and become fused, except at the umbilical ring.\textsuperscript{2}

An overview of the development of the gastrointestinal tract is reviewed in Chapter 66. During stages 15–22 (35–55 days post fertilization) of embryonic development, the midgut increases in length and moves into the extraembryonic coelom within the forming umbilical cord. The midgut returns to the abdominal cavity from the tenth week post fertilization. As it does, the structures that pass within the fetal umbilical cord to the body may be distinguished: cranially, a single (left) umbilical vein that passes from the umbilicus to the liver within the falciform ligament; and caudally, within the connecting stalk mesenchyme, the allantois and its fibrous remnant, the urachus (continuous with the urinary bladder), and two umbilical arteries, which are branches of the internal iliac arteries. Vestiges of the caudal structures remain as the (single) median and (bilateral) medial umbilical ligaments, respectively.

The vitelline duct, which connects the midgut to the involuting yolk sac, is covered by extraembryonic splanchnopleuric epithelium that is continuous with the visceral peritoneum. It is surrounded by the extracoelomic space, and is bounded by extraembryonic somatopleuric epithelium that is continuous with the parietal peritoneum. All of these structures and layers contribute to the umbilical cord, which has an outer covering of amniotic membrane. Failure of midgut reduction and subsequent closure lead to herniation of intra-abdominal structures through the umbilical ring and into the base of the umbilical cord (omphalocele).\textsuperscript{2} Gastroscisis is a relatively common congenital abdominal wall anomaly that results from the herniation of intra-abdominal structures through a developmental defect of the
abdominal wall musculature, usually to the right of the umbilicus.\textsuperscript{2} As is the case for an omphalocele, the abdominal cavity is generally too small to accommodate the intestines, leading to abdominal wall rupture and intestinal evisceration. With gastroschisis there is no hernial sac present, and the herniated bowel is usually covered by a gelatinous exudate, distinguishing it from an omphalocele, which is usually covered by an external amniotic layer and an internal peritoneal layer.\textsuperscript{2}

**Surgical anatomy and approaches**

The anterior abdominal wall is a hexagonal area bounded inferiorly by the inguinal ligament and the pelvic bones, and laterally by the mid-axillary line. Its superior boundaries are the cartilages of the seventh to tenth ribs, and the xiphoid process of the sternum. It consists of one paired longitudinal muscle, rectus abdominis, and three paired anterolateral muscles (external and internal obliques and transversus abdominis). These three paired flat muscles and their aponeuroses contribute to the rectus sheath before fusing in the midline to form the linea alba. The anatomy of the anterior abdominal wall may be reviewed in the context of the anterolateral region and the middle region.

**Fasciae of the anterolateral abdominal wall**

The superficial fascia is external to the muscles of the anterolateral abdominal wall. In the lower abdomen, it forms a superficial fatty layer (Camper's fascia), and a deeper membranous layer (Scarpa's fascia) that continues inferiorly into the perineal region as the superficial perineal fascia (Colles’ fascia). Scarpa's fascia is particularly well defined in children and may be mistaken for the external oblique aponeurosis. The transversalis fascia is a thin but firm layer of connective tissue that covers most of the abdominal wall, located between the deep surface of transversus abdominis and a variable amount of extraperitoneal fat. In the male, it continues at the inguinal canal as the internal spermatic fascia, enveloping the structures that pass through the deep inguinal ring.

**Muscles and aponeuroses of the anterolateral abdominal wall**

When choosing between muscle-splitting and muscle-transecting incisions, in order to avoid injuring the anterior abdominal wall musculature and to
ensure the best possible postoperative outcome, it is important to understand the relationship of the muscles to their aponeurosis and to recognize the specific directions travelled by the muscle fibres, and the position and orientation of their associated neurovascular bundles. External oblique fibres pass inferomedially, travelling from the fifth to twelfth ribs to the outer lip of the anterior half of the iliac crest (Fig. 55.1). An aponeurotic line, formed by the muscle fibres of external oblique, passes vertically inferiorly from the ninth costal cartilage to form the linea semilunaris, located at the lateral margin of the anterior rectus sheath (see Fig. 55.1). Herniation through the linea semilunaris is referred to as a Spigelian hernia, and most frequently occurs inferior to the level of the umbilicus along the semicircular arcuate line (line of Douglas) (Fig. 55.2). Spigelian hernia repair usually employs mesh and may be performed laparoscopically. The arcuate line is located between the umbilicus and pubic crest. Below this line, all aponeurotic layers are reflected anterior to rectus abdominis, creating an area of potential weakness, where aponeurotic fibres from transversus abdominis fuse with those from internal oblique. At the anterior superior iliac spine (ASIS), the medial half of the aponeurosis of external oblique rolls on itself, between the ASIS and the pubic tubercle, forming the inguinal ligament. It is entirely aponeurotic inferior to the level of the ASIS. The external oblique is covered by a thin fascial layer, the external oblique fascia (innominate fascia of Gallaudet), which also continues along the spermatic cord and forms the external spermatic fascia. Internal oblique is located deep to the thicker and bulkier external oblique; its muscle fibres fan out anteromedially from the thoracolumbar fascia and the iliac crest to insert on the lowest three to four ribs (Fig. 55.3). The origin of the lowermost fibres of internal oblique remains controversial: many investigators now believe that these fibres, traditionally believed to arise from the lateral two-thirds of the inguinal ligament, arise from the iliopsoas fascia. None the less, at this level, the muscle fibres of internal oblique run perpendicular to those of external oblique, a distinction that assists their identification intraoperatively. The aponeurosis of internal oblique, which is formed at approximately the same level as that of external oblique, fuses with the corresponding aponeurosis of transversus abdominis to form the conjoint tendon (inguinal aponeurotic falx) (see Figs 55.14 and 55.18). As its name suggests, most of the fibres of transversus abdominis run transversely; its lowermost fibres travel obliquely and inferiorly (see Fig. 55.2). Transversus abdominis arises from the inner surface of the lower six costal cartilages, the thoracolumbar and iliopsoas
fasciae, and the iliac crest. The uppermost fibres of transversus abdominis interdigitate with the diaphragm and its aponeurosis passes medially and fuses with the linea alba. The lower aponeurosis joins the aponeurosis of internal oblique and is inserted into the pubic crest and pectineal line to form the conjoint tendon.
FIG. 55.1 The left anterolateral abdominal wall muscles. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 61.11.)
FIG. 55.2  The left transversus abdominis. The aponeurosis of transversus abdominis fuses into the posterior layer of the rectus sheath above the arcuate line. The position of the lateral border of rectus abdominis is shown by the dashed white line. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 61.12.)
Muscles of the middle abdominal wall

Rectus abdominis is a long, broad, strap-like muscle that runs vertically down the entire length of the anterior abdominal wall on either side of the midline (see Fig. 55.3 and Video 55.1©). Superiorly, it is attached to the fifth,
sixth and seventh costal cartilages and the xiphoid process; inferiorly, it is attached to the pubic crest, ligamentous tissue at the pubic symphysis, and the superior ramus of the pubis. Each rectus abdominis is bounded by the linea alba medially and by the linea semilunaris laterally. The muscle is wider and thinner superiorly and thicker and narrower inferiorly. It is attached to the anterior rectus sheath by three or four fibrous bands (tendinous intersections or inscriptions) that pass transversely across the muscle at the xiphoid and umbilicus, and midway between these two points. These bands must be transected in order to detach the anterior rectus sheath from rectus abdominis when making certain transverse abdominal incisions, such as the Pfannenstiel incision. There are no attachments between rectus abdominis and the posterior rectus sheath. Pyramidalis is a small triangular muscle that has been reported to be absent in 10–70% of the population on either one or both sides. When present, it lies anterior to the inferior portion of rectus abdominis and within the rectus sheath. It arises from the linea alba approximately midway between the umbilicus and pubis, and is attached to the pubis and anterior ligamentous fibres of the pubic symphysis. Pyramidalis must be divided when making a lower midline laparotomy incision because the linea alba lies posteriorly.

Rectus sheath, linea alba and umbilicus

The rectus sheath is of considerable importance because most abdominal incisions divide this strong fibrous structure. Surgeons must be very familiar with the anatomy of the rectus sheath during operations in order to avoid incisonal dehiscence and hernia development after abdominal closure. The sheath consists of anterior and posterior layers that envelop rectus abdominis and pyramidalis (Fig. 55.4; see Figs 55.2, 55.3). External oblique and the anterior part of the aponeurosis of internal oblique form the anterior rectus sheath, and the posterior part of the aponeuroses of internal oblique and transversus abdominis form the posterior rectus sheath. The rectus sheath is best described in three separate areas. Superior to the costal margin there is no posterior rectus sheath because the aponeuroses of internal oblique and transversus abdominis are absent. At this level, the anterior rectus sheath is formed by the aponeurosis of external oblique and the costal cartilages that are located posteriorly (see Fig. 55.4). The second area, where both the anterior and posterior rectus sheaths are present, runs between the costal margin and the arcuate line. The third area is inferior to the arcuate line, where all three aponeuroses (of external and internal oblique, and
transversus abdominis) blend together, forming an anterior rectus sheath. Here, rectus abdominis lies directly anterior to the transversalis fascia, which is thickened at this level. When closing a midline laparotomy incision only the anterior rectus sheath above the costal margin and below the arcuate line requires closure. Between these levels, both the anterior and posterior rectus sheaths are present and both should be included in the midline abdominal closure.

The linea alba is a white fibrotendinous raphe running vertically in the midline for the entire length of the anterior abdominal wall, extending from the xiphoid process to the pubic symphysis. It separates the two recti and is formed by the interlacing and decussating aponeurotic fibres of external and internal oblique and transversus abdominis. Weaknesses of the linea alba can lead to herniations of extraperitoneal fat or peritoneum and abdominal contents, frequently along the linea alba between the xiphoid process and the umbilicus (epigastric hernia). Gradual thinning and widening of the linea alba, along with laxity of the anterior abdominal wall musculature, lead to the development of a diastasis of the rectus abdominis muscles (DRAM). DRAM may commonly develop during pregnancy but may also occur in men.
and children, with premature infants being at the highest risk.\textsuperscript{5} DRAM itself poses no threat of incarceration or strangulation, and surgical repair is usually not warranted.\textsuperscript{6} Underlying the umbilicus is an area in the middle of the linea alba, referred to as the umbilical ring, through which the umbilical cord passes prenatally. It is a fibrous cicatrix that represents the area of fusion between the two medial umbilical ligaments (the obliterated umbilical arteries) and the median umbilical ligament (the partially obliterated remnant of the urachus). The round ligament of the liver/ligamentum teres hepatitis (obliterated umbilical vein) traverses the umbilical ring, arising from its inferior margin, and passes superiority within the falciform ligament. Variability in the attachments of these ligaments may predispose some individuals to the development of an umbilical hernia. True umbilical hernias are congenital defects in which a peritoneal sac protrudes through a patent umbilical ring; they are uncommon in adults but common in children, and most spontaneously resolve by 3 years of age.\textsuperscript{7} Acquired umbilical hernias in adults usually develop through the superior margin of the umbilical ring and are referred to as para-umbilical hernias. They often occur in obese adults and are at risk of incarceration and strangulation. Inferior to the umbilicus, the linea alba is thinner and much less well defined than it is superior to the umbilicus. This is why, when using an open technique to create a laparoscopic umbilical port site, the incision is placed either transumbilical or immediately inferior to the umbilicus, in a location where the abdominal wall is thinner and may be more easily accessed.

**Transversalis fascia**

The transversalis fascia is a layer of connective tissue between transversus abdominis and the peritoneum. Superiorly, it is continuous with the inferior diaphragmatic fascia; inferiorly, it is continuous with the iliac and pelvic fascia, with several thickenings in the inguinal and femoral areas; and posteriorly, it fuses with the anterior lamina of the thoracolumbar fascia (see Fig. 55.5).

**Innervation, vascular supply and lymphatic drainage**

The muscles and skin of the anterior abdominal wall are innervated by the thoraco-abdominal and subcostal nerves (derived from the ventral rami of the sixth to the twelfth intercostal nerves) and by the first lumbar nerve (iliohypogastric and ilioinguinal nerves) (Fig. 55.5).\textsuperscript{3} These segmental nerves
run in an inferomedial direction across the anterior abdominal wall within a neurovascular plane located between internal oblique and transversus abdominis, and are therefore vulnerable to injury when an abdominal wall incision is made. A transversus abdominis plane (TAP) block anaesthetizes these segmental nerves by injecting a long-acting local anaesthetic agent into this neurovascular plane. The block was first described as a landmark-guided technique that involved a single needle entry point within the triangle of Petit, which lies between the lower costal margin and the iliac crest, bounded anteriorly by external oblique, and posteriorly by latissimus dorsi (see Fig. 55.1). A blunt needle is inserted through the skin and advanced blindly through external and internal oblique. After entering the skin, the needle should be gently manoeuvred from side to side to ensure that it has not penetrated the abdominal wall musculature. The needle is then advanced and a double ‘pop’ signifies entry into the TAP, the site for injection of local anaesthetic; ultrasound-guided TAP blocks may be more accurate and reliable.
Huger separated the blood supply of the anterior abdominal wall into three anatomically distinct zones (Fig. 55.6). Zone I is the upper anterior midline of the abdominal wall and is supplied by the superior and deep inferior epigastric blood vessels. Zone II is the anterior abdominal wall inferior to zone I and is supplied by four main blood vessels: the superficial epigastric, superficial external pudendal, inferior epigastric and superficial circumflex iliac arteries (see Fig. 79.3). The musculophrenic, lower intercostal,
The subcostal and lumbar arteries supply zone III, which lies lateral to the linea semilunaris and superior to zone II. The superior epigastric artery is one of the two terminal branches of the internal thoracic artery; it passes anterior to the upper part of transversus abdominis and enters the rectus sheath, where it descends posterior to rectus abdominis (Fig. 55.7). The deep inferior epigastric artery originates from the medial aspect of the external iliac artery immediately superior to the inguinal ligament. It penetrates the transversalis fascia, enters the rectus sheath either at or below the level of the arcuate line, and ascends between rectus abdominis and the posterior rectus sheath before anastomosing with the superior epigastric artery superior to the umbilicus (see Fig. 55.7). The major vessels of the anterior abdominal wall are usually located 4–8 cm from the midline; it is therefore recommended, whenever possible, to place trocars a minimum of 8 cm lateral to the midline (see Fig. 55.7; Table 55.1). The skin and subcutaneous tissue of the anterior abdominal wall drain into the internal thoracic veins medially, the lateral thoracic veins laterally, and the superficial and inferior epigastric veins inferiorly (see Fig. 55.7). The deeper veins accompany the arteries.

Transillumination of the abdominal wall during laparoscopic port placement is a useful technique that can help the surgeon avoid injuring the abdominal wall blood vessels. The superficial lymphatic drainage of the anterior abdominal wall superior to the umbilicus is to the axillary lymph nodes, and to the superficial inguinal lymph nodes inferior to the umbilicus. Deep lymphatic drainage is to the lumbar and common and external iliac lymph nodes.
FIG. 55.6  The blood supply of the anterior abdominal wall separated by zones. (From M. J. Rosen, Atlas of Abdominal Wall Reconstruction, second ed. © Elsevier, 2016, Fig. 1.8a.)
FIG. 55.7 The deep muscles and arterial supply of the anterolateral abdominal wall. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 61.2.)
TABLE 55.1

Distances of superior and deep inferior epigastric arteries from midline

<table>
<thead>
<tr>
<th>Level</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiphoid cartilage</td>
<td>4.5 ± 0.1 cm</td>
<td>4.4 ± 0.1 cm</td>
</tr>
<tr>
<td>Between xiphoid and umbilicus</td>
<td>5.4 ± 0.2 cm</td>
<td>5.5 ± 0.2 cm</td>
</tr>
<tr>
<td>Umbilicus</td>
<td>5.6 ± 0.1 cm</td>
<td>5.9 ± 0.1 cm</td>
</tr>
<tr>
<td>Between umbilicus and pubic symphysis</td>
<td>5.3 ± 0.1 cm</td>
<td>5.3 ± 0.1 cm</td>
</tr>
<tr>
<td>Pubic symphysis</td>
<td>7.5 ± 0.1 cm</td>
<td>7.5 ± 0.1 cm</td>
</tr>
</tbody>
</table>

(Adapted from A.A. Saber, A.M. Meslemani, R. Davis, R. Pimentel, Safety zones for anterior abdominal wall entry during laparoscopy: a CT scan mapping of epigastric vessels, Ann. Surg. 239 (2004) 182–185, Table 2.)

Ventral incisional hernia repair

Ventral incisional hernias may be repaired using either an open or a minimally invasive surgical technique, or a combination of both. These repairs usually involve placement of a mesh product as an onlay, inlay, sublay or underlay (Fig. 55.8). Open and laparoscopic approaches are well established in today’s practice, and each has specific advantages and disadvantages. While there is a significant reduction in risk of incision and mesh infections with the laparoscopic approach, an inability to approximate the midline and allow for restoration of abdominal wall function is a disadvantage of this approach. Intracorporeal closure is easier to perform with robotic surgical techniques and may offer a solution to this problem, but long-term outcomes of such repairs are currently poorly defined. The laparoscopic approach lends itself well to the repair of moderately sized (2–6 cm) solitary hernia defects, or of smaller defects (less than 3 cm) in obese patients.
Though there is significant variability in laparoscopic hernia repair technique, some general principles must be considered. Once safe pneumoperitoneum has been established, the laparoscopic ports are inserted well away from the hernia defect, and adhesions are then divided. The hernia is reduced using atraumatic graspers and the fascial defect is measured intracorporeally before being closed with a non-absorbable suture. A 5 cm circumferential overlap of the fascial edges by mesh will reduce the risk of hernia recurrence, which may in part be due to mesh shrinkage. Intraperitoneal underlay meshes should have an adhesion prevention coating/barrier to reduce the risk of adhesion development and its associated complications, such as bowel obstruction or fistula. A wide variety of mesh products may be utilized for hernia repair, both synthetic (including polyester or polypropylene mesh, or an expanded polytetrafluoroethylene), biological and absorbable, or permanent composite meshes. The mesh is secured in place with transabdominal sutures, tacks or a combination of both.

During an open approach, the hernial sac is usually opened once it has been freed from the fascial edges and the contents of the sac are reduced back into the peritoneal cavity. This can be carried out through either a transverse or a vertical abdominal incision. The fascia can be closed over a sublay mesh; left open and repaired with an inlay (interposition) mesh; or
closed and reinforced with an onlay mesh (see Fig. 55.8). Ideally, the mesh should overlap the defect edges by 3–4 cm circumferentially.\textsuperscript{12,13} Defects smaller than 4 cm have traditionally been repaired primarily with sutures but recent research suggests that mesh repair may even be beneficial for smaller umbilical hernias.\textsuperscript{14} Onlay repair is generally easier and quicker to perform than sublay mesh repair and is frequently utilized in the emergency setting, but has the disadvantage of an increased risk of hernia recurrence and seroma formation.\textsuperscript{13} Subcutaneous drains are usually utilized for these cases. Biological meshes are more commonly chosen if there has been contamination of the surgical field or if there is a significant risk of mesh exposure.\textsuperscript{13} For sublay repairs, the mesh is placed behind the rectus muscle and in front of the posterior rectus sheath (the Rives–Stoppa technique).

**Surgical incisions and component separation**

There are many considerations, beyond surgeon preference, that must be reviewed when deciding on the abdominal incision that will be created for a particular patient undergoing a specific operation, as part of the treatment of a certain problem. It is critical for the surgeon to anticipate the most likely diagnosis, as well as the potential complications that may occur as a consequence of the operation that is being performed. Other important considerations when creating abdominal incisions include an awareness of the challenges presented by the patient's body habitus and prior abdominal surgical history, and an appreciation of how quickly the abdominal cavity must be accessed. Maingot has described the three essential elements that should be considered before creating an abdominal incision as accessibility, extensibility and security.\textsuperscript{15} The incision should provide adequate exposure with minimal damage to abdominal wall muscles and their associated nerve supply, and allow for the best possible cosmesis. Access to the abdominal cavity may be accomplished via one of many different incision types, several of which are uncommonly employed in surgical practice today. In general, incisions may be classified as vertical, transverse, oblique or thoraco-abdominal (Fig. 55.9).
Vertical incisions

Midline incision

The entire abdominal cavity and retroperitoneum may be readily accessed through a midline incision, which is the ‘work horse’ incision most commonly utilized by surgeons today. Midline incisions are quick to perform, avoid major nerves, are located in a relatively avascular site, allow for access to both the upper and lower abdominal organs, and may easily be extended. However, they are more painful than transverse incisions, their closure may more commonly require concurrent repair of a pre-existing hernia(s), and they may have a worse cosmetic appearance because they traverse Langer's lines.

As its name implies, a midline incision is carried out precisely in the abdominal midline. The skin, subcutaneous fat, linea alba, transversalis fascia, extraperitoneal fat and parietal peritoneum are each systematically and carefully divided. Symmetrical lateral digital traction on the incision edges may facilitate separation of the subcutaneous fat in the correct midline axial plane for exposure of the midline fascia. Upper abdominal midline incisions extend from the xiphoid process to the umbilicus. The fibrous linea alba is wider above the level of the umbilicus and therefore is more easily identified than the much thinner infra-umbilical linea alba. Extraperitoneal fat may then be swept aside in order to expose the peritoneum. This is best achieved at the lower aspect of the incision so that the position of the ligamentum teres hepatis and the falciform ligament may easily be identified when entering the abdominal cavity. The ligamentum teres hepatis may also be ligated and divided if it limits exposure within the operative field. Once the peritoneum is encountered, the surgeon should gently elevate it with haemostats and open it sharply in a longitudinal direction, taking great care to avoid injury to the underlying viscera. In the reoperative setting, the surgeon must be especially cautious in order to avoid injuring the intestine and/or other structures that may be adherent to the posterior surface of the
linea alba; entering the peritoneal cavity just superior or inferior to the old incision may avoid adhesions and may potentially be an advantageous approach. Once the peritoneal cavity has been entered, the incision may then be extended as required to provide adequate surgical exposure. Excising the xiphoid process may be a necessary step, as this increases the operative field by four or more centimetres in width, and may provide better access to foregut structures and to the inferior vena cava and hepatic veins. When extending an upper midline incision inferiorly, the surgeon may circumnavigate the umbilicus to either the left or right side, or make a transumbilical incision. Care must be exercised if epigastric, umbilical or incisional hernias are unexpectedly encountered when creating a midline abdominal incision. Peritoneal entry should generally be carried out through the upper end of an infra-umbilical incision in order to avoid bladder injury. Placement of a urinary catheter preoperatively is very important because it decompresses the bladder and reduces risk of injury to it. Similarly, when approaching the pubic symphysis, the surgeon should incise the peritoneum more laterally, off the midline, in order to reduce the risk of bladder trauma (see Fig. 55.9).

**Paramedian incision**

Left or right paramedian incisions are placed lateral and parallel to the midline. The skin and subcutaneous fat are divided, and the anterior rectus sheath is incised vertically along the entire length of the incision. Rectus abdominis is then freed from the anterior sheath and retracted laterally. Great care must be taken to divide any tendinous intersections that are encountered and to ensure that segmental vessels are also ligated and divided. The tough membranous layer of the posterior rectus sheath and the peritoneum are then incised. This incision may be extended in a similar manner to the midline incision but its cranial extension is limited by the costal margin. The deep inferior epigastric artery passes between the posterior rectus sheath and the rectus muscle, either at or below the level of the arcuate line, and usually requires ligation when a low paramedian incision is carried out. These incisions may take longer to perform than other incision types and also have a higher risk of both vascular and nerve injury, but they have the advantage of being at lower risk for incisional hernia development than other vertical incision types (see Fig. 55.9).

**Pararectus (Kammerer–Battle) and transrectus (mid-rectus)**
incisions
Pararectus and transrectus incisions are seldom used today because both result in denervation and vascular compromise with subsequent muscular atrophy. A pararectal incision is made along the lateral border of rectus abdominis, which is retracted medially. A transrectus incision splits the muscle along a vertical plane parallel to the site of a paramedian incision (see Fig. 55.9).

Component separation
Ventral incisional hernias are common and may be very challenging to repair. In 1990, Ramirez and colleagues\textsuperscript{18} described the component separation technique, which was originally developed to allow for primary closure of large midline abdominal wall defects. Even though the technique has evolved over time, its overall objective, to improve the integrity of the abdominal wall by permitting creation of a tension-free closure of the linea alba, has not changed.\textsuperscript{19} This objective may be achieved by utilizing one of several well-described techniques, including anterior component separation (open or endoscopic), retromuscular repair (Rives–Stoppa technique) and posterior component separation (with or without transversus abdominis release).

The open anterior component separation technique was originally described by Ramirez and colleagues\textsuperscript{18,19} and has been modified over time. Essentially, it involves the release of the aponeurosis of external oblique and elevation of rectus abdominis from the posterior rectus sheath. This creates a myofascial advancement flap that is capable of mobilizing each side of the anterior abdominal wall medially by up to 10 cm at the waist line, 5 cm in the epigastrium and 3 cm in the suprapubic region.\textsuperscript{13} In brief, following a midline laparotomy, a subcutaneous flap is raised that exposes the anterior rectus sheath. This dissection is then continued in the subcutaneous plane to approximately 2 cm or more lateral to the linea semilunaris. The aponeurosis of external oblique is then incised longitudinally, just lateral to the edge of rectus abdominis, and separated from the underlying internal oblique (Fig. 55.10). A contralateral component release may also be carried out if a unilateral release does not permit closure of the defect. The defect should be closed and ideally reinforced with a sublay, underlay or onlay mesh.\textsuperscript{13}
The Rives–Stoppa technique\textsuperscript{20,21} involves placement of a retromuscular sublay mesh, and is suitable for moderately sized defects because it will advance the rectus muscle to the midline by a maximum distance of 5 cm on each side.\textsuperscript{13} After a midline laparotomy is performed, the posterior rectus sheath is incised vertically 1 cm or less from the edge of the linea alba on one side (Fig. 55.11). The dissection is continued in a superior and inferior direction for 5–8 cm.\textsuperscript{13} The retromuscular plane of the contralateral rectus
abdominis is then entered in a similar way and lateral dissection next proceeds towards the edge of the rectus sheath envelope bilaterally. The preperitoneal space should be developed if the defect extends below the arcuate line. The posterior rectus sheath and transversalis fascia are then closed in a continuous fashion. A sublay mesh can then be secured in place, followed by closure of the linea alba. For larger defects a posterior component separation may be required. This is an extension of the Rives-Stoppa technique and involves division of the posterior aponeurotic sheath of the internal oblique muscle once the posterior rectus sheath has been incised at its most lateral edge. Dissection is carried out as far lateral, superior and inferior as necessary to close the defect. However, one major disadvantage of this technique is that dissection in the transversus abdominis plane (TAP) results in segmental nerve damage. To avoid this, Novitisky described a modification of the posterior component separation technique by performing a transversus abdominis muscle release (TAR). After the initial steps of the Rives-Stoppa technique are completed, the posterior rectus sheath in the upper third of the abdomen is incised again to expose the underlying fibers of transversus abdominis. Division of the posterior rectus sheath should be completed 0.5–1 cm medial to the linea semilunaris, ensuring that the perforating neurovascular bundles of the thoraco-abdominal nerves are identified and preserved lateral to this incision. The incision is continued in a superior and inferior direction and the arcuate line is divided. Transversus abdominis is then divided and separated from the underlying transversalis fascia and a plane is bluntly developed. A sublay mesh is secured in place, as has already been described.
FIG. 55.11 Posterior component separation (Rives–Stoppa technique). Following a midline laparotomy, the posterior rectus sheath is incised vertically 1 cm or less from the edge of one side of the linea alba and the rectus muscle divided off the sheath. The retromuscular plane of the contralateral rectus can then be entered in a similar way.

Transverse incisions

Upper and lower transverse incisions

Transverse abdominal incisions are frequently utilized in operations that are performed on neonates and children because their abdominal cavities have a more horizontal and ellipsoid orientation, whereas the adult abdomen has a shorter transverse than vertical girth (which favors a vertical midline incision for access). The nerve supply to rectus abdominis is segmental, and therefore transverse incisions that transect both the rectus sheath and muscle cause little damage to its innervation. The incision may also be extended laterally through the flat muscles along the line of the skin incision. Lateral abdominal muscles are richly innervated and usually heal without weakness (see Fig. 55.9).

Pfannenstiel incision

The Pfannenstiel incision is commonly utilized for gynaecological operations and caesarian sections, and for access to the prostate and bladder, but surgical access to the pelvis is limited; cosmesis is generally excellent. These incisions are created by making a gently curving transverse incision along the suprapubic skin crease located 2–5 cm superior to the pubis. Camper's and Scarpa's fasciae are then incised, the anterior rectus sheath and linea alba are exposed and transected, and the upper and lower fascial edges are lifted and dissected away from the adherent rectus and pyramidalis on both sides. The muscles are then retracted laterally to reveal the transversalis fascia and the peritoneum, which are opened along the midline. Great care must be taken
to avoid injuring the bladder: similar precautions to those taken for midline incisions (that is, preoperative placement of a Foley catheter) should be adopted here. The iliohypogastric nerve is at risk of injury during a Pfannenstiel incision and should be preserved (see Fig. 55.9).

**Oblique incisions**

**Subcostal (Kocher) incision**

Subcostal incisions provide excellent exposure of the entire upper abdominal viscera, and access to the biliary tree and gallbladder when placed on the right side, and to the spleen when placed on the left side. The incision on either side may be extended across the midline to create a double Kocher or rooftop incision (Chevron incision). The skin incision begins 2–5 cm inferior to the xiphoid process, approximately 3 cm inferior and parallel to the costal margin. The anterior rectus sheath is incised and rectus abdominis, external and internal oblique and transversus abdominis are all divided along the same oblique line, 3–4 cm inferior to the costal margin. This avoids the need to incorporate the periosteum of the ribs into the closure. The incision is then deepened and the peritoneum is exposed and opened. During transection of rectus abdominis, the superior epigastric artery running posterior to the muscle should be identified and ligated in order to avoid haemorrhage. As the incision is extended laterally, the larger ninth thoracic nerve is usually visualized, and is retracted to ensure its preservation, but the smaller eighth thoracic nerve, also commonly encountered, is often sacrificed (see Fig. 55.9).

**McBurney (gridiron) incision**

For more than a century, the McBurney (gridiron) incision was the incision of choice for appendicectomy, before being largely superseded by a laparoscopic approach. The incision is placed perpendicular to a line that connects the ASIS to the umbilicus through McBurney's point (one-third of the distance from the patient's right ASIS to the umbilicus). If orientated transversely, it is referred to as a Rockey–Davis incision. Both incisions involve cutting the aponeurosis of external oblique along the direction of its fibres, prior to splitting internal oblique and transversus abdominis parallel to their fibres (splitting of muscles involves systematically separating them bluntly along the direction of their fibres). Great care must be taken to avoid
injury to rectus abdominis and its neurovascular bundle when making this incision. When extended cranially and laterally in an oblique direction by further splitting external oblique in order to gain greater exposure of the appendix, caecum and right colon, this incision is referred to as a Rutherford Morrison incision. The iliohypogastric nerve lies deep to internal oblique and should be identified and protected when making this incision (see Fig. 55.9).

**Thoraco-abdominal incision**

A thoraco-abdominal incision gives simultaneous access to both the abdomen and the thorax. Upper laparotomy incisions may be extended to expose either the right or the left hemithorax. A left-sided incision provides excellent exposure of the proximal stomach, lower oesophagus and ascending aorta, and a right-sided incision affords wide exposure of the liver and inferior vena cava. Although they offer excellent exposure and access, thoraco-abdominal incisions are seldom used because of their associated morbidity: specifically, significant associated pain and the need for a postoperative chest drain (tube). To create this incision, the patient is placed in a ‘corkscrew’ or semi-lateral position and the operating table is tilted by 45° from the horizontal plane. The thorax is then rotated into the fully lateral position. The thoracic incision is placed near the inferior portion of the ipsilateral scapula along the posterior axillary line, and extended across the costal margin through the eighth or ninth intercostal space towards the midline of the abdomen. Subcutaneous fat and latissimus dorsi, serratus anterior, external oblique and the intercostal muscles are then all sequentially divided. The pleura is meticulously opened to avoid injuring the lung, and the phrenic vessels are ligated along the line of the incision. The costal cartilage of the ninth rib and the diaphragm are divided medially, avoiding the phrenic nerves. The abdominal cavity is accessed through an upper midline incision, as already reviewed, which may be extended caudally if required.

**Incisions for laparoscopic surgery**

Several laparoscopic abdominal entry techniques exist; there is no evidence that any method has proven superior for the avoidance of major visceral or vascular injuries. However, an open-entry technique is associated with a reduced rate of failed access when compared to a closed-entry technique.
**Closed techniques**

The closed technique involves insertion of a Veress needle into the peritoneal cavity. The patient is placed in a 20–30° Trendelenburg position and the anterior abdominal wall is grasped and elevated. A small incision is then made to accommodate the needle, usually just superior or inferior to the umbilicus, and the needle is advanced perpendicular to the abdominal wall through the linea alba and into the peritoneum. The peritoneal cavity is then insufflated, and once the abdomen is fully distended, the needle is withdrawn and the superficial incision is enlarged to accommodate blind trocar-guided port placement. Alternatively, when multiple intraperitoneal adhesions are expected, the direct trocar entry technique is often used. A transverse incision is made through the skin of the abdominal wall to accommodate the laparoscopic port. A laparoscope is then inserted into a hollow trocar with a transparent tip and, under direct vision through the camera, the trocar and port are passed through the layers of the anterior abdominal wall into the peritoneal cavity.

**Open techniques**

In 1971, Dr Harrith Hasson described the first open technique for port placement for laparoscopy. A 1–2 cm transverse or vertical incision is placed just superior or inferior to the umbilicus, and retractors are then used to distract the subcutaneous tissues. The linea alba may or may not be grasped, and is incised vertically. The peritoneum, which is very thin or deficient in this location, may be opened separately. Stay sutures are commonly placed in the fascia to secure the port and may also be used for closure. A blunt-tipped trocar is inserted through this opening into the peritoneal cavity to allow for port placement, and gas insufflation is initiated. In obese patients, where the linea alba may be quite deep and can be difficult to access, a modification of Hasson's original technique may be helpful. The umbilical cicatrix is grasped firmly and elevated to reveal the linea alba/cicatrix junction. The linea alba and peritoneum can then be incised under direct vision, as already described, and a port may then be inserted safely into the peritoneal cavity using a blunt trocar. Another open technique that may be used for single incision laparoscopic surgery (SILS) involves creating a single transumbilical incision. The umbilicus is everted, its skin is incised vertically and the skin edges are clipped and elevated to expose the umbilical ring and linea alba, which are incised together with the peritoneum. A blunt trocar is used to introduce the
port into the peritoneal cavity and a pneumoperitoneum is established. If an incision for umbilical port placement is made off centre, the extraperitoneal space is inadvertently created and insufflated, which can lead to subcutaneous emphysema and distortion of the view of the peritoneal cavity as a consequence of extraperitoneal dissection by insufflated gas.

**Tips and Anatomical Hazards**

**Abdominal wall closure**

The most common pitfalls and danger areas have already been reviewed throughout this chapter but one important area that requires further comment is abdominal wall closure.

Abdominal incision dehiscence and hernia development commonly occur after laparotomy, and are intimately related to the suture material utilized, and the surgical technique employed, during closure. A slowly absorbable monofilament suture such as polydioxanone has been found to be consistently associated with fewer incisional hernias than rapidly absorbable sutures.27

Another important consideration that may influence the development of an incisional hernia is whether to perform a mass abdominal closure (all abdominal layers excluding the skin), or a layered abdominal closure. The most recent European Hernia Society (EHS) guidelines recommend a single layer aponeurotic closure technique without separate closure of the peritoneum.12

Surgeons have traditionally been taught to close midline laparotomy incisions in a continuous fashion by placing each suture bite 10 mm from the fascial edge at intervals of 10 mm. However, the STITCH (Suture Techniques to reduce the Incidence of The inCisional Hernia) trial recently found that the small bite suture technique (5 mm to 5 mm) is more effective than the traditional larger 10 mm bite technique for prevention of incisional hernia development.28 The STITCH study group therefore recommended that all midline incisions should be closed using this technique. However, one recommendation that has remained consistent throughout the literature is maintaining a suture to incision length ratio of at least 4 to 1.29 Thus, the current literature
suggests that closure of the abdominal wall fascia should be carried out using a continuous small bite single layer aponeurotic closure technique, which employs a slowly absorbable monofilament suture and has a suture to incision length ratio of 4 to 1 or more.\textsuperscript{12,28}
Part 2: Inguinal region
Matthew J Laviolette, Duncan SG Scrimgeour, Sam M Wiseman

Core Procedures

- Paediatric inguinal hernia repair
- Inguinal hernia repair – direct and indirect
- Femoral hernia repair
- Inguinal lymph node biopsy

The inguinal region is that portion of the lower anterior abdominal wall between the anterior superior iliac spine (ASIS) and the pubic tubercle. The aponeurotic attachments of the abdominal wall muscles anchor the lower abdomen to the bony pelvis. The inguinal region also serves as a conduit where the lateral muscles of the lower abdominal wall accommodate the passage of the spermatic cord in men, or the round ligament of the uterus in women, through the inguinal canal. Additionally, the femoral artery and vein pass just beneath the inferior border of the inguinal ligament through the femoral sheath. The surgeon must be keenly aware of the anatomy of the inguinal region because repair of hernias in this area is very common, and each procedure presents its own unique anatomical challenges.

Embryology

The fetal testes and ovary appear during the seventh and tenth weeks of development, respectively. In both sexes, mesenchymal cells form the gubernaculum, an embryonic structure, which attaches the caudal ends of the gonads to the labioscrotal swellings of the inguinal region. In males, the testes descend into the pelvic cavity from the superior lumbar region of the posterior abdominal wall where they originate. The testis and spermatic cord pass into the scrotum, enveloped by an evagination of the peritoneum that is obliterated at its abdominal site of origin after the arrival of the testis within the scrotum. A remnant of peritoneum, the tunica vaginalis, persists and overlies the testis. Patency of the tunica vaginalis may occur (patent
processus vaginalis), resulting in the development of a communicating hydrocele and/or indirect inguinal hernia. If the peritoneal communication is obliterated, a non-communicating (encysted) hydrocele occurs.31 In females, following the descent of the ovaries into the pelvis, the gubernaculum subsequently forms the ovarian and round ligaments. Analogous to a patent processus vaginalis in males, a persistent protrusion of the peritoneum into the labia majora in females is termed the ‘canal of Nuck’, and may predispose to the development of a hydrocele and/or indirect inguinal hernia.30

Surgical anatomy

Muscles, fascia and ligaments

The layers of the abdominal wall within the inguinal region are skin, Camper's and Scarpa's fasciae, external and internal oblique and transversus abdominis muscles (and their investing fasciae), spermatic cord/round ligament, transversalis fascia, preperitoneal fat, and peritoneum. Each of the lateral abdominal wall muscles has a unique transition from lateral muscular fibres to medial aponeurotic fibres that determines their specific utility for the construction of a durable hernia repair (Fig. 55.12).
FIG. 55.12 Muscular to aponeurotic transitions of the lateral abdominal wall muscles. Each of the three lateral abdominal wall muscles has a unique transition from lateral muscular component to medial aponeurotic component. This anatomy emphasizes the utility of each of these muscles in constructing a hernia repair.

The transition of external oblique from muscular fibres to aponeurosis occurs along a plane from the ninth costal cartilage to a point just medial to the ASIS. Below the level of the ASIS, external oblique is entirely aponeurotic and therefore no muscular component of external oblique is encountered within the inguinal region. At its most inferior aspect, the thickened aponeurosis of external oblique extends between the ASIS and the superior ramus of the pubis and condenses to form the inguinal ligament. At its medial termination, the inguinal ligament fans out to broaden its insertion on to the pectineal ligament (Cooper's ligament), and is referred to as the lacunar ligament (Gimbernat's ligament). The pectineal ligament is formed by contributions of aponeurotic fibres from the lacunar ligament, internal oblique, transversus abdominis and pectineus, and inserts on to the periostium of the suprapubic ramus and ilium. Both the lacunar and pectineal ligaments provide robust anchoring points that are readily able to hold sutures for the creation of a durable hernia repair (Fig. 55.13). Laterally, the inguinal ligament is adherent to the iliopsoas fascia. At the internal inguinal ring, the inguinal ligament develops a free edge that allows it to contribute to both the anterior wall (roof) and to the posterior wall (floor) of the inguinal canal.
The lower fibres of internal oblique have a horizontal orientation and contribute to the anterior abdominal wall in the inguinal region. Internal oblique is predominantly muscular as it passes through the inguinal region: this difference between external and internal oblique is important to recognize because the muscular fibres of internal oblique alone are not adequate to hold sutures as part of a hernia repair. The lower border of
internal oblique originates from the iliac fascia and the iliopectineal arch near the ASIS and forms a muscular arch, which, together with the rectus sheath, is inserted into the body of the pubis.\textsuperscript{31} The aponeurosis of internal oblique is commonly described as melding with the aponeurosis of transversus abdominis to form the conjoint tendon. However, Nyhus was able to identify this unified aponeurotic termination in only 3\% of his cadaver dissections.\textsuperscript{31}

Transversus abdominis lies deep to internal oblique and is the innermost muscular layer of the anterolateral abdominal wall. Laterally within the inguinal region, transversus abdominis is composed of muscular fibres. The bulk of its inferior fibres form the transversus abdominis arch, which spans the superior margin of the internal inguinal ring, and usually insert into the rectus sheath or, less commonly, directly on to the pubic ramus.\textsuperscript{31} In contrast to internal oblique, transversus abdominis becomes aponeurotic medial to the internal inguinal ring and therefore provides suitable tissue for incorporation into a hernia repair. While the bulk of the inferior fibres of transversus abdominis contribute to the transversus abdominis arch, a small number of aponeurotic fibres pass inferior to the internal inguinal ring and become incorporated into the iliopubic tract, a thickened aponeurotic band that extends from the iliopectineal arch on to the superior ramus of the pubis. Formed of aponeurotic fibres of transversus abdominis and the transversalis fascia, the iliopubic tract runs deep and parallel to the inguinal ligament. It forms the inferior aspect of the internal inguinal ring before coursing over the femoral vessels and defining the anterior border of the femoral sheath. It also contributes to the posterior wall of the inguinal canal.\textsuperscript{33} A loose weave of aponeurotic fibres travels from the transversus abdominis arch to the iliopubic tract. Within the intervening space, only the underlying transversalis fascia contributes to the posterior wall of the inguinal canal (Fig. 55.14). The transversalis fascia is the investing fascia of transversus abdominis, and separates the abdominal wall from the underlying preperitoneal fat. Nyhus found transversalis fascia to be of sufficient strength to retain sutures in only 20\% of the cadavers he studied. He specifically commented that ‘it possesses little intrinsic strength and, by itself, is a worthless material as far as the construction of a sound hernia repair is concerned’.\textsuperscript{31} This intrinsic weakness in the area medial to the internal ring, between the transversus abdominis arch superiorly and the iliopubic tract inferiorly, is the site where direct inguinal hernias develop. This area is known as Hesselbach’s triangle, and its borders are the deep
inferior epigastric artery superiorly, rectus sheath medially and the inguinal ligament inferiorly (Fig. 55.15).

**FIG. 55.14** The relationship of the lateral abdominal wall muscles to the inguinal canal. The aponeurosis of external oblique has been reflected to expose the inguinal canal. Note how the inferior fibres of both internal oblique and transversus abdominis arch over the internal ring. (From F. H. Netter, Abdomen. Atlas of Human Anatomy, 7th ed. Copyright © 2019 by Elsevier Inc., Plate 262.)
Hesselbach's triangle and the laparoscopic view of the inguinal region. Hesselbach's triangle is defined by the inguinal ligament, inferior epigastric artery and the medial aspect of rectus abdominis. The inguinal ligament is a superficial structure and is not depicted here. However, it is found at the same level as the iliopubic tract. The sites of direct, indirect and femoral hernias and the locations of the triangle of pain and of the triangle of doom are indicated. Abbreviation: TAPP, transabdominal preperitoneal. (Adapted from Y. Pillay, Laparoscopic repair of an incarcerated femoral hernia, Int. J. Surg. Case Rep. 17 (2015) 85–88, Fig. 5.)

Vascular supply

The deep inferior epigastric artery arises from the external iliac artery, just superior to the inguinal ligament, travels along the medial border of the internal inguinal ring, and continues on to supply rectus abdominis. Three branches of the femoral artery (superficial epigastric, superficial circumflex iliac and superficial external pudendal arteries) supply the superficial tissues of the inguinal region. The superficial epigastric artery ascends in close proximity to the internal inguinal ring; the superficial circumflex iliac artery is located laterally; and the superficial external pudendal artery is located medially (see Figs 55.7 and 79.3).
**Lymphatic drainage**

The lymphatics of the inguinal region are the superficial inguinal lymph nodes located adjacent to the termination of the great saphenous vein, and the deep inguinal nodes located beneath the fascia lata along the femoral vein (including the node of Cloquet). The superficial lymph nodes receive lymphatics from the entire lower limb, infra-umbilical abdominal wall, buttock, perineum, anal canal, penis and scrotum (in the male), or labia and vagina external to the hymen (in the female). Lymphatic drainage from the glans penis or glans clitoris usually passes to the deep inguinal nodes. Lymphatic drainage from the testes travels superiorly with the testicular vessels and terminates in the renal and pre-aortic nodes\(^{32}\) (Fig. 55.16). In individuals who present with inguinal lymphadenopathy, thorough examination of all of these draining sites, which may harbour pathology such as malignancy, is critical.
Inguinal lymph node biopsy

Inguinal lymph node biopsy is a commonly performed surgical procedure and is usually undertaken in the setting of clinically pathological nodes for the diagnosis of malignancies such as lymphoma. The skin is incised over the top of the palpable lymph node(s). Tributaries of the great saphenous vein may require ligation if they are encountered. The node(s) is/are then dissected out circumferentially, taking care not to disrupt their capsule. The lymphatics draining into the node should be clipped or tied to reduce the
risk of postoperative seroma/lymphatic leak. The overlying subcutaneous
tissues and superficial fascia should also be closed in order to reduce the risk
of developing a postoperative fluid collection.

**Innervation**

Three important nerves – ilioinguinal, iliohypogastric and genitofemoral –
pass through the inguinal region. The ilioinguinal nerve is a sensory nerve
that supplies the upper medial thigh and the base of the genitals. It usually
originates from the L1 ventral ramus but may receive a contribution from T12
or L2. It passes superior to the iliac crest before descending to enter the
abdominal wall, typically 3 cm medial and 4 cm inferior to the ASIS. It
penetrates transversus abdominis and internal oblique, passes through the
internal inguinal ring immediately deep to the external oblique aponeurosis,
and then travels along with the spermatic cord/round ligament, eventually to
exit the abdominal wall at the external inguinal ring. During hernia repair,
the ilioinguinal nerve is vulnerable to injury or entrapment as it passes
through the inguinal canal, especially when external oblique is opened and
closed, respectively. The iliohypogastric nerve usually originates from the L1
ventral ramus but may arise wholly or in part from the T12 ventral ramus; it
lies superior to the ilioinguinal nerve. Above the iliac crest, the
iliohypogastric nerve bifurcates into lateral and anterior cutaneous branches.
The lateral cutaneous branch provides sensory innervation to the
posterolateral gluteal skin. The anterior cutaneous branch penetrates the
abdominal wall 1.5 cm inferior to the ASIS, in a similar manner to the
ilioinguinal nerve, emerges from the aponeurosis of external oblique
superior to the external ring and innervates the skin of the pubic region. The
genitofemoral nerve originates from the L1 and L2 ventral rami and is
formed within the substance of psoas major; it descends obliquely through
the muscle to emerge on its anterior surface near the medial border, opposite
the third or fourth lumbar vertebra. It then descends beneath the
peritoneum on psoas major, crosses obliquely behind the ureter, and divides
into femoral and genital branches. The femoral branch passes through the
femoral sheath beneath the inguinal ligament, lateral to the femoral artery,
and supplies the skin of the thigh overlying the femoral triangle (defined by
the medial border of adductor longus, the lateral border of sartorius, and the
inguinal ligament superiorly). The genital branch exits the abdomen at the
inferior aspect of the deep ring with the cremasteric branches of the inferior
epigastric vessels, and supplies the cremaster muscle (in the male) and the
skin of the external genitalia\textsuperscript{35} (Fig. 55.17).

\textbf{FIG. 55.17}  Inguinal nerve anatomy. Note the anatomical relationships of the ilioinguinal nerve, iliohypogastric nerve, and genital branch of the genitofemoral nerve. (From Q. Lina Hu, D.C. Chen, Approach to the patient with chronic groin pain. Surg. Clin. N. Am. 98 (2018) 651–65. Copyright © 2018 Elsevier Inc., Fig. 1.)

\section*{Ilioinguinal/iliohypogastric nerve block}

The objective of the ilioinguinal nerve block is to anaesthetize the ilioinguinal and iliohypogastric nerves laterally as they pass through the abdominal wall. A landmark for needle placement is measured at 2 cm medial and 2 cm inferior to the ASIS. A 25-gauge needle is used to pierce the skin, and is slowly advanced until the external oblique aponeurosis is appreciated when resistance to needle passage is encountered. Loss of resistance indicates passage through external oblique. Ultrasound may be used to confirm the anatomy and aid in needle placement. Local anaesthetic is then infiltrated in the space between internal and external oblique, and the needle is advanced until a second loss of resistance is appreciated, indicating needle placement between internal oblique and transversus abdominis. Local anaesthetic is then also infiltrated into this space. Attention must be paid to needle depth because it is important not to penetrate the peritoneum and injure the underlying viscera.\textsuperscript{36}
Inguinal canal

The inguinal canal is bordered laterally by the internal inguinal ring and medially by the external inguinal ring. Superiorly, the canal is formed by the inferior arch of internal oblique and transversus abdominis. Inferiorly, it is composed of the inguinal ligament with medial contributions from the lacunar ligament. The anterior wall (roof) of the canal is formed by the aponeurosis of external oblique, and the posterior wall (floor) is composed of the fused transversalis fascia and iliopubic tract. It would be incorrect to conceptualize the inguinal canal as an adynamic tunnel traversing the three muscle layers of an otherwise static abdominal wall. The entrance of the spermatic cord/round ligament into the canal at the internal inguinal ring occurs immediately inferior to the inferior arch of internal oblique and transversus abdominis: that is, the spermatic cord/round ligament do not pass through these layers, but actually pass beneath them as they form the roof of the inguinal canal. The internal inguinal ring is a defect in the transversalis fascia at a point midway between the ASIS and pubic tubercle, which is reinforced along its inferior border by the iliopubic tract, and along its medial border by the interfoveolar ligament (Hesselbach's ligament). A hernia that enters the inguinal canal through the internal inguinal ring is referred to as an indirect inguinal hernia (Fig. 55.18).
FIG. 55.18  Inguinal canal anatomy. The aponeurosis of external oblique has been reflected to expose the inguinal canal. Note how the inferior fibres of both internal oblique and transversus abdominis arch over the internal ring. A hernia that enters the inguinal canal through the internal inguinal ring is referred to as an indirect inguinal hernia. The conjoint tendon is depicted medially. (From F. H. Netter, Abdomen. Atlas of Human Anatomy, 7th ed. Copyright © 2019 by Elsevier Inc., Plate 263.)
The inguinal ligament at the level of the internal inguinal ring is band-like and has an oblique orientation. It may be conceptualized as a ribbon that externally rotates as it travels medially, achieving a near-horizontal orientation at its insertion. This twisting of the inguinal ligament is important because it allows for external support of the spermatic cord as it exits the internal ring, cradles the cord along the floor of the canal and delivers the cord at the external ring. The external inguinal ring is a triangular opening in the aponeurosis of external oblique that has a superior (medial) and inferior (lateral) crus, as well as a base located on the pubic crest. The superior crus is inserted into the anterior surface of the pubic tubercle, the pubic bone and the pubic symphysis, while the inferior crus is inserted into the pubic tubercle and pubic pecten. The external ring may be quite thickened, fibrous and adherent to the spermatic cord in the presence of a chronic hernia.

The inguinal canal is described as having a ‘shutter mechanism’ that protects it from the development of indirect inguinal hernias during episodes of increased intra-abdominal pressure. This mechanism functions by closing the internal inguinal ring and collapsing the inguinal canal. The interfoveolar ligament along the medial border of the internal inguinal ring forms a sling that is adherent to the transversalis fascia and the aponeurosis of transversus abdominis. During contraction of transversus abdominis, the interfoveolar ligament is pulled superiorly and laterally, closing the internal ring and thereby preventing herniation of abdominal contents. Contraction of internal oblique during coughing pulls its lowest most fibres inferiorly, further closing the inguinal canal and providing additional protection from herniation.

**Contents of the inguinal canal**

During development, the inferior gubernaculum (future round ligament) in females, and the descending testis in males, are enveloped by contributions from three abdominal wall layers as they pass through the inguinal canal. The transversalis fascia overlies the round ligament in females, and in males, forms the internal spermatic fascia, which envelops the testicle, its arteries and veins (pampiniform plexus), and the vas deferens (along with the deferential artery and vein), as well as lymphatics and sympathetic nerve fibres. In both sexes, the overlying cremasteric fascia is derived from internal oblique and its fascia. The cremasteric artery and vein, and the femoral
branch of the genitofemoral nerve are all located deep to the cremasteric fascia. The outermost external oblique fascia forms the external spermatic fascia in males and provides a covering for additional lymphatics and the ilioinguinal nerve\textsuperscript{32} (Fig. 55.19). An analogous fascial layer is also present in females.\textsuperscript{31,32}

![Diagram of the inguinal canal and spermatic cord](image)

**FIG. 55.19** Structures contained within the spermatic cord and relations to the inguinal canal. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013, Fig. 76.16.)

**Inguinal hernia repair approach**

The location of the inguinal canal may be determined by its relationship to three important surface landmarks: ASIS, the pubic tubercle and the inguinal ligament. The internal opening of the canal at the internal ring may be found 2–4 cm superior to the inguinal ligament at the midpoint between the ASIS and the pubic tubercle.\textsuperscript{31} The canal passes medially for
approximately 4 cm, and terminates at the external inguinal ring located 1.5 cm superior and lateral to the pubic tubercle. When an open inguinal hernia repair is performed, the skin is usually incised a few centimetres superior to, and parallel with, the inguinal ligament along the length of the inguinal canal. Palpation of the ASIS, inguinal ligament and pubic tubercle is critical for landmarking the incision, especially in obese people and/or in individuals with large or incarcerated hernias, because normal anatomy may be significantly distorted. The superficial epigastric and superficial external pudendal vessels may be encountered soon after incising the skin and should be ligated or cauterized. The aponeurosis of external oblique is then cleared of fat and connective tissue and is opened along the length of the canal between the internal and external rings. Fingertip palpation of the external ring as a landmark is often a helpful manoeuvre to assist the surgeon in defining the patient's inguinal anatomy. If external oblique is opened by making the incision a few centimetres superior to the inguinal ligament, closure of the aponeurosis will be more straightforward. The ilioinguinal nerve is often adherent to the inner surface of external oblique and should be identified and protected while opening the aponeurosis. The free edges of external oblique are then secured with haemostats and the underlying spermatic cord is dissected out of the canal, exposing the arch of internal oblique superiorly and the inguinal ligament inferiorly. The spermatic cord or round ligament is then isolated and encircled with a Penrose drain, or a hernia ring forceps, at the level of the pubic tubercle. Performance of this manoeuvre more laterally may cause an avoidable injury to the posterior wall of the canal.

The nature of the hernia may then be ascertained by the surgeon. An indirect hernial sac usually appears as a discrete, sharply demarcated, whitish membranous layer anterior and medial to the spermatic cord/round ligament. The well-defined edge of the hernial sac often assists with its identification and separation from the adjacent spermatic cord/round ligament; the sac is next dissected away from these structures to the level of the internal ring. In males, a large hernial sac that extends into the scrotum may be divided, leaving the distal portion of the sac open within the scrotum, and the proximal end should be closed after its contents are inspected. Great care should be taken while dissecting the sac to avoid trauma and injury to the spermatic cord and its contents. In contrast, in females, division of the round ligament may facilitate both direct and indirect inguinal hernia repair. Regardless of whether or not an indirect inguinal hernia is identified, the
floor of the inguinal canal should be carefully evaluated in order to determine if a direct hernia is present. The simultaneous presence of both direct and indirect inguinal hernias is referred to as a pantaloon hernia. A sliding hernia is a variant of an inguinal hernia in which an intra-abdominal viscus makes up a portion of the wall of the hernial sac. Sliding hernias may be direct or indirect; they occur more commonly on the left side than the right side, and most often contain colon (sigmoid on the left side and caecum on the right side). The presence of bowel, omentum, ovary and fallopian tube, or other structures within the hernial sac must be recognized so that they may be protected during dissection, and reduced back into the abdominal cavity prior to hernia repair.

**Open inguinal hernia repair**

**Open paediatric inguinal hernia repair**

In the paediatric patient, inguinal hernias are indirect and their repair is often described as a ‘high ligation’. The hernial sac is often twisted on itself and transfixed prior to excision. Occasionally, female patients may be found to have a sliding inguinal hernia that contains the ovary and/or fallopian tube. Hernia repair in these circumstances requires careful reduction of the adnexa back into the pelvis. Chronic indirect hernias may be found to have an associated diastasis of the internal ring that requires tightening. Indirect hernias in males may also be associated with undescended testes; it is important to confirm the position of the testis both before and after carrying out a repair. Orchidopexy may be combined with a hernia repair in the presence of an undescended testicle.

**Open indirect hernia repair**

An indirect inguinal hernia enters the inguinal canal through the internal (deep) inguinal ring (see Fig. 55.18). Following exposure of the hernia, as already reviewed, repair may be undertaken by primary tissue repair or with a mesh. The two most commonly described primary tissue repairs are the modified Bassini repair and the Shouldice repair.

**Modified Bassini repair**

The hernial sac is dissected to the level of the internal ring, as already discussed. The sac may then be opened and its contents inspected (after
which it is closed), or it may be reduced into the abdomen without being
opened, depending on the clinical presentation and surgeon preference.
Internal oblique is next retracted in order to expose the aponeurosis of
transversus abdominis, which is sutured to the inguinal ligament using
interrupted non-absorbable sutures. The procedure progresses from medial
to lateral until the internal inguinal ring does not gape. A few interrupted
sutures may also be placed lateral to the spermatic cord/round ligament in
order to tighten the internal ring adequately. A relaxing incision in the
anterior rectus sheath may be required in order to bring the aponeurosis of
transversus abdominis and the inguinal ligament together without tension. The external oblique fascia is then closed.

**Shouldice repair**

The hernial sac is reduced into the abdominal cavity and the transversalis
fascia is then opened between the internal inguinal ring and the pubic
tubercle. The medial free edge of the lower flap of the transversalis fascia is
sutured to the lateral edge of the rectus, close to its insertion point. This
suture line is then continued laterally in a running fashion by suturing the
free edge of the lower flap to the undersurface of the upper flap until the
internal inguinal ring is reached. The suture line is then reversed in order to
fix the free edge of the upper flap to the inguinal ligament, and is continued
to the pubic bone. A third running suture is used to reinforce the second
suture line, bringing internal oblique and transversus abdominis together
with the inguinal ligament, between the internal inguinal ring and the pubic
bone. A fourth suture line is created along these same structures, but placed
in a slightly more superficial plane by using the same suture and running it
back to the internal inguinal ring, where it is tied. The external oblique
fascia, subcutaneous tissues and skin are then closed. Current international
guidelines recommend the Shouldice repair when non-mesh inguinal hernia
repair is being carried out because it has a lower recurrence rate than other
suture repairs.

**Inguinal hernia repair with mesh (Rutkow and Robbins repair, Lichtenstein repair)**

The hernial sac is identified, dissected free to the level of the internal
inguinal ring and reduced into the abdomen, as already described. The
Rutkow and Robbins repair has two components. First, a non-absorbable
mesh plug is sized and placed into the internal ring, in the preperitoneal
space, and is then circumferentially secured with non-absorbable sutures. Care must be taken to avoid injury to the spermatic cord in males, and the inferior epigastric artery in both males and females, when securing the plug. Division of the round ligament may facilitate this repair in females. Multiple plugs may be required if a large indirect defect is present. Second, an onlay non-absorbable mesh patch is sized to the floor of the inguinal canal such that it overlaps the pubic tubercle medially; it is tailored to ensure that it is long enough to permit its tails to reinforce the internal ring and adjacent tissues laterally. Suturing the mesh medially to the pubic tubercle, and suturing the tails of the mesh to each other around the spermatic cord or round ligament if it was not divided, to reinforce the internal ring, are important technical aspects of this repair. The onlay mesh is then circumferentially secured with non-absorbable sutures. An opening in the onlay mesh patch does not need to be created in females if the round ligament was divided as part of the repair (Fig. 55.20). The Lichtenstein repair differs from the Rutkow and Robbins repair because it does not employ a mesh plug.37 In both techniques, the external oblique fascia, subcutaneous tissue and skin are then closed to complete the repair. Recent international guidelines favor the performance of a Lichtenstein repair over plug and patch repairs because of increased use of foreign material, the need to enter both anterior and posterior planes and additional cost.38
FIG. 55.20 Mesh plug and patch indirect inguinal hernia repair. A, The external oblique aponeurosis is divided. B, The spermatic cord is isolated and the indirect inguinal hernial sac is dissected to the level of the internal inguinal ring. C and D, The hernial sac is returned into the abdomen, and a mesh plug is secured at the internal ring, in the preperitoneal space, with sutures. E, A mesh patch is placed to reinforce the floor of the inguinal canal and to reconstruct the internal inguinal ring. F, The external oblique aponeurosis is reapproximated. The Lichtenstein repair is similar to the mesh plug and patch repair but omits placement of the plug (steps C and D). (Adapted from R. Zollinger Jr. and E. C. Ellison, Atlas of Surgical Operations, McGraw-Hill Companies, 2011, p. 461.)

Open direct hernia repair

A direct inguinal hernia occurs as a result of a weakness in the floor of the inguinal canal at the point where the transversalis fascia is thin and lacks adequate strength to resist herniation. Hernia repair may be conducted with mesh in a similar manner as already described for an indirect hernia, with the mesh plug being placed with the direct transversalis fascial defect (after reducing the sac), rather than into the indirect defect at the internal inguinal ring. Alternatively, the surgeon may choose to perform a McVay repair or other primary tissue repair.
McVay direct hernia repair

The hernial sac is identified and isolated from the cord, as previously described. The transversalis fascia is then opened along the floor of the inguinal canal and the sac is reduced. A suture line is started medially, bringing together the conjoint tendon and lacunar ligament, and continued laterally along the pectineal ligament to the level of the femoral vein. A transition stitch is then placed, taking a bite of the aponeurotic fibres of transversus abdominis, the ileopubic tract and the inguinal ligament, to close the femoral canal. The external oblique fascia, subcutaneous tissues and skin are then closed.

Femoral sheath and femoral canal anatomy

The external iliac artery and vein exit the abdomen inferior to the inguinal ligament through a funnel-shaped femoral sheath derived from the transversalis and iliopsoas fasciae, which extends for approximately 4 cm before fusing with the adventitiae of the femoral vessels. As it exits the abdomen, the femoral sheath is bounded by the iliopectineal arch laterally, iliopsoas inferiorly, the iliopubic tract superiorly and the lacunar ligament medially. The femoral sheath is subdivided by two fascial septa into a lateral compartment that contains the femoral artery, an intermediate compartment that contains the femoral vein, and a medial compartment known as the femoral canal. The femoral canal terminates inferiorly at the foramen ovalis and contains lymphatic tissue that includes Cloquet’s node, the most superior of the deep inguinal lymph nodes. The femoral canal serves two important roles: to permit the passage of the efferent lymphatic vessels from the deep inguinal lymph nodes into the abdomen, and to permit expansion of the femoral vein when the venous pressure of the lower extremity is elevated. The entrance of the femoral canal into the abdomen is referred to as the femoral ring, and is the site where femoral hernias develop (Fig. 55.21; see Fig. 79.3). Femoral hernias tend to occur more commonly in females because the greater breadth of the gynaecoid pelvis is associated with a larger femoral ring.
FIG. 55.21  The anatomy of the femoral region. The femoral sheath is formed as a continuation of the transversalis and iliopsoas fasciae. It is subdivided by two fascial septa into three compartments: a lateral compartment that contains the femoral artery, an intermediate compartment that contains the femoral vein, and a medial compartment, the femoral canal, which is the site where femoral hernias develop. (From E. L. Menzo, R. J. Rosenthal, Femoral hernias, in Netter's Gastroenterology. Copyright © 2010 by Saunders, an imprint of Elsevier Inc., Fig. 88.1.)

**Femoral hernia repair**

**Lockwood approach**

The surgical approach to a femoral hernia repair is influenced by the experience of the surgeon and the clinical setting in which the hernia is encountered. In the elective setting, when there is a low suspicion that the hernia contains strangulated bowel, Lockwood's infra-inguinal approach to managing a femoral hernia is commonly employed. The advantage of this approach is that the inguinal canal is not disrupted. However, should ischaemic bowel or other incarcerated abdominal viscera be encountered
within the hernial sac, the neck may be difficult to control and a second incision may be required. A minimally invasive approach for repair of a femoral hernia will be reviewed later in this chapter. In the Lockwood approach, an incision is created inferior and usually parallel to the inguinal ligament and immediately on top of the hernia (Fig. 55.22). The hernial sac is next circumferentially dissected free from the overlying subcutaneous tissues, isolating its neck, and it may then be opened and its contents inspected. If the hernia is incarcerated, a relaxing incision may be made superiorly through the inguinal ligament to facilitate its reduction. It is helpful to tag the ends of the divided inguinal ligament with suture because they may be challenging to identify later on during the procedure. Reconstitution of the inguinal ligament should be carried out at the end of the procedure with non-absorbable suture. A lateral incision at the femoral ring may injure the femoral vein, and a medial incision in the lacunar ligament may cause haemorrhage, should an aberrant obturator artery branch (corona mortis) be present. Following reduction of the sac, the femoral ring may then be closed with a primary suture repair or with mesh.
FIG. 55.22 Approaches for femoral hernia repair. Approaches to femoral hernia repair are influenced by both surgeon preference and patient presentation. Classically, three open femoral hernia approaches have been described: Lockwood's infra-inguinal approach (a), Lotheissen's transinguinal approach (b), and McEvedy's high approach (c) (shown here and classically carried out through a vertical incision as depicted here but now often performed through a transverse incision). (Adapted from P.G. Sorelli, N.S. El-Masry, W.V. Garrett, Open femoral hernia repair: one skin incision for all, World J. Emerg. Surg. 4 (2009) 44.)
**Lotheissen approach**

Alternatively, Lotheissen's transinguinal approach to the femoral hernia provides a single technique for its repair, in both the elective and the emergent settings. For this technique, the transversalis fascia at the floor of the inguinal canal is opened between the pubic tubercle and the internal inguinal ring (see Fig. 55.22). The preperitoneal space is then dissected down to the level of the neck of the hernia. The hernia is reduced using a combination of external pressure and traction from within the preperitoneal space, taking care to maintain control of the neck of the hernia. The contents of the sac are inspected and ischaemic bowel or other strangulated contents is/are resected as necessary. Again, the femoral ring may be closed with a primary suture repair or with mesh. The risk of hernia recurrence may be reduced by fixing the conjoint tendon to the pectineal ligament. This is undertaken between the lacunar ligament (medially) and the femoral vessels (laterally). The floor of the inguinal canal is then reapproximated with sutures and may also be reinforced with mesh. The disadvantage with Lotheissen's transinguinal approach is that disruption of the inguinal canal may predispose the patient to subsequent development of a direct inguinal hernia, especially in the setting of a bowel resection, where mesh reinforcement of the inguinal floor is contraindicated at the time of the repair because of an increased risk of infection.

**McEvedy approach**

In the emergent setting, McEvedy's high approach overcomes the limitations of other techniques because it permits both adequate exposure and control of the hernia neck without compromising the inguinal canal. For this technique, though classically described as a vertical incision, now more commonly a transverse incision is placed 4 cm superior to the pubic symphysis and is centred over the lateral aspect of the ipsilateral rectus abdominis (linea semilunaris) (see Fig. 55.22). Dissection is then carried down to the anterior rectus sheath, which is opened vertically. Rectus abdominis is retracted medially in order to expose the underlying transversalis fascia and the peritoneum (dissection takes place inferior to the level of the arcuate line). It may be possible to enter the preperitoneal space and dissect down to the level of the neck of the hernia. Alternatively, the peritoneal cavity may be entered and the incarcerated viscera may be reduced and evaluated from within the abdominal cavity. As already described, the hernia is reduced with
a combination of internal traction and external pressure. Non-viable bowel is resected as required, the femoral ring is closed as already reviewed, the peritoneum and rectus sheath are reapproximated with sutures, and the skin is closed.

Laparoscopic inguinal and femoral hernia repair

Along the deep surface of the abdominal wall, five ligaments help to orient the surgeon to the surrounding inner abdominal wall anatomy. In the midline, running from the bladder to the umbilicus, the median umbilical ligament is the remnant of the embryonic urachus. The medial umbilical ligaments, the remnants of the obliterated umbilical arteries, lie lateral to the median umbilical ligament. The outermost lateral umbilical ligaments are peritoneal coverings of the inferior epigastric arteries (see Fig. 55.15).

Laparoscopic repair is especially valuable in the setting of bilateral or recurrent inguinal hernias, especially in the context of a prior open mesh repair. There are two main laparoscopic approaches: the transabdominal preperitoneal (TAPP) repair and the totally extraperitoneal (TEP) repair. For the TAPP approach, a pneumoperitoneum is first established, the patient is placed in the Trendelenburg position and the hernia is reduced. Starting a few centimetres superior to the hernia, the peritoneum is opened in a horizontal plane, and is then bluntly dissected from the underlying transversalis fascia to create a preperitoneal pocket, in which a mesh is placed to cover the direct, indirect and femoral spaces; the mesh is secured in place with a tacking device (see Fig. 55.15). The TEP approach is undertaken by performing a skin incision just inferior to the level of the umbilicus on the ipsilateral side of the hernia. The anterior rectus sheath is then incised, and the underlying rectus abdominis is elevated to accommodate either a blunt trocar or a balloon dissector. The preperitoneal space is entered and gas insufflation is initiated, using a laparoscopic camera to monitor progress; when a sufficient preperitoneal space has been created, two additional laparoscopic ports are inserted to assist with dissection of the peritoneum off the transversalis fascia, in a manner similar to the TAPP approach. The hernia is then reduced and a mesh is delivered through the port and positioned over the direct, indirect and femoral spaces, ensuring that the peritoneum is inferior to the inferior edge of the mesh. The mesh may then be secured with tacks. Recent guidelines suggest that, provided expertise is available, for elective femoral hernia repair a laparoscopic procedure is
recommended. The femoral vein and inferior epigastric vessels are vulnerable to injury during inguinal and femoral hernia repair.

Tips and Anatomical Hazards

Vascular injury: the inferior epigastric vessels, femoral vein and corona mortis

The corona mortis (crown of death) is a common variant vascular anastomosis between either the external iliac artery or the deep inferior epigastric artery and the obturator artery. It runs along the deep border of the lacunar and pectineal ligaments, and is reported to be present in up to one-third of patients. Its clinical importance is in the setting of an incarcerated femoral hernia. If a relaxing incision is to be made in the femoral ring in order to facilitate reduction of an incarcerated hernia, it is best to avoid incising the lacunar ligament because significant haemorrhage may occur following injury to this unseen but vulnerable vessel (see Fig. 55.21).

Injury to the ilioinguinal nerve

The ilioinguinal nerve is at significant risk of injury when opening external oblique and must be identified and protected; its injury or incorporation into a hernia repair may lead to chronic postoperative pain. Some surgeons routinely choose to excise this nerve during inguinal hernia repairs in order to reduce the risk of chronic postoperative groin pain. In a meta-analysis we have previously reported that planned resection of the ilioinguinal nerve at the time of inguinal hernia repair was associated with a significant reduction in the incidence of chronic postoperative pain.

Injury to the spermatic cord/ischaemic orchitis

Any component of the spermatic cord (vas deferens, blood vessels and so on) may be injured during an inguinal hernia repair.
Ischaemic orchitis occurs during inguinal hernia repair in males when the blood supply to a testicle is compromised. The risk may be reduced by ensuring that the reconstructed external inguinal ring is not too tight and does not strangulate the spermatic cord and/or by limiting the extent of cord dissection and avoiding dissecting beyond the level of the pubic tubercle.

A laparoscopic approach should be considered for repair of recurrent hernias, which have a significantly increased risk of ischaemic orchitis as a consequence of dissecting an already scarred spermatic cord.

Laparoscopic inguinal hernia repair: triangle of pain and triangle of doom

During a laparoscopic inguinal hernia repair, dissection and tack placement beneath the iliopubic tract places neurovascular structures lying within a medial ‘triangle of doom’ or a lateral ‘triangle of pain’ at significant risk of iatrogenic injury. The triangle of doom contains the external iliac and deep circumflex iliac veins and the femoral artery. Its apex is at the internal inguinal ring, and it is bounded medially by the vas deferens in males or round ligament in females, laterally by the gonadal vessels, and inferiorly by the peritoneal edge (see Fig. 55.15).

The triangle of pain contains the femoral and lateral femoral cutaneous nerves and the femoral branch of the genitofemoral nerve. It is bounded by the medial side of the spermatic cord in males or round ligament in females, the iliopubic tract and the iliac crest (see Fig. 55.15).

These areas should be avoided during laparoscopic hernia repair; significant haemorrhage and chronic postoperative pain may result from their encroachment.
References


Single Best Answers (Anterior Abdominal Wall)

1. Which one of the following statements about the anterior rectus sheath is TRUE?

A. Below the arcuate line, all three bilaminar aponeuroses of the three flat anterior abdominal wall muscles blend together to form the anterior rectus sheath

B. The entire anterior rectus sheath is formed from both leaves of the aponeurosis of external oblique and the anterior leaf of the aponeurosis of internal oblique

C. Blunt dissection can easily separate rectus abdominis from the overlying anterior rectus sheath

D. Above the costal margin, all three aponeuroses of the three flat anterior abdominal wall muscles blend together to form the anterior rectus sheath

Answer: A. Below the arcuate line, all three bilaminar aponeuroses of the three flat anterior abdominal wall muscles blend together to form the anterior rectus sheath. Above the costal margin, the anterior rectus sheath is formed by the aponeurosis of external oblique only. Between the costal margin and the arcuate line, the anterior rectus sheath is formed from both leaves of the aponeurosis of external oblique and the anterior leaf of the aponeurosis of internal oblique. Rectus abdominis is attached to the anterior rectus sheath by tendinous intersections that must be divided in order to mobilize the underlying rectus muscle completely.

2. Which one of the following statements regarding the nerves of the anterior abdominal wall is FALSE?

A. The nerves run within a neurovascular plane located between transversus abdominis and internal oblique

A. The nerves run within a neurovascular plane located between transversus abdominis and internal oblique
B. A transversus abdominis plane block can be achieved through the triangle of Petit
C. The thoraco-abdominal nerves are derived from the dorsal (posterior) rami of the sixth to twelfth intercostal nerves
D. The thoraco-abdominal, subcostal, iliohypogastric and ilioinguinal nerves supply the anterior abdominal wall

**Answer:** C. The thoraco-abdominal nerves are derived from the ventral (anterior) rami of the sixth to twelfth intercostal nerves and not the dorsal (posterior) rami.

3. A 68-year-old man with acute appendicitis and a background of ischaemic heart disease and hypertension underwent a laparoscopic appendicectomy. During insertion of a left lower quadrant port, a vessel was ligated to control bleeding. The following day, he complained of worsening left thigh pain. Which one of the following statements is most likely to be TRUE?
A. The ilioinguinal nerve has been injured
B. He has developed an ischaemic left leg
C. A rectus sheath haematoma has formed
D. The lateral cutaneous nerve of the thigh has been injured

**Answer:** B. The deep inferior epigastric artery can become an important part of the collateral blood supply to the leg in patients with aortoiliac occlusive disease. Its occlusion or injury can lead to leg ischaemia.
Clinical Case (Anterior Abdominal Wall)

1. A 69-year-old female with a history of diverticular disease, chronic myelomonocytic leukaemia and a recent diagnosis of a left-sided pulmonary embolism presents to the emergency surgical team complaining of sudden onset of left lower quadrant abdominal pain. Her initial vital signs are a heart rate of 115 bpm, a blood pressure of 90/58 mmHg, oxygen saturations of 97% on air, a respiratory rate of 26 breaths per minute and a temperature of 37.6°C. Abdominal examination reveals increased tenderness in the left lower quadrant and mild tenderness in the infra-umbilical region. An urgent CT of the abdomen and pelvis with intravenous and oral contrast is arranged for suspected acute complicated diverticulitis. The CT demonstrates a small pelvic fluid collection and a large left-sided rectus sheath haematoma with evidence of contrast extravasation from the deep inferior epigastric artery.

A. What are the treatment options for this patient?

The patient is haemodynamically unstable and requires fluid resuscitation and/or blood transfusion. A recent history of pulmonary embolism suggests that the patient is likely to be anticoagulated, and haematological advice regarding anticoagulation reversal should be sought. Most rectus sheath haematomas are self-limiting and can be managed conservatively, but this patient is haemodynamically compromised with evidence of ongoing bleeding. First-line treatment, if available, should be angiography and embolization of the ipsilateral inferior epigastric artery and possibly also embolization of the ipsilateral superior epigastric artery. Should this fail, surgical evacuation of the haematoma, ligation of bleeding vessels and repair of the rectus sheath may be required. Spontaneous rectus sheath haematomas are relatively rare but are becoming more common since the introduction of direct-acting oral anticoagulants. Most patients will report sudden onset of localized abdominal pain associated with a tender palpable non-pulsatile abdominal wall mass on examination. Haematomas are more frequent below the arcuate line because the posterior rectus sheath is absent. The anterior and posterior rectus sheaths are both present above the arcuate line and help to tamponade the bleeding.
Single Best Answers (Inguinal Region)

1. During an open indirect hernia repair, the mesh is secured at its most lateral aspect to reconstruct the internal inguinal ring. While this bite is being taken, a small amount of bleeding is noted at the suture site. Which one of the following statements best describes what you should do?

A. Ensure that you tie the suture snugly to achieve haemostasis
B. Perform a figure-of-eight stitch to achieve haemostasis and reduce the risk of postoperative haematoma
C. Finish tying the suture and apply manual pressure because use of cautery in this area risks injury to the ilioinguinal nerve
D. Remove the suture

Answer: D. The femoral vein is located lateral to the internal inguinal ring. A deep suture bite over this area risks injury to the femoral vein. The suture should be removed and pressure applied.

2. Repair of a femoral hernia is under way. A skin incision has been placed directly over a palpable hernia, and the sac has been dissected down to its neck at the femoral ring. The sac is incarcerated at the neck and a relaxing incision is required to permit reduction of the hernia contents. You recall that the aberrant anatomy known as the corona mortis is a commonly encountered vessel and you wish to avoid troublesome bleeding from injury. Which one of the following describes where you may encounter this vessel when you make your relaxing incision?

A. Along the lateral aspect of the femoral ring
B. Superiorly, by incising the inguinal ligament
C. Medially, by incising the lacunar ligament
D. Inferiorly, along the inferior aspect of the femoral ring
Answer: C. The corona mortis, or ‘crown of death’, is a common variant vascular anastomosis located between either the external iliac artery or deep inferior epigastric artery and the obturator artery. It runs along the deep border of the lacunar and pectineal ligaments.

3. Following an inguinal hernia repair, postoperative neuralgia is most commonly attributable to injury of which one of the following nerves?
   A. Ilioinguinal nerve
   B. Genital branch of the genitofemoral nerve
   C. Iliohypogastric nerve
   D. Femoral branch of the genitofemoral nerve

Answer: A. The ilioinguinal nerve is a sensory nerve to the upper medial thigh and to the base of the genitals. It penetrates transversus abdominis and internal oblique, passes through the internal inguinal ring immediately deep to the external oblique aponeurosis, and travels with the spermatic cord to exit the abdominal wall at the external inguinal ring.
Clinical Case (Inguinal Region)

1. A 66-year-old female presents to hospital with a 24 hour history of nausea and vomiting. At presentation she is afebrile with a heart rate of 94 bpm and a blood pressure of 138/77 mmHg. Physical examination reveals a firm bulge in the left groin, lateral to the pubic bone and inferior to the inguinal ligament. The site is extremely painful to palpation and is found to be warm with overlying erythematous skin changes.

A. What is the most likely cause of this patient's presentation?
The patient has an incarcerated, obstructed femoral hernia. The inguinal ligament contributes to the floor of the inguinal canal. As the hernia is located inferior to this landmark, it is probable that the bulge represents a femoral hernia. The pain, warmth and skin changes associated with the hernia all increase the suspicion that an involved loop of bowel is ischaemic.

B. How should the patient be managed?
As such, the bowel should be inspected to ensure that it is viable and therefore an attempt at reducing the hernia should not be undertaken in the accident and emergency department. The patient should be taken to the operating theatre urgently for evaluation of the bowel and repair of the hernia. In theatre, the hernia may potentially be approached superior or inferior to the inguinal ligament. In this case, a skin incision should be made above the inguinal canal, the canal opened along its length and the floor of the canal also opened; the obstructed loop of bowel may be secured by an assistant's hand or by a surgical instrument. The incarcerated bowel may then be reduced from the femoral ring and inspected for its viability. Viable bowel is returned into the abdomen and the surgeon can complete repair of the hernia according to personal preference. Should the hernia be found to contain ischaemic bowel that requires resection, a tissue repair of the hernia is required because a repair utilizing mesh is at risk of infection, given the contaminated operative field.
Core Procedures

Pancreas

- Pancreaticoduodenectomy (Whipple procedure)
- Distal pancreatectomy ± splenectomy
- Total pancreatectomy

Spleen

- Splenectomy
- Partial splenectomy

Colon and Rectum

- Right hemicolecction ± extended resection
- Left hemicolecction ± extended resection
- Total abdominal colectomy
- Total proctocolectomy
- Anterior resection
- Abdominoperineal resection
- Colostomy

Vascular
• Abdominal aortic aneurysm repair
• Thoraco-abdominal aortic aneurysm repair
• Aorto-bifemoral bypass
• Surgical management for mesenteric ischaemia (such as antegrade or retrograde bypass, embolectomy)

Trauma

• Trauma laparotomy with exploration of retroperitoneum

Kidney

• Nephrectomy
  • Partial nephrectomy

Adrenal (suprarenal) Glands

• Adrenalectomy

Miscellaneous

• Kidney transplantation
• Posterior abdominal wall hernia repair
**Embryology**

Throughout the development of the embryo, the endoderm that lines the yolk sac develops into the epithelial lining of the primitive gut, which eventually differentiates into the foregut, midgut and hindgut. In addition, the surrounding splanchnic mesoderm develops into the supporting muscle, connective tissue and membranous structures. The primitive gut is suspended in the intraembryonic coelom (eventually becoming the peritoneal cavity) by its mesentery, whereby the parietal (somatic) layer of lateral mesoderm lines the coelomic cavity and the visceral (splanchnic) layer lines the primitive gut.¹

Various portions of the primitive gut grow and rotate at different rates, which leads to variation in the length and orientation of the mesentery. As a result, some portions of the mesentery adhere permanently to the posterior parietal peritoneum, causing the intestine to become fixed to the posterior abdominal wall without an apparent free mesentery, thereby becoming retroperitoneal. They are considered secondarily retroperitoneal and are anatomically separated by an avascular plane of areolar tissue from other structures that develop posterior to the peritoneum without a mesentery (for example, kidney). These embryological processes become highly relevant during surgery, as they permit various parts of the intestines (such as the ascending colon) to be mobilized by separation of their respective mesentery from the retroperitoneum along lines of fusion. These manoeuvres provide excellent, rapid and safe access to the retroperitoneum without compromising the blood supply and lymphatics of the intestine, or causing inadvertent injuries to retroperitoneal structures during dissection. Examples of secondarily retroperitoneal structures include the pancreas, duodenum, ascending colon and descending colon.
Surgical surface anatomy

Several incisions provide efficient and safe access to the retroperitoneum (Fig. 56.1). The most common and versatile method is a transabdominal route using a midline incision. This incision can occur anywhere between the xiphoid process and the pubic symphysis (symphysis pubis), depending on the surgical exposure required. After access to the peritoneal cavity is obtained, intraperitoneal structures (such as the small intestine or liver) are retracted in order to access the retroperitoneum. Often, this requires additional mobilization of secondarily retroperitoneal structures, such as a right medial visceral rotation (see ‘Clinical anatomy’ later).
Given the morbidity associated with a midline laparotomy and intraperitoneal access (for example, incisional hernia, postoperative ileus, bowel obstruction), access may alternatively be gained directly to the retroperitoneum by several routes without entering the peritoneal cavity (that is, extraperitoneal access). For example, generous exposure may be obtained into the iliac fossa and pelvis for a variety of urological and gynaecological procedures by performing a Gibson incision, which is an oblique incision that starts two fingers’ breadths superior to the pubic symphysis in the midline and is carried towards the iliac crest in a lateral and superior direction, on either the right or the left side. It may also be extended either into the flank or vertically towards the lower ribs in a direction that is medial to the anterior superior iliac spine but lateral to rectus abdominis. This incision is often used for kidney transplantation in order to access the iliac vessels. Alternatively, a flank incision may be used in order to gain
access to the kidneys and adrenal (suprarenal) glands either through the
eleventh intercostal space, by placing the patient in a lateral decubitus
position with the operating table flexed, or posteriorly through the twelfth
intercostal space, with the patient positioned in the prone jack-knife
position. Other less common incisions for access to the retroperitoneum
include the anterior subcostal (transabdominal, or chevron) incision, or the
modified Makuuchi incision, for complete exposure of the liver and other
right-sided retroperitoneal organs (such as the adrenal gland, inferior vena
cava (IVC), duodenum, head of the pancreas). A thoraco-abdominal
approach will provide excellent exposure of both abdominal and thoracic
cavities by accessing the pleural space through the eighth or ninth intercostal
spaces and following this incision into the peritoneum obliquely through the
diaphragm and rectus abdominis, merging into the linea alba at the midline.
This approach is often used during cancer operations in an attempt to
achieve negative margins during large en bloc resections and extensive
retroperitoneal lymph node dissections (for example, oesophagogastrectomy
for gastro-oesophageal junction tumours), or in order to gain access to the
great vessels for major vascular procedures (for example, open thoraco-
abdominal aneurysm repair).
Clinical anatomy

The retroperitoneum may be divided anatomically into three compartments based on embryological origin (Fig. 56.2): anterior pararenal space (APS, containing the ascending colon, descending colon, duodenum, pancreas and root of the small bowel mesentery), perirenal space (PRS, containing the kidneys, adrenal glands and upper ureters) and the posterior pararenal space (PPS, does not contain any organs). The APS is bounded anteriorly by the posterior parietal peritoneum, and posteriorly by the anterior renal fascia (Gerota's fascia). The PPS is bounded anteriorly by the posterior renal fascia, and posteriorly by quadratus lumborum, transversus abdominis and thoracolumbar fascia. These spaces are separated from one another by avascular interfascial planes, including the retromesenteric plane RMP, located between the APS and PRS, and the retrorenal plane located between the PRS and PPS. These spaces and planes extend through the midline of the posterior abdominal wall and eventually fuse together within the pelvis, which means that fluid collections tend to spread into the pelvis. They are also contiguous with the bare area of the liver and hemidiaphragms, providing a potential route into the thorax and mediastinum.
FIG. 56.2 Compartments and avascular planes of the retroperitoneum at the level of the renal hila; the thickness of the interfascial planes has been exaggerated to illustrate their potentially expansile nature. Note that the perinephric spaces (PRS) are closed medially. The retromesenteric space is continuous across the midline. The retromesenteric anterior interfascial space (RMP), retrorenal posterior interfascial space (RRS) and lateroconal plane communicate at the fascial trifurcation (arrows). Abbreviations: A, aorta; APS, anterior pararenal space; ARF, anterior renal fascia; DPS, dorsal pleural sinus; IVC, inferior vena cava; LCF, lateroconal fascia; PP, parietal peritoneum; PPS, posterior pararenal space; PRF, posterior renal fascia; TF, transversalis fascia. (From R.M. Gore, D.M. Balfe, R.I. Aizenstein, P.M. Silverman, The great escape: interfascial decompression planes of the retroperitoneum. Am. J. Roentg. 175 (2000) 363–370).

Other important intraoperative landmarks are the white lines of Toldt, which are the lateral peritoneal reflections located immediately adjacent to the ascending and descending colon. Incising the white line serves as the gateway to the appropriate avascular interfascial plane that is accessed in order to mobilize the entire hemicolon with its accompanying mesentery medially, away from the primary retroperitoneal structures (such as the kidney, ureters and gonadal vessels).

A thorough understanding of the compartmentalization of the retroperitoneum is critical for the surgical management of abdominal pathology (Videos 56.1 and 56.2). For example, the spread of infections, inflammatory processes and retroperitoneal collections tends to be confined to the compartment of origin (for example, early pyelonephritis) and may provide additional clues as to their organ of origin, while more rapidly
developing processes (such as severe acute pancreatitis) tend to spread through fascial planes and bridging lymphatics. Similarly, haematomas may occur within the retroperitoneum and track through the abdominal wall, manifesting themselves clinically as ecchymosis in the flanks (Grey Turner sign) or periumbilical region (Cullen sign). In the trauma setting, haematoma or haemorrhage associated with an injury to a great vessel within the abdomen is classified into three zones. Zone 1 injuries occur in the midline and may be further categorized as being of either supramesocolic or inframesocolic origin. Supramesocolic zone 1 haematomas should raise suspicion of an injury to the suprarenal aorta, coeliac axis, proximal superior mesenteric artery, or proximal renal arteries, whereas inframesocolic haematomas suggest injury to the infrarenal aorta or the IVC. Zone 2 haematomas are located in the perirenal space and tend to be caused by an injury to the renal artery, renal vein or kidney. Zone 3 haematomas are located within the pelvis and are suggestive of injury to the iliac vessels. Depending on the zone, mechanism of injury (blunt versus penetrating trauma), haematoma characteristics (that is, pulsatile, expanding), presence of peritonitis and haemodynamic parameters, exploration of these haematomas may be mandatory.6

Several intra-abdominal surgical approaches also rely on the relationships of these retroperitoneal spaces and planes, allowing surgeons to gain rapid and safe access to deeper compartments. One very commonly performed surgical manoeuvre is the medial visceral rotation, which may occur from either the right side or the left side. A right medial visceral rotation begins with performance of a Kocher manoeuvre in order to mobilize the duodenal loop and the head of the pancreas. This is achieved by opening the posterior peritoneum lateral to the duodenum and continuing the dissection in the avascular retromesenteric plane, while medializing the duodenum and the head of the pancreas until the common bile duct (superiorly) and superior mesenteric vein (inferiorly) are visualized. The hepatic flexure, which is immediately posterior to the duodenum, often requires additional mobilization in order to perform a complete Kocher manoeuvre. While this technique provides excellent exposure of the IVC and right renal hilum, further medialization may be achieved by performing a Cattell–Braasch manoeuvre. The posterior peritoneum that was initially opened during the Kocher manoeuvre is followed inferiorly along the white line of Toldt, all the way around the caecum and appendix, and then back obliquely upwards towards the ligament of Treitz along the line of fusion of the small bowel
mesentery and posterior peritoneum (Fig. 56.3). By mobilizing the colon and its mesentery off the pararenal space, rapid and extensive exposure of the inframesocolic retroperitoneum may be accomplished, including exposure of the entire infrahepatic IVC, right and left renal hila, right and left iliac vessels, and infrarenal aorta.

**FIG. 56.3** A right medial visceral rotation is performed by dividing the peritoneum lateral to the duodenum, along the white line of Toldt and back up towards the ligament of Treitz. Dashed lines represent retroperitoneal attachments that need to be divided (arrows) in order to perform a right medial visceral rotation.
A left medial visceral rotation is carried out in a similar fashion by incising the white line on the left side, towards the splenic flexure and lateral to the spleen, gaining access to the interfascial planes. Planes of dissection will differ, depending on the specific objectives of the operation. For example, during a segmental colon resection for treatment of cancer, dissection in the retromesenteric plane allows for full mobilization of the left hemicolon until the proximal vascular pedicle at the inferior mesenteric artery has been reached. In this case, there is no need to mobilize the spleen. Therefore, the white line is incised all the way up to the splenic flexure and carried medially along the gastrocolic ligament, in order to mobilize the distal transverse colon and mesocolon. However, in a trauma setting, it may be optimal to mobilize the PPS off the muscles of the posterior abdominal wall by carrying the incision of the white line of Toldt all the way around the spleen and up to the diaphragmatic hiatus. By reflecting the spleen, pancreas and left kidney medially, in a technique known as the Mattox manoeuvre, the surgeon may gain access to one of the least accessible areas of the retroperitoneum: the midline superior mesocolic region, including the suprarenal aorta, left renal vessels, coeliac plexus and its major branches, and the superior mesenteric artery. During splenectomy alone, the posterior peritoneum is opened lateral to the spleen without the need to open the white line of Toldt. Instead, this incision is carried around the diaphragm by taking down the splenophrenic ligament, and inferiorly by taking down the splenocolic ligament, in order to mobilize the spleen. The avascular plane posterior to the spleen and anterior to the left kidney may be dissected in order to allow the spleen to be medialized. If a portion of the pancreas also needs to be resected with the spleen, or if access is needed to the left adrenal gland that lies just posteriorly, the distal pancreas is further mobilized by dissecting within that same posterior plane and opening the posterior peritoneum along the superior and inferior edges of the pancreas.

Access to the supramesocolic retroperitoneum may also be effectively achieved through the lesser sac, either from above the lesser curvature of the stomach by opening the avascular portion of the lesser omentum (pars flaccida), or from below the greater curvature of the stomach by dividing the gastrocolic ligament.

⚠️ **Tips and Anatomical Hazards**
Effective and safe dissection within the retroperitoneum relies heavily on the ability to adhere to basic surgical principles by maintaining the dissection within avascular planes. It is fundamental for the surgeon to place appropriate traction and counter-traction to expose the loose areolar connective tissues adequately that separate the various compartments of the retroperitoneum. For example, during a medial visceral rotation or mobilization of the colon for a hemicolecction, the colon must be pulled medially with enough traction to place the white line of Toldt under tension, and to demonstrate the retromesenteric plane so as to avoid dissecting either too laterally into the abdominal wall, or posteriorly into the retroperitoneum. Other common examples include splenectomy and duodenal Kocherization, during which procedures these organs are pulled medially with enough force to facilitate surgical dissection within the correct plane.

However, pitfalls may occur when the dissection inadvertently strays outside these safe planes into hazardous areas, where important structures (such as ureters, iliac vessels, gonadal vessels or hypogastric nerves) may be obscured by fatty and connective tissues, and may potentially be injured inadvertently. This problem is especially exacerbated in circumstances where there are significant acute and chronic inflammatory changes, when the natural avascular planes that separate these spaces become obliterated and the normal anatomy becomes distorted. For example, a potential ureteric injury may occur when performing a colectomy in the setting of acute diverticulitis with a concomitant perforation in the sigmoid colon, or for chronic diverticulitis with its associated fibrotic changes. Similarly, mobilizing the pancreas for resection may be difficult in the context of acute or chronic pancreatitis, as well as in the presence of an obstructing tumour or in the setting of a traumatic pancreatic transection. The normal anatomy may also be distorted by a neoplasm invading surrounding structures, or in the presence of haematomas that are or are not associated with active bleeding (as in trauma or ruptured abdominal aortic aneurysm, for example).

While placing optimal tension on tissues exposes the desired tissue planes, another common surgical pitfall is encountered when applying overly aggressive traction, resulting in tearing of these fragile tissues and avulsion of important vessels. This pitfall is well described for the right colic and middle colic vessels, which may inadvertently be
avulsed from the superior mesenteric vessels during a right medial visceral rotation. This manoeuvre results in the intestine being suspended by its vascular pedicle, potentially leading to major haemorrhage within the mesenteric root. Similarly, during a left-sided medial visceral rotation, the spleen or left descending lumbar veins may be avulsed during retraction. Great care should be taken by the operating team to apply just enough traction to expose the plane of dissection, without damaging the surrounding vulnerable tissues and structures. This problem may be especially magnified in the setting of minimally invasive surgery (such as laparoscopy or robotic platform), where haptic feedback is very limited and excessive traction may be placed on tissues without the operator being aware that this is happening.

**Right Medial Visceral Rotation**

Injury to right ureter, right gonadal vessels, duodenum, iliac vessels, colon, gallbladder, liver capsule.
Avulsion of middle colic vessels.
Dissection into mesentery, abdominal wall, and Gerota’s fascia.

**Left Medial Visceral Rotation**

Injury to left ureter, left gonadal vessels, duodenum, iliac vessels, hypogastric nerves, colon.

Avulsion of middle colic vessels.
Dissection into mesentery, abdominal wall, and Gerota’s fascia.
With a full Mattox manoeuvre tear of spleen capsule, injury to pancreas and injury of left descending lumbar vein.

**Dissection via the Lesser Sac**

Injury to transverse colon, greater curvature of stomach or epigastric vessels when dissecting gastrocolic ligament.
Injury to oesophagus, portal structures or inferior vena cava when dissecting through hepatogastric ligament, and along supramesocolic
aorta and crura of diaphragm. Dissection into transverse mesocolon.
References

Single Best Answers

1. The pancreas is located in which one of the following retroperitoneal spaces?
   A. Anterior pararenal space
   B. Posterior pararenal space
   C. Perirenal space
   D. Retromesenteric space

   **Answer:** A.

2. A patient undergoes a crash laparotomy after sustaining blunt trauma. The fastest way to obtain access to the superior mesocolic great vessels is through which one of the following options?
   A. Right medial visceral rotation
   B. Kocher manœuvre
   C. Left medial visceral rotation
   D. Lesser sac

   **Answer:** C.

3. To perform a hemicolecotomy, the colon is mobilized by dissecting in which one of the following spaces?
   A. Thoracolumbar fascia
   B. Pararenal space
   C. Retrorenal space
   D. Retromesenteric space

   **Answer:** D.

4. A patient is undergoing a curative *en bloc* resection of a large right
adrenal tumour extending towards the diaphragm. Which one of
the following incisions provides the best exposure?
A. Flank incision
B. Subcostal incision
C. Thoraco-abdominal incision
D. Posterior incision

Answer: C.
Clinical Cases

1. A 56-year-old female with Cushing's syndrome is undergoing a left-sided laparoscopic transabdominal adrenalectomy.
   A. Describe the various structures that need to be mobilized to obtain access to the left adrenal gland. Which avascular planes need to be dissected?
   The lateral attachments of the spleen need to be detached in order to get access and dissect in the avascular splenorenal ligament, which will allow the spleen and distal pancreas to be medialized, thereby exposing the anterior renal fascia (Gerona's fascia) and the perirenal space, which houses the left kidney and adrenal gland.
   The left colon and splenic flexure may also need to be mobilized by taking down the splenocolic ligament, the white line of Toldt and medially towards the midline, dividing the gastrocolic ligament and separating the colon from the retroperitoneal attachments of the pancreas. This will allow the surgeon to dissect in the avascular retromesenteric plane.

2. A 24-year-old male sustains a gunshot wound to the abdomen.
   A. Describe the zone classifications for retroperitoneal haemorrhage in trauma.
   In the trauma setting, haematomas or haemorrhage associated with an injury to a great vessel in the abdomen are classified into three zones. Zone 1 injuries occur in the midline and are further divided into supramesocolic and inframesocolic origin. Supramesocolic zone 1 haematomas should raise suspicion for an injury to the suprarenal aorta, coeliac axis, proximal superior mesenteric artery, or proximal renal arteries, whereas inframesocolic haematomas indicate injury to the infrarenal aorta or the IVC. Zone 2 haematomas are located in the perirenal space and tend to be caused by an injury to the renal artery, renal vein or kidney. Finally, Zone 3 haematomas in the pelvis are suggestive of injuries to the iliac vessels. Depending on the zone, mechanism of injury (blunt versus penetrating trauma), haematoma characteristics (i.e., pulsatile, expanding), presence of peritonitis, and haemodynamic parameters, these haematomas may require mandatory exploration.
Peritoneum, mesentery and peritoneal cavity

J Calvin Coffey, Peter Dockery

Core Procedures

All operations can be performed via open, laparoscopic or robotic approaches and therefore the approach is not specified.

- Stomach: total gastrectomy, partial gastrectomy
- Pancreas: subtotal pancreatectomy, pancreaticoduodenectomy
- Liver: hepatectomy
- Spleen: splenectomy
- Appendix: appendicectomy
- Colon: complete mesocolic excision, total mesocolic excision, partial mesocolic excision (left or sigmoid)
- Rectum: total mesorectal excision (TME), partial mesorectal excision, Hartmann’s procedure, transanal total mesorectal excision (TaTME)
- Repair of malrotation: restoration of mesenteric conformation and pexy for non-rotation

Most intestinal, hepatic, pancreatic and splenic operations are technically based on mesenteric and peritoneal anatomy. The classical appraisal of mesenteric and peritoneal anatomy was founded on the concept of multiple ‘mesenteries’ and has recently been challenged on the grounds that the mesentery is a single and continuous organ. Although the current anatomical model is relatively new, it is evidence-based and universally applicable (even in the setting of congenital abnormalities). It is the anatomical foundation of digestive system surgery distal to the oesophagus.\(^1,2\) All aspects of mesenteric, peritoneal and fascial anatomy cannot be covered in this chapter; the reader is referred to Mesenteric Principles of Gastrointestinal Surgery: Basic
and Applied Science for a comprehensive description.$^3$
**Definitions**

As the peritoneum, mesentery and associated fascia are continuous, there are no distinctive landmarks to indicate the anatomical limits of adjacent regions. Notwithstanding, a nomenclature has developed with reference to each different region. The terms of this nomenclature are categorized as anatomical, surgical and embryological in what follows and are defined and explained in **Table 57.1**.

**TABLE 57.1**

**Anatomical terminology defined and explained**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
</table>
| Mesentery  | The collection of tissues that maintains abdominal digestive system organs in position and in continuity with other systems | It is important to draw attention to a number of aspects of this definition: 
Unlike previous definitions, the words ‘fold’, ‘membrane’ and ‘sheet’ are not used: once the mesentery has been mobilized or detached, it loses the shape it had in situ
Earlier descriptions of the mesentery described it connecting the intestine to the posterior abdominal wall. It is more accurate anatomically to consider the mesentery as maintaining connectivity between abdominal digestive system organs and systems of the body, rather than maintaining ‘direct’ continuity with the posterior abdominal wall. The mesentery is attached to the posterior abdominal wall through a number of anatomical mechanisms, including the apposition of mesenteric regions, the peritoneal bridge or reflection, and vascular, neurological and lymphatic connections
Previous definitions describing the mesentery as a double fold of peritoneum have been omitted from the current definition. It is correct to say that the surface of the mesentery is mesothelial and in continuity with the peritoneum. However, the mesentery has a substantive stroma that increases in volume with age and is the anatomical correlate for many mesenteric functions. It is misleading to highlight one histological element among several |
<p>| Peritoneum | A continuous serous membrane supported by connective tissue, lining the innermost surface of the abdominal wall, from which it is reflected on to viscera where it is continuous with surface mesothelium (<a href="#">Fig. 57.2; see Fig. 57.1B</a>) | The word ‘reflected’ refers to where the peritoneum leaves the abdominal wall to reach and merge with the surface of an adjacent viscus (such as the intestine, mesentery, liver or spleen). Where the peritoneum is reflected on to the mesentery, it is continuous with the mesothelial surface of the mesentery. Collectively, regions of the peritoneum form a mesothelial canopy that assists in maintaining the position of viscera within the abdomen. This is of considerable surgical importance, as the peritoneum obscures certain regions of the mesentery (and related structures) from direct visualization. As a result, it must be sharply incised to provide surgical access to mesentery and fascia. The peritoneum is of considerable pathological and radiological relevance because it also forms a barrier to the spread of disease |</p>
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
<th>Organs apposed to the retroperitoneum include the liver (at the bare area), duodenum, pancreas, mesentery and intestine (at several levels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fascia (Toldt’s)</td>
<td>A connective tissue layer between an organ and retroperitoneum, where these are contiguous</td>
<td></td>
</tr>
<tr>
<td>Spaces and fossae</td>
<td>There are several spaces and fossae that are of historical but are not of surgical relevance</td>
<td></td>
</tr>
<tr>
<td>Peritoneal reflection</td>
<td>Peritoneum bridging contiguous organs (see Figs 57.1B, 57.2)</td>
<td></td>
</tr>
<tr>
<td>Peritoneal folds</td>
<td>A fold occurs where the peritoneum doubles back sharply on itself</td>
<td>These occur at points where the intestine and mesentery undergo a marked conformational change (such as at duodenojejunal, ileocaecal and splenic flexures). Other than serving as landmarks, they are of limited surgical relevance</td>
</tr>
<tr>
<td>Mesoduodenum</td>
<td>Mesentery attached to the duodenum, located posterior to the pancreas and anterior to the posterior abdominal wall</td>
<td>In the adult, the mesoduodenum is located posterior to the head and body of the pancreas and narrows in all planes as it proceeds distally. It is continuous with the dorsal mesogastrium superiorly and with the mesenteric root region (see later) distally</td>
</tr>
<tr>
<td>Falciform ‘ligament’</td>
<td>The most anterior region of ventral mesogastrium located between the anterior surface of the liver and the anterior abdominal wall</td>
<td>It is a region of mesentery and not a ligament</td>
</tr>
<tr>
<td>Mesocolon</td>
<td>Mesentery associated with colon</td>
<td>The mesocolon is a continuation of the small intestinal mesentery and is arbitrarily divisible into regions, according to the region of associated intestine. These include the right, transverse and left mesocolon, the mesosigmoid and the mesorectum. The mesosigmoid is further divided into two regions (medial and lateral), which can be differentiated by the fact that the medial region of the mesosigmoid is apposed to (or flattened against) the retroperitoneum, while the lateral region is mobile</td>
</tr>
<tr>
<td>Meso-appendix</td>
<td>Mesentery associated with the appendix</td>
<td>This is of central anatomical importance because the position of its origin from the ileocaecal region of mesentery partly determines the anatomical location of the appendix (that is, retrocaecal or pelvic)</td>
</tr>
<tr>
<td>Dorsal mesentery</td>
<td>The region of mesentery contiguous with the abdominal wall, including the dorsal</td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td>Description</td>
<td></td>
</tr>
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<td>-------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Ventral mesentery</td>
<td>The region of mesentery contiguous anterior and posterior with the abdominal wall and dorsal mesogastrium, respectively, and consisting of ventral mesogastric and falciform regions</td>
<td></td>
</tr>
<tr>
<td>Mesenteric root region</td>
<td>The area where the upper (mesogastric and mesoduodenal) mesentery narrows and then fans out as the small intestinal mesentery (Fig. 57.3; see Fig. 57.1D).</td>
<td></td>
</tr>
<tr>
<td>Retroperitoneum</td>
<td>The abdominal wall posterior to Toldt's fascia (see Fig. 57.1C)</td>
<td></td>
</tr>
<tr>
<td>Ventral mesogastrum (lesser omentum)</td>
<td>Mesentery bridging the liver and the stomach or duodenum (see Fig. 57.1E)</td>
<td></td>
</tr>
<tr>
<td>Dorsal mesogastrum</td>
<td>Mesentery bridging the stomach and posterior abdominal wall (see Fig. 57.1D,E)</td>
<td></td>
</tr>
<tr>
<td>Greater omentum</td>
<td>The fibroadipose structure extending inferiorly and laterally from the greater curvature of the stomach</td>
<td></td>
</tr>
<tr>
<td>Small intestinal mesentery</td>
<td>Mesentery</td>
<td></td>
</tr>
<tr>
<td>mesogastrial, omental, mesoduodenal, small intestinal mesenteric, mesocolic, mesosigmoidal and mesorectal regions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
mesentery associated with the small intestine (see Fig. 57.1F)

### Surgical terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane</td>
<td>A conceptual interface between two continuous and contiguous surfaces</td>
<td>This is best illustrated by an example. The mesofascial plane is formed by the mesentery and underlying fascia; both are continuous and contiguous (that is, in contact). The plane is the conceptual zone between both. This is centrally important in abdominal surgery because separation of planar components (that is, mesentery and fascia) is a cornerstone of all intestinal surgery.</td>
</tr>
<tr>
<td>Mesenteric detachment</td>
<td>Detachment of a region of mesentery from underlying contiguous fascia</td>
<td>Detachment of an intact mesenteric package is a core technical goal in intestinal surgery. Detachment is complete when the mesentery remains connected only by either adjacent mesentery or vascular points of connectivity at an adipovascular pedicle.</td>
</tr>
<tr>
<td>Mesofascial separation</td>
<td>Separation of the mesentery from underlying fascia</td>
<td>Mesofascial separation over a broad region results in mesenteric detachment.</td>
</tr>
<tr>
<td>Colofascial separation</td>
<td>Separation of the colon from underlying fascia</td>
<td>Colofascial separation over a broad region results in colic detachment.</td>
</tr>
<tr>
<td>Mesenteric disconnection</td>
<td>Division of all anatomical connections remaining after complete mesenteric detachment</td>
<td>Vascular, mesenteric (between adjacent regions) and intestinal connections are all that remain to connect the detached mesentery. Once these are divided, the mesentery (and, by definition, the intestine) is fully disconnected and can be removed.</td>
</tr>
<tr>
<td>Peritonotomy</td>
<td>Sharp incision of the peritoneum</td>
<td>Peritonotomy, followed by traction and counter-traction, is used to expose mesentery, fascia and the mesofascial plane.</td>
</tr>
<tr>
<td>Adipovascular pedicle</td>
<td>Fat heaping around major vessels that helps differentiate these from non-vascular mesentery</td>
<td>Adipovascular pedicles include the ileocolic, middle colic, inferior mesenteric and left colic pedicles. Where multiple vessels are in close proximity, pedicles are not readily identifiable: for example, in the dorsal mesogastrium following division of the coeliac trunk, and in the mesosigmoid, where multiple sigmoidal branches of the superior rectal artery lie in relatively close proximity. The inferior margin of the vental mesogastrium (previously the hepatoduodenal ligament) is a mesenteric pedicle containing the hepatic artery, portal vein and common bile duct, and can be readily differentiated from the non-pedicular region of the vental mesogastrium (previously the gastrohepatic ligament)</td>
</tr>
</tbody>
</table>

### Embryological terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-rotation</td>
<td>Incomplete embryological development of the mesentery, resulting in the right colon and mesocolon taking up a central abdominal position</td>
<td>Development of the mesentery ceases at a certain point, which means the right mesocolic region of the mesentery does not take up a position to the right of the small intestinal mesentery, and instead remains positioned to the left of the developing small intestine and mesentery. The condition is associated with non-attachment of the mesentery.</td>
</tr>
<tr>
<td>Attachment</td>
<td>Flattening and anchorage of mesentery to the posterior</td>
<td>The right and left mesocolon, medial region of the mesosigmoid and mesorectum attach or flatten against the posterior abdominal wall. Importantly, this meaning differs from previous interpretations of ‘attachment’, according to which the mesentery inserted directly into</td>
</tr>
<tr>
<td>Non-attachment</td>
<td>Incomplete or absent mesenteric attachment</td>
<td>This is of considerable surgical and pathobiological importance because it is associated with volvulus in the adult</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Congenital adhesions</td>
<td>Adhesions between two peritonealized surfaces in prolonged and uninterrupted contact</td>
<td>Examples of surgical relevance occur at the lateral aspect of the mesosigmoid between the surface of the mesosigmoid and the peritoneum of the left iliac fossa. A further important example is the adhesions between the undersurface of the greater omentum and the upper surface of the transverse mesocolon</td>
</tr>
</tbody>
</table>

**FIG. 57.2**  
A, C, Peritoneal reflection at the base of the small intestinal mesentery before (A) and after (C) division or peritonotomy. B, D, Corresponding cadaveric images of the reflection at the base of the small intestinal mesentery before (B) and after (D) division. (All colour-coded images taken from a digital model of the mesentery. In Chapters 13 and 14 of Mesenteric Principles of Gastrointestinal Surgery: Basic and Applied Science.)
FIG. 57.3  The mesenteric root region in a cadaver following complete mobilization of an intact mesentery. A, The root region viewed from right to left. B, The right lateral aspect of the root region viewed from below upwards. C, The left lateral aspect of the root region viewed from below upwards.
History

Until recently, the widely accepted model of the mesentery described multiple ‘mesenteries’ (Video 57.1). This was supported by the 1888 findings of Sir Frederick Treves, which were incorporated in all mainstream anatomical, radiological and surgical literature. Treves’s descriptions echoed those of Henry Gray, who, in 1858, first used the term ‘mesenteries’ in his reference text on anatomy. This was a departure from the Renaissance interpretations of Eustachius, Vesalius and Da Vinci. Each depicted (but did not explicitly describe) mesenteric continuity using the term ‘mesenterium’. ‘Mesenterium’ was substituted by the terms ‘mesocolon’ and ‘small bowel mesentery’ during the nineteenth century. The recent identification of a right and a left mesocolon led to the recognition of mesenteric continuity between the small intestinal mesentery and right mesocolon (Fig. 57.1A). Continuity from the duodenojejunal flexure to the mesorectal level was next confirmed (see Fig. 57.1A). Emerging data indicate that the mesentery is continuous from mesogastrium to mesorectum and is narrowed centrally at the mesenteric root region (see Fig. 57.1D). One of the consequences of this continuity is that there are no distinctive landmarks to indicate the anatomical limits of adjacent regions. Notwithstanding, a nomenclature has developed with reference to each different region (see Table 57.1).
FIG. 57.1 A, Mesentery above and below the root region. Mesogastric and mesoduodenal mesentery is located above the root region. Small bowel mesenteric, mesocolic, mesosigmoidal and mesorectal mesentery is located below the root region. B, Peritoneum. If the peritoneum is divided in a coronal plane immediately anterior to the posterior abdominal wall, the resultant cut edge corresponds to the distribution of the peritoneal reflection. C, Toldt's fascia (green region). If all extraretroperitoneal viscera were removed, Toldt's fascia would be apparent in the distribution indicated. Different regions of fascia are arbitrarily named according to the associated region of contiguous mesentery. D, The mesenteric root region and vasculature above and below the root region (see also Fig. 57.2). E, The mesogastrium. The dorsal and ventral mesogastria are illustrated. The dorsal mesogastrium is continuous inferolaterally with the splenic hilum and inferiorly with the mesoduodenum. The mesoduodenum continues distally as the root region of the mesentery. F, Mesentery distal to the mesenteric root region. This consists of small intestinal, right, transverse, left mesocolic, mesosigmoidal and mesorectal regions of mesentery.
Flexures

A flexure occurs between each region of the duodenum; at the ileocaecal junction; at hepatocolic and splenic levels; at the junction between the descending and sigmoid colon; and between the sigmoid colon and rectum. With the exception of the flexure between the second and third parts of the duodenum, a flexure occurs where the intestinal tract changes from attached (to the posterior abdominal wall) to mobile (or vice versa). Given the continuity and contiguity of the intestine, mesentery, peritoneum and fascia, each flexure can be explained in terms of these components.

The flexures most frequently encountered during abdominal surgery are the hepatic and splenic flexures. Flexures share a common underlying anatomical framework: the hepatic flexure will be described here as an exemplar. The mesenteric component of the hepatic flexure is a confluence between the right and transverse regions of the mesocolon and is best described in terms of radial and longitudinal axes. The radial axis of the hepatic and splenic flexures extends radially from the middle colic vascular pedicle to the intestinal margin of the mesentery. During this course, the mesentery changes from attached (to the posterior abdominal wall) to non-attached and mobile. The longitudinal axis extends longitudinally from one mesenteric region to the next in sequence. At the hepatic flexure, the right mesocolic region is fully attached, whereas at the transverse mesocolic region, the mesentery is attached centrally but mobile at the intestinal margin; the reverse occurs at the splenic flexure.
Embryology

This field is broad and will be briefly summarized. Dorsal and ventral mesenteric regions form early in embryological development and provide a mesenteric framework in which numerous organs develop. Development is easily conceptualized when divided into that above and below the mesenteric root region (see earlier). Above the root region, the stomach and liver develop in mesogastric mesentery. This persists into adulthood as the falciform ‘ligament’, the ventral and dorsal mesogastrrium. The pancreas develops at the level of the mesoduodenal mesentery. Below the root region, the small intestinal region of mesentery elongates and coils extensively at its intestinal margin. Following return of the intestine and mesentery post herniation, both adopt a conformation in which the right colon and associated mesentery are on the right, and small intestine and associated mesentery are in the middle. The left colon and mesentery are positioned to the left (see Fig. 57.1F). Importantly, mesenteric continuity is retained into adulthood (see Fig. 57.1A).

‘Rotation’ is the term used to denote the process whereby the midgut region of the intestinomesenteric complex changes position from the middle region of the developing peritoneal cavity to the right side of the cavity. As a result, the small intestine and mesentery (initially located on the right) are displaced to a central position between the right colon and mesentery (on the right) and the left colon and mesentery (on the left). ‘Attachment’ is the process whereby regions of mesentery become flattened and anchored against the posterior abdominal wall. A fascial layer develops between both to anchor them together in position (Figs 57.4, 57.5; see Fig. 57.1C). If rotation does not occur (that is, ‘non-rotation’), then the small intestine and mesentery are not displaced centrally. In addition, the right mesocolon does not become attached to the posterior abdominal wall on the right side, and its attachment (or anchorage) fails. The result is a mesentery (and, by definition, intestine) that may twist around the narrow root region, with devastating consequences.
FIG. 57.4 The mesofascial plane. This is the conceptual zone between contiguous mesentery and underlying fascia. The mesofascial plane occurs at all levels from the mesogastrium to the mesorectum. Separation of planar components is a core activity in intestinal, pancreatic and hepatic surgery. A, The mesofascial plane at ileocaecal level. B, The mesofascial plane at right mesocolic level. C, The mesofascial plane at mesosigmoidal level. (All colour-coded images taken from a digital model of the mesentery. In Chapter 13 of Mesenteric Principles of Gastrointestinal Surgery: Basic and Applied Science.)
Other defects of embryological development include non-attachment, situs inversus and atresia. In non-attachment (Ch. 66), the mesentery has the correct conformation, but does not adequately attach and is prone to twisting. This is called a volvulus. In atresia (Ch. 66), a region of mesentery and the corresponding region of intestine do not form normally. A gap occurs in the mesentery (usually in the region of the intersection with the intestine), around which the normal mesentery continues to develop. In situs inversus, organs ordinarily positioned on the left are now on the right and vice versa. The conformation of the mesentery, peritoneum, intestine and related organs is the same as seen in normality, only in reverse.

**Congenital adhesions**

Focal ‘congenital’ adhesions occur wherever two mesothelial surfaces come into prolonged and relatively uninterrupted contact. They can occur anywhere but tend to be mainly focused in certain regions, including the lateral aspect of the mesosigmoid, where this is in close contact with the
peritoneum of the left iliac fossa,\textsuperscript{17} and between the undersurface of the greater omentum and the upper surface of the transverse mesocolon. It is not uncommon for them to be mistaken for the peritoneal reflection.\textsuperscript{1,2,13,14,18–33}
Mesentery

The following is a description of the anatomical model of the mesentery, on which surgery of the upper and lower gastrointestinal tract is based (Video 57.2). The mesentery proximal to the mesenteric root region is described first, followed by the mesentery distal to the mesenteric root region.

Anatomy proximal to the mesenteric root region

Dorsal mesogastrium and mesoduodenum

The dorsal mesogastrium is a region of mesentery in the posterior wall of the lesser sac (see Fig. 57.1A,D). Toldt's fascia lies posterior to it, separating it from the retroperitoneum (see Fig. 57.1C). The mesogastrium may be detached from the fascia via mesofascial separation (see earlier). This activity aids in identifying and surgically controlling vessels that enter the mesogastrium from the coeliac trunk (see Fig. 57.1D). At the oesophago-gastric junction, the mesogastrium narrows to an apex, from which it continues into the thorax as the meso-oesophagus. At the lesser curvature of the stomach, the mesogastrium curves sharply forward towards the liver as the ventral mesogastrium (see Fig. 57.1E). Inferiorly, the dorsal mesogastrium continues as the mesoduodenum, which narrows anteroposteriorly; in front of it lies the pancreas (see Fig. 57.1E). The dorsal mesogastrium continues laterally as the splenic hilum to the spleen. The mesoduodenum narrows in all planes as it approaches the mesenteric root region (see Fig. 57.1E). Regions of the developing mesoduodenum cradle the origin of the superior mesenteric artery and the termination of the superior mesenteric vein in the mesentery of the root region. The latter is of considerable anatomical and surgical importance. The body of the pancreas is above and anterior to the root region, while the head, and in particular the uncinate process, are posterior to and below it. From here, the mesentery fans out extensively to span the intestine distal to the duodenojejunal flexure (see Figs 57.1D,F, 57.3).

The spleen is located in the left upper quadrant under the left hemidiaphragm (see Fig. 57.1E). The lienorenal peritoneal reflection is at the lateral margin of the spleen and curves superomedially as the lienophrenic reflection. Together, these regions of peritoneal reflection form the upper lateral boundary of the lesser sac and the lateral limit of the dorsal
mesogastrium (see Fig. 57.1B). On the right, the dorsal mesogastrium is limited by the liver, where it is apposed to the abdominal wall at the bare area (see Fig. 57.1B,C).^{38,39}

**Ventral mesogastrium**

The relationship between the ventral and dorsal mesogastria (as well as the ventral and dorsal mesoduodena) is of considerable anatomical importance (see Fig. 57.1E). Continuity provides the mesenteric frame in which branches of the coeliac trunk reach many different organs.^{40} It is also the anatomical frame in which elements of the biliary tree and portal venous system pass from one organ to another (see Fig. 57.1D).

In the adult, the portal vein, bile duct and hepatic artery are located in the inferior margin of the ventral mesogastrium.^{41} Previously, this region was termed the ‘hepatoduodenal ligament’ and the remainder of the ventral mesogastrium was called the ‘gastrohepatic ligament’.^{42} As neither term has a distinct anatomical correlate and their usage is confusing, they are not used here (see Table 57.1 for further explanation). The inferior margin of the ventral mesogastrium is thickened compared with the rest of the mesogastrium, giving rise to a pedicle (the ‘portal pedicle’) (Fig. 57.6; see Fig. 57.1D,E).^{1,2,18,43}
Greater omentum

The greater omentum is suspended from the greater curvature of the stomach; the gastroepiploic arterial arcade is at their intersection. The greater omentum is apposed to the upper surface of the transverse mesocolon in a highly variable manner that is mediated by diffuse adhesions between both structures. A similar mechanism of attachment occurs between the greater omentum and the peritoneal reflection at the hepatic and splenic flexures. Attachment to the splenic peritoneal reflection is usually extensive, which has implications for surgical mobilization of the splenic flexure. A peritoneal reflection occurs between the greater omentum and the upper border of the transverse colon; it is well developed in the midline region but narrows laterally to an apex at either pole of the transverse colon.

Falciform ‘ligament’
The falciform ‘ligament’ is the most anterior remnant of the ventral mesogastrium. It is a midline structure located between the anterior surface of the liver and the inner surface of the anterior abdominal wall. Its inferior border is thickened and called the ligamentum teres. Superiorly, it narrows towards an apex, from which the triangular and coronary peritoneal reflections of the liver extend laterally.\(^{45}\)

**Anatomy distal to the mesenteric root region**

**Small intestinal mesentery**

The base of the small intestinal mesentery (that is, where it continues as the right mesocolon) is relatively short (see Fig. 57.1F). The intestinal margin of the small intestinal mesentery is extensively plicated and several feet in length. As a result, the mesentery expands considerably from its base to the intestinal margin.\(^{1,2,12,18,20,24,25}\)

**Right mesocolon**

The right mesocolon is a continuation of the small intestinal mesentery and is the region of the mesentery attached to the caecum and ascending colon (see Fig. 57.1F). It is flattened against the posterior abdominal wall but maintained anatomically separate by Toldt's fascia.\(^{1,2,12,18–20,24,26,27}\)

**Transverse mesocolon**

The transverse mesocolon is made up of mesenteric components of the hepatic and splenic flexures as these converge on the middle colic vascular pedicle (Fig. 57.7). It changes from attached to mobile along its radial axis, which extends from the origin of the middle colic artery to the intestinal margin of the mesentery. Its longitudinal axis extends from the mesenteric component of the hepatic to the splenic flexure. The transverse mesocolon elongates at the intestinal margin and folds extensively to adopt a highly variable conformation. It does not have a formal ‘attachment’, as depicted in classic anatomical appraisals (see Fig. 57.7).\(^{1,2,12,18–20,24–27}\)
Left mesocolon

The left mesocolon is continuous with the transverse mesocolon at the splenic flexure (see Fig. 57.7). It extends from the midline laterally across the posterior abdominal wall of the left flank to the descending colon (Fig. 57.8). Toldt's fascia separates it from the retroperitoneum. The left mesocolon continues distally as the medial and *attached* region of the mesosigmoid. 1,2,12,18,20,22–24,26,28,29
**Mesosigmoid**

The mesosigmoid is continuous distally with the mesorectum and proximally with the left mesocolon. It is best considered in terms of vertical and horizontal axes. The vertical axis extends from the left mesocolon to the mesorectum and spans the attached region of the mesosigmoid. The horizontal axis extends from the midline laterally and has two regions, attached and mobile.\(^1,2,12,18,20,22–24,26,28,29,46\)

**Mesosigmoid: horizontal axis**

At the flexure between the descending and sigmoid colon, the horizontal axis of the mesosigmoid extends from the midline to the flexure (see Fig. 57.1F). Here, the mesosigmoid is flattened against the posterior abdominal wall. At the rectosigmoid flexure, the mesosigmoid is flattened against the posterior abdominal wall. In between these two flexures, the sigmoid lengthens.\(^46\) Both sigmoid colon and mesosigmoid are detached from the posterior abdominal
wall and are mobile. The mobile component of the mesosigmoid fans out so that the intestinal margin of the mesentery is longer than the region where it is attached. This differential in length is exaggerated in some patients, leading to the development of volvulus.  

The line along which the mesosigmoid is detached from the abdominal wall is diagonally orientated in the left iliac fossa. The associated peritoneal reflection has a similar orientation and extends from the junction between the descending and sigmoid colon to that between the sigmoid colon and rectum. 

**Mesorectum**

The mesorectum is the distal continuation of the attached region of mesosigmoid and ends at an apex at the pelvic floor (see Fig. 57.1F). At the proximal rectum, the mesorectum encases the posterior and posterolateral rectum. In the mid rectum, and below the anterior peritoneal reflection, the mesorectum continues anteriorly to form a mesorectal collar around the distal rectum (see Fig. 57.1F). Where the mesorectum is attached to the pelvis, it is separated from it by Toldt's fascia.
Peritoneum

The peritoneum and mesentery are closely related; peritoneal anatomy is best understood when considered in the context of mesenteric anatomy (Video 57.3). The following description of the peritoneum will focus separately on the peritoneum proximal and distal to the superior mesenteric root region.

Peritoneal anatomy proximal to the mesenteric root region

Peritoneum bridges the space between viscera (including the mesentery) and the inner surface of the abdominal wall (see Fig. 57.5). The peritoneal bridge is called the reflection and its regions are often (though not always) named according to the structures bridged (for example, the omentocolic reflection). The term Jackson's membrane has been used in reference to regions of the reflection.

Reflections associated with the liver are the coronary and triangular reflections (see Fig. 57.1B). When the falciform ‘ligament’ and the left coronary reflection are divided, the left lobe of the liver can be retracted medially to expose the space beneath the left dome of the diaphragm. If the spleen is gently retracted towards the midline, the peritoneal reflection lateral to it (the lienorenal reflection) comes under tension and is readily observed. It continues upwards towards the diaphragm as the lienophrenic reflection (that is, the left lateral limit of the lesser sac), and inferolaterally around the inferior pole of the spleen as the splenocolic (or lienocolic) reflection (see Figs 57.1B, 57.5).

The omentocolic reflection connects the undersurface of the greater omentum with the transverse colon (see earlier). If this reflection and adhesions between the omentum and underlying transverse mesocolon are divided, the greater omentum is detached and can be retracted upwards under the diaphragm. This exposes the posterior surface of both the stomach and the ventral mesogastrium anteriorly. Posteriorly, the pancreas, splenic hilum, transverse mesocolon and dorsal mesogastrium become visible (see Fig. 57.1E). Division of the splenocolic reflection exposes the mesenteric component of the splenic flexure. As a result, the splenocolic reflection is of considerable surgical relevance. In adults, this region of the
reflection is not immediately apparent because the greater omentum attaches to it just inferior to the spleen (see earlier).\textsuperscript{1,2,18,19,22,23,27,28,35} When the colic component of the hepatic flexure is retracted inferiorly, a reflection of peritoneum on to the colon is evident: the hepatocolic reflection (see Fig. 57.5). Medially, this is continuous with the serosa of the duodenum, and laterally, the hepatocolic reflection is continuous with the right peritoneal reflection between the abdominal wall in the right paracolic gutter and the right colon (see later).\textsuperscript{1,2,18–20,22,23,27,28,35}

**Peritoneal anatomy distal to the mesenteric root region**

A peritoneal reflection occurs where the small intestinal mesentery attaches to the posterior abdominal wall (the small intestinal peritoneal reflection) (see Figs 57.1B, 57.2). The peritoneal reflection in this location continues around the inferolateral aspect of the ileocaecal region and then around and on to the lateral aspect of the right colon as the right peritoneal reflection. In the past, surgeons identified the right peritoneal reflection by the presence of the white line of Toldt.\textsuperscript{30,52,53} The reflection can always be identified, irrespective of whether a ‘white line’ is apparent, and as such, usage of the white line of Toldt to guide dissection should be avoided.\textsuperscript{1,2,18–20,22,23,27,28,35} The reflection continues around the cephalad aspect of the hepatic flexure as the hepatocolic reflection (see earlier). The omentocolic reflection is always evident beneath the greater omentum and the transverse colon.\textsuperscript{1,2,18–20,22,23,27,28,35}

The cephalad aspect of the splenic flexure is obscured from direct visualization by the splenocolic reflection and adherence of the greater omentum to this. The splenocolic reflection continues as the left peritoneal reflection at the lateral aspect of the descending colon. The left peritoneal reflection continues distally on the lateral aspect of the mesosigmoid and then into the pelvis as the left pararectal peritoneal reflection (see Figs 57.1B, 57.4, 57.5). A peritoneal reflection occurs at the most medial region of the left mesocolon at the midline (the midline reflection); it continues distally at the medial margin of the mesosigmoid and then caudally into the pelvis as the right pararectal reflection.\textsuperscript{1,2,18–20,22,23,27–29,35}

**In the pelvis**
In the male pelvis, the right and left pararectal reflections meet in the anterior midline as the anterior reflection: this marks the true anatomical end point of the peritoneal cavity in the male. From here, the reflection continues over the posterior surface of the bladder on to the inner surface of the anterior abdominal wall. Laterally, the peritoneal bridge formed by the pararectal reflection continues as the peritoneum overlying the lateral pelvic side wall.\textsuperscript{1,2,18–23,28,29,35,47}

In the female pelvis, the pelvic side-wall peritoneum is reflected on to the rectum and mesorectum at the pararectal reflections. These meet in the anterior midline, posterior to the uterus, as the anterior reflection, which becomes continuous with the posterior serosal surface of the cervix and uterus. Anteriorly, peritoneum is reflected from the uterus and cervix to the posterior surface of the dome of the bladder. An opening occurs at the lateral extent of the uterine tube.\textsuperscript{1,2,18–23,28,29,35,47}

**Toldt's fascia**

Toldt's fascia occurs wherever digestive system viscera (including mesentery) are flattened against the abdominal wall (Video 57.4). It functions to assist anchorage of the mesentery and, by definition, related structures in position.\textsuperscript{1,2,18,20–24,26,31}

**Toldt's fascia on the right**

The fascia occurs beneath the right colon and has a lateral limit at the right peritoneal reflection (see Fig. 57.1C). Medially, it continues under the right mesocolon and has a medial limit at the reflection of peritoneum at the base of the small intestinal mesentery. The hepatocolic reflection marks the superolateral limit of the fascia. Superomedially, it continues beneath the duodenum and the head of the pancreas. It merges in this region with the fascia from the left side and continues cephalad between the dorsal mesogastrium and the retroperitoneum. The bare area of the liver is also separated from direct contact with the posterior abdominal wall by Toldt's fascia (see Fig. 57.1C). The lienophrenic and lienorenal regions of peritoneal reflection are lateral limits of the fascia in the left upper quadrant.\textsuperscript{1,2,18–28,31,35}

**Toldt's fascia on the left**
On the left side, the fascia occurs between the left mesocolon and retroperitoneum (see Fig. 57.1C). In this region, it is often called Gerota's fascia. It continues laterally under the left colon and is limited by the left peritoneal reflection. Medially, it is limited by the reflection at the medial margin of the left mesocolon (that is, the midline reflection). It continues distally posterior to the medial region of the mesosigmoid (that is, the region flattened against the retroperitoneum) (see Fig. 57.1C). Here, the left peritoneal reflection limits further extension of the fascia. It continues distally in the pelvis between the mesorectum and the pelvic side wall. Anteriorly, it sometimes condenses to form Denonvilliers’ fascia. Where the mesorectum tapers to an apex above the pelvic floor, the fascia condenses to fill the potential space at this level and has been called Waldeyer's fascia.1,2,18–26,28,29,31,35,56

Beneath the left mesocolon, Toldt's fascia continues proximally under the body of the pancreas and mesoduodenal mesentery (see Fig. 57.1C). From here, it continues cephalad under the dorsal mesogastrium. The fascia posterior to the dorsal mesogastrium converges at the oesophago-gastric junction, from where it continues into the thorax, posterior to the meso-oesophagus.1,2,18–26,28,29,31,35

**White line of Toldt**

Wherever fascia intersects mesothelium, a faint white trace occurs, called the white line of Toldt. This is mainly observed on the right and left sides of the abdomen where the fascia posterior to the colon meets the peritoneal reflection. It also occurs beneath the right and left mesocolon and can be observed if these are reflected off the retroperitoneum. While it may be used by surgeons to guide division of the peritoneum, it should not be relied on to do so, as it is highly variable in location and appearance.1,2,18–26,28,29,31,35
Vascular supply, innervation and lymphatic drainage

The vascular supply, lymphatic drainage and innervation of digestive system viscera within the abdomen are more easily understood when considered in the context of a central mesenteric framework (Video 57.1). As will be seen in the following text, each system exploits anatomical properties of the mesenteric frame to supply or drain viscera.

Venous anatomy of intraperitoneal organs

Below the root region, the inferior mesenteric vein (IMV) lies in the left mesocolon. Within the mesentery of the root region, it leaves the left mesocolon and joins either the superior mesenteric vein (SMV) or the splenic vein (see Fig. 57.1D). At the root region, the SMV at first lies lateral to the superior mesenteric artery (SMA) (see Fig. 57.1D). It passes posterior to the body of the pancreas in the mesoduodenal mesentery, where it is joined by the splenic vein to become the portal vein. The portal vein leaves the mesoduodenal mesentery to enter the ventral mesogastric mesentery and travels towards the liver in the portal pedicle of the ventral mesogastrium (see Fig. 57.1D).

Arterial anatomy of intraperitoneal organs

The coeliac trunk enters the dorsal mesogastrium and divides into the left gastric, common hepatic and splenic arteries (see Fig. 57.1D). The left gastric artery continues to the left, in mesogastrium, to the junction between the dorsal and the ventral mesogastria, and then continues in the latter along the lesser curvature of the stomach. The larger splenic artery travels left and laterally in the dorsal mesogastrium towards the splenic hilum. The common hepatic artery travels inferiorly in the dorsal mesentery and branches into the hepatic, right gastric and gastroduodenal arteries. Each vessel enters the ventral mesogastrium. The hepatic artery continues in the portal pedicle, which is the inferior margin of the ventral mesogastrium, to reach the liver. The right gastric artery enters the ventral mesogastrium to supply the lesser curvature of the stomach. The gastroduodenal artery continues inferiorly in the mesoduodenal mesentery to the level of the upper
The SMA immediately enters the mesentery at the root region and shortly afterwards gives off the middle colic artery, which enters the transverse mesocolon (see Figs 57.1D, 57.7). A right colic artery arises from the middle colic artery in approximately 25% of cases. The middle colic artery and right colic artery are initially located in the transverse mesocolon. The right colic artery exploits the continuity between the right and transverse mesocolons to enter the right mesocolon and continue to the right colon.

The inferior mesenteric artery (IMA) arises from the aorta directly and enters the left mesocolon. It gives off the left colic artery, which runs in the left mesocolon, and continues as the superior rectal artery, which runs within the mesosigmoid into the mesorectum. All the major vessels contribute to an arterial arcade located within the mesentery at its intersection with the intestine.

**Lymphatic drainage of intraperitoneal organs**

The structures involved in the lymphatic drainage of digestive system viscera within the abdomen develop in the mesenteric frame, and are generally described as being distributed in tandem with the major arteries supplying the organs.

**Innervation of intraperitoneal organs**

Preganglionic sympathetic nerves travel via the thoracic splanchnic nerves to the coeliac, superior mesenteric and inferior mesenteric plexuses and similarly named ganglia, from which postganglionic nerves continue to innervate the viscera. Parasympathetic innervation is supplied by the vagus, via the coeliac and superior mesenteric plexuses (Chs 59, 60). Visceral afferents, conveying pain and other gut sensations, travel with the splanchnic and vagus nerves.

**Tips and Anatomical Hazards**
As reviewed earlier, digestive system visceral anatomy (within the abdomen) is centred on a mesenteric framework. It is widely accepted that, for patients undergoing an operation for cancer, mesenteric-based surgery is associated with optimal short- and long-term outcomes (Video 57.5). Digression from the mesenteric roadmap is hazardous and associated with increased rates of iatrogenic injury to structures such as the ureter, common bile duct, duodenum and spleen, as well as increased intraoperative haemorrhage and postoperative complications.1,2,13,14,18–33,76,77

Increasingly, surgeons are adopting mesenteric-based approaches in the management of inflammatory (for example, diverticular disease and Crohn’s disease) and other conditions. The development of haemostatic mechanisms for the division and control of the mesentery has allowed surgeons to broaden the repertoire of diseases in which the mesentery can be resected for therapeutic purposes.1,2,13,14,18–33,76–80

The orientation of organs above the superior mesenteric root region is important. The body of the pancreas is oriented obliquely or diagonally from the C-shape of the duodenum, across the posterior abdominal wall, to the hilum of the spleen (under the left dome of the diaphragm). The colic and mesenteric components of the splenic flexure are located close to the spleen and thus positioned high in the left upper quadrant, whereas the hepatic flexure is located beneath the liver and thus is much lower than the splenic flexure. The transverse colon and mesocolon therefore have an oblique orientation from hepatic to splenic flexure. The overall orientation of the transverse colon, mesocolon and pancreas has important implications for the surgeon.

Within the abdomen, all digestive system visceral resections involve dissection of the peritoneum and mesentery.
Key surgical activities are common to all. These include peritonotomy, mesofascial separation, mesenteric detachment and disconnection, intestinal detachment and disconnection (see Figs 57.4, 57.5). An important difference exists between approaches adopted proximal and distal to the mesenteric root region. Surgery distal to this region follows a strictly mesenteric-based approach, whereas a hybrid approach is used proximal to the root region. Rather than conduct mesogastric separation and detachment to identify
and control major blood vessels, most surgeons dissect directly through the dorsal and ventral mesogastria (as well as the splenic hilum).

A mesenteric angle, the proximal mesosigmoidal angle, occurs at the junction between the descending colon and the sigmoid colon. Another mesenteric angle, the distal mesosigmoidal angle, occurs at the junction between the sigmoid colon and the rectum. These angles are of considerable surgical and endoscopic significance.1,2,13,14,18–28,30,31

In the right iliac fossa, confluent small intestinal and right mesocolic regions of mesentery taper towards an apex at the junction between the ileum and caecum (see Fig. 57.1F). The meso-appendix originates from the posterior surface of the confluence (see Fig. 57.1F). This anatomical relationship is of considerable relevance, as it is a primary determinant of the final position of the appendix. If the meso-appendix is retromesenteric in location, it follows that the appendix is retromesenteric and the technique of appendicectomy must be adapted accordingly.

The ileocaecal mesenteric confluence houses large quantities of lymphatic tissue, which explains why mesenteric adenitis usually affects the right side of the abdomen. The lymphatic watershed in this region may also explain the frequency with which Crohn's disease develops here.

Between adipovascular pedicles (see Table 57.1), mesentery thins out and can be translucent (see Fig. 57.6). These anatomical properties help in localizing major blood vessels. Translucent interpedicular regions can be safely divided through to isolate major vessels for controlled skeletonization, ligation and division (see Fig. 57.6).

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Single Best Answers

1. In the adult, which one of the following statements about the left mesocolon is true?
   A. It is absent in the majority
   B. It is always present
   C. It is present in a minority
   D. It is continuous with the mesorectum

   **Answer: B.** Left and right mesocolic mesenteric regions are always present in the adult. Previous descriptions indicated that they were highly variable and present only in a minority of adults. The mesentery is now regarded as continuous, and right and left mesocolic regions are always identifiable.

2. Which one of the following statements is true?
   A. There are multiple mesenteries
   B. There is one fragmented mesentery comprised of multiple separate parts
   C. The adult mesentery is absent at several intestinal levels and present at others
   D. There is one mesentery comprised of several regions in continuity

   **Answer: D.** There is one mesentery, which is continuous. This concept is centrally important to understanding the anatomy of the mesenteric frame, and the implications this has for abdominal digestive system organ anatomy (as well as associated vascular and neurological anatomy).

3. Mesofascial separation leads to which one of the following processes?
A. Complete disconnection of a region of mesentery
B. Division of the peritoneum
C. Disruption of the integrity of the mesenteric package
D. Detachment of a region of mesentery from the posterior abdominal wall

**Answer: D.** Mesofascial separation involves separation of attached regions of mesentery from underlying fascia. As the latter overlies the posterior abdominal wall, separation leads to detachment of the mesentery from the posterior abdominal wall. Mesofascial separation is a surgical technical activity that is widely used in intestinal surgery.

4. Which one of the following statements about the mesofascial plane is true?
   A. It is a conceptual zone between mesentery and fascia
   B. It is directly visible on entering the peritoneal cavity during an intra-abdominal procedure
   C. It is the least used plane in intestinal surgery
   D. It must be avoided when conducting abdominal surgery

**Answer: A.** This is one of the most important planes in intra-abdominal surgery. It is a conceptual zone rather than an anatomical structure. It occurs between the mesentery and underlying fascia, and almost invariably must be accessed in all resectional surgery. Dissection in this plane is the safest and most oncologically successful means of dissection in intestinal surgery.

5. Which one of the following statements about the mesofascial plane is true?
   A. It is confined to the pelvis, where it is formed by the mesorectum and surrounding fascia
B. It is not present at the level of the mesosigmoidal region of mesentery
C. It is continuous
D. It contains the inferior mesenteric artery

Answer: C. Just as the mesentery and underlying fascia are continuous, so the mesofascial plane, formed where both meet, is continuous. Continuity of the mesentery, fascia and intervening plane means that the same technical activities can be applied at all intestinal levels, when conducting a resection. For example, separation of the components of the mesofascial plane (that is, mesentery and fascia) is essential during complete mesocolic excision, total mesocolic excision and total mesorectal excision.

6. Which one of the following statements about the white line of Toldt is true?
A. It is a reliable anatomical marker that is always present
B. It is a reliable anatomical marker that should always be identified
C. It may guide dissection but should not be relied on to do so
D. It occurs at the confluence between two regions of the peritoneal reflection

Answer: C. In the past, much emphasis was placed on the identification of the white line of Toldt in aiding the commencement of surgical mobilization of the mesentery and intestine. However, less emphasis should be placed on the white line of Toldt in this context because it is highly variable in presence and appearance. In contrast, the peritoneal reflection is universally present and serves as a reliable starting point for visceral and mesenteric mobilization.

7. Which one of the following statements about major vessels that
supply or drain digestive system viscera in the abdomen is true?
A. They are located in Toldt's fascia
B. They are located in the mesenteric frame
C. They never enter the mesentery before reaching their anatomical targets
D. They travel between the aorta and the overlying mesentery

Answer: B. All major vessels are positioned within the mesenteric frame, which they exploit to travel to or from abdominal viscera. This concept is of considerable surgical importance because mobilization of a region of mesentery permits the safe identification of arteries and veins contained within it. Their dissection, control and division is made technically easier and safer when the surrounding mesenteric package has been correctly detached and mobilized.

8. Which one of the following statements about the right mesocolon in the adult is true?
A. It is absent in the majority
B. It is present in a minority
C. It is continuous with the mesorectum
D. It is always present

Answer: D. Left and right mesocolic regions of mesentery are always present in the adult. Previous descriptions indicated that they were highly variable and present only in a minority of adults, but as we now recognize that the mesentery is continuous, it follows that right and left mesocolic regions of mesentery are always identifiable.

9. Which one of the following statements about Toldt's fascia is INCORRECT?
A. It is continuous
B. It is anatomically limited by the peritoneal reflection
C. It intersects the peritoneal reflection to generate the white line of Toldt
D. It is anatomically separate from Denonvilliers’, Waldeyer's and Gerota's fascia

**Answer: D.** Toldt's fascia is continuous. It occurs whenever viscera or mesentery are attached to the posterior abdominal wall, where it is interposed between both. This relationship applies throughout the abdomen and becomes centrally important in abdominal surgery, where identification of the plane between fascia and viscera or mesentery is a core technical requirement. Denonvilliers’, Waldeyer's and Gerota's fascia are separate regions of Toldt's fascia and are not separate anatomical entities.

10. Which one of the following statements about mesenteric pedicles is correct?
A. They are confined to mesentery distal to the mesenteric root region
B. They can contain biliary as well as vascular structures
C. They are of limited surgical importance
D. They are always absent from the ventral mesogastrium

**Answer: B.** Mesenteric pedicles are of considerable surgical importance. They arise as a result of the accumulation of adipose tissue around vessels, unlike non-pedicular regions of mesentery that contain less fat. The difference in the amount of fat between pedicular and non-pedicular regions of mesentery means that pedicles are readily identifiable during surgery. The portal pedicle contains the common hepatic and common bile ducts, in
addition to the portal vein and hepatic artery.

11. Regarding the portal pedicle, which one of the following statements is correct?
   A. It contains only vascular structures
   B. It is at the inferior margin of the ventral mesogastrium
   C. It is an appendage of the dorsal mesogastrium
   D. It is distal to the mesoduodenum

   **Answer: B.** The portal pedicle is of considerable surgical and anatomical importance. It is at the inferior margin of the ventral mesogastrium and contains the portal vein, much of the biliary tree, and hepatic artery. It can be readily differentiated from the remainder of the ventral mesogastrium, which contains much less adipose tissue.

12. Which one of the following statements about the coeliac trunk is true?
   A. It enters the ventral mesogastrium
   B. It enters the dorsal mesogastrium
   C. It enters the mesosigmoid
   D. It enters the mesorectum

   **Answer: B.** Major arteries arise from the aorta and immediately enter adjacent mesentery, which provides an anatomical frame in which they can pass to target organs within the abdominal digestive system. This is a particularly important concept for surgeons since identification and mobilization of the mesentery permits safe exposure, control and division of the branches of the coeliac trunk.

13. The middle colic pedicle is a component of the mesentery at which one of the following structures?
A. Splenic flexure
B. Hepatic flexure
C. Transverse mesocolon
D. Mesoduodenum

**Answer: C.** The middle colic pedicle contains the middle colic artery. The latter arises from the anterior surface of the superior mesenteric artery distal to the mesenteric root region and enters the transverse mesocolon. Both the artery and pedicle are highly relevant in surgery as they must be fully detached before the artery can be safely divided. This is an essential activity in total mesocolectomy where the entire colon and mesentery are to be resected.

14. Which one of the following options forms the anterior reflection?
A. The left pararectal peritoneal reflection alone
B. The right pararectal peritoneal reflection alone
C. The omentocolic reflection
D. Coalescence of left and right pararectal peritoneal reflection

**Answer: D.** The anterior reflection is the anatomical termination of the peritoneal cavity in the pelvis, formed by contributions from the right and left pararectal reflections. It serves as an important anatomical landmark in rectal and urogenital surgery. After division, the anterior region of the distal mesorectum is seen in association with Toldt's fascia. Anterior to the fascia, the seminal vesicles and prostate are visualized in the male and the vagina is apparent in the female.

15. Mobilization of the greater omentum requires which one of the following procedures?
A. Division of the omentocolic reflection and adhesions between the greater omentum and the transverse mesocolon
B. Division of the left lateral peritoneal reflection
C. Division of congenital adhesions alone
D. Mesofascial separation

**Answer: A.** The greater omentum adheres to the upper surface of the transverse mesocolon. It is also attached to the upper margin of the transverse colon by the omentocolic region of the peritoneal reflection. Laterally, it attaches to variable degrees to the mesentery of the hepatic and splenic flexures. Mobilization of the greater omentum is usually (though not always) achieved by first dividing the omentocolic reflection, exposing the adhesions between the greater omentum and the upper surface of the underlying transverse mesocolon. Once these have been divided, the omentum is usually mobile enough to place it under the diaphragm and expose the lesser sac, pancreas and posterior surface of the stomach.

16. Which one of the following best describes non-rotation (malrotation)?
   A. It is caused by failure of the embryological process that leads the right colon and mesocolon to adopt a position in the right flank region of the peritoneal cavity
   B. It is rarely seen and never causes morbidity
   C. It is almost always associated with adequate mesenteric attachment to the posterior abdominal wall
   D. It is an abnormality of rotation.

**Answer: A.** This is the most common cause of emergency presentation due to an abdominal crisis in the first year of life. It arises because intestinal and mesenteric development has ceased
at a certain point in development, and is not due to a failure of rotation around the superior mesenteric artery, as previously thought. It is always associated with mesenteric non-attachment.

17. Which one of the following statements about attachment is true?
A. It requires development of ligaments to hold organs in position
B. It refers to the mesentery and its attachment to the posterior abdominal wall
C. It involves all regions of the mesentery
D. It is never present in volvulus

**Answer: B.** Attachment is an essential embryological process that occurs after the intestine and mesentery have adopted their final conformation. It involves the development of Toldt's fascia between the mesentery and the posterior abdominal wall. Mobile regions of mesentery are not attached. If the differential between attached and non-attached regions of mesentery is sufficient, the mesentery and intestine twist around the attached region (leading to volvulus).

18. Which one of the following statements about volvulus (twist), which occurs when mesenteric attaches to the posterior abdominal wall, is correct?
A. It is extensive
B. It involves several regions of mesentery
C. It leads to intestinal elongation and twisting
D. It is minimal and acts as a region around which mobile and non-attached mesentery twists

**Answer: D.** Mobile regions of mesentery are not attached. If the
differential between attached and non-attached regions of mesentery is sufficient, the mesentery and intestine twist around the attached region (leading to volvulus).

19. Which one of the following statements about the root region of the mesentery is true?

A. It extends diagonally from the duodenojejunal junction to the ileo-caecal junction across the posterior abdominal wall
B. It contains the superior mesenteric artery alone
C. It is approximately 12 cm in length
D. It is the narrowing of mesentery that occurs between the mesoduodenum and distal mesentery

Answer: D. This is a core anatomical concept. The root region is the term arbitrarily given to the zone where the mesoduodenum narrows and continues as the mesentery distal to this. This region of mesentery is narrow and contains the superior mesenteric artery and superior mesenteric vein. Importantly, it is not oriented across the posterior wall of the abdomen, as depicted in previous descriptions.

20. The course of the hepatic artery involves which one of the following mesenteric regions?

A. The dorsal mesogastrium, the splenic hilum and the portal pedicle
B. The dorsal mesogastrium, the mesoduodenum and the portal pedicle
C. The dorsal mesogastrium, the mesoduodenum and the transverse mesocolon
D. The dorsal mesogastrium and the portal pedicle (that is, the ventral mesogastrium)
**Answer:** D. The hepatic artery is an excellent example of a vessel that passes through a number of mesenteric regions (in which it gives off a number of branches) to reach its final anatomical target organ. During its course, it lies first in the dorsal mesogastrium and then enters the portal pedicle, within which it passes towards the liver.

21. Which one of the following best describes the regions of mesentery through which the inferior mesenteric vein course passes?

A. Mesenteric root region, left mesocolon, mesoduodenum  
B. Mesenteric root region, mesoduodenum, left mesocolon  
C. Left mesocolon, mesenteric root region, mesoduodenum  
D. Left mesocolon, right mesocolon, mesenteric root region, mesoduodenum

**Answer:** C. The inferior mesenteric vein has a variable path but in general first lies in the left mesocolon, then the mesenteric root region and finally in the mesoduodenum, where it joins either the splenic or superior mesenteric vein. The main educational point is that veins and arteries use the mesenteric frame to reach or drain target organs of the digestive system within the abdomen.

22. Which one of the following best describes the regions of mesentery through which the superior mesenteric vein course passes?

A. Small intestinal mesentery, mesenteric root region, mesoduodenum  
B. Mesenteric root region, small intestinal mesentery, mesoduodenum  
C. Mesenteric root region, mesoduodenum, small intestinal mesentery  
D. Left mesocolon, small intestinal mesentery, mesenteric root
The course of the superior mesenteric vein lies in the small intestinal mesentery, then the mesenteric root region, and finally the mesoduodenum, where it is joined by the splenic vein to form the portal vein. The portal vein then enters the portal pedicle, and passes through this to reach the liver.

23. Which one of the following letters on Fig. 57.9 identifies the left gastric artery?
A. 
B. 
C. 
D. 

Answer: A. The coeliac trunk arises from the aorta and immediately enters the dorsal mesogastrium, in which it usually divides into the common hepatic, the left gastric and the splenic arteries. The left gastric artery then uses continuity between the dorsal and ventral mesogastria to reach the lesser curvature of the stomach.

24. Which one of the following best describes the regions of mesentery through which the inferior mesenteric artery/superior rectal artery pass?
A. Left mesocolon, mesorectum 
B. Mesorectum, mesosigmoid, left mesocolon 
C. Mesosigmoid, mesorectum, left mesocolon 
D. Left mesocolon, mesosigmoid, mesorectum 

Answer: D. The inferior mesenteric artery arises from the anterior surface of the aorta and enters the left mesocolon; it next
enters the mesosigmoid and thereafter the mesorectum. After it gives off the left colic artery (usually in the left mesocolon), it becomes the superior rectal artery.

25. Which one of the following sequences best describes the steps involved in surgical mobilization of the spleen?

A. (1) Mobilization of the greater omentum; (2) medialization of the spleen and detachment of the splenic hilum, via mesofascial separation, from the posterior abdominal wall; (3) peritonotomy of lienophrenic and lienorenal regions of the peritoneal reflection

B. (1) Mobilization of the greater omentum; (2) peritonotomy of lienophrenic and lienorenal regions of the peritoneal reflection; (3) medialization of the spleen and detachment of the splenic hilum via mesofascial separation, from the posterior abdominal wall

C. Medialization of the spleen and detachment of the splenic hilum via mesofascial separation, from the posterior abdominal wall

D. (1) Peritonotomy of lienophrenic and lienorenal regions of the peritoneal reflection; (2) medialization of the spleen and detachment of the splenic hilum via mesofascial separation, from the posterior abdominal wall

**Answer:** B. Mobilization of the spleen is entirely mesenteric-based. The correct plane can be accessed only after division of the peritoneal reflection. The broad steps are as follows: the greater omentum is first mobilized to provide access to the lesser sac. The peritoneal reflection associated with the spleen is divided, thereby providing the surgeon with access to the mesofascial plane formed by the splenic hilar region of mesentery and underlying fascia. Once these are separated, the spleen can be medialized and its associated vessels easily identified,
controlled and divided.

26. Which one of the following sequences best describes the steps involved in surgical mobilization of the rectum?

A. (1) Mobilization of the splenic flexure; (2) division of both pararectal regions of the peritoneal reflection; (3) mesofascial separation of the mesorectum from fascia; (4) division of the anterior reflection; (5) mesofascial separation

B. (1) Mobilization of the left mesocolon; (2) division of both pararectal regions of the peritoneal reflection; (3) mesofascial separation of the mesorectum from fascia; (4) division of the anterior reflection; (5) mesofascial separation

C. (1) Mobilization of the mesosigmoid; (2) division of both pararectal regions of the peritoneal reflection; (3) mesofascial separation of the mesorectum from fascia; (4) division of the anterior reflection; (5) mesofascial separation

D. (1) Mobilization of the right mesocolon; (2) division of both pararectal regions of the peritoneal reflection; (3) mesofascial separation of the mesorectum from fascia; (4) division of the anterior reflection; (5) mesofascial separation

**Answer: C.** Mobilization of the mesorectum is entirely mesenteric-based. The correct plane can be accessed only after division of the peritoneal reflection. The broad steps are completed in the following order: (1) mobilization of the mesosigmoid; (2) division of both pararectal regions of the peritoneal reflection; (3) mesofascial separation of the mesorectum from fascia; (4) division of the anterior reflection; (5) mesofascial separation.

27. Which one of the following sequences best describes the steps involved in surgical mobilization of the mesentery during complete mesocolic excision of the right colon?

A. (1) Peritonotomy of pararectal regions of the peritoneal
reflection; (2) mesofascial separation of small intestinal mesentery; (3) peritonotomy of the reflection at the ileocaecal region; (4) mesofascial separation of the right mesocolon; (5) peritonotomy of the right lateral reflection; (6) mesofascial separation to mobilize the right mesocolon

B. (1) Peritonotomy of reflection at the base of the small intestinal mesentery; (2) mesofascial separation of the small intestinal mesentery; (3) peritonotomy of the reflection at the ileocaecal region; (4) mesofascial separation of the right mesocolon; (5) peritonotomy of the right lateral reflection; (6) mesofascial separation to mobilize the right mesocolon

C. (1) Peritonotomy of the reflection at the base of the mesosigmoid; (2) mesofascial separation of the left mesocolic mesentery; (3) peritonotomy of the reflection at the ileocaecal region; (4) mesofascial separation of the right mesocolon; (5) peritonotomy of the right lateral reflection; (6) mesofascial separation to mobilize the right mesocolon

D. (1) Peritonotomy of the reflection at the base of the small intestinal mesentery; (2) mesofascial separation of the left mesocolic mesentery; (3) peritonotomy of the reflection at the ileocaecal region; (4) mesofascial separation of the transverse mesocolon; (5) peritonotomy of the right lateral reflection; (6) mesofascial separation to mobilize the right mesocolon

**Answer: B.** Mobilization of the right mesocolon is entirely mesenteric-based. The correct plane can be accessed only after division of the peritoneal reflection. The broad steps are as follows: (1) Peritonotomy of the reflection at the base of the small intestinal mesentery, (2) mesofascial separation of the small intestinal mesentery; (3) peritonotomy of the reflection at the ileocaecal region; (4) mesofascial separation of the right mesocolon; (5) peritonotomy of the right lateral reflection; (6) mesofascial separation to mobilize the right mesocolon.
28. Which one of the following sequences best describes surgical mobilization of the greater omentum?

A. (1) Division of the omentocolic reflection; (2) division of adhesions between the omentum and the upper surface of the transverse mesocolon; (3) direct division of the greater omentum at the splenic and hepatic flexures

B. (1) Direct division of the greater omentum at the splenic and hepatic flexures; (2) division of adhesions between the omentum and the upper surface of the transverse mesocolon; (3) division of the omentocolic reflection

C. (1) Division of adhesions between the omentum and the upper surface of the transverse mesocolon; (2) division of the greater omentum at the splenic and hepatic flexures; (3) division of the omentocolic reflection

D. (1) Division of adhesions between the omentum and the upper surface of the transverse mesocolon; (2) division of the greater omentum at the splenic and hepatic flexures; (3) division of the left lateral reflection

Answer: A. The steps involved in mobilization of the greater omentum are usually: (1) division of the omentocolic reflection; (2) division of adhesions between the omentum and the upper surface of the transverse mesocolon; (3) direct division of the greater omentum at the splenic and hepatic flexures. These steps must proceed in this order because it is not possible to access adhesions between the greater omentum and the transverse mesocolon without first dividing the omentocolic reflection.

29. Which one of the following sequences best describes how to access and mobilize the duodenum/head of the pancreas surgically?

A. (1) Mobilization of the greater omentum; (2) medialization of the duodenum by separation from underlying fascia; (3)
medialization of the head of the pancreas by separation from underlying fascia; (4) division of the hepatocolic region of the peritoneal reflection towards the duodenum; (5) division of the reflection lateral to the second part of the duodenum

B. (1) Mobilization of the greater omentum; (2) division of the splenocolic region of the peritoneal reflection towards the duodenum; (3) medialization of the duodenum by separation from underlying fascia; (4) medialization of the head of the pancreas by separation from underlying fascia

C. (1) Division of the hepatocolic region of peritoneal reflection towards the duodenum; (2) division of the reflection lateral to the second part of the duodenum; (3) medialization of the duodenum by separation from underlying fascia; (4) medialization of the head of the pancreas by separation from underlying fascia

D. (1) Mobilization of the greater omentum; (2) division of the hepatocolic region of the peritoneal reflection towards the duodenum; (3) division of the reflection lateral to the second part of the duodenum; (3) medialization of the duodenum by separation from underlying fascia; (4) medialization of the head of the pancreas by separation from underlying fascia

**Answer: D.** This is referred to as Kocherization of the duodenum and is important in freeing the duodenum during most operations involving the duodenum and the head of the pancreas. The steps involved are: (1) mobilization of the greater omentum; (2) division of the hepatocolic region of the peritoneal reflection towards the duodenum; (3) division of the reflection lateral to the second part of the duodenum; (3) medialization of the duodenum by separation from underlying fascia; (4) medialization of the head of the pancreas by separation from underlying fascia.
30. Which one of the following best describes the anatomical composition of the splenic flexure?

A. Colon, splenic mesenteric confluence between transverse and right mesocolon, Toldt's fascia and splenocolic peritoneal reflection
B. Splenic mesenteric confluence between right and left mesocolon, Toldt's fascia and splenocolic peritoneal reflection
C. Colon, splenic mesenteric confluence between right and left mesocolon, Toldt's fascia and splenocolic peritoneal reflection
D. Colon, splenic mesenteric confluence between transverse and left mesocolon, Toldt's fascia and splenocolic peritoneal reflection

**Answer: D.** All flexures can be understood in terms of four anatomical components. This is surgically relevant, as mobilization of all flexures can be understood in terms of the same principles: namely, division of the reflection to provide access to the mesofascial plane, followed by separation of the components of the plane. When mesofascial separation has been completed along the radial and longitudinal axes of the flexure, mobilization is complete.

31. Which one of the following best describes the anatomical composition of the hepatic flexure?

A. Colon, hepatic mesenteric confluence between transverse and right mesocolon, Toldt's fascia and hepatocolic peritoneal reflection
B. Hepatic mesenteric confluence between transverse and right mesocolon, Toldt's fascia and hepatocolic peritoneal reflection
C. Colon, mesenteric confluence between transverse and left mesocolon, Toldt's fascia and hepatocolic peritoneal reflection
D. Colon, hepatic mesenteric confluence between right and left
mesocolon, and Toldt's fascia

**Answer: A.** All flexures can be understood in terms of four anatomical components. This is surgically relevant, as mobilization of all flexures can be understood in terms of the same principles: namely, division of the reflection to provide access to the mesofascial plane, followed be separation of the components of the plane. When mesofascial separation has been completed along the radial and longitudinal axes of the flexure, mobilization is complete.

32. From which one of the following does the meso-appendix originate?
A. Anterior surface of the mesentery in the ileocaecal region
B. Right mesocolon
C. Undersurface of the mesentery at the ileocaecal region
D. Small intestinal mesentery

**Answer: C.** The appendix is highly variable in location because its position is determined by the position of its root and that of the meso-appendix. The meso-appendix always arises from the undersurface of the mesentery in the ileocaecal region. This region can be mobile or attached to the posterior abdominal wall. If it is attached to the posterior abdominal wall, the meso-appendix becomes positioned between both, and the appendix takes up a retrocaecal position as a result.
FIG. 57.9  The upper region of the mesentery and associated vasculature.
Clinical Cases

1. An elderly patient presents acutely to the Accident and Emergency department with severe right iliac fossa pain that has been ongoing for several weeks. CT assessment of the abdomen demonstrates an inflammatory mass (phlegmon) in the right iliac fossa without evidence of a tumour. He undergoes an exploratory laparotomy. The peritoneal reflection at the base of the small intestinal mesentery and the ileocaecal region of mesentery are divided, allowing access to the mesofascial plane. Separation of components of the plane enables mesenteric detachment from the posterior abdominal wall and (by definition) intestinal mobilization. A wide ulcer of the posterior surface of the mesentery is identified; it arose due to the presence of a perforated retrocaecal appendix (Fig. 57.10).

The meso-appendix extends from the undersurface of the ileocaecal
mesentery. As a result, the appendix often takes up a retrocaecal position, and the ileocaecal intestine and mesentery must be mobilized before the appendix can be seen. In this case, perforation of a retrocaecal appendix has led to the development of an abscess posterior to the ileocaecal region of mesentery. This region of mesentery has partially walled off the abscess but developed a large ulcer in the process.

2. A 45-year-old female presents to the Accident and Emergency department complaining of excruciating abdominal pain. Throughout her life she has repeatedly suffered similar episodes. She has modified her diet to include liquids only, in an effort to prevent further episodes of pain. As a neonate, she underwent two emergency laparotomies to correct an embryological abnormality and was diagnosed with Hirschsprung's disease. On this occasion, she undergoes an emergency laparotomy at which her entire small intestine and mesentery is seen to be twisted (Fig. 57.11A). Non-rotation is identified as the underlying pathology. She undergoes an extensive adhesiolysis, restoring the mesentery to its normal conformation. The peritoneum is mobilized off the mesentery and joined to the posterior abdominal wall, thereby creating a normal peritoneal reflection.
During embryological development, the right colon and mesocolic region of mesentery are positioned cephalad to the developing small intestine and mesentery. The right colon and mesocolon subsequently take up a position in the right flank, displacing the small intestine and mesentery into the centre of the abdomen. The final mesenteric conformation is maintained by attachment of the mesentery to the posterior abdominal wall and formation of the peritoneal reflection. If the right colon and contiguous mesentery do not take up this final position, attachment of the mesentery fails, the small intestine and mesentery are located to the right, and the intestine and mesentery take up an abnormal conformation. As a result of failed attachment, the mesentery can twist on the root region. This patient is
experiencing intermittent abdominal pain secondary to intermittent torsion of the mesentery around the root region. Once the normal mesenteric conformation is achieved and maintained, by recreating a peritoneal reflection, her symptoms will resolve entirely (Fig. 57.11B).

3. A 38-year-old male presents electively for excisional surgery for Crohn's disease. He has been treated with medication for several years. Over the past two years, he has developed cramping abdominal pain secondary to intestinal narrowing and requires surgery to correct this. At surgery, he is found to have a transition zone where mesenteric and mural disease manifestations of Crohn's change from not present (that is, normal, see Fig. 57.1) to present, and thereafter to severe (Fig. 57.12A). He undergoes a resection of the intestine and region of mesentery. His postoperative recovery is uncomplicated and he has remained symptom-free over the past four years.
In the past, Crohn's disease was thought to arise as a result of mucosal inflammatory abnormalities that spread inwardly to involve all layers of the intestine and led to a ‘transmural’ appearance of inflammation. Given the suggested primacy of the mucosa in the pathogenesis of Crohn's disease, conventional surgical approaches have generally divided the intestine flush with the mesentery, thus leaving the mesentery behind (Fig. 57.12B).
While it has long been recognized that the mesentery is abnormal in Crohn's disease, the suggestion that mesenteric events exert a net pathobiological effect on contiguous intestine is recent but gaining in acceptance. Emerging data indicate that when the mesentery is included as part of an intestinal resection for Crohn's disease, long-term outcomes are better, compared with those seen in patients who undergo a conventional resection (that is, mesentery retained).

This patient undergoes an ileocolic resection, in which the abnormal mesentery was also included as part of the resection. To date, he has remained symptom-free and has not required the institution of further medication for Crohn's disease.
Abdominal oesophagus and stomach

Mazin Al-kasspooles, Peter J DiPasco, Erich M Wessel

**Core Procedures**

- Oesophagectomy for gastro-oesophageal junction cancer: resection of the oesophagus generally with creation of a gastric conduit to facilitate a thoracic or cervical anastomosis
- Subtotal or total gastrectomy and lymph node retrieval for cancer: varying amounts of gastric resection are required, depending on the location of the malignancy
- Fundoplication for repair of hiatal hernias: division of the muscular layers of the distal oesophagus and proximal stomach for conditions such as achalasia
- Heller myotomy for achalasia: division of the vagus nerves in order to decrease gastric acid production
- Peptic ulcer surgery
Embryology

The organs that are derived from the primitive foregut extend from the base of the tongue to the region of the ampulla of Vater. Their corresponding arterial supply comes from the coeliac axis with generous collateral circulation provided by branches of the thyrocervical trunk, aorta and superior mesenteric artery.\textsuperscript{1–5} The oesophagus and stomach represent the proximal enteric organs of the foregut; the duodenum, liver and pancreas constitute the remainder. Unequal growth of the walls of the stomach leads to rotation and elongation on the left side of the stomach, which ultimately becomes the greater curvature.
Surgical anatomy

The abdominal oesophagus is the distal continuation of the thoracic oesophagus and is 1–3 cm in length. It crosses the oesophageal hiatus at the level of the tenth to eleventh thoracic vertebrae and lies posterior to the left lateral segment of the liver, anterior to the left crus of the diaphragm. It is tethered to the oesophageal hiatus by the phreno-oesophageal ligamentous complex (Fig. 58.1). The superior layer of the phreno-oesophageal ligament is continuous with the subpleural endothoracic fascia above the diaphragm and is thicker and contains more elastin than its inferior counterpart; it runs cranially and obliquely to fuse firmly with the wall of the oesophagus. The inferior layer is an extension of the subperitoneal transversalis fascia below the diaphragm and is thin and only loosely attached to the oesophagus.2–10

FIG. 58.1 The anatomical structures around the abdominal oesophagus. Note the gastro-oesophageal fat pad (sub-hiatal fat ring). (Reprinted from Netter Anatomy Illustration Collection. © Elsevier Inc. All Rights Reserved.)
The stomach is the first entirely intra-abdominal organ of the gastrointestinal tract and it is the widest part of the tract (Video 58.1). It is a hollow, comma-shaped organ located in the left upper abdomen, and can greatly increase in volume when distended. It is tethered by the abdominal oesophagus and oesophageal hiatus proximally, the duodenum distally, and the lesser and greater omenta along its lesser and greater curvatures, respectively. The concave, medial border of the stomach is the lesser curvature. It follows a gentle curve from the medial side of the oesophagus as it terminates in the cardia of the stomach. Approximately three-quarters of the way along the lesser curvature, the stomach makes a sharp turn to the right at the angular incisure (incisura angularis). A line at this point, transecting the stomach perpendicular to its long axis, defines the transition from the body of the stomach to the pyloric antrum. The lesser omentum, consisting of the hepatoduodenal and hepatogastric ligaments, is a double layer of peritoneum that runs from the portal plate to the lesser curvature and proximal duodenum. The distal portion of the hepatogastric ligament is thinner and more translucent. The inferior edge of the lesser omentum is the anterior boundary of the omental foramen. The convex surface of the stomach is the greater curvature, which runs from the fundus (the proximal dome of the stomach that lies to the left of the intra-abdominal oesophagus) to the pylorus. The greater omentum, a double layer of peritoneum consisting of the gastrocolic, gastroplenic and gastrophrenic ligaments, is draped along the greater curvature of the stomach. The gastrocolic ligament contains the gastroepiploic vessels that run in close proximity to the greater curvature of the stomach; the gastroplenic ligament contains the short gastric vessels, and the gastrophrenic ligament is largely avascular.\textsuperscript{2–10}

The long axis of the stomach runs from superior to inferior and from left to right, directly overlying the lesser sac, which is not generally a large space. The stomach therefore directly overlies the pancreas and the major vasculature of the retroperitoneum. Laterally, it is in contact with the hilum of the spleen and the diaphragm; the posterior aspect of the liver is often anterior and to the left.\textsuperscript{2,3,6–10}

**Vascular supply and lymphatic drainage**

**Arterial supply**

The arterial supply of the stomach is predominantly via the coeliac trunk, directly from the left gastric artery, and indirectly from the gastroepiploic,
right gastric and short gastric arteries. This redundant blood supply and rich submucosal plexus allow division of multiple feeding arteries without compromising gastric viability. The most striking example of the richness of the blood supply is in the setting of an oesophagectomy with reconstruction by a gastric conduit (Figs 58.2–58.4). After this operation, the sole blood supply of the gastric conduit is the right gastroepiploic artery: this single vessel can provide an adequate blood supply for the neo-oesophagus, together with its cervical anastomosis. However, the rich blood supply of the stomach also means that ligation of the gastric vasculature is often a futile manœuvre to control bleeding from a gastric ulcer. The left gastric artery is the smallest of the three branches of the coeliac trunk. It ascends briefly towards the left crus, contributes branches to the intra-abdominal oesophagus, and then turns inferiorly where it follows the lesser curvature to anastomose eventually with the right gastric artery within the lesser omentum. With the surgeon's left palm facing posteriorly over the abdominal aorta, gentle downward traction can facilitate exposure of the left gastric artery for easy ligation. This manœuvre also facilitates palpation of the splenic and hepatic arteries, which must be preserved. It is important to remember that accessory or replaced left hepatic arteries may arise from the left gastric artery. When present, the vessel can be palpated as it crosses the lesser omentum on its way to the porta hepatis. The right gastric artery can arise from the hepatic artery proper or from any of the surrounding blood vessels. It travels retrogradely over the first portion of the duodenum in the lesser omentum, and ascends along the lesser curvature to anastomose with the left gastric artery. The left and right gastroepiploic vessels run along the greater curvature of the stomach. The right gastroepiploic artery arises from the gastroduodenal artery just inferior to the first portion of the duodenum, runs in close proximity to the greater curvature and anastomoses with the left gastroepiploic artery at the midportion of the greater curvature: this area may often be appreciated during surgery as an indentation of the perigastric fat. The short gastric vessels arise from the distal splenic artery and supply the fundus and left superior portion of the greater curvature. If traction is applied to the spleen or stomach, the surgeon must be conscious of avoiding traction injury to these vessels; their meticulous ligation is required during splenectomy to avoid haemorrhage.
FIG. 58.2  Standard mobilization of the stomach for oesophageal replacement after transhiatal oesophagectomy. The mobilized stomach is based on the right gastric and right gastroepiploic vascular arcades after division of the left gastric artery and left gastroepiploic vessels. A pyloromyotomy and Kocher manoeuvre are performed routinely. (From M.B. Orringer, Transhiatal esophagectomy without thoracotomy, Oper. Tech. Thorac. Cardiovasc. Surg. 10 (2005) 63.)
FIG. 58.3 After all nodal tissue is swept onto the specimen, the left gastric artery is clamped with an endovascular stapler. (Adapted permission from the McGraw-Hill companies from D.J. Sugarbaker, M.M. Decamp, M.J. Liptay, Surgical procedures to resect and replace the esophagus. In: M.J. Zinner (ed.), Maingot's Abdominal Procedures, tenth ed., Stamford, CT: Appleton & Lange, 1997, pp. 885–910.
FIG. 58.4  Creation of a gastric conduit after oesophagectomy. After the stomach has been completely mobilized, the gastric conduit is constructed by repeated firings of a thick tissue GIA 75 mm stapler parallel to the greater curvature of the stomach. (From P.A. Linden, D.J. Sugarbaker, Esophagectomy via right thoracotomy. In: Pearson's Thoracic and Esophageal Surgery, third ed. © 2008, pp. 590–596, Fig. 54.7. ISBN: 978-0-443-06861-4.)

Venous drainage

The venous drainage of the stomach largely follows that of the arterial supply, with a few important exceptions. The left gastric (coronary) vein drains the lesser curvature of the stomach. It can be found travelling in the lesser omentum, towards the portal vein; it communicates with the azygos venous system in the region of the gastro-oesophageal junction, thereby providing the route for development of oesophageal varices in the setting of portal hypertension. Thrombosis of the splenic vein in the setting of pancreatitis can produce engorgement of the short gastric and gastroepiploic veins. If this is severe or long-standing, it will lead to the development of gastric varices, which, much like oesophageal varices, can produce a life-threatening bleeding diathesis. Splenectomy is curative for this problem.²,⁸

Lymphatic drainage

The lymphatic network of the stomach is contiguous with other intra-abdominal lymphatics. Within the proximal stomach, lymphatics drain cephalad along with the lymphatics of the oesophagus. There are 16 lymph
node stations for the stomach (Table 58.1). During gastrectomy, three levels of lymph node dissection may be performed. A D1 lymph node dissection includes the perigastric lymph nodes (stations 1–6). A D2 lymph node dissection includes the perigastric lymph nodes, as well as those lymph nodes that are associated with vessels of the coeliac trunk (stations 7–11). A D3 resection includes the nodes of the surrounding retroperitoneum, including the para-aortic, middle colic and superior mesenteric nodes, in addition to the perigastric and coeliac nodal basins (stations 12–16).\textsuperscript{11}

<table>
<thead>
<tr>
<th>Station number</th>
<th>Anatomical location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Right of cardia</td>
</tr>
<tr>
<td>2</td>
<td>Left of cardia</td>
</tr>
<tr>
<td>3</td>
<td>Lesser curvature</td>
</tr>
<tr>
<td>4</td>
<td>Greater curvature</td>
</tr>
<tr>
<td>5</td>
<td>Suprapyloric</td>
</tr>
<tr>
<td>6</td>
<td>Infrapyloric</td>
</tr>
<tr>
<td>7</td>
<td>Left gastric</td>
</tr>
<tr>
<td>8</td>
<td>Common hepatic</td>
</tr>
<tr>
<td>9</td>
<td>Coeliac</td>
</tr>
<tr>
<td>10</td>
<td>Splenic hilum</td>
</tr>
<tr>
<td>11</td>
<td>Splenic artery</td>
</tr>
<tr>
<td>12</td>
<td>Portal triad/hepatoduodenal ligament</td>
</tr>
<tr>
<td>13</td>
<td>Pancreatic head</td>
</tr>
<tr>
<td>14</td>
<td>Superior mesenteric</td>
</tr>
<tr>
<td>15</td>
<td>Middle colic</td>
</tr>
<tr>
<td>16</td>
<td>Para-aortic</td>
</tr>
</tbody>
</table>

**TABLE 58.1**

**Lymph node stations of the stomach**

**Innervation**

The stomach is innervated by the anterior and posterior vagal trunks, which are the continuation of the left and right vagal plexuses, respectively. The anterior and posterior vagal trunks carry mixed autonomic signals: parasympathetic innervation is supplied from the vagus nerves, and sympathetic innervation is supplied by visceral branches from the sympathetic trunk. The posterior vagal trunk runs along the posterior aspect of the abdominal oesophagus and continues along the lesser curvature of the stomach, terminating in the rich nerve plexus of the coeliac trunk. Branches of the posterior vagal trunk innervate the parietal cells of the stomach, as well as the pylorus. The anterior vagal trunk crosses diagonally along the anterior
aspect of the abdominal oesophagus, continues within the pars flaccida of the lesser omentum and contributes to the innervation of the gastric parietal cells, pylorus and liver.\textsuperscript{3,10} Gastric ulcers can develop in any portion of the stomach and are not necessarily associated with acid hypersecretion (Fig. 58.5; Table 58.2).

\textbf{FIG. 58.5}  Classification of gastric ulcers based on their anatomical location. (From J.B. Matthews, W. Silen, Operations for peptic ulcer disease and early operative complications. In: M.H. Sleisenger, J.S. Fordtran (eds), Gastrointestinal Disease, Philadelphia: Saunders, 1993.)
# TABLE 58.2

## Types of ulcer that cause peptic ulcer disease

<table>
<thead>
<tr>
<th>Ulcer type</th>
<th>Location</th>
<th>Acid secretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Lesser curvature near the angular incisure</td>
<td>Low</td>
</tr>
<tr>
<td>II</td>
<td>Antral and duodenal</td>
<td>High</td>
</tr>
<tr>
<td>III</td>
<td>Prepyloric</td>
<td>High</td>
</tr>
<tr>
<td>IV</td>
<td>High along the lesser curvature</td>
<td>Low</td>
</tr>
<tr>
<td>V</td>
<td>Diffuse (non-steroidal anti-inflammatory drug-related)</td>
<td>Low</td>
</tr>
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Surgical approaches and considerations

Exposure of the intra-abdominal oesophagus can be facilitated by division of the left triangular ligament of the liver and retraction of the left lateral segment of the liver. The right hand of the surgeon may easily reach behind the left lateral segment of the liver, and scissors or electrocautery can be used to divide the left triangular ligament. Caution must be exercised in order to avoid inadvertent injury to the left hepatic vein as it enters the inferior vena cava. This may be avoided by exploiting the diaphragm’s surface anatomy, and following the course of the phrenic vein as it traverses toward the hepatic vein confluence. The angle and location of the phrenic vein may act as a surrogate for the convergence of the left hepatic vein with the vena cava (Fig. 58.6, see Fig. 34.11). The anterior surface of the stomach is easily identifiable at the time of laparotomy or laparoscopy.9,10

During a laparoscopic Heller myotomy for achalasia (Fig. 58.7), the anterior peritoneal reflection at the gastro-oesophageal junction is divided, an anterior gastro-oesophageal junction fat pad (normally present) is next excised and the phreno-oesophageal ligament is divided, allowing excellent visualization of the distal oesophagus and proximal stomach. Great care must be taken not to disrupt the vagus nerves, crural muscles and posterior gastro-oesophageal attachments. The right (anterior) vagus nerve is mostly to
the right of the midline; it may be swept to the right within the mobilized fat pad and is not always visualized. A myotomy is performed 6 cm proximally on to the oesophagus and 2 cm distal on to the stomach. Gastro-oesophageal reflux is common after a myotomy and therefore a concurrent fundoplication is usually recommended.10
In order to visualize the posterior surface of the stomach, the surgeon...
must divide either the lesser or greater omentum. Complete division of the gastrocolic ligament, followed by cephalad retraction of the stomach, allows maximum exposure of the posterior surface of the stomach, the lesser sac and the pancreas. This manoeuvre is particularly important in the setting of trauma, where it is necessary to exclude injury to the posterior wall of the stomach and the structures in the retroperitoneum behind the lesser sac. However, division of either omentum must be performed with caution. The right and left gastroepiploic arteries run within the gastrocolic ligament of the greater omentum, in close proximity to the body of the stomach. The left gastroepiploic artery branches off the distal splenic artery and runs from left to right; it anastomoses with the right gastroepiploic artery, which arises from the gastro-duodenal artery and travels from right to left. In the region of the pylorus, a thinning of the gastrocolic ligament usually facilitates entry into the lesser sac, while avoiding injury to the gastroepiploic vasculature. Similarly entry into the lesser sac through the lesser omentum must be carried out with caution in order to avoid inadvertent injury to the left and right gastric arteries and the vagal trunks. In addition, a meticulous search for a replaced or accessory left hepatic artery must be undertaken because these vessels also run through the lesser omentum. The inferior portion of the lesser omentum (pars flaccida) is thinner and more translucent than adjacent omental tissues and may generally be safely entered to avoid injury to the surrounding vasculature. Distal dissection of the pars flaccida in the vicinity of the pylorus often reveals a lymph node that lies directly over the common hepatic artery (Starzle’s node). During laparoscopy, the lesser sac can be entered through the omental foramen posterior to the hepatoduodenal ligament.

The lumens of the oesophagus, stomach and duodenum can be directly visualized with endoscopy. Retroflexion of an endoscope is required for full evaluation of the fundus and cardia of the stomach. The spleen, pancreas, liver and biliary tree can be evaluated by endoscopic ultrasound, which allows for visualization well beyond the gastric wall. A skilled endoscopist may also perform transgastric biopsies of these adjacent structures with relative ease and safety.

**Hiatal hernias**

Hiatal hernias involve laxity of the phreno-oesophageal ligamentous complex, with a variable involvement of the gastro-oesophageal junction and
the gastric fundus (Fig. 58.8). In type 1 hiatal hernias, also called sliding hiatal hernias, the gastro-oesophageal junction herniates above the oesophageal hiatus of the diaphragm. Type 2 hiatal hernias, also called para-oesophageal hernias, are those where the gastro-oesophageal junction remains fixated but the gastric fundus herniates alongside the oesophagus. Type 2 hiatal hernias have a greater risk of incarceration and strangulation, and thus warrant surgical repair. A type 3 hiatal hernia represents a combination of types 1 and 2 hiatal hernias, where the gastro-oesophageal junction and fundus of the stomach are both herniated above the diaphragm. Type 4 hiatal hernias are those in which the hernia sac contains another organ, such as the spleen, pancreas, left lateral segment of the liver, or colon.2,7,8
Surgical repair of hiatal hernias involves reduction of the contents and repair of the hernia defect, with or without a concurrent fundoplication, such as a Nissen, Toupet or Dor. These procedures create a favourable pressure gradient that acts to prevent reflux by bringing the gastro-oesophageal junction into the abdomen and lengthening the functional area (Figs 58.9, 58.10). For massive hiatal hernias, in which the entire stomach is intrathoracic, actual repair of the hernia defect may be impossible and a pexying gastrostomy tube may be required to prevent the stomach from reherniating into the chest. The most commonly performed open gastrostomy is the Stamm gastrostomy. The anterior surface of the gastric antrum is the usual location for gastrostomy tube placement. After confirmation that the antrum can reach the anterior abdominal wall without tension, concentric purse string sutures are placed on the anterior surface;
the sutures are tagged with clamps but not tied down. A 5 mm incision is made in the skin several fingers’ breadths below the costal margin, preferably lateral to rectus abdominis to avoid inadvertent injury to the epigastric vessels. A clamp is passed through the skin incision, the abdominal wall and the peritoneum, and used to grasp a second clamp, which is then pulled from internal to external. This clamp is used to grasp the gastrostomy tube, which is then pulled internally. A small gastrotomy is made and the tube is inserted into the stomach. The inner, and then the outer, purse string sutures are tied down and the stomach is pexied to the abdominal wall with interrupted permanent sutures surrounding the gastrostomy. If the needle is left on the outer purse string suture after it has been tied down, it can be used as the lateral stitch to secure the stomach to the abdominal wall. Combined thoracic and abdominal approaches may also be required for treatment of massive hiatal hernias.
FIG. 58.9  A, Nissen fundoplication. B, Toupet fundoplication. C, Dor fundoplication.
(From B.K. Oelschlager, T.R. Eubanks, C.A. Pellegrini, Hiatal hernia and gastroesophageal reflux disease. In: C.M. Townsend, R.D. Beauchamp, M.B. Evers, K.L. Mattox (eds), Sabiston Textbook of Surgery: The Biological Basis of Modern Surgical Practice, twentieth ed. Copyright © 2017 by Elsevier, Inc. All rights reserved, Fig. 41.8A–C.)
Gastric and duodenal ulcers

A truncal vagotomy, which represents one of several gastric acid reduction procedures, requires exposure of the proximal stomach and the abdominal
oesophagus. After the proximal stomach is mobilized, the oesophagus can be encircled with a Penrose drain. The vagal trunks are then easily palpated, often being described as feeling like a guitar string beneath the peritoneum. A 4–6 cm segment of each trunk, extending down on to the gastric body, is then excised. This procedure must be accompanied by a gastric drainage procedure (such as a Heineke–Mikulicz or Finney pyloroplasty) because the pylorus will fail to relax after division of the vagal trunks. If the vagal trunks are divided too low, the surgeon runs the risk of missing the posterior nerve innervating the lesser curvature, eponymously known as a nerve of Latarjet. Procedures that denervate the body of the stomach but preserve the pyloric branches of the vagal trunks can achieve the goal of decreased acid production without the need for a pyloroplasty.

Gastric and duodenal ulcers are frequently encountered by the general surgeon. However, the prevalence of proton pump inhibitor use among the general population has greatly decreased the incidence of elective peptic ulcer surgery. The vast majority of surgeries being performed for peptic ulcer disease are for complications such as haemorrhage and perforation. Rarely, anatomical resections are required for patients presenting with perforated gastric or duodenal ulcers who are not currently on proton pump inhibitor therapy. Often, an omental patch, or Graham patch, can be performed as long as the patient is deemed likely to be compliant with long-term medical therapy. At the time of diagnostic laparoscopy or exploratory laparotomy, the abdomen is thoroughly irrigated to remove free enteric contents. A full-thickness biopsy of the ulcer edge, including healthy tissue, should be obtained for *Helicobacter pylori* testing and to exclude malignancy as the underlying cause of the ulcer. The ulcer edge should then be debrided sharply to healthy tissue. A nasogastric tube is placed and the tip is confirmed to be just proximal to the defect. A well-vascularized tongue of omentum can then be draped over the defect and secured with non-absorbable sutures. The defect can be closed primarily prior to being buttressed with omentum but this step is not required. Large defects may not be amenable to closure. If the defect is closed, it should be closed transversely, perpendicular to the long axis of the alimentary canal, so as to prevent stenosis. The patient is left nil by mouth with nasogastric decompression for 5 days, during which time parenteral nutrition is started. Water-soluble contrast can be instilled through the nasogastric tube on postoperative day 5 to exclude a leak, at which time the patient can resume oral intake.
As endoscopists and interventional radiologists have improved their techniques for treating bleeding duodenal ulcers, the general surgeon often encounters these patients after endoscopic and angiographic attempts to control haemorrhage have failed and it is not uncommon for these patients to be in extremis. Aggressive measures should be taken to resuscitate these patients but this should not delay operative intervention. A longitudinal duodenotomy is made over the first part of the duodenum and it is extended through the pylorus. Manual pressure should be applied directly on the ulcer bed. A Foley catheter can be passed down the duodenum and inflated to prevent reflux of blood and pancreaticobiliary secretions into the proximal duodenum. The superior and inferior portions of the gastroduodenal artery are oversewn, as well as the lateral pancreatic branches. Particular care should be taken to avoid taking overly deep bites with sutures because the common bile duct runs immediately posterior to the gastroduodenal artery in this area and is therefore susceptible to injury. The duodenotomy is closed transversely to avoid stenosing the duodenum.

When patients who are felt to be unlikely to comply with medical therapy after surgery, or those who are already on maximum medical therapy, present with complications of peptic ulcer disease, an anatomical resection of a perforated ulcer is indicated. For distal peptic ulcers (types 1–3), an anatomical resection can generally be completed and this can be accompanied by some form of vagotomy if high acid secretion is suspected (see earlier). Type 4 ulcers may be amenable to wedge resection. Reconstruction after a distal gastrectomy can be completed in a variety of ways. Gastroduodenostomy (Billroth I) is a reasonable form of reconstruction, though it is performed less often than previously. This procedure often requires an extensive Kocher manœuvre to mobilize the duodenum, such that the anastomosis can be completed without undue tension. There is often a size mismatch between the gastric remnant and the duodenum, and a sewn or stapled gastroplasty may be required. Although it is appealing to have the gastrointestinal tract in anatomical continuity, there is no benefit in terms of nutrition or function with this form of gastroenteric reconstruction.\(^2,4–10\) A side-to-side or end-to-side gastrojejunostomy (Billroth II) is another method of restoring gastrointestinal continuity. The anastomosis can be made in an antecolic or retrocolic fashion. The retrocolic approach can be performed by tenting up the transverse mesocolon and using the operative lights to illuminate the middle colic vessels. A window is made in the mesentery, the jejunum is brought through the defect and the
anastomosis is completed. The defect in the transverse mesocolon is loosely closed around the jejunum. The pancreaticobiliary or afferent limb of the gastrojejunostomy should be made as short as possible without placing the anastomosis under tension. This helps prevent the development of afferent limb syndrome and the potential for a subsequent catastrophic duodenal stump blowout. In addition, meticulous surgical technique should be used to ensure that the anastomosis is not narrowed by over-aggressive mucosal or Lembert sutures. Creation of a Roux-en-Y gastrojejunostomy is another commonly performed method to re-establish gastrointestinal continuity. Although this technique requires creation of a jejunojejunostomy in addition to the gastric anastomosis, a properly created Roux limb will result in less alkaline reflux than either a Billroth I or a Billroth II reconstruction and further decreases the risk of an afferent limb syndrome. A combination of studies in dogs and humans suggests that a Roux length of 40–50 cm will be long enough to prevent alkaline reflux but short enough to avoid the risk of Roux stasis syndrome. The jejunojejunostomy is usually fashioned around 20 cm distal to the ligament of Treitz.

**Gastric volvulus**

Gastric volvulus is a potentially devastating consequence of the stomach's mobility around its proximal and distal fixation points. Proximally, the stomach is tethered by the oesophagus and intra-abdominal oesophagus. Distally, the pylorus remains relatively fixed by its distal continuation with the duodenum as it enters the retroperitoneum to the right side of midline. Gastric volvulus can occur along the long axis of the stomach, described as being organoaxial, or along a line that runs between the lesser and greater curvatures of the stomach, described as being mesoaxial (Fig. 58.11).
Tumours of the gastro-oesophageal junction

The Siewert classification separates tumours of the gastro-oesophageal junction into three types. Type I tumours represent malignancies of the distal oesophagus; type II tumours are those that arise from the cardia of the stomach. Surgical resection of tumours in these areas mandates an oesophagogastrrectomy. However, type III tumours, which arise below the cardia, can often be treated with a gastrectomy alone.\textsuperscript{12,13}


**Tips and Anatomical Hazards**

Complete evaluation of the gastric body is best performed by dividing the gastrocolic ligament.
Identifying and preserving the right gastroteiploic artery is critical to maintain perfusion of a gastric conduit after oesophagectomy.
The afferent limb of a Billroth II gastrojejunostomy should be as short as possible to avoid afferent limb syndrome.
When a sewn gastrojejunostomy is performed, the suture purchase on the small bowel side of the anastomosis should be as small as possible to avoid narrowing the lumen and causing afferent or efferent obstruction.
Understanding the aetiology of gastric ulcers based on their location is critical in deciding what type of surgical intervention is warranted, if any.
References

1. On upper endoscopy, a surgeon notices an ulcer in the distal gastric antrum, approximately 1 cm proximal to the pylorus. It appears superficial, is non-bleeding and has a shaggy, ill-defined border. Which one of the following types of peptic ulcer does this best describe?
A. Type 1
B. Type 2
C. Type 3
D. Type 4
E. Type 5
F. Marginal ulcer

**Answer:** C. Isolated prepyloric ulcers are classified as type 3 and are associated with high gastric acid secretion. Type 1 ulcers are along the lesser curvature near the incisura and are not associated with high gastric acid secretion. Type 2 ulcers are present in the antrum and duodenum and are associated with high gastric acid production. Type 4 are high along the lesser curvature and are not associated with high gastric acid secretion. Diffuse ulceration, or type 5 ulcers, are associated with non-steroidal anti-inflammatory drug (NSAID) use. Marginal ulcers are associated with gastroenteric anastomoses and occur when enteric mucosa is exposed to gastric acid. They are also associated with NSAID use and smoking.

2. While dissecting through the lesser omentum during a Nissen fundoplication, the surgeon encounters pulsatile bleeding from a prominent artery and has difficulty gaining control. Which one of the following vessels is likely to have been injured?
A. Right gastric artery
B. Gastroduodenal artery
C. Splenic artery
D. Superior mesenteric artery
E. Replaced left hepatic artery

**Answer: E.** A small portion of the population have a hepatic artery that arises from the left gastric artery. This vessel is termed ‘replaced’ because there is no left hepatic artery arising from the hepatic artery proper. The vessel is termed ‘accessory’ if it is present in addition to an artery arising from the hepatic artery proper.

3. A patient undergoes a laparotomy for a cancer of the distal pancreas. Which one of the following manoeuvres provides optimal evaluation of the lesser sac and pancreas?
   A. Division of the gastrocolic ligament
   B. Kocherization of the duodenum
   C. Right lateral to medial visceral rotation (Cattell–Braasch manoeuvre)
   D. Mobilization of the left lateral segment of the liver

**Answer: A.** Division of the gastrocolic ligament broadly opens up the lesser sac and provides optimal visualization of the pancreas. The other options would not be helpful in this scenario.

4. Which one of the following arteries creates the sole blood supply to a gastric conduit during an oesophagectomy?
   A. Right gastroepiploic artery
   B. Left gastric artery
   C. Inferior phrenic artery
   D. Right gastric artery

**Answer: A.** The right gastroepiploic artery arises from the
gastroduodenal artery and courses along the greater curvature of the stomach. The remaining blood vessels are excluded from the conduit to allow adequate mobilization of the conduit.

5. During a Heller myotomy, approximately how many centimetres from the gastro-oesophageal junction on to the oesophagus should the muscle fibres be split?
   A. 0
   B. 1
   C. 3
   D. 6
   E. 12

   Answer: D. During a laparoscopic Heller myotomy, the anterior reflection of the peritoneal membrane to the structures at the hiatus is divided. An anterior fat pad at the gastro-oesophageal junction is usually present and should be excised. The phrenoesophageal ligament is divided, providing excellent exposure to the abdominal oesophagus and proximal stomach. Dissection should be performed anteriorly. Care should be taken not to widen the hiatus and disruption of the posterior attachments should be minimized. The distal oesophageal muscle fibres are split for a distance of approximately 6 cm above the gastrooesophageal junction and the dissection is then carried out for another 2 cm on to the stomach. A fundoplication is advised, given the significant risk of subsequent gastro-oesophageal reflux.

6. A patient has recurrent multifocal carcinoid tumours after several endoscopic resections. It has been determined that the patient needs an antrectomy. Which one of the following options defines the division point along the lesser curvature of the stomach?
   A. Halfway along the lesser curvature of the stomach from the
gastro-oesophageal junction and pylorus
B. Pylorus
C. Angular incisure
D. 6 cm proximal to the pylorus
E. 10 cm proximal to the pylorus

Answer: C. Approximately three-quarters of the distance along the lesser curvature from the gastro-oesophageal junction to the pylorus, the stomach makes an acute turn to the right called the angular incisure. From this point, a line drawn perpendicular to the long axis of the stomach should be used for transection, separating the gastric antrum from the body of the stomach. A complete antrectomy is essential in order to eradicate secretion of gastrin into the blood stream.

7. A patient presents acutely ill and unstable, with severe abdominal pain and a labile blood pressure. Based on the CT scan, it is likely that the patient has gastric ischaemia/necrosis due to a volvulus along the long axis of the stomach. Which one of the following options is the best anatomical description of the site?
A. Organoaxial
B. Mesoaxial
C. Splenoaxial
D. Pancreaticoaxial
E. Phrenoaxial

Answer: A. Gastric volvulus can have catastrophic consequences, most notably ischaemia or necrosis due to mechanical disruption of the blood supply. The stomach is fixed proximally to the intra-abdominal oesophagus and distally at the pylorus. A volvulus is due to the mobility of the stomach about
these proximal and distal fixation points. A volvulus along the long axis of the stomach is referred to as being organoaxial, while a volvulus that is rotated along a line that runs from the lesser curvature to the greater curvature is referred to as being as mesoaxial (see Fig. 58.11).

8. Which one of the following nodal stations is NOT considered to be part of a D1 resection for gastric cancer?
   A. Lesser curvature of the stomach
   B. Greater curvature of the stomach
   C. Paraduodenal
   D. Gastro-oesophageal junction
   E. Splenic hilum

Answer: E. The extent of lymph node dissection that should be carried out during gastric resection for cancer continues to be a topic of ongoing debate. All experts agree that, as the minimum, a D1 dissection should be performed. D1 lymph nodes are perigastric and include stations 1–6 (see Table 58.1). Depending on the clinical staging and location of the cancer, a D2 dissection may be necessary. These lymph nodes comprise stations 7–11, which, although located farther from the stomach, are considered to drain naturally from the stomach. D2 dissections, which include splenic hilum lymph nodes, have been shown to be associated with greater postoperative morbidity. However, expert surgeons can perform these dissections with less risk to the patient; in several South East Asian countries such as Japan, para-aortic nodal retrieval, considered D3 lymph nodes, is often performed. Interestingly, in North America, standard of care arbitrarily sets the bar at 15 or more lymph nodes, with no consideration of the extent of dissection.

9. A replaced or accessory left hepatic artery most commonly arises from which one of the following arteries?
A. Splenic
B. Gastroduodenal
C. Left gastroepiploic
D. Left gastric
E. Right gastroepiploic

**Answer: D.** During any gastric procedure requiring entry into the lesser sac, care should be taken to identify an accessory or replaced left hepatic artery, which most commonly arises from the left gastric artery. When present, this vessel may be palpated easily along the lesser omentum as it travels to the porta hepatis.

10. Oesophageal varices are supplied primarily by which one of the following vessels?
A. Right gastric vein
B. Left gastric (coronal) vein
C. Left gastroepiploic vein
D. Right gastroepiploic vein
E. Short gastric veins

**Answer: B.** Gastric venous drainage largely follows the arterial vessels. The left gastric (coronal) vein travels from right to left along the lesser omentum towards the gastro-oesophageal junction, where it receives oesophageal venous drainage, and then turns back from left to right in order to drain into the portal vein. Portal hypertension, causing reversal of blood flow, can create oesophageal varices that receive most of their supply from the left gastric vein and drain into the azygos/hemiazygos venous system.
Clinical Case

1. A 68-year-old male with a large sliding oesophageal hernia and long-standing history of gastro-oesophageal reflux disease presents to his surgeon complaining of dysphagia. He has been diagnosed with a locally advanced Siewert type II gastro-oesophageal adenocarcinoma. The patient completes neoadjuvant chemoradiation therapy and now presents for a resection.

A. Describe the Siewert classification of adenocarcinomas of the gastro-oesophageal junction.

Type I cancers are considered distal oesophageal cancers and located 1–6 cm above the Z line of the gastro-oesophageal junction. Type II cancers are located from 1 cm above to 2 cm below the Z line, and are considered true gastro-oesophageal junction cancers. Type III cancers are located 2–5 cm below the Z line and considered subcardiac cancers.

B. Which types are treated with an oesophagectomy?

In general, types I and II are treated with an oesophagectomy. Type III tumours are considered subcardiac tumours and should be treated with a total gastrectomy.

C. Describe the blood supply to the stomach.

The five sources of blood supply to the stomach are the short gastric branches given off directly from the splenic artery or from branches to the spleen; branches from the left gastric artery, which originates directly from the coeliac trunk; branches from the right gastric artery, which is a direct branch off the common hepatic artery; branches from the left gastroepiploic artery, which comes off the splenic artery; and branches from the right gastroepiploic artery, which comes off the gastroduodenal artery.

D. Which artery provides the blood supply to the gastric conduit?

The right gastroepiploic artery.

E. Describe how the various vessels to the stomach are approached during an oesophagectomy.

During an oesophagectomy, care is taken to protect and preserve the right gastroepiploic vessels, which will provide the majority of the blood supply to the gastric conduit. A distinction between the boundaries of the left and right gastroepiploic systems is most often present. Vessels travelling towards the stomach via the left gastroepiploic and splenic arteries can be divided with
impunity. After the attachments between the posterior stomach and retroperitoneum are divided, the stomach may be retracted anteriorly and cephalad, exposing the coronary vein and left gastric artery take-off from the coeliac trunk. The pedicle can be divided with a stapler flush with the retroperitoneum. Left gastric and coeliac lymph nodes should be included with the specimen. Care should be taken to identify and protect the splenic artery and the hepatic artery proper. The right gastric artery is a small vessel that runs in the lower half of the lesser curvature of the stomach and can be divided a few centimetres from the pylorus.
Small intestine

Todd PW McMullen

Core Procedures

- Small intestinal resection and anastomosis
- Small intestinal bypass
- Stricturoplasty
- Ileostomy creation and reversal

Surgery of the small intestine was rarely performed successfully prior to the development of anaesthetics and antisepsis. The advances of Bigelow and Lister allowed operations on the small intestine to become an essential part of the practice of the early surgeons who managed wartime injuries, treated colic, and were faced with common diseases such as appendicitis. In over 120 years of intestinal surgery, generations of surgeons have developed and refined techniques for small intestinal resection and anastomoses, many of which have not changed substantially over the past three decades, despite the advent of staplers and vessel-sealing devices. When textbooks that describe small bowel resections for different disease processes are reviewed, their reports and commentaries are strikingly similar in their description of the techniques they used and the commonly encountered pitfalls.

The small intestine is the primary site within the gastrointestinal tract for the absorption and digestion of nutrients, and therefore surgery performed on the small intestine, regardless of the indication, must first and foremost aim to preserve intestinal length. Surgery may also have an impact on the role of the small intestine as an important immunological and endocrine interface, despite the fact that this role is much less well understood. Ultimately, the guiding principle that underlies all small intestinal operations is to preserve intestinal length and continuity. The indications for surgery on the small intestine are numerous and include procedures for treatment of
neoplasms, inflammatory diseases, infections and perforations, as well as traumatic injuries. \textsuperscript{3,4} However, in all of these cases, the affected intestinal segment is typically resected and gut continuity is restored by anastomosing the two healthy ends together. The remarkable redundancy of the small intestine, as well as its resilience to insult, has allowed generations of surgeons to teach themselves, and their trainees, the cautious practice of surgery.
Embryology

The embryological origin of the small intestine is complex, as is reflected by the multiplicity of cell types derived from the ectoderm, mesoderm and endoderm that comprise its absorptive, immunological and endocrine functions. The alimentary tube forms at 4–8 weeks of gestation, when its luminal and serosal surfaces develop. The developing intestine lengthens as it herniates and rotates in an anticlockwise direction around its vascular supply, the superior mesenteric artery (SMA), prior to returning to the body cavity (Ch. 66). The final steps of differentiation and production of intestinal enzymes are completed at approximately 12 weeks of gestation.
Clinical anatomy

Anatomically and surgically, the small intestine is usually defined as three segments, the duodenum, jejunum and ileum, with an approximate total length of 6 metres. The duodenum is primarily retroperitoneal as it follows the head and body of the pancreas. While the ligament of Treitz defines the origin of the jejunum, there are no surgical landmarks that identify its transition to the ileum; it is typically defined as being composed of the distal 59% of the small intestine. The jejunal and ileal segments are free within the abdominal cavity, tethered only to the retroperitoneum proximally by the ligament of Treitz, and distally at the caecum where the ileum terminates at the ileocaecal valve.

Histological variation in the four layers of the small intestinal wall (mucosa, submucosa, muscularis externa and adventitia/serosa) is part of what defines the three intestinal segments beyond the traditional surgical landmarks (Fig. 59.1). The jejunum may be distinguished by its more prominent mucosal folding and thicker lumen. The mucosa is subdivided into a lining epithelium, an underlying lamina propria (a layer of loose connective tissue, where many of the glands are also found) and a thin layer of smooth muscle, the muscularis mucosae. The absorptive cells, enterocytes, generate microvilli that appear as a striated brush border on the surface of the villi and help to increase the effective surface of the small intestine by 600-fold. At least seven different cell types (including enterocytes, goblet cells, Paneth cells, enteroendocrine cells, tuft cells and lymphocytes) populate this layer and are regenerated from the crypt base as part of an ongoing process of proliferation, differentiation and recycling. The submucosa is a connective tissue layer that provides the dense network of arteries and lymphatics that is key for the movement of nutrients through the small intestine. It is also considered the strongest layer of the intestinal wall and, as such, is critical for suturing and manipulating intestine for anastomotic procedures.
Chyme is moved along the small bowel by peristalsis, coordinated by the myenteric plexus within the submucosa and primarily generated by the muscularis propria. Distension of the stomach initiates gastroenteric and gastroileal reflexes that increase glandular secretion and peristaltic activity in the duodenum and small bowel, and relax the ileoocaecal junction. The serosal surface, or adventitia, serves as the outer connective tissue envelope of the small intestine.

**Vascular supply, lymphatic drainage and innervation**

The gastroduodenal artery (usually a branch of the common hepatic artery) forms a plexus of pancreaticoduodenal vessels that is most prominent along...
its interface with the pancreas; it usually gives off retroduodenal branches that supply the first part and proximal portion of the second part of the duodenum, and a supraduodenal artery that supplies the anterosuperior part of the proximal duodenum. However, the vascular supply of the small intestine is derived primarily from the SMA. Given the importance of blood supply to anastomotic viability, it is very important for the surgeon to understand the anatomical variations that may be encountered during operations on the small intestine. Most variability is observed in the second- and third-order branches of the SMA. The first-order branches typically involve the right colic artery and the ileocolic trunk, which supply the jejunum and terminal ileum (Fig. 59.2). The vascular arcades of the ileal and jejunal segments typically exhibit two orders of branching; the distal perforators enter the small intestine less than a centimetre apart, providing a highly redundant and intricate vascular supply with significant intramural anastomoses. The density of this blood supply appears to be more pronounced in the jejunum, where branched vasa recta and an increased density of plicae circulares (producing thicker jejunal walls) differentiate the jejunum from the ileum. Venous drainage of the small intestine is primarily derived from the superior mesenteric vein (SMV), which develops within the mesentery, ascends along the right side of the arterial arcade, and typically joins the splenic vein ultimately, to form the portal vein just deep to the neck of the pancreas.
FIG. 59.2 The vascular arcade supplying the small bowel and the related tributaries. The overlying omentum and transfers: the cutaway reveals the superior mesenteric artery and its first-order and second-order branches to the small
The lymphatic system of the small intestine regulates tissue fluid homeostasis, participates in immune surveillance, and transports dietary fat and fat-soluble vitamins from the gut lumen. It is organized into two networks. Lacteals from the villi drain into a plexus of lymphatics in the submucosa and are joined by vessels from lymph spaces at the bases of solitary lymphoid follicles. A coarse plexus of lymphatics also runs in the muscularis externa between the two muscle layers; submucosal and muscular networks share few connections but both communicate freely with larger, valved collecting lymphatics at the mesenteric border of the small intestine.

Duodenal lymphatics run to superior and inferior pancreaticoduodenal lymph nodes, and from there to supra- and infrapyloric, hepatoduodenal, common hepatic, coeliac and superior mesenteric nodes. Jejunal and ileal lymphatics drain from mesenteric nodes initially to superior mesenteric nodes around the root of the superior mesenteric artery. Individual segments of small bowel have a relatively wide field of lymphatic drainage, which makes radical surgical resection of draining lymph nodes difficult if the blood supply to the remaining unaffected small bowel is to be preserved.

The innervation of the small intestine includes the enteric nervous system (made up of motor neurones, intrinsic sensory neurones, and interneurones lying within the wall of the gut), the autonomic nervous system (sympathetic and parasympathetic innervation) and visceral (sensory) afferents. The coeliac plexus surrounds the coeliac trunk and the superior mesenteric artery. It contains the coeliac ganglia, which lie on either side of the coeliac trunk, medial to the adrenal (suprarenal) glands and anterior to the crura of the respiratory diaphragm. It receives a significant input from the thoracic splanchnic nerves, which carry preganglionic sympathetic fibres from the lower seven thoracic sympathetic ganglia. The greater splanchnic nerves are derived from the fifth to the ninth or tenth thoracic ganglia. They descend obliquely in the posterior mediastinum, give off branches to the descending aorta, perforate the crura of the diaphragm and end in the coeliac ganglia. The lesser splanchnic nerves are usually formed by the rami of the ninth and tenth thoracic ganglia (occasionally by the tenth and eleventh ganglia). They pierce the diaphragm with the greater splanchnic nerves and end on the aorticorenal ganglia. When present, the least splanchnic nerves originate from the lowest thoracic ganglia and enter the abdomen with the sympathetic trunks before ending in the renal plexuses. Cadaveric studies
have confirmed that the greater splanchnic nerves are invariably present, the lesser splanchnic nerves are present in up to 90% of individuals, and the least splanchnic nerves occur in approximately 50% of individuals.\(^7\)

The duodenal wall is innervated by postganglionic sympathetic axons distributed via peri-arterial plexuses on the branches of the coeliac trunk and superior mesenteric artery. The jejunum and ileum are innervated by parasympathetic and sympathetic fibres via the superior mesenteric plexuses. The sympathetic nerves are vasoconstrictor to the vasculature and inhibitory to the musculature of the jejunum and ileum; sympathetic neurotransmitters also have an immunomodulatory role by influencing mucosa-associated lymphoid tissue. Preganglionic parasympathetic axons travel in the vagus nerves and are secretomotor to the mucosa and motor to the smooth muscle of the jejunum and ileum. Visceral afferents from the small bowel, conveying pain and other gut sensations, travel with the splanchnic and vagus nerves, predominantly the latter.
Congenital anomalies

While congenital anomalies may represent a relatively uncommon indication for small intestinal surgery overall, especially on adult patients, it is still important to be aware of the spectrum of anomalies, and how to address them at operation if they are unexpectedly encountered. The most common anomalies are those that involve non- or malrotation and incomplete fixation (Ch. 66). Such congenital anomalies fall on a spectrum that ranges from complete to incomplete or reversed rotation. The central point is the ligament of Treitz, in that the duodenal–jejunal junction is fixed to the left of the spine, with a colonic attachment in the right lower quadrant. Under circumstances of non-rotation, the mesentery of the small intestine becomes a narrow pedicle, creating the potential for volvulus and obstruction, and potentially even strangulation. Other anomalies of the small intestine that the surgeon may encounter include a Meckel's diverticulum, duodenal webs or atresia, jejunal atresia and small bowel duplications. Congenital anomalies may not be recognized until later in life, when a patient presents with an unrelated problem, such as appendicitis. They may be identified preoperatively by imaging or at the time of laparotomy. Irrespective of aetiopathogenesis, the treatment is similar: the redundancy of the small intestine will usually permit resection of the defective segment and primary anastomosis.
Surgical anatomy and considerations

Small intestine resection and anastomosis

It is important to preface any technical description of surgical resection or anastomosis in intestinal surgery with the observation that there are relatively few prospective trials to guide the choice of surgical technique. The surgical resection of the small intestine, whether performed for treatment of a neoplasm, perforation, infection, or an inflammatory segment due to Crohn's disease, is defined by the careful ligation of the proximal and distal vascular arcades that supply the affected segment(s). Traditionally, ligation of vessels was completed by employing sutures, together with application of clip and tie techniques, but it is now more common to use energy devices on second-order vessels, with ligation of the larger named vessels being reserved for sutures.\(^3,9\) As shown in Fig. 59.3, sectioning of the small intestine begins by defining the margins of the resection for the proximal and distal segments, which may then be controlled using clamps, or now more commonly by staplers that both seal and divide the small intestine. The resection is completed by ligation of the vessels supplying that segment of small intestine. For benign disease, the vascular isolation of a segment of small intestine may be limited to the most distal branches of the vascular arcades. For neoplasms – in particular, neuroendocrine tumours that typically have an impressive propensity for lymphatic spread and also may have a significant associated desmoplastic reaction – the small intestinal mesenteric dissection may extend all the way up to include division and ligation of the first-order branches that come off the SMA. Once the affected small intestine and its supplying mesentery have been removed from the surgical field, the proximal and distal ends are brought together for their anastomosis. Multiple orientations are possible for restoring continuity when the intestine is anastomosed, including side-to-side, end-to-end and end-to-end configurations (see Fig. 59.3C,D). These anastomoses may be completed with staplers or they may be sutured by hand. In the case of sutured anastomoses, the surgical technique may be either single- or double-layered (see Fig. 59.3). It is important to note that a great deal has been written about the methods and configuration of intestinal anastomoses. Surgical literature reported in the 1980s and 1990s suggests equivalence between sutured and stapled anastomoses.\(^10\) However, with advancing technology, the use of staplers has supplanted suturing in most practices; evidence-based outcomes
slightly favour the use of staplers for some diseases and anastomotic configurations.\textsuperscript{11}
FIG. 59.3 Small intestine resection and anastomosis. The small bowel pathology that may represent a neoplasm, stricture or ischaemia, is isolated as shown with its vascular pedicles dissected and ligated with sutures or using thermal devices. (A) Once the segment has been isolated a stapler can be used to divide and seal the bowel (B) which then can be brought together as an end to end anastomosis with sutures (C), or as a side to side anastomosis with sutures (D) or staples (E).
Creation of the small bowel anastomoses using the stapler method requires the open end of the new lumen created with the stapler be closed with either sutures or staples. (Adapted from Shackelford’s Surgery of the Alimentary Tract, vol. 5, fifth ed. © Saunders, 2001, Fig. 19-1, p. 238.)

**Intestinal bypass**

Restoring intestinal continuity in the setting of an unresectable tumour – for example, a neuroendocrine neoplasm – may require a straightforward bypass procedure without a resection. In the case of a resection involving the duodenum or stomach, a Roux-en-Y or Billroth procedure is typically utilized to restore continuity. Pancreatic procedures such as the Puestow procedure may involve a small intestine-to-pancreas anastomosis. The circumstances and anatomical relationships may vary but the surgical principles applied for controlling the vascular arcade, and the techniques utilized for anastomosis, remain similar. For gastric, duodenal or pancreatic surgery, the small intestine is typically divided 20 cm from the ligament of Treitz, and the distal end is brought up for anastomosis to the duodenum, biliary tree or stomach in order to restore gut continuity. The anastomosis may be created using sutures or a stapler, as outlined above, and the excellent blood supply of the small intestine usually facilitates a high success rate for healing without complication, regardless of the configuration or the technique utilized for the creation of these anastomoses.

**Strictureplasty**

Preserving intestinal length becomes acutely important notably for Crohn’s disease and cases of ischaemia, where long segments of small intestine may be compromised by a single event or multiple episodes.\(^{12}\) While the specific value is somewhat dependent on the patient’s age and severity of disease, the minimum length of small intestine required for survival, in the absence of exogenous parenteral nutrition, is typically considered to be 1.5–2 metres. If much of the small intestine has been compromised, stricturoplasty is a technique that may be utilized to treat a stenotic segment that has been compromised by inflammation or ischaemia. A Heineke–Mikulicz stricturoplasty does not involve resecting the intestinal segment, but rather dividing it longitudinally along its anti-mesenteric border, and then closing this incised defect transversely using a running or interrupted suturing technique (Fig. 59.4). This is typically used for shorter segments of disease
that are typically less than 8 cm. For longer segments, a Finney procedure may be carried out: the affected segments are opened and a neolumen is created using sutures. It is important to note that, for either method, there is intervening normal small intestine between the stricturoplastied segments.

FIG. 59.4 Stricturoplasty. Once the small intestine is isolated, a longitudinal incision along the antimesenteric side is made in the strictured segment through the full thickness of the bowel wall (A). Sutures are then used to close this longitudinal opening transversely (B). (Adapted J. Ponsky, M.J. Rosen, Atlas of Surgical Techniques for the Upper GI Tract and Small Bowel, Saunders Elsevier. © 2010, p. 215, Fig. 25.4.)

Ileostomy

For patients unable to undergo distal anastomoses in order to restore continuity between the small intestine or colon, an ostomy or intestinal stoma may be required to divert the flow of gut contents in a controlled manner. The ostomy may be either temporary or permanent. It is important for the absorptive function of the small intestine to be maximized, and therefore creation of an ileostomy should ideally be carried out at the most distal site possible. Diversion of the intestinal stream more proximally, such as at the jejunum, may result in a high-output ostomy, where the patient is at risk of dehydration, electrolyte anomalies and weight loss due to insufficient nutrient absorption. There are two main surgical options for creation of an ileostomy: creation of either an end ileostomy or a loop ileostomy. One of the
most important elements of ostomy creation is selection of an ideal location in the abdominal wall. Important surgical considerations for stoma creation include ensuring the presence of an adequate adhesive surface, avoiding skin folds, and selecting a site that the patient can easily visualize and manipulate. When possible, preoperative marking of potential stoma sites may help ensure that an optimal location is utilized. The ostomy must pass through rectus, if at all possible. For an end ileostomy (Fig. 59.5A,B), the vascular arcade of the divided bowel is tailored to allow for maximum intestinal length, and also to permit it to protrude through the abdominal wall without tension, which potentially might cause its retraction or vascular compromise. Creation of the mucocutaneous junction that facilitates postoperative stoma care is another important consideration. The small bowel mucosa is opened and affixed to the cutaneous cut rim using interrupted sutures (see Fig. 59.5C,D). Note that the abdominal wall defect should also be loose enough not to constrict or obstruct the intestine, but not so loose that predisposition to parastomal hernia formation becomes a concern. A loop ileostomy is performed in a very similar manner to an end ileostomy, except that the proximal and distal limbs are both opened. Usually there is some asymmetry, with the proximal limb opening being created larger than the distal limb in order to prevent overflow.
Feeding tube placement (jejunostomy feeding tube)

Under circumstances requiring exogenous administration of enteral feeds due to compromised continuity or function of the proximal gastrointestinal tract, a feeding tube may be placed within the proximal jejunum in order to...
provide external access for nutrition. Typically, a loop of proximal jejunum, 15–20 cm distal to the ligament of Treitz, is brought up to the abdominal wall and a feeding tube is placed into the small intestine. Although there are several different surgical techniques and feeding tube types, the tube is typically secured to the small intestine using full-thickness purse string absorbable sutures that may be placed using either a single or double layer suturing technique. The small intestine is then usually affixed to the anterior abdominal wall using interrupted sutures. In some cases, the Witzel surgical technique may be performed by using sutures to create a serosal tunnel over a short segment of the tube as it exits the small intestine.

**Tips and Anatomical Hazards**

For surgical procedures where the small intestine is a bystander for the removal of another neoplasm, the absence of adhesions and inflammation makes its manipulation relatively straightforward and safe. Conversely, during reoperative surgery due to adhesions and/or inflammation, the handling of the intestine can be extraordinarily challenging. Dilated bowel is particularly prone to serosal tearing and thus handling dilated bowel must be performed with extreme care; sharp dissection is the rule when trying to discriminate between adhesive loops or other structures. In some cases, radiation treatments to the pelvis for other disease processes can make the danger of handling the small intestine extreme. Attempts to dissect and resect may be impossible and, instead, performing a bypass procedure to avoid enterotomies, should the length of intestine permit, may be more appropriate.

The importance of stoma placement under circumstances where continuity is not preserved cannot be overstated. Patients can be debilitated due to leaking stomas that cause excoriation of the skin, and even suffer from subcutaneous and deep infections with fistulae. Managing these problems may require weekly, or even daily, visits from specialized enterostomal therapists, and even ultimately necessitate resiting of the stoma, along with all the complications and risks associated with reoperation. Site selection for the ostomy is ideally completed with the help of an enterostomal therapist, where
the placement is centred on rectus in a flat area that has no creases or protuberances, and also can be easily seen by the patient. This should be done with consideration of the patient standing, supine and sitting, to minimize the potential for problems and maximize function.

Two of the more serious acute complications of operations performed on the small intestine are bleeding and anastomotic failure. To avoid either of these complications, careful attention to haemostasis and an understanding of the anatomy of the blood supply of the intestine are essential for good surgical outcomes. For example, haemostasis in the acutely inflamed and toxic patient with Crohn's disease may be challenging, regardless of whether ligation of vessels is done by hand-suturing or using energy devices; in most cases, both techniques may be utilized, depending on the location and size of the vessel. Creating an intestinal anastomosis with the best chance for success again requires good knowledge of the intestinal vasculature in order to ensure the best possible blood supply, as well as to avoid tension, and be certain that healthy ends are present when restoring continuity.

Potential complications that may occur acutely or in the postoperative period include an internal hernia through an inadequately reapproximated mesenteric defect, or intestinal stenosis due to compromised small bowel blood supply. In each of these circumstances, the timing is not predictable. In both cases, a laparotomy may be required to address the hernia and the potential for obstruction and strangulation, as well as for resecting a stenotic segment that has compromised luminal flow. As indicated above, a good vascular supply is the key to a healthy anastomosis and functioning small intestine; when closing mesenteric defects, care must be taken not to disrupt the blood supply when sutures are placed to bring the mesenteric edges together.

Intestinal function may be defined in the simplest terms by intestinal length. Any procedure involving resection of long segments of small intestine requires detailed knowledge not only of the length of the entire specimen being removed, but also of the length of healthy intestine remaining, as steps must be taken to preserve length; this may potentially require multiple segmental resections and anastomoses, and/or ‘second look’ procedures.
References

**Single Best Answers**

1. Which one of the following layers of intestine is essential for strength and suturing?
   A. Serosa
   B. Mucosa
   C. Submucosa
   D. Myenteric plexus

   **Answer: C.** The submucosa is the strongest layer; its relatively enhanced levels of connective tissue contribute to its strength and ability to hold sutures.

2. Which one of the following cell types is most responsible for nutrient absorption in the intestinal epithelium?
   A. Enterocytes
   B. Goblet cells
   C. Lymphocytes
   D. Paneth cells

   **Answer: A.** The goblet cells, Paneth cells and lymphocytes contribute to maintenance of the gastrointestinal barrier and have an immune function, whereas enterocytes are the primary site for intestinal absorption of nutrients.

3. Handsewn anastomoses are associated with fewer anastomotic leaks. Is this statement true or false?
   A. True
   B. False

   **Answer: B.** While randomized studies are relatively limited, there is no evidence for improved outcomes when using handsewn
anastomoses for either neoplastic disease or inflammatory processes.

4. Which one of the following arteries provides the primary vascular supply of the small intestine?
   A. Gastroduodenal artery
   B. Inferior mesenteric artery
   C. Right colic artery
   D. Superior mesenteric artery

   **Answer: D.** The superior mesenteric artery is the main vascular arcade for the small intestine, as well as the proximal colon and pancreas.

5. Which one of the following sites describes where a jejunostomy feeding tube is typically placed?
   A. 5 cm from the ligament of Treitz
   B. 80 cm from the ligament of Treitz
   C. In the terminal ileum
   D. 20 cm from the ligament of Treitz

   **Answer: D.** Placement of a feeding tube in the small intestine proximal to 20 cm from the ligament of Treitz, or distal, may result in reflux or poor absorption, respectively.
Clinical Cases

1. A 75-year-old female presents to the emergency department with 36 hours of abdominal pain and ongoing vomiting. She has been unable to pass flatus or stool for the past 24 hours. Other than an antihypertensive she does not take any other medications. She had undergone a hysterectomy approximately 30 years ago. Her examination reveals a distended abdomen with no signs of peritonitis. She is afebrile and does not demonstrate abnormal haematologic or chemical indices with the exception of the slightly elevated creatinine which is a new finding. Her abdominal x-rays reveal air/fluid levels with a paucity of colonic gas.

A. Describe your approach to the initial management of this case.
She is admitted to hospital, resuscitated with fluids, a nasogastric tube is placed and she is sent for a CT scan which reveals distended small bowel with a transition point in what appears to be the ileum in the right lower quadrant. It appears to be a mid to high-grade obstruction with virtually complete collapse of the small bowel distal to the obstruction. There are no signs of vascular disease, neoplasms or other abnormalities.

B. After a period of conservative therapy for another 48 hours the patient demonstrates no signs of improvement. The patient remains otherwise well and there are no signs of strangulation or ischaemia indicating compromise of the small intestine. Describe your approach to operative management of this case.
The patient is taken to the operating room for laparotomy; a midline incision is used to gain access to the abdominal cavity. A single adhesive band is identified within the right lower quadrant that has caused the obstruction and this is released sharply. The bowel is otherwise healthy despite the site of constriction which quickly normalizes in colour once the adhesive band is released. The procedure is then completed.

2. A 58-year-old male presents with acute on chronic abdominal pain with a five-month history of weight loss. He was experiencing postprandial discomfort and some distention for the past few months. On this admission he has a 24-hour history of increasing abdominal pain and distention, no flatus and presents with
peritonitis. He is febrile, demonstrating signs of a systemic inflammatory response with mild hypotension that responds to fluid resuscitation. He denies any previous surgical history, but on further questioning has had episodes of diarrhoea and potentially cutaneous flushing over the past six months. He has no other medical problems.

A. Describe your approach to the initial management of this case.

A CT scan was carried out. It showed a large mesenteric mass in the right lower quadrant with extensive liver metastases that involved both lobes of the liver, with potential signs of peritoneal seeding and what appeared to be a closed loop obstruction with an ischaemic distal small bowel.

B. After resuscitation and initiating antibiotic therapy he is taken to the operating room for an emergent laparotomy which reveals a primary tumour in the ileum with extensive lymphatic metastases and a large calcified mass in the mesentery. There are innumerable liver metastases and some peritoneal seeding. There appears to be only a single mass within the submucosa of the small bowel in the region of the mesenteric mass, which likely represents the primary neuroendocrine tumour. There are no other abnormalities within the small or large intestine. The mass involves the vascular arcade up to the proximal aspect of the superior mesenteric artery, and therefore cannot be resected without compromising the blood supply of the small intestine. Describe your approach to the operative management of this case.

The ischaemic small bowel adjacent to the mesenteric mass, that includes the small primary tumour, is resected after ligation of the tributaries of the superior mesenteric artery near the small intestine, and staplers are used to divide the lumen and seal the intestine. The affected segment is sent for pathological analysis, together with a liver biopsy and sampling of the peritoneal seeding. The terminal ileum has sufficient length and laxity that it can be placed side to side with the proximal small intestine to create an anastomosis using a stapler to create the new lumen, and sutures to oversew the openings used for the stapler placement. Intestinal continuity has been restored, permitting the patient to undergo further pathological assessment to allow the final treatment plan to be devised.
Colon, rectum and anus

Siham Zerhouni, Sami A Chadi, Fayez A Quereshy

Core Procedures

Colon and Appendix

- Segmental colectomy
- Appendicectomy
- Hartmann's procedure

Rectum

- (Low) anterior resection
- Abdominoperineal resection

Anal Canal

- Internal anal sphincterotomy
- Fistulotomy
- Incision and drainage of perianal abscess
- Haemorrhoidectomy
Clinical anatomy

The colon is a capacious tubular conduit that extends from the ileocaecal junction to the anus and frames the small intestine. It is approximately 150 cm long, which is about 25% of the length of the small intestine. Its diameter ranges from 2.5 cm (sigmoid colon) to 7.5 cm (caecum), and significant augmentation may occur with distension.¹

The anatomical characteristics that differentiate the small intestine from the large intestine are used clinically when assessing imaging or when evaluating anatomy during an operation. In addition to possessing a larger calibre and restricted mobility, the large bowel is distinguished by taeniae coli, haustra, plicae semilunares and appendices epiploicae. The three taeniae coli are bands of longitudinal smooth muscle that start at the base of the appendix and merge at the level of the rectosigmoid junction. They are located in fairly constant positions beneath the serosal surface of the colon, except in the transverse colon. They are found on the anti-mesenteric aspect of the colon, directly opposite the mesentery (taenia libera), posterolaterally (taenia omentalis) and posteromedially (taenia mesocolica) midway between the taenia libera and the mesentery. They contract longitudinally, forming haustra, outpouchings of the colon that result in the formation of circumferential folds of the bowel wall, plicae semilunares. Haustations may be absent in the caecum and relatively sparse in the ascending and proximal transverse colon; they become more pronounced beyond the middle of the transverse colon. Appendices epiploicae are fatty tags that arise from the serosa of the colon (Fig. 60.1).¹
The large bowel is divided into the caecum, appendix, ascending colon, transverse colon, descending colon, sigmoid colon, rectum and anal canal (see Fig. 60.1). The terminal ileum enters the caecum at its posteromedial
aspect; its angulated entry is maintained by superior and inferior ileocaecal folds. The ileocaecal valve consists of two semilunar mucosal lips that fuse, regulating ileal emptying by preventing backward reflux of colonic contents. Clinically, a competent ileocaecal valve can lead to a closed loop type of large bowel obstruction if there is an obstructing distal lesion.\(^2\)

The appendix is a blind-ended tubular structure arising from the posteromedial caecum approximately 2 cm below the ileocaecal junction. It is 2–20 cm in length and has an average diameter of 5 mm. Its position varies: in order of frequency, the appendix may be retrocaecal, retrocolic, pelvic (descending), subcaecal or ileocaecal. The mesentery of the appendix is attached to the caecum and the proximal appendix, and contains an appendicular artery, a branch of the ileocolic artery (Video 60.1)\(^3\).

The rectum is a wide, easily distensible reservoir that lacks haustra, appendices epiploicae and taeniae. It exhibits three curvatures that correspond to three intraluminal folds: the left superior, right middle and left inferior folds, known collectively as the valves of Houston (Fig. 60.2). They are encountered during endoscopic evaluation of the rectum and are absent after surgical mobilization of the rectum. The preoperative endoscopic measurement of a rectal lesion from an anal landmark (for example, the anal verge) is often found to be even higher after the rectum is elongated by operative mobilization. The rectum is surrounded by perirectal fat containing terminal branches of the inferior mesenteric artery and lymph nodes, and is enveloped by the fascia propria (see Fig. 68.2).
The anal canal may be defined anatomically or surgically (see Fig. 60.2). The anatomical canal extends from the anal verge to the dentate line, which
marks the point of transition from visceral afferent to somatic afferent innervation. In the mid-anal canal, 6–10 vertical mucosal folds form the anal (haemorrhoidal) columns. They frequently contain a terminal branch of the superior rectal artery and vein, supplemented to a variable degree by middle and inferior rectal vessels; dilated submucosal veins in the upper anal canal form an internal rectal (haemorrhoidal) venous plexus (Fig. 60.3). The submucosal vessels are most prominent in the left lateral, right posterior and right anterior quadrants of the wall of the canal (at approximately 3, 7 and 9 o’clock when viewed in the lithotomy position); here, the subepithelial tissues are expanded into three ‘anal cushions’. Although variable in number and position, the cushions help to seal the anal canal and contribute to the maintenance of continence to flatus and fluid. They are important in the pathogenesis of haemorrhoids.

Muscles
The internal anal sphincter is a continuation of the circular muscle of the muscularis propria of the rectum; it terminates approximately 1 cm proximal to the most distal edge of the external sphincter at an important surgical landmark, the intersphincteric groove. The surgical (functional) anal canal is approximately 4 cm in length and extends from the anal verge to the anorectal ring (the anorectal junction), at which point the external sphincter transitions to puborectalis. Clinically, the surgical anal canal is used when assessing low-lying lesions by digital rectal examination and by imaging. The muscles of the pelvic floor include levator ani (iliococcygeus, pubococcygeus and puborectalis) and coccygeus (see Fig. 68.3). The fibres of puborectalis pass back from the pubic symphysis and run alongside the internal anal sphincter at the level of the anorectal junction, forming a sling around the anal canal. Iliococcygeus and pubococcygeus are generally responsible for providing an uplifting mechanism for the pelvic floor. Iliococcygeus originates from the ischial spines and obturator fascia, passing in a curvilinear fashion posteriorly and medially around the anal canal to insert into the sacrum, coccyx and anococcygeal raphe (or ligament). Pubococcygeus is internal to ileococcygeus, originating from the pubic symphysis and obturator fascia, and inserts into the sacrum, coccyx and anococcygeal raphe. Its more medial location and encompassment of the urethra, vagina and anus make it the ‘levator hiatus’; weakening of this hiatus is often implicated in cases of pelvic organ prolapse.

**Vascular supply**

The colon receives its arterial supply from the superior mesenteric artery (SMA) and the inferior mesenteric artery (IMA). The SMA arises from the anterior surface of the aorta at the level of the lower border of the body of the first lumbar vertebra. It runs steeply downwards, posterior to the splenic vein and body of the pancreas, with the superior mesenteric vein on its right, and directly anterior to the left renal vein, the uncinate process of the pancreas and the third part of the duodenum. It then enters the root of the mesentery of the small intestine and passes obliquely downwards and to the right, giving off several branches to the large intestine; it supplies the small intestine, caecum, appendix, ascending colon and most of the transverse colon. The colic branches of the SMA include the middle, right and ileocolic arteries, of which the latter is the most constant. Variations in branching patterns occur in up to 20% of patients.
The IMA arises from the anterior or left anterolateral aspect of the aorta behind the inferior border of the third part of the duodenum 3–4 cm above the aortic bifurcation, at the level of the third lumbar vertebra. It runs obliquely down to the pelvic brim, beneath the peritoneal floor of the left infraocolic compartment, initially anterior and then to the left of the aorta. It gives off the left colic and sigmoid arteries, and crosses the origin of the left common iliac artery medial to the ureter, with the inferior mesenteric vein lying between them. Beyond the pelvic brim, it continues in the root of the sigmoid mesocolon as the superior rectal artery (superior haemorrhoidal artery). The marginal artery of Drummond is a series of arcades that run parallel to the colon and connect the right and left colonic arterial supply. Even though it often terminates at the sigmoidal arteries, its path can be disrupted at one or more points. The arc of Riolan, also known as the meandering mesenteric artery, serves as a second vascular anastomosis between the SMA and the IMA; it arises as a branch of the left colic artery and terminates at the left branch of the middle colic artery.

The right and left inferior and middle rectal arteries are branches of the internal pudendal artery, itself a branch of the internal iliac artery. The contribution of the middle rectal artery varies, depending on the size of the superior rectal artery. It is because of this rich vascular supply that division of the superior and middle rectal arteries during a low anterior resection operation does not result in rectal necrosis (see Fig. 60.3). The venous supply mirrors the arterial supply of the colon and the anorectum. On the right side, the veins join the superior mesenteric vein (SMV), and on the left side the veins enter the inferior mesenteric vein (IMV). Both the SMV and IMV drain into the portal vein. The inferior and middle rectal veins eventually enter the internal iliac vein (the systemic circulation) (Fig. 60.4). The point where the portal system (superior rectal vein) and the systemic circulation (the inferior and middle rectal veins) meet is a potential site for the development of varicosities, especially observed in the context of portal hypertension due to advanced liver disease.

Lymphatic drainage
The lymphatic drainage of the colon follows its vascular supply via four main nodal stations. The initial draining nodes (epiploic nodes) are located just below the peritoneum and appendices epiploicae, and drain to the paracolic nodes adjacent to the marginal artery and other vascular arcades. Paracolic nodes drain to intermediate nodes along the primary colic vessels leading to the main or principal nodes located along the superior and inferior mesenteric vessels; these main nodal chains drain into the cisterna chyli and into the main lymphatic system.6

Upper and mid-rectal nodal drainage follows the same drainage as that of the rectosigmoid and sigmoid colon, along the inferior mesenteric vessels to the cisterna chyli. The lower third of the rectum can drain along the superior rectal vessels to the inferior mesenteric vasculature, but also drains along the middle colic nodes to the internal iliac nodal system. The anal canal proximal to the dentate line drains along the inferior mesenteric and internal iliac nodal system, whereas drainage below the dentate line is via the inferior rectal lymphatics to the superficial inguinal lymph nodes.6

**Innervation**

The innervation of the large intestine includes the enteric nervous system (made up of motor neurones, intrinsic sensory neurones, and interneurones lying within the wall of the gut); the autonomic nervous system (sympathetic and parasympathetic innervation); extrinsic sensory innervation (visceral afferents); and somatic motor innervation (external anal sphincter).

The cell bodies of preganglionic sympathetic fibres supplying the midgut are found in the intermediolateral columns of the fifth to the twelfth thoracic spinal segments and those of the hindgut in the intermediolateral columns of the first and second lumbar spinal segments. Postganglionic sympathetic neurones from both sources release noradrenaline (norepinephrine), causing presynaptic inhibition within enteric circuits, slowing gut motility and driving contraction of the ileocaecal valve and internal anal sphincters. Sympathetic supply to the midgut is conveyed to the coeliac and superior mesenteric plexuses via the greater and lesser splanchnic nerves; postganglionic axons are distributed with branches of the SMA. Sympathetic supply to the hindgut is conveyed via the lumbar splanchnic nerves that synapse in the abdominal aortic and inferior mesenteric plexuses, and via sacral splanchnic nerves that synapse in the superior and inferior hypogastric plexuses. Postganglionic fibres are distributed with branches of the IMA;
they inhibit colonic muscle and stimulate contraction of the internal anal sphincter. The lower rectum is innervated by presacral nerves (a fusion of the aortic plexus and lumbar splanchnic nerves). Below the sacral promontory, the presacral nerves form the hypogastric plexus and branch into the right and left hypogastric nerves towards the pelvic plexus. The pelvic plexus lies on both sides of the pelvis at the level of the lower third of the rectum (Fig. 60.5).
The parasympathetic supply to the midgut is conveyed by the vagus nerve, via the coeliac and superior mesenteric plexuses, whereas the hindgut receives its parasympathetic innervation from the pelvic splanchnic nerves. The cell bodies of the pelvic splanchnic nerves are located in the second to fourth sacral spinal segments and their axons enter the inferior hypogastric.
plexus, where some synapse. From here, axons may pass directly to the rectum and other pelvic viscera, or ascend either within the hypogastric nerves to the superior hypogastric plexus to be distributed along branches of the IMA, or pass directly through the retroperitoneal tissues to reach the splenic flexure and the descending and sigmoid colon. Most preganglionic parasympathetic neurones synapse in intramural plexuses in the gut wall on postganglionic neurones that innervate the glands (secretomotor) and muscle (motor) of the large intestine. Parasympathetic stimulation is integral to colonic propulsion and defaecation and to relaxation of the internal anal sphincter (S2, 3, 4).

Visceral afferent impulses mediating sensations of distension and spasm from the midgut travel with the vagus nerve, while the hindgut is innervated by afferent neurones with cell bodies in the lumbar (mostly L2, 3) and sacral (mostly S1, 2) dorsal root ganglia. These fibres travel alongside autonomic nerves and are often erroneously referred to as ‘sympathetic afferents’ or ‘parasympathetic afferents’.

Levator ani is innervated by nerves that originate mainly from the third and fourth sacral spinal segments, with lesser contributions from the second segment. These nerves enter the pelvis just above, and sometimes pierce, ischiococcygeus, to pass along the ventral surface of ischiococcygeus and pubococcygeus, supplying these muscles and sending fibres to puborectalis. The pudendal nerve may also supply pubococcygeus from its lateral surface through its inferior rectal and perineal branches.

The external anal sphincter is innervated by the inferior rectal branch of the pudendal nerve (S2, 3, 4). The intersphincteric autonomic nerves supplying the internal anal sphincter are derived from Auerbach’s nerve plexus in the most distal part of the rectum and the inferior rectal branches of the pelvic plexus that run along the conjoint longitudinal muscle coat. Sympathetic nerves mediate sphincteric contraction, and parasympathetic nerves mediate sphincteric relaxation. The upper anal canal contains various specialized nerve endings that sense pressure (Golgi–Mazzoni bodies), touch (Meissner's corpuscles), friction (genital corpuscles) and cold (Krause's bulbs), in an area known as the anal transition zone (ATZ).

**Defaecation**

Defaecation is the act of voiding stool from the anus and involves the coordinated function of the colon and rectum, pelvic floor and anal sphincter.
mechanism. Distension of the rectum results in contraction of the external sphincter to preserve continence, but also leads to relaxation of the internal sphincter, a reflex known as the recto-anal inhibitory reflex (RAIR). This is thought to allow the ATZ to sample the rectal contents to assess consistency (whether solid, liquid or flatus). An impairment in RAIR has been demonstrated in patients with conditions including obstetric pudendal nerve injuries, proctitis, after mucosectomy and Hirschsprung’s disease.

Gross faecal continence is often correlated with puborectalis function because the muscle remains contracted at rest to allow for an anterior horizontal force that essentially obstructs the outlet of the rectum. Appropriate relaxation of puborectalis straightens the angle between the rectum and anal canal for ease of passage of rectal contents.
Surgical approaches and considerations

Colon

Surgically, the right colon can be approached through either lateral to medial and medial to lateral directions, or along its caudal to cephalad axis. The lateral to medial approach begins with an incision along the white line of Toldt, located where the parietal peritoneum converges over the top of the viscera to become the visceral peritoneum (Ch. 57). This gives access to the areolar plane, which separates the colon and mesocolon from the retroperitoneal structures and the retroperitoneal fascia. The dissection is carried towards the hepatic flexure, and the colon is retracted superomedially to expose Gerota’s fascia and the right ureter. Medially, the duodenum is encountered, over which the retroperitoneal fascia is draped, intimately adherent to the posterior fascia of the ascending mesocolon. The ascending and proximal transverse mesocolon can be further mobilized to lift the pancreatic head medial to the duodenum off the mesocolon and the mesocolic fascia, so as to reach the take-off of the middle colic vein.

In the medial to lateral approach, often used laparoscopically, the ileocolic pedicle is exposed and ligated. This is performed by lifting the caecum or appendix or adjacent mesocolon anteriorly to visualize the mesocolic fold anterior to the ileocolic pedicle. The visceral peritoneum anterior to the mesocolic fat, anterior to the ileocolic pedicle, is incised and the vessels are dissected out and ligated. It is important to ensure that the duodenum has been freed of its mesocolic attachments before performing this manoeuvre in order to avoid iatrogenic injury during the ligation (Fig. 60.6), and to ensure that the vessels are being taken high to facilitate the oncological adequacy of lymph node retrieval and mesocolic compartmental resection. The mesocolon between the ileocolic vessels and the middle colic vessels is quite thin, a feature that allows the surgeon to establish a plane in the thin mesentery leading to the middle colic vessels (which have a short common stump before bifurcating into their left and right middle colic branches). It is important to be aware of this anatomy when deciding whether to perform a traditional right hemicolectomy (taking the right branch of the middle colics) or an extended right hemicolectomy (where the middle colic stump is taken to ensure adequate lymph node retrieval). In the caudal to cephalad approach, it is important to understand the mesenteric and mesocolic anatomy. The terminal ileal mesentery is continuous with the ascending
colon. The junction between the two structures is retracted anteriorly and the visceral peritoneum posterior to the mesocolon is incised, allowing for development of the avascular plane between the mesocolon and the retroperitoneal fascia. The duodenum is visualized medially and the ureter posteriorly. This dissection is then carried up to the hepatic flexure, after which the lateral and cephalad attachments are freed.

At the completion of either of these approaches, the hepatocolic and gastrocolic ligaments must be addressed. A decision needs to be made as to whether the greater omentum will be removed en bloc with the specimen or dissected off the transverse colon. In the former situation, the omentum is retracted caudally and the lesser sac is entered by dissecting into the omentum, caudal to the location of the gastroepiploic vessels. The dissection is then carried out laterally, while simultaneously dissecting the hepatocolic ligament anterior to Gerota's fascia, lateral to the duodenum and inferior to the liver. Alternatively, when the greater omentum is left behind, the omentum is retracted anteriorly and the adhesive plane between the epiploicae of the transverse colon and the greater omentum is separated in order to enter the lesser sac, posterior to the omentum but anterior to the transverse mesocolon. The dissection is then carried out laterally in a manner
that is similar to the previous approach. The omentum is next incised at the level of the distal transection margin so as to expose the transverse colon, at which point it is skeletonized of mesocolic and omental fat to allow for subsequent transection. The bowel is divided distally and proximally at the level of the terminal ileum, taking care to ensure that the vascular supply has been taken first. This allows a period of ‘ischaemic demarcation’ that guides the surgeon to the most appropriate location for bowel transection. The anastomosis is then fashioned with either a hand-sewn or stapled technique. The principle of a ‘high ligation’ in colonic and rectal surgery implies ligating the blood supply as close as possible to its take-off from the major contributing vessel in order to ensure adequate lymph node harvest.

The left colon can be approached via a medial to lateral or a lateral to medial approach. As with the right side, the lateral to medial approach begins with an incision along the white line of Toldt on the left. Superomedial retraction of the left colon and lateral to medial dissection exposes Gerota’s fascia, the left ureter and eventually the sacral promontory. The gastrocolic ligament is then divided and the splenic flexure is mobilized, taking great care to avoid iatrogenic trauma and resulting haemorrhage from the spleen. Unlike the hepatic flexure, the splenic flexure is usually deeper, more superior and acutely angled. The superior rectal (haemorrhoidal) and left colic vessels or the IMA are isolated and ligated (either a single or multiple vessels are ligated, depending on the extent of colonic resection and the extent of lymph node harvest that is required) (Fig. 60.7).
The medial to lateral approach to the dissection of the inferior mesenteric artery during resection of the rectum. The critical structure in the background, the ureter, is identified and its vermiculation is confirmed prior to clipping any structures in this area. Note the close proximity of the ureter to the superior rectal artery (clipped) and the left colic artery in this medial approach.

The medial to lateral approach to left colon resection involves an initial incision medial to the IMV that allows dissection of the plane above Gerota's fascia. The IMV is localized at the inferior border of the pancreas and lateral to the ligament of Treitz. Division of the IMV allows the eventual identification of the IMA and its branches. The blood supply is then divided and dissection in the retroperitoneal space continued up to the line of Toldt. During colonic resection, the interruption of the marginal artery of Drummond may affect the vascularity of the remaining bowel, specifically at the splenic flexure and the sigmoid colon. The splenic flexure is the region where the vessels supplying the midgut (SMA) and hindgut (IMA) anastomose. The pattern of these anastomoses varies and consequently this ‘watershed’ area, referred to as Griffiths’ critical point, is often the anatomical location that is most severely affected by ischaemic colitis. Sudek’s critical point, where the lowest sigmoid arteries anastomose with the superior rectal artery, is a site where ischaemia may occur as a result of interruption of the marginal artery.

Vascular anastomosis, whether enterocolic or colocolic, is an important concept to be aware of during colonic resection. The option of stapled versus hand-sewn anastomosis is based on the quality of the tissue, as assessed by the operator during surgery. When there are limitations in the amount of bowel available or concerns regarding oedematous tissue, a hand-sewn approach is preferred because of the option of a single versus a two-layered anastomosis, performed at the surgeon's discretion, and based on clinical assessment of the tissues and personal experience. Stapled anastomoses are
quick to perform but provide only a single staple height for the staple line, based on the specific instrument selected. Anastomoses can also be performed using isoperistaltic or antiperistaltic approaches, depending on the relative orientation of the proximal and distal bowel limbs. Patients with Crohn's disease are often anastomosed with isoperistaltic anastomoses after ileocolic resection because this facilitates proximal enteric intubation during postoperative disease surveillance endoscopy.

Surgery remains the cornerstone of management for acute appendicitis. Over the last 20 years, laparoscopic appendicectomy has become the favoured approach, reflecting the diagnostic ability of laparoscopy (especially in female patients), its aesthetic advantages and the abbreviated recovery time associated with this technique. In laparoscopic appendicectomy, three trocars are positioned in the lower abdomen and a thorough evaluation of the peritoneal cavity is conducted to confirm the diagnosis. The distal appendix is grasped with an atraumatic instrument and retracted cranially and anteriorly. The mesoappendix is placed under tension and monopolar cautery used to incise the peritoneal envelope overlying the appendiceal artery, which is subsequently skeletonized and divided using surgical clips. The remaining mesoappendix is next divided using sharp dissection with electrocautery. The integrity and quality of the base of the appendix are evaluated: if viable without evidence of perforation, the appendix is secured 2 mm above the caecal pole using pre-tied endoloop sutures, and divided and retrieved through a 10 mm abdominal aperture (often in a sterile bag). In circumstances where the base of the appendix is necrotic or perforated, an endomechanical stapler may be used to divide the caecal pole after caecal mobilization. Care must be taken to identify and preserve the ileo-caecal valve and terminal ileum.

The incision for an open appendicectomy is classically made at McBurney's point (a point two-thirds of the distance from the anterior superior iliac spine along an imaginary line drawn towards the umbilicus). Alternatively, surgeons plan their incisions to correspond to the point of maximal tenderness on clinical examination at the time of evaluation. A 5 cm incision is made with careful dissection through the layers of the abdominal wall. The peritoneal cavity is entered under direct vision and the appendix delivered into the wound using careful manual exploration. Once the appendix is delivered, the appendiceal artery and corresponding mesoappendix are divided using haemostats and ties. The integrity of the appendiceal base is evaluated in the same manner as in the laparoscopic approach; if healthy, the
base is first crushed by a haemostat and then secured with a non-absorbable tie (classically a silk tie). The mucosa of the appendiceal stump is frequently cauterized to prevent the theoretical development of a mucocele. The appendiceal stump is imbricated into the caecal pole using a purse-string suture. Necrotic or perforated bases are managed using an endomechanical stapling device. Proponents of the open technique frequently cite the lower cost and operative time associated with this approach.

Rectum

Our understanding of rectal surgery was revolutionized by Professor Richard ‘Bill’ Heald with his description of total mesorectal excision (TME), where embryological planes were followed around the mesorectal envelope to ensure a complete resection of the primary tumour and all mesorectal tissue. TME has been shown to decrease the likelihood of local rectal cancer recurrences\(^\text{10}\) and provides the underlying rationale for the oncological approach to rectal cancer surgery and low anterior resection (LAR).

The approach to LAR can be performed lateral to medial or medial to lateral. As is the case for colonic segmentectomy, the lateral to medial approach begins with an incision at the line of Toldt on the left side, after mobilization of the various non-embryological adhesions between the sigmoid colon and the left lateral abdominal wall. Once these are dissected, the flattened mesocolon of the sigmoid colon can be visualized in continuity with the parietal peritoneum. The establishment of the plane between the left mesocolon and the retroperitoneum is most reliable in the descending colon, just proximal to the sigmoid colon, which can be carried inferiorly. The sigmoid colon and upper rectum are then retracted superomedially in order to identify the left gonadal vessels; the left ureter lies posterior to these vessels at the level of the sigmoid fossa. If the ureter is difficult to identify here, it can also be identified draping over the iliac vessels at the level of the pelvic brim. Following this mobilization, the IMA is identified and ligated. In the medial to lateral approach, more often performed laparoscopically, the presacral plane is entered by dissecting the visceral peritoneum anterior to the hypogastric nerve plexus and entering the presacral plane while leaving the hypogastric nerves in their posterior location. The IMA or the target tributary vessel (for example, the superior rectal or sigmoid artery) is identified and ligated after the position of the left ureter and its non-involvement in the perivascular tissue of the IMA have been confirmed. This
is especially important in situations where there is sigmoid, rectosigmoid or upper rectal inflammation (such as in higher T-stage tumours, tumours with endoscopic stents, diverticulitis) because the inflammatory process can often draw the ureter close to the IMA pedicle. Often, a brief lateral mobilization of the sigmoid adhesions is performed to linearize the colon further, prior to initiating the medial approach, thereby increasing the reliability of the anatomical landmarks. All of this work has set the stage for the TME dissection. It is often advantageous to delineate the proximal transection margin by coming across the mesocolon, typically performed on the cephalad aspect of the ligated vascular pedicle and carried out to the desired point of proximal transection, dividing the marginal vessels.\textsuperscript{11}

The TME dissection is performed by dissecting posterior to the mesorectum, being mindful of important structures including the presacral fascia (which covers the sacrum), coccyx, hypogastric nerves, medial sacral artery and presacral veins. Dissection deep to this fascia can cause significant bleeding and injure the hypogastric plexus. At the level of S4, the retrosacral fascia (fascia of Waldeyer,) projects anteroinferiorly from the presacral fascia, and serves as an important landmark for the plane that is used to guide the posterior rectal dissection. Anteriorly, the rectoprostatic or rectovaginal fascia (Denonvilliers’ fascia) separates the extraperitoneal rectum beyond the fascia propria from the prostate, urinary bladder and seminal vesicles in men, and from the vagina in women; it serves as another important landmark for the TME dissection.

Dissection posterior to the mesorectal fascia and anterior to the presacral fascia is facilitated by identification and preservation of the hypogastric nerves (\textbf{Fig. 60.8}). As often mentioned by Professor Heald, it is important to remain on ‘the yellow side of the white’, referring to exposing the mesorectal fat envelope and leaving the white fascia behind. Lateral dissection of the TME needs to proceed with careful attention to the hypogastric nerves as they bifurcate and run laterally, usually caudal to the sacral promontory. Unfortunately, nerve injury during TME is a common occurrence; it may lead to bladder paresis (7–59% risk), impotence (15–45% risk), ejaculatory dysfunction (32–42% risk) or sexual dysfunction (up to 100% risk).\textsuperscript{1}

Hypogastric denervation alone results in retrograde ejaculation (sympathetic fibres) and bladder dysfunction, whereas injury to the nervi erigentes (parasympathetic fibres) with preservation of the hypogastric nerves may result in erectile dysfunction. Damage to the periprostatic plexus can result in erectile impotence and a neurogenic (flaccid) bladder.\textsuperscript{1}
Lateral TME dissection is best performed after having maximized the posterior dissection as far caudally as possible. The right and left ureters are identified, even though the dissection is much more medial to these structures. Persisting posteriorly creates flaps of peritoneum and mesorectal tissue laterally that can be reliably approached in the appropriate plane. This will invariably result in the ligation of the middle rectal vessels and their adjacent nerves. Anteriorly, the mesorectum is very thin. The peritoneal reflection is incised to reveal the anterior compartments. A conscious decision must be made either to preserve Denonvilliers’ fascia or to include it in the dissection (usually determined by the absence or presence, respectively, of an anterior component to the tumour). Anteriorly, the seminal vesicles are visualized in men, and the rectovaginal septum and vagina are identified in women. Digitation of the vagina can help identify the appropriate plane of dissection. Eventually, the pelvic floor muscles (levator ani) are encountered, usually posteriorly initially and then laterally.

Transection of the rectum depends on the level of the tumour and the pathology that mandated surgical excision. Anastomoses are usually performed using a circular stapler but can also be performed with a hand-sewn colo-anal technique.¹²

Local excision has often been performed for distal rectal masses where the surgeon uses traditional anoscopes to access the distal rectum and resect polyps or tumours for both diagnostic and therapeutic purposes, under a general anaesthetic. More recently, laparoscopic instrumentation has been
used with the added detail of 2D or 3D laparoscopes, through transanally placed ports and rectal insufflation, to resect these lesions more precisely. The detailed optics of these procedures (transanal minimally invasive surgery, TAMIS, or transanal endoscopic microsurgery, TEMS) permits more precise visualization and inclusion of the various layers of the rectal wall, as well as access to more proximal aspects of the rectum. These features have been demonstrated to result in lower rates of local recurrence and margin-free resections,\textsuperscript{13} and are potential alternatives to proctectomy in patients with earlier stage cancer, mainly T1N0.\textsuperscript{14} More recently, these transanal endoscopic techniques have been adapted to a new ‘bottom-up’ approach to rectal cancer surgery, known as the transanal total mesorectal excision (taTME), which boasts the advantage of alleviating the difficulties of a TME in the distal third of the rectum.\textsuperscript{15}

### Anal canal

The anal glands are located between the internal and external sphincters, within the intersphincteric space. They are connected to the anal canal at the level of the anal crypts (depressions found at the dentate line) (see Fig. 60.2). The anatomical relationships of the muscles of the anal canal create several potential spaces into which abscesses may develop and decompress. The most common spaces include the ischioanal, intersphincteric and supralelevator spaces (Fig. 60.9). The ischioanal space is lateral to the external sphincter and medial to the ischial tuberosity; when percutaneously drained, a trans-sphincteric fistula may develop. Intersphincteric collections may also decompress cephalad into the supralelevator space, either along the intersphincteric space or after decompressing from an ischioanal abscess. Intersphincteric collections can also drain caudally into the perianal skin, forming a perianal abscess. On sagittal assessments, the deep postanal space may be appreciated, presenting cephalad to the anococcygeal ligament and posterior to the anal canal, and representing the site of a horseshoe abscess that will subsequently decompress laterally and circumferentially, around the anal canal. Cephalad to this area is the supralelevator space, located above the levator musculature. Caudally, the superficial postanal space is located below the anococcygeal ligament.
In anticipation of the procedure that will need to be performed, it is...
important for the surgeon to be aware of the path followed by most fistulae that are cryptoglandular in origin. Goodsall’s rule is commonly quoted in such cases. To understand this rule, the perianal skin is divided in anterior and posterior compartments, centred around the anus. When an external opening is identified in the posterior half of the perianal skin, the tract takes a curvilinear path towards an internal opening in the posterior midline. When the external opening is present in the anterior half, the tract takes a perpendicular, direct path to the same location in the anal canal. There are two main exceptions to this rule: firstly, when the external opening in the anterior half is more than 3 cm lateral to the anus, the tract will probably have originated from the posterior midline and followed a curvilinear course around the anus to this location; and secondly, in cases of non-cryptoglandular fistulae – such as Crohn’s disease, HIV, infectious proctitis and trauma, amongst other causes – the fistula tracts often do not follow the stipulations of Goodsall’s rule.

The approach to the anal canal depends on the pathology being treated. In situations involving benign perianal abscesses, a simple incision and drainage with excision of a small section of overlying skin is performed to relieve the septic process. When these abscess drainage sites persist, they often form the external openings to anal fistulae, mostly emanating from the dentate line where the internal opening is located (Fig. 60.10). Examinations under anaesthesia are often necessary either to treat these fistulae definitively or to drain their associated septic process. Placement of seton drains along the fistula tracts helps to keep the internal and, more importantly, the external openings patent, to allow for persistent drainage of the septic process and eventual definitive treatment using one of the several techniques available. The latter may be subdivided into sphincter-sparing or transecting protocols, depending on the anatomical path taken by the fistula and the volume of external sphincter involved. The most straightforward treatment is often for intersphincteric tracts that do not involve any component of the external sphincter, or for subcutaneous tracts that do not involve any muscle. A fistulotomy in both of these cases results in minimal to no persistent incontinence, although transient liquid incontinence may occur. In female patients with low sphincter pressures or anteriorly located fistulae, surgeons are less inclined to cut any volume of external sphincter, given the potential risk of faecal incontinence. Alternatively, trans-sphincteric fistulae involving less than 30% of the external sphincter, or less than 1 cm of muscle (in men), can often be treated with a primary fistulotomy; this is often
preferred because rates of successful treatment are higher than for sphincter-preserving techniques. In cases where the risks of incontinence after sphincter transection are too high, sphincter-preserving techniques, such as endorectal advancement flaps or ligation of the intersphincteric tract, are performed. The former involves dissecting out a segment of rectal tissue at the level of the internal opening of the fistula and extending this distally to cover the internal opening, relying on the redundancy of the rectal mucosa. The latter procedure, ligation of intersphincteric fistula tract (LIFT) surgery, involves dissecting into the intersphincteric space to identify the intersphincteric component of a trans-sphincteric fistula, at which point it is ligated proximally and distally.
FIG. 60.10  Anorectal abscess and fistula. (From M. H. Floch, Anorectal abscess and fistula, in Netter's Gastroenterology, 2nd ed. Copyright © 2010 by Saunders, an imprint of Elsevier Inc., Fig. 165-1.)
An awareness of the anatomy of the anal canal is important for oncological purposes. The anus cannot be preserved with distal rectal malignancies involving the internal and external anal sphincters, or when an anastomosis to the anus would be inadvisable because of functional concerns, such as baseline incontinence. In these situations, the anus is removed *en bloc* with the rectum. A decision must be made by the surgeon as to whether or not levator ani on one or both sides of the distal rectum should also be removed. In these circumstances, the surgeon can often initiate the dissection along the external sphincter circumferentially, using the coccyx as a guide to the appropriate plane of communication with the abdominal dissection. The coccyx is also often removed *en bloc*; it serves as an excellent guide for the insertion of the levator muscles. In select situations where the anus cannot be preserved but there are no oncological concerns necessitating a complete resection of the sphincter, an intersphincteric resection can be performed. In such cases, the intersphincteric groove is palpated at the level of the anal verge and the intersphincteric plane is entered to guide the surgeon proximally to the TME dissection, which is carried out from above. This allows for preservation of the external sphincter, which aids in closure of the perineum and pelvic floor. Furthermore, it is important for the surgical team to be cognizant of the need to close the new dead space created in the pelvis by virtue of the resection of the anal canal and perineum, in addition to the levator musculature. In such situations, multilayered closures are recommended with absorbable sutures, starting at the level of the levator ani muscles of the pelvic floor, in an anterior to posterior fashion. Percutaneous abdominal drainage is often placed to divert lymphatic fluid that often pools in the pelvis away from the pelvic floor and perineal closure, so as to prevent the creation of draining sinuses. Additionally, in cases of pelvic exenteration, where other pelvic organs are removed *en bloc* with the rectum and anus, myocutaneous interpositional flaps are often necessary from the rectus, gracilis or gluteus musculature, in order so that the defect can be filled and closed.

The intersphincteric groove is a critical landmark for an internal sphincterotomy, offered to patients with a chronic anal fissure with the objective of releasing the internal anal hypertension. It is important to be aware of the circular nature of the internal sphincteric fibres to avoid iatrogenic injury to the external sphincter.

The location of the anal (haemorrhoidal) columns is of importance to the
proctologic surgeon. The classically reported locations of 4, 7 and 11 o'clock in the lithotomy position correlate with the left lateral, right anterior and right posterior positions, respectively. Various approaches are available for management of haemorrhoidal disease, depending on the degree of disease, and the involvement of tissue close to the dentate line, wherein somatic sensation exists. Grade I or II internal haemorrhoids can often be treated with lifestyle modifications or rubber band ligation. Anoscopy is necessary to visualize the anal column and to visualize the dentate line reliably to ensure it is avoided. The haemorrhoid can be banded through using suction mechanisms or by grasping the tissue and pulling it into the banding device. Additionally, the option of sclerotherapy and cryotherapy exists for treatment of high-risk patient populations. In the appropriately selected patient, such as one with symptomatic grade III or IV internal haemorrhoids, or mixed internal and external haemorrhoids, an excisional haemorrhoidectomy can be very effective. The external haemorrhoidal tissue is dissected superficial to the external and internal sphincters, which are often exposed. The haemorrhoidal column is dissected off the internal anal sphincter and left tethered to its pedicle; a suture ligature is then applied to the pedicle. The defect is either left open (Milligan–Morgan technique)\(^\text{17}\) or closed proximally to distally (Ferguson technique).\(^\text{18}\) It is important to remain aware of the amount of anodermal tissue being resected to reduce the risk of anal stenosis.

**Tips and Anatomical Hazards**

The following structures are at risk of injury during operations on the lower gastrointestinal tract:

- **Ascending colon:** duodenum, right kidney, liver, gallbladder, right ureter, terminal ileum.
- **Transverse colon:** transverse mesocolon, stomach, liver, gallbladder, spleen.
- **Descending/sigmoid colon:** spleen, left ureter, gonadal vessels, iliac vessels.
- **Rectum:** left ureter, iliac vessels, hypogastric nerves, nervi erigentes, bladder, uterus, prostate.
- **Anus:** external sphincter, perineal body.
The surgical anal canal extends from the anal verge to the top of the anal sphincter muscles, whereas the anatomical anal canal extends from the anal verge to the dentate line.

A key structure to identify in the medial to lateral approach when performing a right hemicolecotomy is the duodenum; further mobilization of the duodenum can lift the pancreatic head to reach the origin of the middle colic vein eventually.

The principle of a ‘high ligation’ in colonic and rectal surgery implies ligation of the blood supply as close as possible to its take-off from the major contributing vessel so as to ensure adequate lymph node harvest.

During TME dissection, it is important to remain on ‘the yellow side of the white’: that is, to expose the mesorectal fat envelope and leave the white fascia behind. This aids preservation of the hypogastric nerves.

There are three key tenets of a successful gastrointestinal anastomosis: firstly, there must be a tension-free union of the two intestinal segments; secondly, both segments must have a rich vascular supply; and thirdly, the mechanical integrity of the anastomosis must be ensured. In circumstances of a stapled circular anastomosis, the latter principle requires two complete anastomotic rings or ‘doughnuts’ following stapler application. During mobilization of the right mesocolon during a laparoscopic right hemicolecotomy, the ileocolic artery and vein are dissected out and clipped. Care must be taken to ensure the duodenum has been mobilized off the posterior aspect of the right mesocolon to avoid injury to both the duodenum and the pancreas during the vascular ligation.

During colorectal anastomoses, full mobilization of the left colon along with the splenic flexure is frequently required to fashion a tension-free reconstruction. Additional left-sided colonic length can be achieved by division of the IMV at its origin at the inferior border of the pancreas and by mobilization of the distal transverse mesocolon off its attachments to the inferior border of the pancreas.

During laparoscopic resections of the colon and rectum (including appendicectomies), retraction can be augmented through patient positioning. For example, steep Trendelenburg with left anterior tilt can help facilitate sigmoid and rectal mobilization with ‘auto-retraction’ of the transverse colon and small bowel to the upper abdomen.
During resections of the transverse colon, care must be taken to skeletonize the middle colic vessels without injury to the SMA or SMV. Prior to division of the middle colic artery, temporary occlusion of this vessel using a ‘bulldog’ or atraumatic instrument with an evaluation of distal ileal vascular integrity can avoid unintentional division or injury to the SMA.

During left colon, sigmoid and rectal resections, identification of the left ureter is a prerequisite prior to vascular ligation or intestinal division. The left ureter can be found laparoscopically during the medial to lateral dissection immediately behind the superior rectal artery. Alternatively, the left ureter can be found at the pelvic inlet medial to the left gonadal vessels running anterior to the iliac bifurcation.

Goodsall’s rule stipulates that cryptoglandular fistular tracts with external openings in the posterior half of the perianal skin will have an internal opening in the posterior midline (curvilinear tract), whereas external openings in the anterior half of the perianal skin will have internal openings at the perpendicular linear point from the anal canal.
References


Single Best Answers

1. Which one of the following statements about malrotation of the midgut is true?
   A. Malrotation occurs due to a failure of the midgut loop to complete the final 90° of rotation
   B. The malrotated caecum is located below the pylorus
   C. The malrotated caecum is fixed by lateral adhesions to the posterior abdominal wall, commonly known as Ladd's bands
   D. Lateral adhesion attachments of the caecum can pass over the duodenum and can cause duodenal obstruction
   E. All of the above

   **Answer:** E.

2. Which one of the following statements about the taeniae coli is true?
   A. They represent longitudinal segments of smooth muscle that contract to form the haustra
   B. There are two main segments of taeniae coli: namely, the taeniae mesocolica and taeniae omentalis
   C. They extend on to the anterior surface of the extraperitoneal rectum
   D. All of the above
   E. None of the above

   **Answer:** A. There are three taeniae coli (taenia libera, mesocolica and omentalis), located on the anterior surface of the colon. They fuse at the level of the top of the rectum, marking the junction between the rectosigmoid colon and rectum.

3. Which one of the following statements describes the delineation
of the deep postanal space?
A. It is caudal to the anococcygeal ligament and superficial to the skin
B. It is deep to the anococcygeal ligament and caudal to the levator musculature
C. It is deep to the levator musculature and superficial to the rectosacral ligament
D. None of the above

**Answer: B.** The deep postanal space is the space deep to the anococcygeal ligament and caudal to levator ani. It is an important landmark in the management of perianal abscesses and its appropriate identification is critical in the drainage of horseshoe abscesses.

4. Which one of the following statements about the hypogastric plexus of nerves is true?
A. It originates from the periprostatic plexus and nervi erigentes
B. It is an important landmark in a total mesorectal excision, which should be initiated posterior to this nerve bundle at the level of the inferior mesenteric artery pedicle
C. It is a parasympathetic nerve bundle responsible for ejaculatory function in men
D. It branches into right and left nerve bundles distal to the sacral promontory

**Answer: D.** The hypogastric nerves form as a presacral plexus of nerves representing a fusion of the aortic and lumbar splanchnic nerves. The plexus contains sympathetic nerves that are responsible for ejaculatory function in men and potentially vaginal lubrication in women. The plexus is an important landmark in a total mesorectal dissection, where the dissection is
completed anterior to the hypogastric plexus in order to preserve genitourinary function in this patient population.

5. Which one of the following statements about the watershed areas of the colon or regions of hypovascularity is true?
A. Sudek's point refers to the point where the midgut and hindgut meet with variable anastomosis of the marginal artery at the splenic flexure
B. Griffith's point is a point where the lowest sigmoid arteries meet the superior rectal artery
C. Both areas of hypovascularity usually occur due to the interruption of the marginal artery
D. None of the above is true
E. All of the above are true

Answer: B. Sudek's point is located in the distal sigmoid colon and can be an area of hypovascularity because the extent of anastomosis between the distal sigmoid arterial supply and the superior rectal artery is variable. Griffith's point is present at the splenic flexure and is the region where the midgut and hindgut vasculature anastomose. The marginal vessels of the distal aspects of the left branch of the middle colic artery and the distal aspects of the left colic artery contribute to perfusion in this area.
Clinical Case

1. A 49-year-old male presents to the clinic with a history of haemorrhoids treated with diet control; he has had bilateral inguinal hernia repairs in the past. He has no significant medical history and is not on any medications. His family history is remarkable for a maternal aunt who was diagnosed with breast cancer at age 50. He presents with 2 months of rectal bleeding and thin stool. A colonoscopy shows a low-lying sessile lesion at the anorectal junction (Fig. 60.11) and biopsy shows that this is a low-grade adenocarcinoma. Staging CT scans do not reveal any distant metastasis. MRI (Fig. 60.12) suggests that the lesion is a T2N0 with concerns about involvement of the mesorectal fascial margin at the anorectal junction where minimal mesorectal fascia exists.

**FIG. 60.11** Colonoscopy shows a low-lying sessile lesion (arrow) at the anorectal junction.
A. What management options should be considered for this patient with rectal cancer?

A long course of neoadjuvant chemoradiation would be indicated, given the concern about clearance of the mesorectal fascial margin.
Chemoradiation involves the administration of between 4500 Gy and 5040 Gy (depending on whether a boost of 540 Gy is given), over the course of 5 weeks, with concurrent capecitabine or 5-fluorouracil. Alternatively, especially when radiation may be contraindicated, the surgeon could proceed directly to an extra-levator abdominoperineal resection that would allow for the reliable preservation of the circumferential resection margin. Briefly, this involves an abdominal dissection along the mesorectal fascia to the pelvic floor, and perineally, a circumanal incision and dissection proximally along the external sphincter to the levator muscles. Resection of the coccyx often allows for a more direct communication with the abdominal dissection. Anteriorly, care must be taken not to injury the membranous urethra in men or the vagina in women. The dissection is considered circumferentially as the levators are dissected off their attachments to the pelvic side wall, thereby allowing for a conical dissection of the mesorectum distally and ensuring a negative circumferential resection margin.

B. The patient is restaged with a repeat endoscopy and MRI. He has a very good response to chemoradiation and subsequently is brought into the operating theatre for an abdominoperineal resection. What are the anatomical surgical considerations to bear in mind?

As this is a rectal tumour that abuts the dentate line, the perineum and anus must be resected en bloc with the tumour. This can be carried out via an open or laparoscopic approach from the abdominal aspect. A total mesorectal excision must be performed, taking care to resect the mesorectal package as per Heald's principles. High ligation with transection of the superior rectal (haemorrhoidal) artery at its take-off from the inferior mesenteric artery should be considered to ensure adequate nodal harvest.
Liver

Amar Gupta, Elijah Dixon

**Core Procedures**

**Liver Biopsy**

- Percutaneous liver biopsy
- Transjugular liver biopsy

**Hepatic Resection**

- Left lateral sectionectomy
- Left hepatectomy
- Extended left hepatectomy
- Right posterior sectionectomy
- Right anterior sectionectomy
- Right hepatectomy
- Extended right hepatectomy
- Central (mesoaxial) hepatectomy
- Segmental hepatic resection

**Liver Transplantation**
Embryology

The development of the liver primordium can be seen from stage 11 (29–30 days post fertilization) as an outgrowth of the ventral foregut endoderm.\(^1\) Multiple molecular signals have been implicated in early liver development, including fibroblast growth factor and the forkhead box family of proteins.\(^2\) As liver development continues, pluripotent hepatoblasts differentiate into hepatocytes and cholangiocytes arranged in hepatic cords. The septum transversum mesenchyme forms a hepatic endothelial plexus by stage 12 (30–32 days post fertilization). This receives blood from the vitelline veins, from stage 13 (31–33 days post fertilization), and later also from the cranial portions of both umbilical veins. The remaining septum transversum mesenchyme forms the diaphragm inferiorly and the connections of the liver to the body wall anteriorly. As the liver grows, the peritoneal cavity surrounding the liver expands; its walls form the lesser omentum, the visceral peritoneum covering the liver and the falciform ligament anteriorly.\(^1\) Contact between the developing liver capsule and adjacent mesenchyme is maintained in a portion of future diaphragm, constituting the eventual bare area of the liver. The liver is the main centre for haemopoiesis in the fetus. The fetal hepatic circulation is initially composed of right and left vitelline veins and the left umbilical vein. These transport blood to the hepatic sinusoids and the right horn of the sinus venosus, which becomes incorporated into the right atrium of the developing heart. By the second month of fetal development, a larger channel, the ductus venosus, allows blood to bypass the hepatic sinusoids and deliver oxygenated blood from the umbilical vein directly to the right atrium.\(^1\) Eventually, the vitelline veins coalesce to form the superior mesenteric vein, splenic vein and portal vein. After birth, the umbilical vein closes and forms the ligamentum teres hepatis, while the ductus venosus forms the ligamentum venosum.
Surgical surface anatomy

The liver is a solid organ, lying under the right ribcage with a variable amount of extension across the midline to the left. The majority of the liver is covered by the fibrous capsule of Glisson, as well as the overlying visceral peritoneum, apart from a small surface of liver to the right of the inferior vena cava (IVC) that is in direct contact with the diaphragm and constitutes the bare area of the liver (Fig. 61.1A). Areas of peritoneal reflection are termed ‘ligaments’ and act as suspensory anchors for the liver to the abdominal wall and diaphragm. The peritoneal reflection from the right diaphragm and Gerota’s fascia to the posterior surface of the liver forms the posterior leaflet of the right triangular ligament. These attachments must be taken down early during mobilization of the right liver to avoid parenchymal injuries due to traction. Laterally, the peritoneum reflects to the left and the right liver, forming the left and the right anterior triangular ligaments, respectively. The anterior extensions of the triangular ligaments to the diaphragm constitute the left and right coronary ligaments (Fig. 61.1B). The left and right anterior coronary ligaments fuse on the anterior surface of the liver to form the falciform ligament, which suspends the liver to the anterior diaphragm. The ligamentum teres hepatis, the obliterated remnant of the fetal umbilical vein, runs from the umbilicus to the inferior margin of the liver at the falciform ligament, where it enters the umbilical fissure (Fig. 61.1C). Although historic anatomical descriptions of the liver divided the liver into left and right lobes along the umbilical fissure, this depiction has long since been abandoned in favour of the functional anatomy, as reviewed later in this chapter. Along the posterior surface of the liver, the fibrous remnant of the obliterated ductus venosum, the ligamentum venosum, runs from the left portal vein to the left hepatic vein (Fig. 61.1D). Division of the ligamentum venosum allows for better visualization of the posterior aspect of the left hepatic vein and is usually required for safe dissection. Posteriorly, the liver sits on top of the IVC and right adrenal (suprarenal) gland, with the right, middle and left hepatic veins draining directly into the suprahepatic IVC. Careless dissection of the bare area of the liver during right lobe mobilization can result in injury to the right adrenal gland, especially when it is intrahepatic in nature. The gallbladder is located in the cystic fossa to the right of the liver hilum, and is separated from the liver parenchyma by the cystic plate. When cholecystectomy is performed, the avascular plane between the gallbladder and cystic plate must be entered and maintained.
Straying off the gallbladder into the cystic plate, especially near the gallbladder infundibulum, can result in catastrophic injuries to the hilar structures of the liver. The caudate lobe is a dorsal segment of liver to the left of the IVC, and is separated from the overlying left lateral segment by the gastrohepatic ligament (lesser omentum) and the ligamentum venosum. As the caudate lobe extends to the right, it separates the left portal vein and IVC as the caudate process, and eventually fuses to the right liver. In the majority of patients, the most posterior aspect of the caudate gives off a fibrous band that encircles the IVC and joins with a corresponding fibrous band from the right posterior liver, referred to as the hepatocaval ligament (Fig. 61.2). The hepatocaval ligament is often thin and avascular; however, in a minority of patients it may contain some hepatic parenchyma. Uncommonly, the caudate lobe may wrap completely around the IVC and fuse to the right lobe posteriorly. The hilum of the liver receives the porta hepatis, which contains the main portal vein, hepatic artery proper and common hepatic duct. The anatomical details of the liver hilum will be reviewed later in this chapter. The sulcus of Rouvière is an important landmark to the right of the hilum and is present in 70–80% of livers. This 2–3 cm cleft contains the right posterior pedicle, and its identification is vital for safe laparoscopic cholecystectomy and liver surgery. Access and ligation of the posterior portal pedicle through the sulcus of Rouvière facilitates inflow control to segments 6 and 7 during right posterior sectionectomy. The foramen of Winslow is an anatomical window posterolateral to the porta hepatis and allows access to the lesser sac, as well as control of the contents of the porta hepatis. Manual compression or clamping of the porta hepatis (the Pringle manœuvre) is possible through the foramen of Winslow, halting all inflow to the liver (except in the case of an aberrant left hepatic artery), allowing for reduced blood loss during liver trauma surgery and hepatectomy.
FIG. 61.2
Anatomy of the caudate lobe of the liver.
Clinical anatomy

The intrahepatic architecture of the liver has been described in many different publications over the last century. The most widely used depiction of functional liver anatomy was described by Claude Couinaud, and is now summarized using the Brisbane 2000 terminology of liver anatomy and resections. This functional liver anatomy is based on the three hepatic veins that travel in three portal scissurae (Fig. 61.3). The middle hepatic vein scissura divides the liver into right and left hemilivers along a line connecting the suprahepentic IVC and cystic fossa, known as Cantlie's line. The right and left hepatic vein scissurae divide the liver into four separate portal sections. These sections are further divided into eight portal segments based on their supply by independent portal pedicles, each containing a portal vein, hepatic artery and bile duct. The right liver is divided by the right scissura into anterior (segments 5 and 8) and posterior (segments 6 and 7) sections, while the left liver is divided by the left scissura into medial (segment 4) and lateral (segments 2 and 3) sections. Of note, the umbilical fissure contains the umbilical portion of the left portal pedicle and is therefore not a portal scissura. Instead, the left portal scissura, containing the left hepatic vein, runs posterior to the ligamentum venosum. Segment 1 consists of the caudate lobe, which receives its portal venous and arterial blood supply from small branches of the left and right portal pedicle. The biliary drainage of the caudate is usually through small ducts that drain to both the left and the right hepatic ducts, or to the biliary confluence itself. Venous drainage of the caudate lobe is unique in that it is the only segment that has direct drainage into the IVC through the short hepatic veins.
FIG. 61.3  Portal venous anatomy and segmental anatomy of the liver. (Right lateral = right posterior; right medial = right anterior.) (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 67.4.)
Microscopic anatomy

The functional liver unit has been described in a variety of ways and, to date, no clear model has been shown to be ideal in describing the liver's complex structure and function. Each model includes portal tracts, containing a terminal portal vein and hepatic artery, as well as terminal hepatic veins. The space separating these terminal structures is filled with hepatocytes, the hepatic sinusoids and intrahepatic bile ducts.

The hepatocyte represents the primary cell type present in the liver parenchyma, making up approximately 80% of the liver by volume. Hepatocytes are polygonal, polarized cells, with clear apical and basal poles, arranged in 1–2 cell-thick plates that are separated by sinusoids along the villous apical poles. Approximately 24 hepatocytes separate each portal tract from a terminal hepatic vein. Sinusoids are lined by specialized sinusoidal endothelial cells with fenestrated membranes; they lack a basement membrane, a feature that facilitates transport of material between hepatocyte and sinusoid. The space between the hepatocyte and the sinusoidal endothelial cell is the space of Disse. It contains a rich extracellular matrix and hepatic stellate cells (Ito cells) that play an important role in inflammation and fibrosis. Specialized macrophages, Kupffer cells, located in the sinusoids act as phagocytes and antigen-presenting cells. The basal pole of each hepatocyte secretes bile into a network of bile canaliculi that drain into canals of Hering, lined by both hepatocytes and cholangiocytes. These canals traverse the portal tract as bile ductules, eventually forming the cholangiocyte-lined terminal bile duct in the portal tract.\(^\text{11}\)

The hexagonal liver lobule was originally suggested to be the functional unit of the liver by the English anatomist Francis Kiernan in 1833.\(^\text{12}\) This lobular model has a central vein (terminal hepatic vein), surrounded by cords of hepatocytes and sinusoids, as described above. Each lobule has six portal tracts, arranged at the apices of a hexagon, which supply oxygen and nutrient blood and drain bile from the unit.

Aron Rappaport introduced the liver acinus as the functional unit of the liver\(^\text{13}\); this model was later modified by Matsumoto et al.\(^\text{14}\) The centre of the acinar unit is a portal tract, with terminal hepatic veins located at the periphery of the unit. The parenchyma is divided into three zones, based on their proximity to the portal tract. Zone 1 (periportal) is immediately adjacent to the portal vessels and thus receives the highest concentration of oxygen and portal nutrients. Zone 3 (centrilobular) is adjacent to the hepatic vein
and thus receives the lowest oxygen concentration and the least concentration of portal nutrients. Zone 2 is the area between zone 1 and zone 3 (Fig. 61.4). This model may explain the centrilobular necrosis seen in ischaemic hepatitis because zone 3 has the lowest available oxygen concentration and is therefore most susceptible to ischaemia.¹⁵

**Arterial anatomy**

Hepatic arterial anatomy is highly variable, and may originate from the coeliac trunk or the superior mesenteric artery (SMA), or a combination of both. Classic hepatic arterial anatomy involves a common hepatic artery arising from the coeliac trunk, usually distal to the origins of the left gastric artery and splenic artery. The common hepatic artery courses anterolaterally and runs along the superior border of the pancreas. Quite often, a lymph node lies directly anterior to the common hepatic artery as it travels laterally to the right. Cephalad to the neck of the pancreas, the gastroduodenal artery (GDA) takes off in a caudal direction, at which point the hepatic artery proper turns cephalad and enters the porta hepatis medial to the common bile duct and anterior to the portal vein. The right gastric artery is a small branch from the hepatic artery proper and travels caudad in a plane anterior to the GDA. Division of the right gastric artery allows for excellent exposure of the porta hepatis and is often required for adequate access to the GDA. The hepatic artery proper bifurcates into a left and a right hepatic artery at
the hepatic hilum. The right hepatic artery travels transversely, posterior to the common hepatic duct in 90–95% of patients, and eventually courses through the triangle of Calot, at which point the small cystic artery branches off and travels towards the gallbladder. As the right hepatic artery enters the hilar plate, it often bifurcates into anterior and posterior branches, with the latter entering the sulcus of Rouvière as it joins the right posterior portal pedicle. The bifurcation into anterior and posterior right hepatic arteries is often exposed by division of the cystic artery and cystic duct; during right hepatectomy, division of the right anterior and posterior hepatic arteries will expose the right portal vein branch. The left hepatic artery continues cephalad towards the umbilical fissure, where it enters the umbilical plate; it often gives off a middle hepatic artery that courses cephalad to the right side of the umbilical fissure to supply segment 4 (Fig. 61.5).

![Classical hepatic artery anatomy](https://www.elsevier.com/books-and-journals/gray-s-anatomy/standring/1119263889/f0679)

Although the classical anatomy described above is present in the majority of people, variant hepatic arterial anatomy is quite common, and may be found in 24–45% of cases. A thorough knowledge of the locations of
possible aberrant vessels, as well as precise surgical technique, is required to avoid injury to these arteries. Accessory hepatic arteries provide arterial supply to segments of the liver in addition to the arterial supply from the classical configuration described above. Replaced hepatic arteries represent the sole arterial supply to segments of the liver, with no additional supply from usual anatomy.

There are multiple classification systems that describe hepatic arterial anatomy, ranging from simple to extremely complex. Hiatt et al described the hepatic arterial anatomy in 1000 donor livers for transplantation and identified six types, as summarized in Table 61.1. Normal anatomy (type 1) was observed in 55–76% of cases. A replaced or accessory left hepatic artery (type 2), present in 10–20% of cases, usually arose from the left gastric artery and coursed through the gastrohepatic ligament to reach the liver hilum. A replaced or accessory right hepatic artery (type 3), present in 10–15% of cases, arose from the proximal SMA and travelled posterior to the portal vein before taking a cranial course in the porta hepatis, lying posterior to the common bile duct and lateral to the portal vein. In 2% of cases, both aberrant left and right hepatic arteries were present (type 4). A completely replaced common hepatic artery (type 5) was observed in 1.5–4% of cases, arising from the SMA to follow a course similar to an aberrant right hepatic artery (Fig. 61.6). The remaining arterial aberrations (type 6) were extremely uncommon, found in only 0.2–0.5% of cases, and included a common hepatic artery arising directly from the aorta, or from the left gastric artery.

### TABLE 61.1

<table>
<thead>
<tr>
<th>Type</th>
<th>Arterial anatomy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Classic anatomy</td>
<td>55–76%</td>
</tr>
<tr>
<td>2</td>
<td>Aberrant left hepatic artery</td>
<td>10–20%</td>
</tr>
<tr>
<td>3</td>
<td>Aberrant right hepatic artery</td>
<td>10–15%</td>
</tr>
<tr>
<td>4</td>
<td>Both aberrant left and right hepatic arteries</td>
<td>2%</td>
</tr>
<tr>
<td>5</td>
<td>Replaced common hepatic artery</td>
<td>1.5–4%</td>
</tr>
<tr>
<td>6</td>
<td>Common hepatic artery from aorta or other</td>
<td>0.2–0.5%</td>
</tr>
</tbody>
</table>
Portal venous anatomy

The confluence of the superior mesenteric vein and splenic vein posterior to the neck of the pancreas forms the main portal vein (PV). The main PV is a high-flow, low-pressure vein that travels cephalad in the porta hepatis, where it lies posterior to the hepatic artery and bile duct. During pancreaticoduodenectomy, division of the GDA allows for excellent exposure of the suprapancreatic PV. The main PV bifurcates to deliver left and right branches in the hilum of the liver. The left portal vein assumes a 3–4 cm extrahepatic transverse course before entering the umbilical fissure, where it pursues an anterior and caudal path. Branches to segments 2, 3, and 4 arise from this umbilical portion of the left portal vein, as does the ligamentum teres hepatis. As a result, the ligamentum teres hepatis allows excellent access to the umbilical portion of the left portal pedicle – crucial to performing open and laparoscopic left lateral sectionectomies, as well as biliary bypass procedures. The right portal vein has a short, 1–2 cm extrahepatic course and typically branches into anterior and posterior right branches, each assuming their respective positions within the portal sheath. Several variations in portal venous anatomy exist, including a single trifurcation of the main PV into right anterior, right posterior and left branches; and a right anterior or posterior PV that originates from the left PV. Portal venous supply to the caudate lobe is variable but usually consists of multiple branches from both the left and right main portal veins (see Fig. 61.3).

Several portal venous tributaries are relevant to liver anatomy. The left gastric (coronary) vein, which enters the main portal vein, travels medially
with a cranial trajectory, and serves as an excellent landmark for the underlying take-off of the splenic artery. The epicholedochal veins of Saint form a fine network of venous drainage on the surface of the bile duct that drains into the paracholedochal veins of Petren. These marginal veins travel parallel to the bile duct, usually in the 3 and 9 o'clock positions, and form a plexus with the gastric and pancreaticoduodenal veins. The veins of Sappey make up small tributaries of the peripheral left portal vein, and serve to drain the diaphragm and falciform ligament. All of these tributaries have significant physiological relevance, as they serve as possible portosystemic shunts in the face of portal hypertension.

**Hepatic venous anatomy**

Hepatic venous outflow consists of the right, middle and left hepatic veins. As already described, these hepatic veins travel in scissurae and divide the liver into separate sections as they course cephalad towards the suprahepatic IVC. The right hepatic vein has a short extrahepatic course, often veiled by the hepatocaval ligament, and enters directly into the IVC. Division of the hepatocaval ligament is necessary to visualize the caudal and right lateral aspects of the right hepatic vein adequately, allowing for safe dissection. Anatomical studies have shown that the hepatocaval ligament is in close association with a caudate vein in 69% of cases, and thus should be ligated before dividing to ensure haemostasis. The middle and left hepatic veins often form a common trunk within the liver parenchyma, and this then enters the IVC to the left of the right hepatic vein. A variable number of short hepatic veins drain the caudate lobe directly into the retrohepatic IVC. These short, thin-walled veins must often be carefully ligated and divided during hemihepatectomy and piggyback liver transplantation procedures. Although the hepatic venous drainage of the liver is not as variable as its arterial supply, variations are seen, often as an inferior right accessory vein, or moderately sized veins that drain segments 6 and 7 directly into the IVC.

Unlike intrahepatic portal veins, which are enveloped in a thick fibrous sheath together with a corresponding artery and bile duct, the hepatic veins are thin-walled vessels that lack a covering. This difference is readily visible on ultrasound, allowing for clear differentiation of the hepatic veins from portal veins. Knowledge of the intrahepatic course and drainage patterns of the hepatic veins allows for preoperative planning and intraoperative identification and ligation of large branches, which is crucial for safe liver
surgery. This knowledge of hepatic vein anatomy is even more important during live donor liver procurement because large hepatic vein branches may need to be preserved and reimplemented in the recipient to allow for adequate outflow.

**Lymphatic drainage**

Hepatic lymphatic drainage occurs through a combination of portal, sublobar and superficial lymphatic vessels. Approximately 80% of hepatic lymph travels through portal lymphatic vessels, which course along the hepatic veins or portal sheaths and drain into the lateral phrenic nodes or porta hepatis nodes, respectively. Sublobar lymphatic vessels travel along the vena cava, while superficial lymphatics form a subcapsular plexus. The superficial lymphatics from the anterior surface of the liver drain to phrenic and pancreaticocolienal nodes, while the posterior surface drains primarily to porta hepatis nodes.

**Innervation**

The successful transplantation of a deinnervated liver allograft suggests that innervation is not vital for basic hepatic function. Nevertheless, more recent studies have demonstrated that in such livers important modifications in glucose and lipid metabolism, as well as liver regeneration, may be observed. The liver is innervated by both sympathetic and parasympathetic nerves derived from the coeliac plexus and thoracic splanchnic nerves, and the hepatic division of the anterior vagus nerve, respectively.

**Plate anatomy**

The plate system of the liver consists of a thick fibrous sheath that envelops small blood vessels and bile ducts at the hilum. Four plates are included in the system: the hilar plate at the central hilum; the cystic plate at the gallbladder fossa; the umbilical plate at the umbilical fissure; and the Arantius plate at the ligamentum venosum. Vasculobiliary elements must pass through the hilar and umbilical plates in order to enter the liver parenchyma; on doing so, they gain a fibrous sheath as they course along their respective paths, developing a Glissonian sheath that surrounds each intrahepatic portal pedicle. At the level of the hilar plate, the biliary elements
are essentially inseparable from the plate itself, which means that a safe
dissection plane around the hilar bile ducts can be developed by carefully
dissecting the plate from the liver parenchyma. This technique is invaluable
during operations requiring manipulation of the hilar structures, such as
those performed for treatment of hilar cholangiocarcinoma.

**Tips and Anatomical Hazards**

Thorough knowledge of classical anatomy, as well as possible
anatomical variations, is crucial for safe liver surgery.
Use of high-quality preoperative CT and MRI scans, as well as
intraoperative ultrasound and cholangiography, allows for accurate
identification of anatomical structures and surgical planning.
Advanced parenchymal transection techniques, coupled with a firm
understanding of intrahepatic anatomy, allow for more parenchymal-
sparing resections.
Identification and division of ligamentous and fibrous attachments,
such as the ligamentum venosum and hepatocaval ligament, allow for
direct visualization of anatomical structures and safer dissection.
The Pringle manœuvre should be used intermittently in cases of
uncontrolled bleeding to reduce inflow during liver trauma and
hepatectomy.
A detailed understanding of the hilar and plate anatomy is required for
safe surgical dissection in these areas during liver and biliary surgery.
References

13. Rappaport AM, Borowy ZJ, Lougheed WM, Lotto WN. Subdivision of hexagonal liver lobules into a structural and


Single Best Answers

1. With which one of the following structures does the fetal umbilical vein correlate in the adult?
   A. Superior mesenteric vein
   B. Ligamentum teres hepatis
   C. Portal vein
   D. Ligamentum venosum

   **Answer: B.** The obliterated fetal umbilical vein forms the ligamentum teres hepatis in the adult. The superior mesenteric vein and portal vein are the remnants of the vitelline veins, while the ligamentum venosum is the obliterated ductus venosus.

2. Which one of the following structures separates the caudate lobe from the left liver?
   A. Hepatocaval ligament
   B. Falciform ligament
   C. Triangular ligament
   D. Gastrohepatic ligament

   **Answer: D.** The caudate lobe is separated from the left liver by the gastrohepatic ligament. The hepatocaval ligament is a fibrous band encircling the right retrohepatic inferior vena cava. The falciform ligament is formed by two separate areas of peritoneal reflection that have fused to suspend the liver from the anterior abdominal wall. The triangular ligaments are peritoneal reflections from the liver to the diaphragm and abdominal wall.

3. Using the Brisbane 2000 terminology, which one of the following structures divides the liver into left and right halves?
   A. Falciform ligament
B. Middle hepatic vein scissura  
C. Ligamentum teres hepatis  
D. Porta hepatis

**Answer: B.** The middle hepatic vein scissura runs along a line approximated by the suprahepatic inferior vena cava and the gallbladder fossa, making up Cantlie's line and dividing the liver into a left and a right half. The falciform ligament, ligamentum teres hepatis and porta hepatis have no role in defining the segmental anatomy of the liver.

4. In classical hepatic anatomy, the right hepatic artery is a branch of which one of the following vessels?  
A. Common hepatic artery  
B. Gastroduodenal artery  
C. Hepatic artery proper  
D. Coeliac artery

**Answer: C.** Classic hepatic arterial anatomy consists of a common hepatic artery arising from the coeliac trunk. The gastroduodenal artery takes off in a caudal direction from the common hepatic artery; the hepatic artery proper then bifurcates into a left and a right hepatic artery at the hepatic hilum.

5. Which one of the following liver segments drains directly into the inferior vena cava through the short hepatic veins?  
A. Segment 1  
B. Segment 3  
C. Segment 6  
D. Segment 8

**Answer: A.** The caudate lobe (segment 1) drains directly into the
inferior vena cava via the short hepatic veins. Segment 3 is drained by a branch of the left hepatic vein; segment 6 is drained by a branch of the right hepatic vein; and segment 8 is often drained by branches of both the right and middle hepatic veins.
Clinical Case

1. A 56-year-old male with known alcoholic cirrhosis presents with a 3 cm × 3 cm × 2 cm mass in segments 6 and 7 of the liver. Imaging confirms a diagnosis of hepatocellular carcinoma. He has been abstinent for 5 years and has no other medical comorbidities.

A. Describe the typical surface and segmental anatomy of segments 6 and 7 of the liver.

Segments 6 and 7 make up the right posterior section of the liver. There are no obvious surface landmarks to demarcate the right posterior section, which makes up all of the liver parenchyma posteromedial to the right scissura.

The segmental anatomy is defined by the hepatic vein scissurae and portal sheath distribution. The right posterior section lies posteromedial to the right scissura and is supplied by the right posterior portal vein.

B. Describe the surface landmark used to identify the portal sheath to segments 6 and 7.

The sulcus of Rouvière is a cleft in the liver parenchyma, present in 70–80% of livers, to the right side of the porta hepatis. It contains the right posterior portal pedicle and can be isolated to gain control of the contents of the portal sheath.

C. What vascular aberrations should be identified prior to treating this patient?

Segments 6 and 7 receive their arterial blood supply from the right posterior hepatic artery, which is a branch of the right hepatic artery. Classically, this is a branch of the hepatic artery proper; however, in 10–15% of patients, an aberrant right hepatic artery arises from the superior mesenteric artery.

The portal venous supply to segments 6 and 7 is from the posterior branch of the right portal vein. Although this is usually a branch from the right portal vein, several variations in portal venous anatomy exist, including a single trifurcation of the main portal vein into a right anterior, a right posterior and a left branch, or as a right anterior or posterior portal vein originating from the left portal vein. These possible variations demand high-quality portal venous imaging prior to resection.

The majority of hepatic venous drainage of segments 6 and 7 occurs via the
right hepatic vein; however, there are often large aberrant hepatic veins draining areas or entire segments of the right posterior section directly into the inferior vena cava. Knowledge of these aberrant veins is paramount prior to embarking on mobilization and surgical resection of segments 6 and 7.
Liver biopsy, resections and a brief overview of transplantation

Pilar Leal-Leyte, Daniel Zamora-Valdes, Peter TW Kim

Core procedures

- Right hepatectomy for malignancy
- Left hepatectomy for malignancy
- Extended right hepatectomy for malignancy
- Extended left hepatectomy for malignancy
- Live donor right hepatectomy
- Live donor left hepatectomy
- Caudate lobe resection
Clinical anatomy

Liver resection (LR) is divided into anatomical and non-anatomical resections. Non-anatomical LR refers to the partial resection of parenchyma in one or more liver segments, while anatomical LR refers to the complete resection of one or more liver segments (Table 62.1).

**TABLE 62.1**

Commonly performed liver resections, corresponding segments and divided structures

<table>
<thead>
<tr>
<th>Liver resection/divided structure</th>
<th>Segments</th>
<th>Hepatic artery</th>
<th>Portal vein</th>
<th>Hepatic vein</th>
<th>Bile duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right hemihepatectomy</td>
<td>5, 6, 7 and 8</td>
<td>Right hepatic artery</td>
<td>Right portal vein</td>
<td>Right hepatic vein</td>
<td>Right hepatic duct</td>
</tr>
<tr>
<td>Left hemihepatectomy</td>
<td>2, 3 and 4</td>
<td>Left and middle (A4) hepatic arteries</td>
<td>Left portal vein</td>
<td>Left hepatic vein</td>
<td>Left hepatic duct</td>
</tr>
<tr>
<td>Left lateral sectionectomy</td>
<td>2 and 3</td>
<td>Left hepatic artery</td>
<td>Left portal vein branches to segments 2 and 3 (P2 and P3)</td>
<td>Left hepatic vein</td>
<td>Bile duct tributaries from segments 2 and 3 (B2 and B3)</td>
</tr>
<tr>
<td>Right posterior sectionectomy</td>
<td>6 and 7</td>
<td>Right posterior hepatic artery</td>
<td>Right posterior portal vein</td>
<td>Right hepatic vein</td>
<td>Right posterior hepatic duct</td>
</tr>
<tr>
<td>Extended right hemihepatectomy</td>
<td>4, 5, 6, 7 and 8</td>
<td>Right and middle (A4) hepatic arteries</td>
<td>Right portal vein and left portal vein branches to segment 4 (P4)</td>
<td>Right and middle hepatic veins</td>
<td>Right hepatic duct and bile duct tributaries from segment 4 (B4)</td>
</tr>
<tr>
<td>Extended left hemihepatectomy</td>
<td>2, 3, 4, 5 and 8</td>
<td>Left, middle (A4) and right anterior hepatic arteries</td>
<td>Left and right anterior portal veins</td>
<td>Left and middle hepatic veins</td>
<td>Left and right anterior hepatic ducts</td>
</tr>
<tr>
<td>Caudate lobe resection</td>
<td>1 and 9</td>
<td>Caudate branch from left, proper or right hepatic artery</td>
<td>Caudate branches from left and right portal veins</td>
<td>Short hepatic veins to the inferior vena cava and caudate tributaries to the middle hepatic vein</td>
<td>Bile duct tributaries from caudate lobe (B1 and B9)</td>
</tr>
</tbody>
</table>

The first step in LR is mobilization of the liver by division of its peritoneal attachments. Division of the falciform ligament towards the diaphragm leads to the suprahepatic inferior vena cava (IVC) and the three hepatic veins. The left hemiliver is mobilized by dividing the left triangular peritoneal attachment. The pars flaccida of the gastrohepatic ligament is divided and
the pars densa, which contains the hepatic branch of the vagus nerve, is examined for aberrant left arteries or veins. Division of these structures allows the exposure of sulcus of Arantius and the ligamentum venosum; division of the ligamentum venosum allows for extraparenchymal control of the left hepatic vein (LHV) and/or middle hepatic vein (MHV) (Fig. 62.1). The space between the round ligament and the liver parenchyma between segments 3 and 4 is known as the space (recess) of Rex. Division of the parenchyma covering the space of Rex caudally can expose the pars umbilicalis of the left portal vein (LPV) and its branches (Fig. 62.2).

**FIG. 62.1** The sulcus of Arantius, as observed after mobilizing the left hemiliver and dividing the ligamentum venosum. Note the groove between the inferior vena cava (IVC) and the left hepatic vein (LHV). This space can be further dissected to obtain extraparenchymal control of the LHV during left lateral liver section or left hemihepatectomy. Other abbreviations: LPV, left portal vein; MHV, middle hepatic vein; PV, portal vein; RPV, right portal vein. (From L.H. Blumgart, L.H. Schwartz, R.P. DeMatteo, Surgical and radiologic anatomy of the liver, biliary tract, and pancreas. In: Blumgart's Surgery of the Liver, Biliary Tract and Pancreas, sixth ed. Copyright © 2017 by Elsevier, Inc. All rights reserved. Fig. 2.12.)
FIG. 62.2  A, The approach to ‘anatomical’ extended right hemihepatectomy. On entering the space of Rex, the right-sided (segment 4) branches of the pars umbilicalis of the left portal vein are dissected independently, ligated and divided. B, The point of division of the portal and biliary structures during standard resection (ES) and resection for hilar tumours, particularly perihilar cholangiocarcinoma (EC). The parenchymal transection plane is 1 cm to the right of the round and falciform ligaments. During standard resection, the segment 4 bile ducts (B4) are divided...
The right hemiliver is mobilized by dividing the right triangular ligament and the right part of the coronal peritoneal attachments. Division of the retrocaval (Makuuchi's) ligament allows identification of the right hepatic vein (RHV) and the groove between the RHV and MHV. The caudate lobe is mobilized by dividing the retrocaval ligament and the parietal peritoneum covering the adventitia of the IVC, after mobilizing both the left and right hemilivers. Full mobilization of the caudate lobe requires ligation and division of its caval outflow. The hepatic pedicles, which contain the branches of the hepatic artery, portal vein and bile ducts, can be accessed by first separating the confluence of the hepatic ducts from the base of segment 4b, a manoeuvre known as lowering the hilar plate (Fig. 62.3A). This space, directly above the hepatic duct confluence, can be traced to the other side of the incisura transversa (sulcus of Haller) and used to encircle the left and right pedicles. The pedicles can be divided en bloc without dissecting out the individual structures (extra-Glissonian approach). The division of the cystic extension of the hilar plate allows identification of the right anterior pedicle, which can be approached in a similar fashion. The right posterior pedicle can be identified in Rouvière's sulcus.¹
The rationale for these manoeuvres is the concept that the liver capsule surrounds the liver parenchyma independent of the parietal peritoneum and the adventitia of the IVC, even in the bare area of the liver, and the portal pedicles and the hepatic veins. The plate/sheath system is independent from the liver capsule. It is a thick layer of fibrous connective tissue that has been described as a shirt with the front cut away, leaving the back and the sleeves (Fig. 62.3B). It can be divided in the plate (back of the shirt) and the Glissonian sheath around the sectorial and segmental portal pedicles (sleeves). It can be further divided into four: the cystic plate in the gallbladder fossa, the hilar plate around the incisura transversa, the Arantian plate around the ligamentum venosum, and the umbilical plate around the pars umbilicalis of the LPV.
Liver resection

Liver resections include oncological resections for liver tumours, live donor hepatectomy, and resection of tumours that involve the hilum of the liver (such as hilar cholangiocarcinoma) (Table 62.2).

**TABLE 62.2**
Different types of liver resection

<table>
<thead>
<tr>
<th>Type of liver resection (LR)</th>
<th>Goal</th>
<th>Anatomical criteria</th>
<th>Liver volume criteria*</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR for liver tumours</td>
<td>Resect the involved part of the liver with negative margins</td>
<td>After resection, the patient should be left with at least two adjacent segments with an intact vascular inflow, outflow and biliary drainage</td>
<td>≥20–40% depending on the degree of underlying liver disease</td>
</tr>
<tr>
<td>LR for hilar tumours and cholangiocarcinoma</td>
<td>Resect the involved part of the bile duct and the liver with negative margins</td>
<td>After resection, there should be a margin of at least 10–20 mm between the bile duct tumour and the bile duct division point. The patient should be left with at least two adjacent segments with an intact vascular inflow, outflow and biliary drainage</td>
<td>≥25% after biliary decompression</td>
</tr>
<tr>
<td>LR for living donation</td>
<td>Resect the intended part of the liver while leaving enough functioning liver for the donor and providing a large enough graft for the intended recipient</td>
<td>After resection, the donor should be left with at least four adjacent segments with an intact vascular inflow, outflow and biliary drainage</td>
<td>≥30%</td>
</tr>
</tbody>
</table>

*Percentage of functional liver volume required to remain in the patient.

**Oncological resection for liver tumours**

The goal is to resect the involved part of the liver with negative margins (R0 resection) while preserving enough functioning liver parenchyma with an intact vascular inflow and outflow and biliary drainage. Adequate liver parenchyma is defined as a minimum of two adjacent liver segments with intact vascular inflow and outflow, biliary drainage and a future liver remnant volume of 20–40%, depending on the condition of the liver parenchyma. The affected parenchyma is resected; the dissection of hilar structures depends on the surgeon's preference and the extent to which it has been invaded by the tumour. The hilar structures can be dissected and ligated independently (intra-Glissonian) or they can be addressed without dissecting them out (extra-Glissonian approach).
Liver resection for live donor hepatectomy

The safety of the donor is the most important part of a living donor hepatectomy operation. The goal of this procedure is to ensure that enough functioning liver parenchyma is left in the donor while providing the intended recipient with unharmed vasculature and bile duct in the graft. The minimum amount of future liver remnant required in the donor is 30–35% to ensure safe donation. Every effort is made to preserve a proper haemostatic parenchymal transection plane, free of bile leaks, taking care to preserve the vascular and biliary structures that remain in the donor. The main technical differences between live donor hepatectomy and oncological hepatic resection are: firstly, parenchymal transection is performed without dividing the inflow and outflow, while accurately identifying and preserving intrahepatic tributaries of the hepatic vein (for example, segment 5/8 veins); secondly, the dissection of the bile duct is performed close to the bile duct confluence in order to preserve the blood supply of the bile duct of the intended graft and also preserve the integrity of the donor's common hepatic duct; and thirdly, division of the vascular structures is performed at the end of the operation just prior to excision of the graft.

Hilar tumours

Liver resection for tumours that involve the hepatic hilum (e.g. hilar cholangiocarcinoma) is more complex. Extensive dissection of the vascular structures in the porta hepatis is necessary to ensure resectability prior to division of the hepatic parenchyma. The need to resect the hepatic duct in the future liver remnant far enough into the future liver remnant to ensure a negative bile duct margin means a more extensive dissection of the branches and the hepatic arteries. The likelihood of major vascular involvement of the future liver remnant and vascular reconstruction needs to be planned.
Brisbane nomenclature

Multiple terms have been used to describe liver resections: trisegmentectomy and trisectionectomy, lobectomy and hepatectomy have been used interchangeably while the concepts segment, subsegment, sector, section, area and subarea became confusing after the integration of French, German and English literature. Since clear terminology and classification are necessary for accurate communication, the Brisbane nomenclature of Hepatic Anatomy and Resections was established in Brisbane in 2000 at a consensus meeting sponsored by the International Hepato-Pancreato-Biliary Association. This nomenclature has been adopted worldwide. The Brisbane nomenclature is anatomically correct, consistent, self-explanatory, precise, concise and translatable, and ensures agreement on anatomical and surgical terms. The term section is preferred to sector and the term hemiliver is used instead of lobe. Nomenclature is classified by first-, second- and third-order division anatomy.

First-order division

Hemiliver-oriented resections

First-order division anatomy refers to the division of the liver into right and left hemilivers along the mid-liver plane; right and left hemihepatectomy are the surgical terms. The left hemiliver includes segments 2–4, and the right hemiliver includes segments 5–8. The caudate lobe (segments 1 and 9) is not included in either hemiliver; if it is resected, it should be included in the description. The mid-liver plane divides the two hemilivers between the centre of the IVC and the gallbladder fossa, closely following the course of the MHV. This plane of division is not a straight line and there is no external fissure associated with it. After both arterial and portal right hemiliver inflow is occluded, an irregular line of demarcation can be drawn between the two hemilivers, usually in the form of a reversed question mark (¿).

Arterial anatomy

The left hemiliver arterial inflow is provided by two arteries: the segment 4 artery (A4; sometimes described as the middle hepatic artery) and the left hepatic artery, which provides arterial inflow for segments 2 (A2) and 3 (A3; Fig. 62.4). A4 usually crosses the ventral side of the pars transversa of the
LPV (84% of patients); it may cross the left intersectorial plane from left to right after originating from an aberrant left hepatic artery (13%), or cross the mid-liver plane from right to left after originating from the right anterior hepatic artery (3%). A4 may arise from the RHA (55%), from the LHA (30%) or the proper hepatic artery (PHA) (5%). Multiple A4s can be found in 10% of patients. The frequent origin of A4 from the RHA and PHA (70% of cases) leads to a complicated situation during donor evaluation for left hemihepatectomy because there is poor arterial cross-flow between A4 and the LHA, leading to the need for dual arterial reconstruction when A4 does not arise from the LHA.
The left hemiliver arterial inflow is normally provided by the left hepatic artery (LHA). A–D, The left hepatic artery (LHA) provides inflow for segments 2 and 3 (A2 and A3). Its course is relatively constant as, regardless of having a normal or aberrant origin, it courses caudal and lateral to the umbilical fissure (92% of cases). E–G, Either the LHA or a segmental branch may have an aberrant course, crossing the umbilical fissure cranially from medial to lateral (the remaining 8% of cases). Segment 4 origin is highly variable and can originate from the right hepatic artery (A, E, F and G), the LHA (B), an aberrant LHA (C) or the right anterior hepatic artery (D). Its course is relatively constant, crossing the ventral side of the pars transversa of the left portal vein (84% of patients); uncommonly, it crosses the umbilical fissure from left to right (13%; C) or crosses the mid-liver plane from right to left after originating from the right anterior hepatic artery (3%; D). Abbreviations: aLHA, aberrant left hepatic artery; rLHA, replaced left hepatic artery.

The right hemiliver arterial inflow is normally provided by two arteries, the right anterior and posterior sectorial arteries (Fig. 62.5). These arteries originate from the RHA, which crosses left to right behind (75–88%) or in
front of the common bile duct/common hepatic duct (CBD/CHD; 8–25%). The RHA courses lateral to the CBD and CHD without crossing in 4% because it originates from either the gastroduodenal artery or the superior mesenteric artery. Rarely, the RHA can originate from the coeliac trunk or directly from the aorta; in these cases, it courses behind the bile duct and the main portal vein. Regardless of the number of arteries and/or their origin, arterial structures to the right of the CHD and above the cystic duct can generally be divided during a right hemihepatectomy for cancer. The exception to this rule is the exceedingly rare variation where the proper hepatic artery bifurcates laterally to the CHD and the entire arterial inflow of the left hemiliver originates to the right of the CHD with the right anterior hepatic artery (RAHA).
FIG. 62.5 Arterial inflow to the right hemiliver. The right hepatic artery provides inflow to all segments. A–D, Regardless of its origin and variations, all arterial inflow to the right hemiliver lateral to the common hepatic duct can be safely divided. E, The exception is a rare detoured left hepatic artery that branches lateral to the common hepatic duct and provides the right anterior hepatic artery. The origin of the right hepatic artery is the proper hepatic artery (A); aberrant origins include the superior mesenteric artery (C), the gastroduodenal artery (D), the coeliac trunk and the aorta. The right hepatic artery generally bifurcates after crossing the common hepatic duct, either anteriorly (D) or posteriorly (A, C and E). Infrequently, the right hepatic artery may bifurcate at the level of the common hepatic duct before crossing it (B). Dotted lines signify the point of transection of the artery if a right hepatic resection is performed. Abbreviations: A2, segment 2 artery; A3, segment 3 artery; A4, segment 4 artery; A6, segment 6 artery; A7, segment 7 artery; GDA, gastroduodenal artery; LHA, left hepatic artery; RA, right anterior hepatic artery; RP, right posterior hepatic artery.

During right hemihepatectomy for living donation, the identification of extrahepatic sectorial and/or segmentary/subsegmentary branches (seen in 66% of cases) is crucial to preserve the arterial inflow to the graft. Extrahepatic sectorial branches may be encountered in up to 33% of cases. Extrahepatic segmentary or subsegmentary arteries (either A6 or A7) may occur in 35% of cases. These arteries may bifurcate lateral to the CHD, or posterior or medial to the CHD. On occasion, medial bifurcation of the RHA results in an RAHA anterior to the CHD and a right posterior hepatic artery (RPHA) posterior to the CHD. During living donor right hemihepatectomy, dissection of the RHA medial to the CHD is associated with an increased risk of biliary complications in the donor, and dissection is therefore limited to
the lateral aspect of the CHD; anatomical variations leading to multiple right hepatic arteries to the right of the CHD may require multiple arterial reconstructions in the recipient. During left and extended left hemihepatectomy for cholangiocarcinoma, an RHA crossing posterior or anterior to the CHD may be invaded by cholangiocarcinoma, which may result in the need for vascular reconstruction.

**Portal vein anatomy**

The main portal vein (MPV) bifurcation has relevance when considering all anatomical LRs. The LPV originates from the MPV in a perpendicular fashion, while the right portal vein (RPV) continues in the same direction as the MPV. The LPV has a long course in the incisura transversa (pars transversa) until it reaches the umbilical fissure, turning anteriorly in a perpendicular fashion (pars umbilicalis). The embryological communication of the pars transversa with the IVC is obliterated in adults and is represented by the ligamentum venosum. The embryological communication of the pars umbilicalis with the placenta is obliterated in adults and is represented by the round ligament ([Fig. 62.6](#)). The RPV is shorter and sometimes absent (up to 20% of cases). The right anterior and posterior portal veins may originate directly from the MPV (portal vein trifurcation up to 7% of cases). The posterior portal vein may be the first branch of the MPV and the right anterior portal vein may originate from the pars transversa (1.7–5%) or even the pars umbilicalis (0.8%). In rare cases, there is no MPV bifurcation and an arch-like MPV gives branches to the sections and segments independently (<0.1%; [Fig. 62.7](#)). Variations in portal vein branching are associated with variations in right-sided biliary anatomy. The RPV may occasionally provide small branches to segment 4, and the pars transversa infrequently provides small branches for segments 5 and 8 (see [Fig. 62.6](#)).
The portal vein begins at the confluence of the superior mesenteric and splenic veins. It courses to the right at an angle of 50° behind the pancreas and inside the hepatoduodenal ligament. Above the pancreas, it receives the coronary vein and the posterior superior pancreaticoduodenal vein, as well as other smaller tributaries. Its terminal branches are the left and right portal veins. The left portal vein has a long, usually unbranched, segment with a perpendicular course to the main portal vein (pars transversa); the left portal vein has an abrupt angulation at the level of the umbilical fissure, which it courses alongside (pars umbilicalis); the terminal portion of the pars transversa is the ligamentum venosum, while the terminal portion of the pars umbilicalis is the round ligament.
Hepatic vein anatomy

The left hemiliver outflow is via the LHV and the MHV. During live donor left hemihepatectomy, both LHV and MHV are taken with the graft and implanted into the recipient, while during LR for liver tumours, the MHV is preserved in the future liver remnant if possible.
The right hemiliver outflow is via the RHV and the MHV. The RHV drains segments 6 and 7 and the lateral aspect of segments 5 and 8. The MHV drains the medial aspect of segments 4, 5 and 8. The most common accessory hepatic vein in the right hemiliver is a right inferior hepatic vein that drains part of the posterior section, more commonly segment 6, directly into the IVC. Right inferior hepatic veins are present in 35–50% of patients and can often be multiple, draining at different anteroposterior planes of the IVC.

The outflow of the right hemiliver is highly relevant during right hemihepatectomy for living donation. Segment 5 and 8 tributary veins, as well as a potential right inferior hepatic vein, are routinely reconstructed to provide venous drainage if the size is greater than 5 mm.

In order to preserve adequate outflow in live donor right hemihepatectomy, most centres perform live donor right hemihepatectomy with preservation of the MHV in the donor (Fig. 62.8A) and preservation of segment 5 and 8 venous tributaries to the MHV in the graft. In 70% of cases, the MHV is formed distally by the confluence of segment 4 and 5 tributaries, with distal segment 8 tributaries (Fig. 62.8B). In 20% of cases, the MHV receives multiple small tributaries from segments 5 and 8 (Fig. 62.8C), and in the rest, the MHV provides the dominant drainage of the anterior section, which may be associated with the right inferior hepatic vein and a small or absent RHV, requiring multiple reconstructions in the recipient.
**FIG. 62.8** Applied anatomy of the middle hepatic vein (MHV). Most of segment 4 and the medial aspect of segments 5 and 8 are drained by the MHV. A,E,F, During right hemihepatectomy for living donation, the MHV may be preserved in the donor (planning shown in A, remnant in donor shown in F) and the right anterior section outflow reconstructed with interposition grafts ('modified' right hemiliver allograft, shown in E). B–D, The right anterior section MHV outflow variants include: type I, most right anterior section outflow is provided by two or more large tributaries ('strong-right' type, 70% of cases; B); type II, a small medial area of the right anterior section outflow is provided by multiple small tributaries ('weak-right' type, 20% of cases; C); and type III, where most of right anterior section outflow is provided by large tributaries, sometimes associated with right inferior hepatic veins and a small right hepatic vein ('complex-right' type, 10% of cases; D). G, During ‘extended’ right hemihepatectomy for living donation, the MHV is harvested with the allograft (planning shown in G). H–J, The point of division of the MHV is planned to allow preservation of segment 4a drainage, which can be observed directed to the left hepatic vein (57–63% of cases, H), to the MHV (5–10% of cases, I) and combined (28–36% of cases, J). Other abbreviation: IVC, inferior vena cava.

**Biliary anatomy**

The left hepatic duct (LHD) is long and runs anterior to the LPV (Fig. 62.9A,B). This allows intrahepatic biliary reconstruction in cases of bile duct injury, which may be facilitated by a small resection of the base of segment 4b (Hepp–Couinaud procedure). The LHD receives bile ducts from segments 1–4; it may be absent in less than 2% of patients, when it is substituted by independent drainage of B2–B3 and B4 to the CHD (Fig. 62.9C).
FIG. 62.9  Biliary drainage of the left hemiliver. The bile ducts of the left lateral section (B2 and B3) form the left hepatic duct to the left of the umbilical fissure (A, B, C and E), at its level (G) or to its right (E and G). Multiple B4s may be encountered. B4 may drain into the left hepatic duct directly (62–78%; A–E, G), indirectly through B3 (19–34%; F) or directly into the common hepatic duct (0.4–3%) or the right hepatic duct. B4 drainage is classified according to its proximity to the umbilical fissure (55–70%; A), to the liver hilum (30–35%; B), and a combined type in case of multiple B4s (10%; C).

B4 drainage is highly variable; there may be one (up to 89% of cases) or multiple ducts. B4 may join the LHD directly (63–78%), indirectly through B3 (19–34%), or directly into the CHD (0.4–3%). Less than 1% of patients have B4 drainage to the right anterior or right posterior hepatic duct. B4 variations have been classified according to their proximity to the umbilical fissure (55–70%; Fig. 62.9D) or to the liver hilum (30–35%; Fig. 62.9E), and a combined
type in cases of multiple B4s (10%; Fig. 62.9F).

The left bile duct is divided close to the biliary confluence during live donor left hemihepatectomy. During right hemihepatectomy for cholangiocarcinoma, in addition to resection of the CBD, the LHD is divided at the confluence of B4 and B2–B3, or even further proximally if B4 drains close to the biliary confluence, which will require reconstruction of multiple bile ducts.

The right posterior hepatic duct (RPHD) is the most variable second-order bile duct. It can join the right anterior hepatic duct (RAHD) to form the right hepatic duct (RHD; 74% of cases; Fig. 62.10E) or join the LHD (Fig. 62.10B,C) or the CBD (Fig. 62.10F) directly, in which case there is no proper RHD (26%). The variations in the right-sided bile ducts can be further classified according to the position of the RPHD in relation to the right anterior portal vein as supraportal (83–85% of the cases) or infraportal (12%). The right posterior section may have a combined drainage (infraportal B6 and supraportal B7 in 3–5%), a situation that creates a significantly different position of the RPHD inside the hilar plate after parenchymal transection through the mid-liver plane during right hemihepatectomy for living donation, as well as a different number of bile ducts to reconstruct in the graft (Fig. 62.11).
FIG. 62.10  Variations in the anatomy of the right hemiliver bile ducts.  

A, The most common pattern of the biliary confluence (approximately 50% of cases), where a supraportal right posterior hepatic duct (RPHD) joins the right anterior hepatic duct (RAHD) to form the right hepatic duct (RHD). The x line measures the length of the RHD and its classification is included on the figure. The y line measures the length of the cephalic portion of the RPHD and its classification is included on the figure.  

B, The biliary confluence formed by the RPHD, RAHD and the left hepatic duct (LHD; approximately 15% of cases).  

C, An RPHD draining into the LHD (approximately 15% of cases).  

D, A rare variant (approximately 1% of cases): the RAHD draining into the common hepatic duct (CHD).  

E,F, An infraportal RPHD draining into the RHD and the CHD, respectively (12% of cases).  

G, A combined course of the right posterior section ducts, where both supraportal and infraportal segmentary/subsegmentary ducts are identified (3–5% of cases).
FIG. 62.11  A, An intraoperative cholangiogram of a case with supraportal right posterior hepatic duct drainage. Arrow denotes the right hepatic duct, right hepatic artery and the portal vein. B, If the division plane of the hilar plate follows the mid-liver plane (red line A), the caudal segment of the supraportal duct could be denuded or sometimes injured during transection. The division of the hilar plate should therefore be perpendicular to the axis of the duct (white line).

Second-order division

Second-order division refers to division of the liver in four sections. The left hemiliver is divided in medial (segment 4) and lateral sections (segments 2–3) by the left intersectorial plane while the right hemiliver is divided in anterior (segments 5 and 8) and posterior sections (segments 6–7) by the right intersectorial plane.

Extended LR includes sections from both sides of the liver, where segments 4–8 are resected in extended right hemihepatectomy, and segments 2–5 and 8 are resected in extended left hemihepatectomy. The caudate lobe (segments 1 and 9) is not included routinely in either form of extended LR; if it is resected, it is included in the description. Resection of segments 4, 5 and 8 is referred to as central LR or mesohepatectomy.

The Brisbane nomenclature allows description of any form of anatomical resection through the segments and/or sections resected. In the case of resection of the left medial section and the right anterior section, this could be described as bisectionectomy of these structures.

Anatomy for liver resections involving the left intersectorial plane
The left intersectorial plane follows the falciform ligament and the umbilical fissure anteriorly, and the sulcus of Arantius posteriorly. This plane follows the pars umbilicalis; a segment 4a vein occasionally drains into the LHV that crosses the plane. To preserve the contralateral branches of the LPV, the transection plane is 1 cm lateral to the falciform ligament during a left lateral section LR for liver tumours (Fig. 62.12A), and 1 cm medial to these two structures during left lateral section LR for living donation (Fig. 62.12B), mesohepatectomy and extended right hemihepatectomy.

**Arterial anatomy**

The LHA may course to the left (92%) or right (5%) of the pars umbilicalis (see Fig. 62.4). There may be either no LHA or an early bifurcation, causing one segmental branch to run on each side (3%) of the pars umbilicalis. If present, the aberrant LHA courses to the left of the pars umbilicalis. Multiple arterial branches to the left lateral section may be present and may potentially be a contraindication for living donation. During LR for cholangiocarcinoma, an LHA coursing to the right of the pars umbilicalis may be associated with invasion by the tumour and may require reconstruction.

**Portal vein anatomy**

Segment 4 portal vein supply comes from the distal and medial aspect of the pars umbilicalis and there are usually 2–8 branches. Segment 4 portal vein supply can occasionally (10% of patients) originate from the pars transversa. The identification of A4 is important during living donation and split liver transplantation. During left lateral section procurement for living donor liver transplantation (LDLT) (see Fig. 62.12B), split liver transplantation and associated liver partition and portal vein ligation for staged hepatectomy (ALPPS; see Fig. 62.12E), the portal vein branches going to segment 4 are ligated and divided.
FIG. 62.12  Liver resections (LRs) involving the left intersectorial plane. A, The plane of parenchymal transection in a left lateral section LR for liver tumours lateral to the left intersectorial plane. B,D,E, The plane of parenchymal transection in a left lateral section LR for living donation medial to the left intersectorial plane. This plane is also used during extended right hemihepatectomy (D and E), and during mesohepatectomy and segment 4 LR. C, The remnant liver in the donor after left lateral section LR; note the harvesting of the left portal vein with the allograft and the ligation of segment 4 portal vein branches. E,F, Associated liver partition and portal vein ligation for staged LR (ALPPS). During the first stage of the procedure (E), segment 4 portal vein branches are ligated during division of the parenchyma medial to the left intersectorial plane, and the right portal vein is ligated; the right hepatic artery, all veins and bile ducts are preserved. Five to ten days later, the left lateral sections have undergone hypertrophy due to redirection of portal inflow to this section, while the rest of the liver has continued to support the remnant by arterial inflow only. Once the size of the future liver remnant is adequate, the second stage is performed by dividing the remaining structures and removing the specimen. Other abbreviation: IVC, inferior vena cava.

Hepatic vein anatomy
The left lateral section is drained by the LHV (Fig. 62.13). The most common anatomy is that segment 2 and 3 veins join to form an LHV, which in turn
joins the MHV to form a common trunk (see Fig. 62.13A). Separate segment 2 and 3 veins may join the MHV to form a common trunk (14–20%) (see Fig. 62.13B). The segment 2 vein may join the MHV to form a common trunk and the segment 3 vein drains into the MHV (5–13%).

**FIG. 62.13** Outflow of the left lateral section. A, In 70% of cases, the left hepatic vein is formed by the confluence of the segment 2 (V2) and segment 3 (V3) tributaries. B, In 15–20% of cases, V2 and V3 join the middle hepatic vein independently to form the common trunk. C, In the remaining 10–15% of cases, V3 drains to the middle hepatic vein crossing the left intersectorial plane. Other abbreviation: IVC, inferior vena cava.

**Biliary anatomy**

During left lateral section LR for living donation, bile duct division is performed to the right of the umbilical fissure (see Fig. 62.9D). This allows for a single-duct anastomosis in 90% of cases, regardless of B2–B3 duct morphology, except in the case of absent B2–B3 confluence and/or an infraportal B3.

In 20–30% of cases, a small subsegmentary B3 duct joins the LHD distal to the B2–B3 confluence (see Fig. 62.9E). In these cases, the small bile duct can be ligated in the allograft without compromising biliary drainage; however, failure to identify and ligate this branch has been associated with postoperative bile leaks.

Among patients with cholangiocarcinoma needing extended right hepatectomy, caudate lobe resection is frequently required. During extended right hemihepatectomy for cholangiocarcinoma, bile duct division is performed to the left of the umbilical fissure (see Fig. 62.2). The approach to the LHD is facilitated by ligating and dividing the portal vein branches going to segment 4 at its origin, through dissection medial to the round ligament.
This optimizes the bile duct margin and often results in more than one bile duct to be reconstructed.

**Anatomy for liver resections involving the right intersectorial plane**

The right intersectorial plane closely follows the course of the RHV. It follows a very irregular course, starting on the right margin of the IVC, then the superior layer of the coronary peritoneal attachment to 3–4 cm from the junction of the latter with its inferior layer; then it curves anteriorly (forming a letter ‘S’) to a point on the inferior hepatic border between the gallbladder fossa and the right margin of the liver. It subsequently travels parallel to the gallbladder fossa until the transverse fissure (where the right posterior pedicle is located) and crosses the caudate process to reach the IVC. The unusual curvature of this plane is the result of the generous size of segments 6 and 8 and the comparatively small size of segments 5 and 7. The right intersectorial plane is the longest anatomical plane of parenchymal transection in liver surgery.

**Arterial anatomy**

The right posterior hepatic artery (RPHA) courses infraportally in the liver hilum (75–80% of cases). It may also course supraportally (8–12%). A7 may be supraportal while A6 is infraportal (8–12%, combined type; [Fig. 62.14]).\(^8,9\) Therefore, 20% of patients may be at risk of RPHA injury during division of the right anterior pedicle. During right posterior section (RPS) LR for living donation, a supraportal or a combined-type RPHA poses a complex dissection and reconstruction. It is currently recommended to divide the structures of the right posterior pedicle after completion of parenchymal transection to optimize exposure of the supraportal RPHA.
Portal vein anatomy

Patients with a right posterior portal vein originating from the MPV have an infraportal RPHA, a higher prevalence of infraportal RPHD (50%) and a larger average volume of the RPS than patients with other anatomical variants (Fig. 62.15B). This anatomical variation facilitates extended left hepatectomy; its incidence is much higher among patients undergoing this procedure than that observed in the general population (20% compared to 5%). The same variation is highly favourable for RPS LR for living donation.
FIG. 62.15  A, The point of division of the bile duct during a standard extended left hemihepatectomy (ES) and during a procedure for hilar tumours (EC). The left and right anterior portal vein are divided independently (ES). If needed, points of division of the portal vein are shown (EC). B, The hilar anatomy of a patient with an independent right posterior portal vein arising from the main portal vein with an infraportal right posterior hepatic artery (RPHA) and duct (RPHD). The dotted lines show the points of division of the hepatic artery, portal vein and bile duct for a
Segment 7 portal inflow may be derived from the right anterior portal vein instead of the right posterior portal vein. During anatomical RPS LR for liver tumours close to the right posterior portal vein, right anterior portal vein inflow may allow sparing of part of segment 7. During RPS LR for living donation or mesohepatectomy, segment 7 portal vein inflow should be analysed carefully, as right anterior portal vein inflow will be sacrificed, compromising segment 7 inflow.

**Hepatic vein anatomy**

The variations of the RHV follow those of the MHV and the right inferior hepatic vein. During RPS living donor hepatectomy and left trisectionectomy, the plane of transection parallels the medial aspect of the RHV and can be identified by right posterior pedicle temporary occlusion.

**Biliary anatomy**

During RPS LR for living donation, the RPHD is divided ventrally and lateral to the right posterior portal vein. During extended left hemihepatectomy for cholangiocarcinoma, the RPHD is divided distal to Rouvière's sulcus, increasing the oncological margin by an average of 9 mm compared to that of a left hemihepatectomy. Segment 8 has three or more subsegmental bile ducts (B8a, ventral; B8b, lateral; and B8c, dorsal) and a variant where B8c drains to the RPHD (17%) instead of to the RAHD. The inclusion of part of the dorsal portion of segment 8 (B8c) with normal biliary drainage (B8c draining to the RAHD) during right posterior sectorectomy for living donation may lead to persistent bile leaks after LDLT.

**Third-order division**

Third-order division refers to division of the liver in nine segments. The planes dividing the segments are referred to as intersegmental planes. Parenchymal transection following intersectorial and intersegmentary planes crosses fewer and smaller vessels, and consequently there is less bleeding. Although the evidence is not definitive, anatomical (specifically, segmental) resections are thought to be better oncological resections because they
remove possible satellite lesions and reduce the potential for microscopic vascular dissemination within the portal vein inflow to the segments involved by the lesion. Comprehensive anatomical studies, along with advanced imaging techniques, enable proper preoperative preparation, including tridimensional digital reconstruction. Segmental LRs are approached through different techniques using intraoperative ultrasound. The techniques include marking the surface of the intended segment with cautery, injecting the portal vein branch supplying the segment with methylene blue, and balloon occlusion of the portal vein branches.

**Caudate lobe resection (segment 1/9)**

The caudate lobe is posterior to the hepatic hilum and anterior to the IVC, and extends from the inferior edge of the liver to the terminal hepatic veins. Liver tumours arising in the caudate lobe are intimately related to the posterior surface of the hepatic veins and the umbilical fissure; this narrow margin is a decisive factor between an isolated caudate resection or a left hemihepatectomy including the caudate lobe.

Couinaud divided the caudate lobe into segment 1, or Spiegel's lobe, to the left of the MHV, and ‘segment 9’ to the right of the middle vein. ‘Segment 9’ was further divided by Couinaud into the caudate process to the right of the RHV and the paracaval portion of the two hepatic veins (Figs 62.16–62.18). According to Couinaud's segmentation of the liver, no portal fissure can be crossed by a portal pedicle. Since the right portal pedicles can cross to segment 1 and the left portal pedicles can cross to segment 9, the concept of ‘segment 9’ was abandoned in 2002.
FIG. 62.16 A dorsal view of the liver illustrating the relationship of the caudate lobe to the hilar structures and the inferior vena cava (IVC). A, The IVC is retrohepatic. B, The caudate lobe wraps around the IVC with a thin portion running posterior to it. C, The short hepatic veins and right adrenal vein drain into the IVC. Other abbreviations: LHV, left hepatic vein; MHV, middle hepatic vein; RHV, right hepatic veins. (From L.H. Blumgart, L.H. Schwartz, R.P. DeMatteo. Surgical and radiologic anatomy of the liver, biliary tract, and pancreas. In: Blumgart's Surgery of the Liver, Biliary Tract and Pancreas, sixth ed. Copyright © 2017 by Elsevier, Inc. All rights reserved. A, Fig. 2.20b. B, Fig. 2.1b.)
FIG. 62.17  A ventral view of the liver at the level of the termination of the hepatic veins, showing the relationship of the caudate lobe to the hepatic veins. The caudate lobe can be divided into subsegments according to its relation to the middle (MHV) and right hepatic veins (RHV). Other abbreviation: IVC, inferior vena cava.
FIG. 62.18 A frontal view of the caudate lobe and its relation to the portal vein, hepatic veins and bile duct. The biliary drainage of the subsegments is shown, demonstrating right/left cross-drainage. The most frequent site of drainage of the caudate process and the paracaval portion is the right posterior (RP) hepatic duct, while Spiegel's lobe drains more commonly to the left hepatic duct. Abbreviations: IVC, inferior vena cava; LHV, left hepatic vein; MHV, middle hepatic vein; RA, right anterior duct; RHV, right hepatic vein.

Given its location, it is difficult to remove the caudate lobe where there are large tumours; in these cases, the caudate lobe can be accessed after mobilization of the right or left hemiliver or both, with or without transection of the mid-liver plane.

Caudate arteries originate from an independent branch of the left or right hepatic artery, branches from both left and right hepatic arteries, or arterial branches from the communicating artery. The small portal vein tributaries originating from the main portal vein bifurcation (80% of cases), left (90%)
and/or right (80%), should be controlled. These small veins may be anterior or posterior, and are separated from the caudate lobe artery and bile duct for a short distance, making them accessible extrahepatically. Identification and ligation of the retrocaval ligament and caudate veins draining into the IVC allow complete mobilization of the caudate lobe. Spiegel’s lobe drains directly into the IVC, whereas the paracaval portion and the caudate process drain to the IVC and to the dorsocaudal tributaries of the MHV.

Caudate lobe bile ducts (B1 and B9) drain posteriorly at the confluence of the right and left hepatic ducts (see Fig. 62.18). B1 drains more commonly to left-sided ducts (LHD in 40% or its branches in 25%), while B9 (caudate process and the paracaval portion) drains more commonly to right-sided ducts (RPHD in 45% or RHD in 15%). Right/left crossover is common, with 30% of B1 draining into right-sided ducts and 35% of B9 draining into left-sided ducts.\textsuperscript{10} The location of cholangiocarcinoma causes frequent invasion of B1–9, particularly on left-sided tumours. Most centres perform routine caudate lobe resection but some do it selectively, depending on the patient's anatomy, tumour location and intraoperative frozen section.

\textbf{Tips and Anatomical Hazards}

- Extrahepatic isolation of MHV and LHV can be performed by dividing the ligamentum venosum and developing a plane between the IVC and the MHV/LHV trunk.
- Clearly identify and ensure the patency of arterial and portal inflow of the future remnant prior to division of the structures at the porta hepatis.
- In a case of bleeding from intrahepatic hepatic vein tributaries during parenchymal transection, close the liver and consider total vascular exclusion for control.
- The most cranial portion of the caudate lobe is in close proximity to the posterior aspects of the MHV and LHV; when dividing this part of the caudate lobe, take care not to injure these veins.
- During hemihepatectomy, if bile duct anatomy is not clear, lower the hepatic duct plate and perform an intraoperative cholangiogram to confirm the anatomy.
- During a mesohepatectomy (resection of segments 4, 5 and 8) for
oncological reasons, stay sufficiently posterior to obtain an adequate oncological margin behind the MHV.

The tributaries to the MHV (segment 5 and 8 veins) may lead to troublesome bleeding during parenchymal transection for right hepatectomy.
A right posterior duct anatomical variant may be injured in left hepatectomy: in particular, an aberrant right posterior duct draining into the left duct.
During a hepatectomy for a tumour close to the confluence of the hepatic veins, ensure that the outflow of the remnant liver is preserved.
References


1. Which one of the following conditions is NOT a contraindication to a percutaneous liver biopsy?
   A. Hepatic amyloidosis
   B. Liver cirrhosis
   C. Medically complicated obesity (body mass index of over 40)
   D. Massive ascites
   E. Biliary hamartomas

**Answer:** E. Biliary hamartomas represent a frequent incidental finding during imaging studies or after liver resection (Fig. 62.19). They are benign, no intervention is needed for their management, and they do not represent a contraindication to percutaneous liver biopsy. Coagulopathy is frequent among patients with amyloidosis and normal platelet and International Normalized Ratio (INR), and is due to acquired factor X deficiency. Amyloid deposits in vessel walls result in weak, frail vessels. Bleeding after percutaneous biopsy of liver and kidneys affected by amyloidosis is unfortunately high and a transjugular or transfemoral approach is therefore preferred if a biopsy is required. Patients with liver cirrhosis documented by clinical findings and imaging studies do not benefit from liver biopsies because these will not assist with the diagnosis or management of the disease. The histological findings that frequently assist in the assessment of the aetiology of liver disease often ‘wear off’ once cirrhosis is established. The risk of bleeding is higher among patients with ‘stiff’ livers, particularly if associated with portal hypertension. Therefore, liver cirrhosis is a relative contraindication to a percutaneous liver biopsy. In patients with questionable findings, a transjugular approach is a safe way to obtain a tissue diagnosis and assess portal vein pressure in a single procedure. Obesity is a relative contraindication to a percutaneous approach to a liver
biopsy. This is based solely on the distance between the skin and the liver, which may add complexity to the procedure. If a random parenchymal biopsy is required, an ultrasound-guided percutaneous liver biopsy could be performed by an experienced operator. The distance between the hepatic veins and the liver parenchyma is unaffected by obesity, and therefore a transjugular approach is an adequate alternative. The presence of fluid between the liver capsule and the parietal peritoneum can prevent clot formation after a percutaneous liver biopsy. Therefore, ascites of any aetiology is a relative contraindication to a percutaneous liver biopsy. If ascites is mild or moderate, a paracentesis can be performed immediately before the biopsy; if ascites is severe, a transjugular approach is preferred.

FIG. 62.19  A liver allograft with multiple biliary hamartomas (von Meyenburg complex) after multiorgan procurement. Note the multiple white nodules across the visible liver segments. These nodules are pale and are not indurated. Histologically, they represent disorganized clusters of dilated bile ducts lined by a single layer of cuboidal cells and surrounded by abundant stroma; they are thought to arise from embryonic bile duct remnants that have failed to involute.

2. The term mesohepatectomy refers to the resection of the central segments of the liver with or without the caudate lobe. Which
one of the following groups of segments is included in the term?
A. Segments 4, 5 and 6
B. Segments 1, 2 and 3
C. Segments 6, 7 and 8
D. Segments 4, 5 and 8
E. Segments 2, 3 and 4

**Answer:** D. Segments 4, 5 and 8. The Brisbane nomenclature can be used to describe any form of liver resection according to the segments involved. However, central liver resection (mesohepatectomy) is not included in the consensus and can be described as a bisectionectomy; resection of the medial section of the left hemiliver and the anterior section of the right hemiliver; or as resection of segments 4, 5 and 8 (Fig. 62.20). This procedure is performed for tumours originating in the centre of the liver, frequently involving the middle hepatic vein. The entire area drained by such a vein is removed and the vein divided at its termination. The middle (A4) and right anterior hepatic arteries are ligated, as well as the portal vein branches to segment 4 (P4) and the right anterior portal vein. The bile ducts draining segment 4 (B4) and the right anterior hepatic duct are also ligated. The caudate lobe, if involved, may be resected, and this should be included in the description of the procedure.
FIG. 62.20  Mesohepatectomy corresponds to the resection of the medial left section (segment 4) and the right anterior section (segments 5 and 8), both mostly drained by the middle hepatic vein (MHV). The portal branches to segment 4 (P4) and the right anterior portal vein (RAPV) are divided. The liver remnant consists of the left lateral section (LLS; segments 2 and 3) and the right posterior section (RPS; segments 6 and 7). The caudate lobe (segments 1 and 9) may be resected if needed.

3. Which one of the following groups of structures needs to be divided during an extended left hemihepatectomy?
A. Left hepatic artery, portal vein, bile duct and hepatic vein
B. Left, middle and right anterior hepatic arteries, portal veins and bile ducts, left and middle hepatic veins
C. Left, middle and right posterior hepatic arteries, portal veins and bile ducts, left and middle hepatic veins
D. Left and right anterior hepatic arteries, portal veins and bile ducts, left hepatic vein
E. Left and right posterior hepatic arteries, portal veins and bile ducts, left hepatic vein
**Answer:** B. Left, middle and right anterior hepatic arteries, portal veins and bile ducts, left and middle hepatic veins. The Brisbane nomenclature defines an extended left hemihepatectomy as the resection of segments 2, 3, 4, 5 and 8, including the left lateral and medial section, as well as the right anterior section. This procedure is performed for tumours originating in the centre of the liver and affecting the left lateral section and its inflow, outflow and/or biliary drainage. The left and middle hepatic veins are divided. The left, middle (A4) and right anterior hepatic arteries are ligated, as well as the left portal vein and the right anterior portal vein. The left and right anterior hepatic ducts are ligated. An extended left hemihepatectomy is technically complex but usually safe in terms of future liver remnant, since the volume of the right posterior section is generally over 30% of the total liver volume. The caudate lobe, if involved, may be resected, and this should be included in the description of the procedure. Certain anatomical patterns are favourable for this type of resection (see Fig. 62.15), such as an independent right posterior portal vein, which is associated with an infraportal right posterior hepatic artery (100% compared to 80% in the general population) and a higher incidence of infraportal right posterior hepatic duct (50% compared to 15% in the general population).

4. During an extended right hemihepatectomy with caudate lobe resection, which one of the following pairs of liver segments is preserved?
   A. Segments 2 and 3
   B. Segments 5 and 8
   C. Segments 6 and 7
   D. Segments 2 and 4
   E. Segments 3 and 5
Answer: A. Segments 2 and 3. The Brisbane nomenclature defines an extended right hemihepatectomy as the resection of segments 4, 5, 6, 7 and 8, including the left medial section, as well as the right anterior and posterior sections. This procedure is performed for large liver tumours originating to the right of the umbilical fissure or hilar tumours involving predominantly the right side inflow and/or outflow. The middle and right hepatic veins are divided. The middle (A4) and right hepatic arteries are ligated, as well as the right portal vein and the segment 4 portal vein branches. The right hepatic duct and segment 4 bile ducts are ligated. This resection can be approached by transecting the parenchyma 1 cm to the right of the left intersectorial plane, including the portal vein and bile ducts of segment 4 in that plane. During resection of hilar tumours (in particular, perihilar cholangiocarcinomas) by entering the space of Rex, segment 4 portal vein branches of the pars umbilicalis of the left portal vein can be dissected and divided (see Fig. 62.2). This allows the surgeon to enter the left pedicle and divide the left hepatic duct to the left of the umbilical fissure, thereby maximizing the margin of oncological resection while preserving the inflow to the liver remnant. This is known as ‘anatomical’ extended right hemihepatectomy. The caudate lobe, if involved, may be resected, and this should be included in the description of the procedure. The volume of the left lateral section is usually approximately 20% of the total liver volume, making manipulation of the liver remnant often necessary before the resection.

5. Division of the right anterior pedicle can be complicated by which one of the following processes?
   A. Injury to the left hepatic duct
   B. Injury to the right posterior hepatic artery and duct
   C. Injury to the right posterior portal vein
   D. Injury to the right hepatic vein
E. Injury to the caudate lobe

**Answer: B.** Injury to the right posterior hepatic artery and duct. The most common course of the right posterior hepatic duct, present in 85% of patients, is around and behind the right anterior portal vein, described in the literature as a ‘supraportal’ right posterior hepatic duct. Approximately 3% of patients have a segmentary/subsegmentary duct draining to the right hepatic duct with a supraportal course, while the rest of the right posterior section drains into the right or common hepatic duct (Fig. 62.21). This supraportal course is sometimes described in the literature as ‘Hjorstjö’s crook’, in honour of the Swedish physician Carl-Herman Hjortsjö, who studied the topography of the intrahepatic bile ducts by means of cholangiography in the 1950s. Through an extra-Glissonian approach, if the right anterior pedicle is divided proximally (close to the liver hilum), supraportal bile ducts may be injured, causing postoperative biliary leakage and/or obstruction that is hard to manage. To prevent this, the right anterior pedicle should always be divided as high as the oncological resection allows. In a similar fashion, but less frequently, the right posterior hepatic artery runs around and behind the right anterior portal vein in 10% of cases: this is described as a ‘supraportal’ right posterior hepatic artery (see Fig. 62.14). In 10% of cases, a segmentary/subsegmentary branch of the right hepatic artery (A7) may run supraportal, while the rest of the arterial supply of the right posterior section is infraportal. If the right anterior pedicle is divided proximally (close to the liver hilum), supraportal hepatic arteries may be injured, causing ischaemia of the remnant right posterior section, and this may lead to postoperative liver failure.
6. Outflow reconstruction after a deceased donor liver transplant can NOT be performed through which one of the following alternatives?

A. Total vena cava replacement
B. ‘Piggyback’ technique
C. End-to-side inferior vena cava anastomosis
D. Side-to-side inferior vena cava anastomosis
E. Inferior vena cava to left renal vein anastomosis

**Answer: E.** Inferior vena cava to left renal vein anastomosis. Total vena cava replacement was the first technique for outflow reconstruction employed during the early days of liver transplantation and is still being used today. Perioperative management has enabled surgeons to perform total vena cava replacement, even without extracorporeal circulation. In this technique, the entire liver of the recipient is resected without dissection of the retrohepatic vena cava, which is removed with the diseased liver, and two caval anastomoses are performed (supra- and infrahepatic). The ‘piggyback’ technique corresponds to the anastomosis between the suprahepatic inferior vena cava of the allograft and the hepatic veins of the recipient, ligating the
infrahepatic vena cava of the allograft. Either the common trunk of the left and middle hepatic vein can be used or a venoplasty of the three veins is performed in the recipient. In this technique, the diseased liver is completely dissected off the retrohepatic inferior vena cava and all hepatic caval outflow is ligated and divided. End-to-side and side-to-side anastomoses are variations of the piggyback technique. The dissection is carried out in the same fashion, but the anastomosis is performed directly to a venotomy in the inferior vena cava and not to a natural orifice. During end-to-side anastomosis, the suprahepatic vena cava is attached to an anterior venotomy in the inferior vena cava in the recipient, and the infrahepatic vena cava in the allograft is ligated. During side-to-side anastomosis, both the suprahepatic and the infrahepatic vena cava in the allograft are ligated and a posterior venotomy is performed in the allograft vena cava, which is attached to an anterior venotomy in the recipient's vena cava. Although the left renal vein can be used for reconstruction of portal inflow in cases with portal vein thrombosis and spontaneous splenorenal shunts, it is not used for venous outflow reconstruction during liver transplantation.
Clinical Cases

1. A 74-year-old man is found to have an incidental liver lesion in the caudate lobe (Fig. 62.22). He has a past history of three coronary artery stents and requires a liver resection.

**FIG. 62.22** A,B, Coronal (A) and axial (B) T2-weighted MR imaging of the abdomen shows a dumbbell-shaped mass in the caudate lobe with a solid mass in the centre and two hyperintense areas on each side. The mass displaces the hilar structures towards the right.
A. Describe the anatomical relationship of the caudate lobe with the surrounding structures.

The caudate lobe is posterior to the hepatic hilum in close proximity to the proper hepatic artery, the portal vein bifurcation and the hepatic duct confluence. The caudate lobe is attached to the inferior vena cava, partially encircling it on its anterior, medial and lateral surfaces (see Fig. 62.22). It extends from the termination of the hepatic veins cephalad to the inferior edge of the liver caudad.

B. Describe the anatomical division of the caudate lobe.

The caudate lobe can be divided in two segments, segment 1 and segment 9. Segment 1 corresponds to Spiegel’s lobe, the portion of the lobe that is located medial to the middle hepatic vein and encircles the inferior vena cava medially. Segment 1 is in close relation to the sulcus of Arantius, ligamentum venosum, pars transversa of the left portal vein, left hepatic artery, left bile duct and left hepatic vein. If an aberrant left hepatic artery is present in the gastrohepatic ligament, it runs anterior to segment 1 before it enters the liver through the sulcus of Arantius.

Segment 9 corresponds to the portion of the caudate lobe lateral to the middle hepatic vein. It can be further divided into the caudate process lateral to the right hepatic vein, and the paracaval portion located between the middle and right hepatic veins (see Figs 62.16, 62.17). Segment 9 is in close relation to the anterior and lateral surface of the inferior vena cava, the portal vein bifurcation and the bile duct confluence (see Fig. 62.18).

C. Why is this knowledge important for planning caudate lobe resections?

Isolated caudate lobe resection is not commonly performed due to frequent involvement of the surrounding structures. Involvement of the inflow or outflow structures, such as the left hepatic artery, left portal vein or posterior aspect of the left and/or middle hepatic veins, often necessitates a concomitant left hemihepatectomy in addition to caudate lobe resection (Fig. 62.23). In the current case, the tumour (intrahepatic cholangiocarcinoma) has invaded the caudal and lateral portion of the left portal vein, inducing atrophy of segment 2 (Fig. 62.24), and this requires a left hemihepatectomy with caudate lobe resection.
Axial T2-weighted MR imaging of the patient shows the intimate relationship of the tumour in the caudate lobe to the left (LHV) and middle hepatic veins (MHV), as well to the inferior vena cava.
2. A 59-year-old man is found to have obstructive jaundice secondary to perihilar cholangiocarcinoma involving the hepatic duct confluence and the left hepatic duct (Fig. 62.25). He has no relevant past medical history. He requires a left hemiliver resection, caudate lobe resection and portal vein reconstruction.
FIG. 62.25  A. A multiplanar three-dimensional reconstruction of magnetic resonance cholangiopancreatography (MRCP) shows dilation of the left and right hepatic ducts with amputation at the level of the biliary confluence due to a tumour (dotted white circle). The tumour is above the cystic duct and involves the biliary confluence, extending to the point of drainage of B4 into the left hepatic duct. The right posterior hepatic duct is supraportal and drains separately from the right anterior hepatic duct, to either the left hepatic duct or the hepatic duct confluence. B, Axial contrast-enhanced CT on a venous phase shows direct contact of the tumour (blue circle; note the plastic stents inside) with the main portal vein (PV) close to the origin of the right portal vein (RPV). Other abbreviations: CBD, common bile duct; GB, gallbladder.
A. Describe the anatomy of the portal vein.

The adult main portal vein is 7–10 cm long and 0.8–1.4 cm in diameter. The normal flow through the vein is commonly described as hepatopetal, meaning that the blood flows towards the liver. The portal vein contains no valves and the flow can be away from the liver (hepatofugal flow) in cases where the resistance of the liver is high (as in hepatic venous thrombosis, also known as the Budd–Chiari syndrome).

The portal vein originates at the confluence of the superior mesenteric vein and the splenic vein (splenomesenteric confluence; see Fig. 62.6). The inferior mesenteric vein can reach the portal vein through the splenic vein (50% of cases), the superior mesenteric vein (30%) or directly into the splenomesenteric confluence (20%).

The portal vein courses behind the neck of the pancreas until it reaches the hepatoduodenal ligament above it with an angle of 50° to the right side of the abdomen. Under normal circumstances, most of the tributaries to the portal vein are small. The two largest and most consistent suprapancreatic
tributaries are the coronary vein to the left and the posterior superior pancreaticoduodenal vein to the right (see Fig. 62.6); the coronary vein may alternatively drain into either the splenic vein or the splenomesenteric confluence. Other small tributaries include the cystic vein and the pyloric vein.

B. Describe the branches of the portal vein.

The portal vein enters the liver through the transverse fissure and bifurcates into the right and left portal veins; variation in the branching patterns is common (see Fig. 62.7).
FIG. 62.27  

A, A left hemihepatectomy with portal resection and reconstruction. Note how the angle of the right portal vein is similar to that of the main portal vein. B, The point of division of the main and right portal veins, and the proximal point of division with the maximal oncological margin during left hemihepatectomy. C, The remnant right hemiliver and the shortened main portal vein. The dark area in A–C represents the area resected; the clear area represents the remnant liver. D, An operative photograph of the case after resection and reconstruction of the portal vein and after division of the right anterior and posterior bile ducts. Note the skeletonized and tortuous right hepatic artery. E, Axial contrast-enhanced CT on a venous phase shows a patent portal vein 6 months after the operation. Abbreviation: LC, left cholangiocarcinoma; PV, portal vein; RHA, right hepatic artery; RPV, right portal vein.

The first-order branches of the portal vein are the right and left branches; the second-order branches of the right portal vein are the right anterior and right posterior branches; the left portal vein has only third-order branches.

The portal vein is anterior to the paracaval portion of the caudate lobe; the right portal vein is anterior to the caudate process; the left portal vein is anterior to Spiegel’s lobe.

The right portal vein, if present, is short and follows a similar angle inside the liver. It gives small branches to the caudate lobe and occasionally to segment 4, and follows the distribution of the right hepatic arteries and right bile ducts.

The anatomical pattern of the left portal vein is different (see Fig. 62.6). It is constant and remarkably longer than the right, and has a perpendicular angle to the main and right portal veins. In its long course, it is embedded in the transverse fissure (pars transversa) until it reaches the umbilical fissure, turning anteriorly in a perpendicular fashion (pars umbilicalis). The embryological communication of the pars transversa with the inferior vena cava is obliterated in adults, where it is represented by the ligamentum
venosum. The embryological communication of the pars umbilicalis with the placenta is obliterated in adults, where it is represented by the round ligament. The pars transversa usually gives no branches, although it can occasionally provide small branches to segment 4 and the right anterior section. The pars umbilicalis gives multiple terminal medial and lateral branches to the respective left sections. This anatomical pattern is different from the distribution of the branches of the left hepatic artery and left bile duct.

C. Why is this knowledge important during portal vein resection and reconstruction during liver resection?

In cases where the portal vein is compromised, en bloc resections can be performed. These resections include the distal portion of the main portal vein, the bifurcation of the portal vein and the proximal portion of the portal vein of the remnant liver.

During right hemihepatectomy with portal vein resection, dissection of the left portal vein is relatively straightforward due to the fact that the pars transversa of the left portal vein is more accessible, but the reconstruction is complex because the angle of the main portal vein is away from the left portal vein. The main portal vein is ‘held down’ by the small tributaries around the pancreas; dividing these tributaries frees up the main portal vein, rendering it more mobile so it can be directed to the left portal vein. However, this manoeuvre effectively lengthens the available main portal vein; if it is not shortened significantly during its anastomosis to the left portal vein, the reconstruction may be redundant and can kink after the liver is returned to its natural position and the retraction of the intestines is released (Fig. 62.26).

In marked contrast, although dissection during left hemihepatectomy with portal vein resection is more complex, the reconstruction is straightforward because the main portal vein and the dorsal right portal vein have the same angle and a similar diameter (Fig. 62.27).

3. A healthy 45-year-old woman wishes to donate part of her liver to her friend, who suffers from primary sclerosing cholangitis. She undergoes multidisciplinary evaluation and is found to be a suitable right hemiliver donor (Fig. 62.28).
A. Briefly describe the anatomy of the biliary system in the right hemiliver.

The right biliary system drains the right hemiliver. Anatomical variations are extremely common. Although subsegmental and segmental ducts may drain directly into the right hepatic duct, the normal anatomy is as follows: segment 6 bile duct (B6) and segment 7 bile duct (B7) come together to form the right posterior hepatic duct (RPHD), while the segment 8 duct (B8) and segment 5 duct join to form the right anterior hepatic duct (RAHD).

The course of the RPHD can be supraportal (above and behind the right anterior portal vein in 85% of cases) or infraportal (below and in front of the right anterior portal vein in 15% of cases). The drainage of the RPHD is variable. The supraportal RPHD may join the RAHD and form the right hepatic duct (normal anatomy), or it may drain into the biliary confluence or into the left hepatic duct. The infraportal RPHD may join the RAHD and form the right hepatic duct, or drain directly into the common hepatic duct or the cystic duct. Variations of the RAHD are rare but it may drain directly into the common hepatic duct (see Fig. 62.10).

B. Why is knowledge of the anatomy of the extrahepatic right posterior hepatic duct important during cholecystectomy?

Understanding the extrahepatic biliary anatomy is critical during both open and laparoscopic cholecystectomy. Although the inflammatory process
around the gallbladder definitely plays a role, most major bile duct injuries are due to misidentification. Extrahepatic aberrant hepatic ducts may be mistakenly identified as the cystic duct or cystic artery and divided (Fig. 62.29). The most common target for extrahepatic bile duct injury is the RPHD, but the same principle applies in injuries that involve the extrahepatic right hepatic ducts and, infrequently, the RAHD.

![A](image1.png) ![B](image2.png)

**FIG. 62.29**  
A, An intraoperative transcystic cholangiogram of the clinical case showing a right posterior hepatic duct (RPHD) draining into the common hepatic duct (CHD) at the level of the cystic duct. B, An operative view of the hepatoduodenal ligament after cholecystectomy and dissection of the right hepatic artery (RHA). Note how the extrahepatic portion of the right posterior hepatic duct may be susceptible to injury during cholecystectomy in cases where inflammation of the gallbladder infundibulum does not allow precise dissection. Other abbreviation: CBD, common bile duct; RAHD, right anterior hepatic duct.

C. Why is this knowledge important during a right hemihepatectomy for living donation?  
Variable biliary anatomy creates challenges in identifying the RPHD during hilar dissection and the number of bile ducts that require reconstruction in the recipient. An infraportal RPHD is associated with the most favourable outcome after biliary reconstruction, while supraportal RPHD variations are associated with higher morbidity, particularly among donors with a short right hepatic duct (<14 mm) and a long cephalic segment.
(>13 mm) of a supraportal RPHD. If the division plane of the hilar plate after division of the RAHD followed the mid-liver plane, the caudal segment of the supraportal duct could be denuded or sometimes directly even injured during transection. Division of the hilar plate after division of the RAHD should therefore be perpendicular to the axis of the duct.
Mastering operations within the complex right upper quadrant requires a solid fund of anatomical expertise. Surgeons who dedicate themselves to understanding the anatomy of the pancreas, gallbladder and biliary tree are rewarded not only with a better appreciation of disease pathogenesis and biological behaviour, but also with the skills to anticipate and plan for
operative challenges and pitfalls.

**Embryology**

Development of the pancreas occurs in tandem and in close association with that of both the duodenum and the biliary system. Ventral and dorsal evaginations of the endodermal epithelium form at the junction of the foregut and midgut, and proliferate into the relevant mesogastria, which contain splanchnopleuric mesenchyme. The dorsal pancreatic bud is seen in stage 13 (31–33 days post fertilization) and the ventral pancreatic bud arises in stage 14 (32–34 days post fertilization) from the neohepatic diverticulum in close approximation with the developing bile duct. The ventral pancreatic bud and the bile duct rotate from a position within the ventral mesogastrium to one in the dorsal mesogastrium. By stage 17 (39–41 days post fertilization), the ventral and dorsal pancreatic buds have fused. Three-dimensional reconstruction of the ventral and dorsal pancreatic buds has confirmed that the dorsal bud forms the anterior part of the head of the pancreas, the pancreatic body and tail, and the ventral bud forms the posterior part of the head of the pancreas and the posterior part of the uncinate process. At this stage, the hepatic ducts and gallbladder are also lengthening. The dorsal mesoduodenum is affected by movements of the dorsal mesogastrium (with which it is continuous cranially) and the formation of the lesser sac, and the pancreas continues to grow retroperitoneally and extend into the splenorenal ligament.

The ventral pancreas forms the proximal portion of the major duct of Wirsung, which is joined with the common bile duct (CBD) in a Y configuration forming the hepatopancreatic ampulla of Vater. Persistence of the ventral pancreatic bud is thought to contribute to the formation of choledochal cysts due to the anomalous union of the pancreatic and biliary ducts. Indications for surgical management of choledochal cysts include high-risk features of malignancy (nodule or thickening of the cyst) or presence of stones, debris or obstruction due to the cyst. The majority of choledochal cysts (types I and IV) are treated with total extrahepatic excision followed by Roux-en-Y hepaticojejunostomy or hepaticoduodenostomy.

The hepatopancreatic ampulla then opens on the medial wall of the second part of the duodenum at the major duodenal papilla. The distal component of the major pancreatic duct and the entire minor pancreatic duct of Santorini are formed by the dorsal pancreas. Conventionally, the minor duct
fuses with the major duct, forming a common channel. This entire region is known as the pancreaticobiliary junction, and in some cases, the CBD and pancreatic duct may unite outside the duodenal wall to form an abnormally long common channel.  

Fusion of the pancreatic ducts occurs late in development or in the postnatal period, and 85% of infants have patent accessory ducts. Failure of fusion of the primordial dorsal and ventral pancreas results in pancreas divisum, whereby the body, tail and parts of the pancreatic head are drained by the minor duct of Santorini. Individuals with this anatomical variation may have a greater predisposition for recurrent pancreatitis secondary to a heightened tendency for stone and stricture formation, although this remains controversial. For surgeons, this varied anatomy is important, as up to 10% of patients may have their major pancreatic duct drainage occurring through the minor duct. The minor duct courses near the gastroduodenal artery (GDA), which is commonly ligated during duodenal surgery, and care must be taken to avoid injuring this structure in procedures that do not involve resection of the pancreatic head.
Pancreatic head and neck

Surgical surface anatomy

The pancreas lies in the retroperitoneum, sequestered from the plethora of abdominal organs. This location partly accounts for the insidious nature of pancreatic diseases and makes their management challenging. The pancreas is a smooth, soft gland with a lobulated surface and a shape conventionally described as a flattened tongue. The pancreas proper is divided into four anatomical zones: head, neck, body and tail (Fig. 63.1). The uncinate process may also be considered as a fifth zone with its own unique anatomical relationships. For the purposes of this chapter, the uncinate process will be considered as part of the pancreatic head. Major pancreatic divisions are described in relation to the superior mesenteric artery (SMA) and vein (SMV), which course posteriorly to the pancreas. The pancreatic head lies laterally to the right of these vessels and the neck lies anteriorly, essentially linking the head to the pancreatic body and tail.
When approached anteriorly, the pancreatic head and neck are obscured by the stomach, greater omentum and transverse colon (see Fig. 63.1B). Anterosuperiorly, the pancreatic head and neck are near the gastric antrum and pylorus, and subsequently surrounded by the second and third portions of the duodenum, resulting in a ‘bare area’ that is devoid of any peritoneum. Inferiorly, the pancreatic head shares a close relationship with the transverse colon. Furthermore, the pancreatic neck serves as a landmark for the origin of the transverse mesocolon and the middle colic artery, which arises from
the SMA. In addition, the inferior border of the pancreas lies superiorly to the third and fourth portions of the duodenum, leading to the ligament of Treitz and the duodenal-jejunal flexure.

The anterior surface of the pancreas is covered by a layer of visceral peritoneum, separate from the peritoneum that surrounds the neighbouring anterior structures. Access to the anterior pancreatic head and neck may be achieved through several routes when considering its anatomical relationships. Division of the gastrocolic ligament, which runs as an avascular plane between the stomach and transverse colon along the greater omentum, permits entry into the omental bursa (or lesser sac). Further dissection of the peritoneum posteriorly to the stomach will expose the pancreas. This is a route favoured by many surgeons when performing pancreatic resections or requiring access to this area for pancreatic trauma. Access to the lesser sac, and therefore the pancreatic head and neck, may be obtained through the stomach, an approach that is relevant when managing penetrating injuries of the stomach, and exploited clinically in patients requiring endoscopic drainage of symptomatic pancreatic pseudocysts secondary to pancreatitis. Finally, another route of access to the pancreatic head and neck is through the transverse mesocolon. Clinically, this approach carries no significant advantage over the others, and access through this structure risks injury to the middle colic vessels that supply the colon. However, this close anatomical relationship is of importance, particularly in patients with pancreatic neoplasia and retrocolic Roux-en-Y anastomoses to the stomach, as this limb may become obstructed by large pancreatic tumours. More commonly, exposure of the pancreatic head and neck is achieved through removal of the greater omentum from the transverse colon, allowing for a wide exposure of the entire pancreas.

Posteriorly, the pancreatic head and neck are covered by a layer of tissue referred to as the fusion fascia of Treitz. This loose connective tissue provides a boundary between the pancreatic parenchyma proper and the structures of the retroperitoneum: specifically, the superior mesenteric vessels, splenic vessels and portal vein (PV). Furthermore, the major posterior pancreaticoduodenal arcades supplying the pancreas are located between the fascia and the posterior surface of the pancreas.

In procedures such as pancreaticoduodenectomy, colloquially referred to as the Whipple procedure, one of the key early steps involves mobilization of the pancreatic head and neck. As these structures are intimately associated with the duodenal C-loop, mobilization of the entire complex is required, and
this is referred to as the Kocher manœuvre. This manœuvre starts along the longitudinal plane of the second part of the duodenum (D2) by incising the peritoneum between D2 and the inferior vena cava posteriorly. Dissection in this space permits exposure of the posterior duodenum (important for exposure in retroduodenal perforations), as well as the posterior pancreatic head and neck. In performing the Kocher manœuvre, the fusion fascia of Treitz remains on the pancreatic side and leaves a bare caval side. Therefore, the dissection plane remains avascular as the pancreaticoduodenal arcades are carried with the pancreas. Posteriorly, the inferior vena cava, left renal vein and aorta are exposed as the pancreas is rotated off the retroperitoneum, with eventual exposure of the SMA and SMV.

Identification of the SMV inferiorly is critical in operations on the pancreatic head and neck, as it conventionally serves as the location of pancreatic transection. A quick way to find the SMV is by identifying the middle colic vein located in the transverse mesocolon and following it proximally until it joins with the right gastroepiploic vein, forming the trunk of Henle, which inserts into the SMV. However, the surgeon should exercise caution when following this approach because a variety of small venous tributaries may be encountered. At the level of the pancreatic neck, the SMV commonly joins the splenic vein to form the PV, which then courses superiorly into the hepatoduodenal ligament, and eventually the liver. In most cases, the anterior surface of the SMV and PV has no vascular branches, and this allows for safe dissection between these structures and the posterior surface of the pancreatic neck. This is also important for management of retropancreatic PV, SMV and SMA injuries, as exposure may be achieved quickly by negotiating this avascular plane along with subsequent transection of the pancreatic neck.

**Clinical anatomy and variants**

**Arterial supply**

The arterial system of the pancreatic head and neck is supplied by a rich vascular network originating from both the coeliac axis and the SMA (Fig. 63.2).
FIG. 63.2  A, The arterial supply of the pancreas. B, A CT angiographic reconstruction. The black arrow shows the coeliac trunk, and the white arrow shows the superior mesenteric artery. Anastomotic arcades, both ventral and dorsal, can be seen coursing around the head of the pancreas. The body and tail of the pancreas are supplied by multiple pancreatic branches (PB) from the splenic artery and the dorsal pancreatic artery (DPA), which, in this example, arises from the superior mesenteric artery and gives origin to the transverse pancreatic artery (TPA). Other abbreviations: AIPD, anterior inferior pancreaticoduodenal artery; ASPD, anterior superior pancreaticoduodenal artery; CHA, common hepatic artery; GDA, gastroduodenal artery; IPD, inferior pancreaticoduodenal artery; LGA, left gastric artery; LHA, left hepatic artery; PIPD, posterior inferior pancreaticoduodenal artery; PSPD, posterior superior pancreaticoduodenal artery; RGE, right gastroepiploic artery; RHA, right hepatic artery; SA, splenic artery. C, The anterior and posterior pancreaticoduodenal arterial arcades and a typical communicating artery. (Adapted with permission from S.A. Mirjalili, M.D. Stringer, The arterial supply of the major duodenal papilla and its relevance to endoscopic sphincterotomy, Endoscopy 43 (2011) 307–311.)

This blood supply is also shared by the other structures located in this region: specifically, the duodenum, the bile ducts and the liver. The vasculature is structured as a series of arcades with numerous branches supplying the pancreas. As a consequence, an anatomical system of redundancy is created, protecting the critical functions of the pancreas (and other organs) from pathology of the source blood vessel. Although the
conventional anatomy will be described, arterial variation does exist and will be highlighted, where clinically relevant.

The pancreatic head/neck, along with the duodenal C-loop, is supplied by four major pancreatic arcades. Along the right superior border of the pancreas, the coeliac axis can be identified by dissecting through a filmy, often transparent, layer of peritoneum known as the hepatogastric ligament, located between the stomach and the hepatoduodenal ligament that contains the portal structures. The Spigelian lobe of the caudate lobe of the liver will be encountered along with the stomach and oesophagus. Posterior to these structures is the peritoneum overlying the aorta and the coeliac axis. This anatomy is of importance when control of the supraceliac aorta is required, particularly for trauma or for evaluation of pancreatic neck masses invading the coeliac axis, when a modified Appleby procedure is required. The Appleby procedure was originally developed for management of locally advanced gastric cancer that invades the neck of the pancreas and the coeliac axis. In these cases, it is important to confirm retrograde flow from the SMA through the GDA for perfusion of the liver. Planned arterial resection at the time of pancreatectomy may then be performed safely.

The coeliac axis has three major divisions: the common hepatic artery (CHA), the splenic artery and the left gastric artery. The CHA courses in the direction of the hepatoduodenal ligament and branches into the hepatic artery proper and the GDA. The GDA courses inferoposteriorly to D2 and branches into the right gastroepiploic artery (which courses in the greater omentum) and the pancreaticoduodenal artery, at the level of the first part of the duodenum (D1). The pancreaticoduodenal artery further branches into the anterior–superior (ASPD) and posterior–superior (PSPD) pancreaticoduodenal arteries. The ASPD is responsible for blood supply to the pancreatic head/neck, uncinate process, ventral duodenum and proximal jejunum, whereas the PSPD supplies the dorsal surfaces of the aforementioned and the distal CBD. Of clinical importance, identification of the GDA is critical during a pancreaticoduodenectomy, and often may be discovered by identifying the hepatic artery during dissection of the hepatoduodenal ligament and then following this artery proximally to where it joins with the CHA. Exposure of the CHA and the GDA may also be greatly facilitated by removal of the CHA lymph node, otherwise known as the station 8A node. In addition, during the dissection carried out for a pancreaticoduodenectomy, jejunal branches of the ASPD should be identified and preserved in order to ensure viability of the proximal jejunum.
When the duodenum is mobilized, the CBD branch of the PSPD (termed the artery of the papilla of Vater) often courses anteriorly and to the right of this structure distally. Compromise of this vessel may result in devascularization and unwanted ischaemia of the CBD and D2.\textsuperscript{14}

The second major vascular arcades arise from branches of the SMA. The SMA courses through the root of the small bowel mesentery at the inferior border of the pancreas and anterior to the uncinate process. In this location, the SMA branches into the inferior pancreaticoduodenal artery (IPD), which runs behind the SMV, and further subdivides into the anterior inferior (AIPD) and posterior inferior (PIPD) pancreaticoduodenal arteries. These branches will then fuse at the level of the pancreatic head, either anteriorly or posteriorly, with their respective superior counterparts, forming an arcade. In up to 56\% of patients, the IPD is non-existent, and the AIPD and PIPD arise from a common pancreaticojejunal trunk with the first-order jejunal branches.\textsuperscript{15} After giving off this first-order branch, the IPDs course posterior to both the SMA and the SMV towards the pancreatic head. Knowledge of this variation is important during mobilization of the third portion of the duodenum and the ligament of Treitz because this jejunal branch may be injured and cause vascular compromise of the fourth portion of the duodenum. In approximately one-quarter of individuals, the AIPD and PIPD arise as separate branches from the SMA.

The splenic artery forms the major blood supply to the body and tail of the pancreas. It contacts the gland approximately 2 cm to the left of the neck of the pancreas on its superior border and runs posteriorly. Of note, in this location the splenic artery branches into the dorsal pancreatic artery, which courses posteriorly and to the left of the pancreatic neck. However, it does give off a right branch posteriorly, which unites with the posterior arcade, and therefore supplies a portion of the dorsal pancreatic head and neck. No branches to the pancreatic head or neck arise from the left gastric artery. However, awareness of the left gastric artery is important because it occasionally may give rise to a replaced left hepatic artery, which may be located in the hepatogastric ligament, and this must be excluded prior to any dissection of this region.

**Venous drainage**

Venous anatomy of the pancreatic head and neck is important in oncological surgery of this region because venous involvement has an impact on prognosis of disease and may also mandate an alternative surgical approach.
The anterior surface of the SMV and PV are commonly devoid of any branches. This facilitates dissection of the pancreas in procedures such as pancreaticoduodenectomy, although surgeons must be aware that this is not always the case.\textsuperscript{16}

Anatomy of the SMV is variable and complex. At the level of the uncinate process, the SMV is formed by the union of two major first-order branches, an ileal branch and a jejunal branch\textsuperscript{17} (Fig. 63.4).
These branches represent the drainage vessels for the small intestine and the ascending/transverse colon. The ileal branch is often larger and more vertically oriented in a cranio-caudal fashion, whereas the jejunal branch courses posterior to the SMA to join the ileal branch in forming a common trunk at the root of the small bowel mesentery. In up to 10% of individuals, these two branches remain separate and each inserts into the splenic vein. In this scenario, the jejunal branch remains anterior to the SMA. When mobilization of the SMV is performed during pancreaticoduodenectomy with a posterior jejunal branch, venous branches to the uncinate must be ligated.
to separate it from the jejunal branch. With an anterior jejunal branch, the uncinate branches usually empty directly into the ileal branch, precluding its ligation. Furthermore, an anterior jejunal branch should suggest a high probability of variant vascular anatomy, such as lack of a common SMV trunk. When tumour involves the infrapancreatic SMV, often one of these branches may be ligated, relying on the anastomotic networks present between the ileal branch and the jejunal branch.

The ASPD vein joins with the right gastroepiploic vein above the merging point of the ileal branch and jejunal branch, and, together with the middle colic vein, inserts into the SMV as the trunk of Henle at the inferior border of the pancreatic neck. However, in up to 50% of patients, these vessels may drain separately into the SMV and possibly along its anterior surface. The PSPD commonly enters the PV directly above the superior margin of the pancreas; the IPD veins enter the SMV along the inferior pancreatic neck. Typically, the inferior mesenteric vein (IMV) courses along the duodenal–jejunal flexure and under the inferior margin of the pancreatic body to insert into the splenic vein. Therefore, the inferior margin of the pancreas is a landmark for identification of this vessel, particularly during colonic resections when division may be required. Surgeons must recognize if the IMV inserts along the confluence of the SMV/PV, or into the jejunal branch of the SMV, so as not to mistake the IMV for this higher-order SMV branch.

An important application of this detailed vascular anatomy is apparent when cancer involves the PV, preventing safe ‘tunnelling’, and subsequent dissection in a pancreaticoduodenectomy. This has led to a procedure known as the Whipple at the splenic artery (WATSA), whereby the SMV and PV are identified and controlled superior and inferior to the gland, and the pancreas is transected to the right of the contact point of the splenic artery. In this procedure, the various venous tributaries, including the IMV insertion point, are identified and ligated as deemed appropriate. Finally, the location of vessel insertion in relation to the pancreatic duct is critical. The surgeon should be aware that these vessels insert posterior to the pancreatic duct, allowing for avascular access to the anterior surface. This is of importance in patients with chronic pancreatitis and ductal dilation who require operative decompression in the form of a lateral pancreaticojejunostomy, also referred to as a Puestow procedure (Fig. 63.5). In this procedure, the anterior surface of the pancreatic duct is incised and anastomosed to a limb of the jejunum.
Pancreatic body and tail

Surgical surface anatomy

The blood supply of the body and tail of the pancreas arises from the dorsal pancreatic artery and other branches originating from the splenic artery. In addition, small arteries run within the parenchyma along the superior and inferior borders and are fed by the splenic and/or pancreaticoduodenal arteries. The lymphatic drainage of the left half of the pancreatic body and tail is typically to the splenic hilum lymph nodes (station 10). Tumours within the superior and inferior borders of the right half of the pancreatic body typically drain to the infrapancreatic and gastroduodenal lymph nodes, and are not addressed in a standard distal or subtotal pancreatectomy.

The distal pancreas is covered anteriorly by the parietal peritoneum. Posteriorly, the anterior renal fascia overlies the kidney, forming a potential cavity known as the anterior pararenal space\(^1\) (see Fig. 56.2).

This space is of clinical importance when performing a standard retrograde anterior modular pancreaticosplenectomy (RAMPS) where the anterior pararenal fascia (Gerota’s fascia) is removed with the specimen. RAMPS was developed in an attempt to reduce the rate of positive resection margins and low lymph node counts, with good success for resections of cancers of the body and tail of the pancreas.\(^2\) In a posterior RAMPS for tumours abutting or involving the fascia, the anterior renal fascia along with the left suprarenal gland, is removed with the specimen.

Clinical anatomy and variants

A thorough understanding of pancreatic body and tail anatomy is critical for procedures not involving the duodenum or distal bile duct. Resection and reconstructive procedures of the pancreatic body and tail are performed for a variety of benign and malignant conditions, such as chronic pancreatitis, neuroendocrine tumours, symptomatic recalcitrant pseudocysts, pancreatic trauma, pancreatic adenocarcinoma, and cystic and solid neoplasms of the pancreas. The standard approach for resection of the body and tail of the pancreas is via an upper midline laparotomy that reaches from the xiphoid process to the umbilicus. Alternatively, a bilateral subcostal incision or a laparoscopic approach may be employed.
Arterial supply
The transverse pancreatic artery, also known as the inferior pancreatic artery, arises from the dorsal pancreatic artery and gives off multiple branches to the body and tail. Occasionally, it originates from the GDA or the ASPD, crossing the anterior surface of the pancreatic head in order to reach the inferior border of the neck, body and, eventually, tail of the gland.

Venous drainage
The venous drainage of the pancreatic body and tail is of particular importance in the RAMPS procedure. A tunnel overlying the SMV is created inferiorly to meet the superior pancreatic dissection. The right gastric artery and coronary vein are ligated and the GDA is retracted to the right side in order to facilitate the exposure. The pancreas is divided at this point, which allows for dissection on to the coeliac trunk and identification, dissection and isolation of the splenic artery and vein. The splenic vein is encircled and ligated at the SMV junction, followed by the splenic artery. If there is tumour invasion, the portion of the vein can be excised and reconstructed. Vascular involvement along the splenic vein is almost always due to pancreatic body and tail tumours. However, the vascular encasement not only may extend to the splenic vein, but also may involve the IMV and short gastrics, and sometimes extend into the transverse mesocolon. Therefore, diligence is important to evaluate the extent of tumour spread. A RAMPS procedure is typically adequate to provide an en bloc R0 resection, though, sometimes, adjacent organs (that is, colon and stomach) or vessels (coeliac) must be partially resected. Of note, the R classification describes pathological specimen resection margins as follows: R0 to clear margin, R1 to microscopic residual tumour and R2 to macroscopic residual tumour.
Gallbladder

Surgical surface anatomy

The gallbladder is a small, hollow organ connected to the CBD via the cystic duct. The gallbladder stores, concentrates and releases bile to the duodenum in response to the hormone cholecystokinin (CCK), aiding in fat digestion.

The gallbladder resides in a shallow fossa firmly attached by connective tissue to the liver between segments 4B and 5. It is covered by peritoneum that is continuous with the visceral surface of the liver. Rarely, the gallbladder may be intrahepatic or connected to the duodenum by the cystoduodenal ligament, increasing the risk of torsion.22 Along the inferior liver surface just posterior and inferior to the gallbladder is the fissure of Gans, or Rouvière's sulcus, which overlies the point at which the right posterior pedicle gives off the inferior segment 6 branch. This anatomical landmark is crucial to identify, and often used as a guide during laparoscopic cholecystectomy, because the cystic duct and artery course anterosuperiorly to the sulcus, while the CBD lies posteroinferiorly.

The gallbladder is divided into the fundus, body and neck. The fundus is located at the lateral end of the gallbladder, and frequently projects beyond the inferior border of the liver adjacent to the transverse colon. The body lies within the gallbladder fossa and continues medially until tapering into the neck. The neck is adjacent to the porta hepatis, and typically has a mesentery to the liver through which the cystic artery courses.

The cystic plate is part of the perihilar system of fibrous tissue just anterior to the hepatic parenchyma and sits between the liver and the gallbladder. Small bile ducts, less than 1 mm in size and known as ducts of Luschka, may enter the gallbladder's posterior wall through the cystic plate. In 5% of patients, large bile ducts deep to the cystic plate may exist, arising from the orifice of segment 6, 7 or the right posterior sector duct, from which bile leakage may occur.23 Prior to ligating one of these small ducts, cholangiography is recommended to avoid compromise of a draining duct. Ligation of the ducts of Luschka can be performed safely and without adverse outcomes, as these ducts only penetrate the liver for about 1 cm.24 When gallbladder cancer is encountered or suspected, it is critical to excise the entire cystic plate and a rim of tissue from sections 4B and 5 to ensure a clear resection margin. A portal lymphadenectomy is also needed for proper staging. Thus, understanding the potential for draining ducts in this area is
critical.

The length of the cystic duct is usually 2–4 cm. It passes posteriorly and medially from the neck of the gallbladder to unite with the common hepatic duct and form the CBD. The cystic duct mucosa has 2–10 crescentic folds that create an internal spiral contiguous with those in the gallbladder neck. The cystic artery typically arises from the right hepatic artery and runs within the hepatocystic triangle before coursing on to the anterior surface of the gallbladder, where it gives off its tributaries.

Clinical anatomy and variants

Laparoscopic cholecystectomy is one of the most commonly performed operations in the United States. Thus, a thorough understanding of gallbladder anatomy and variants is critical for the practice of any surgeon.

The hepatocystic triangle is bordered by the common hepatic duct to the left, the margin of the right lobe of the liver superiorly and the proximal part of the gallbladder and cystic duct to the right. The original triangle of Calot is smaller and the cystic artery forms its superior border (Fig. 63.6). The hepatocystic triangle is covered by a double layer of peritoneum and contains a variable amount of lymphatics, autonomic nerves, fatty connective tissue, the cystic artery and occasionally an accessory bile duct.
The critical view of safety (CVS) is a surgical approach that is used to identify the cystic artery and cystic duct; when employed, it has been shown to reduce bile duct injury.\textsuperscript{26,27} A video is available to review the components of the CVS.\textsuperscript{28} Completion of the CVS requires three components in both the anterior and the posterior views to be satisfied\textsuperscript{29}: complete clearance of the hepatocystic triangle of fat and fibrous tissue; identification of only two structures connected to the gallbladder (the cystic artery and cystic duct); and elevation of one-third of the base of the gallbladder off the cystic plate.

Unfortunately, the CVS cannot be safely obtained in some patients due to inflammation, bleeding, or anatomical variations that preclude safe dissection at the neck of the gallbladder. When this situation occurs, the surgeon should adopt alternative techniques for addressing the gallbladder disease. Such techniques include early cholangiography performed through the gallbladder, tube cholecystostomy, partial cholecystectomy, retrograde or ‘top down’ approach, and asking for assistance from another experienced surgeon.\textsuperscript{30} Conversion to open cholecystectomy is also advised if the surgeon is comfortable with open biliary surgery. Failure to employ these techniques when anatomy is unclear and CVS cannot be achieved results in a
significantly increased risk of bile duct injury. Additional variants that may
be encountered include a double or absent cystic duct, or the cystic duct
receiving an anomalous hepatic duct from segment 5 of the liver. Variable
cystic arterial anatomy must also be appreciated (Fig. 63.7).

![Variant anatomy of the cystic artery. From S. Standring (ed.), Gray's
Anatomy, forty-first ed. © Elsevier, 2016, Fig. 68.10.]

Although review of all variations is beyond the scope of the chapter, the
surgeon should know that the cystic artery may arise from the hepatic artery
proper and cross anterior to the CBD or common hepatic duct, prior to
joining the gallbladder.
Extrahepatic biliary tree

Surgical surface anatomy

The hepatoduodenal ligament is a bundle of anatomical structures located within the lesser omentum and containing the proper hepatic artery, PV and CBD. The hepatoduodenal ligament terminates superiorly and inferiorly at the liver and duodenum, respectively. Medially, the ligament is bordered by the hepatogastric ligament (lesser omentum), and its lateral border forms the anterior boundary of the epiploic foramen of Winslow. The foramen serves as one approach for access to the lesser sac. Isolation and compression of the hepatoduodenal ligament is a critical surgical skill, also known as the Pringle manoeuvre, used to reduce hepatic bleeding. This manoeuvre can be performed by dividing the hepatogastric ligament medially, and encircling the hepatoduodenal ligament with a clamp or finger.

The right and left hepatic ducts exit the liver and unite to form the common hepatic duct within the hepatoduodenal ligament, to the right of the porta hepatitis. The right extrahepatic duct is typically short (0.5–2.0 cm) and vertically orientated, whereas the left duct is longer (1.5–3.5 cm) and more oblique. The common hepatic duct lies anterior to the PV and to the right of the hepatic artery. It is then joined by the cystic duct to form the CBD. The CBD courses above the duodenum for 3–4 cm and then passes within or behind the pancreas to enter D2. In about 2% of patients, the right hepatic ducts may insert low, where the right hepatic sectional ducts join the common hepatic duct close to the entry of the cystic duct. Additionally, the right hepatic artery may become adherent to the gallbladder in the setting of inflammation or fibrosis. This tethering effect, with obliteration of normal anatomy, can place the patient at risk of a vasculobiliary injury during laparoscopic cholecystectomy.31

When the CBD joins the duodenum, a segment remains behind the first portion of the duodenum with the GDA and to its left side. It then enters the pancreas and runs in a groove on the posterior surface of the pancreatic head, and may be embedded into the gland. In addition, the PSPD branch of the GDA courses anteriorly to the CBD at the superior border of the pancreas prior to twisting around the right side of the bile duct, and travelling to the posterior surface of the head of the pancreas. As previously discussed, vigilance must be exercised when dissecting the duct at this location to avoid compromise of this vessel.
Clinical anatomy and variants

The hepatic ducts and CBD receive their arterial blood supply from several sources. The CBD typically has a network of 2–4 small arteries travelling at the 3 and 9 o'clock positions around the circumference of the duct. Branches may arise from the right hepatic artery and cystic artery superiorly, the PSPD artery/retroduodenal artery (branches from the GDA), and a retroportal artery from the SMA or coeliac trunk inferiorly. The retroduodenal and pancreatic segments of the CBD are less well vascularized, and therefore it is important to avoid dissection of this segment in order to avoid ischaemic injury and possible subsequent stricture. During a CBD exploration, a choledochotomy is conventionally performed longitudinally, as opposed to transversally along the mid-CBD, in order to avoid the aforementioned arterial branches located along its medial and lateral borders. Venous drainage of the CBD and hepatic duct occurs through two small cystic veins that drain into either the PV branches within the liver or into the portal venous plexuses.32

While comfort with extrahepatic biliary duct anatomy is essential for the treatment of many different disorders, bile duct injury is unfortunately one of the more common indications for biliary surgery. There are many possible causes of bile duct injury, although unfamiliarity with anatomical variants of the biliary and vascular tree, along with surgeons’ inexperience, would be the most common. The Strasberg classification system is utilized to describe the different types of bile duct injury that may be encountered (Fig. 63.8).
FIG. 63.8 The Strasberg classification system for biliary injury. Class A: injury to small ducts in continuity with the biliary system, including the duct of Luschka or the cystic duct. Class B: injury to a sectoral duct with obstruction and no bile leak. Class C: injury to a sectoral duct with bile leak from a duct. Class D: a lateral injury to extrahepatic biliary ducts. Class E1: injury >2 cm from the bifurcation of the right and left bile ducts. Class E2: injury <2 cm from the bifurcation of the right and left bile ducts. Class E3: injury at the bifurcation of the right and left bile ducts. Class E4: injury involving the right and left bile ducts but without the lumens in continuity. Class
E5: complete occlusion of all bile ducts either from injury or from injury in combination with stricture. (Adapted from A.W. Alseidi, R.K. Smith, W.S. Helton, Bile duct injury. In: L.J. Moore (ed.), Common Problems in Acute Care Surgery, New York: Springer Science and Business Media, 2013, Fig. 21.2.)

While bile duct injury can be primarily repaired, this approach is not recommended for complete bile duct transection. If more than 50% of the circumference of the bile duct is surgically divided or thermally damaged, disruption of the bile duct wall is best managed by Roux-en-Y hepaticojejunostomy (Fig. 63.9) or choledochoduodenostomy, depending on the health of the duodenum and the location of the injury along the bile duct.
FIG. 63.9 Completion of the anastomosis in the presence of a transhepatic transanastomotic stent. A, The posterior row of fine, interrupted, absorbable sutures is placed from the bile duct to the jejunum. B, After the posterior row is secured, the distal portion of the stent is passed into the lumen of the bowel with a forceps. C, The anterior row of interrupted sutures is then placed and serially tied. D, The completed anastomosis; the upper end of the silastic catheter is brought out through the skin. (Adapted from K. Lillemoe and W. Jarnagin, Master Techniques in Surgery: Hepatobiliary and Pancreatic Surgery, Wolters–Kluwer, October 2012, ISBN 9781608311729, Fig. 17.12.)

This procedure is conventionally performed by creating an anastomosis between the end of the bile duct and the side of the jejunum. Injuries located
below or at the biliary bifurcation, without compromise to the left or right hepatic duct in a patient with a well-vascularized and patent duct (greater than 8 mm), may be safely managed with a Roux-en-Y hepaticojejunostomy. The Hepp–Couinaud approach, with a side-to-side anastomosis, is preferred and associated with the best long-term results.\textsuperscript{33,34}

### Tips and Anatomical Hazards

- **Pancreas:** recognition of pancreas divisum and awareness of surgical implications.
- **Gallbladder:** awareness of potential aberrant cystic duct and/or cystic artery anatomy.
- **Biliary tree:** awareness of potential aberrant biliary anatomy, including the possibility of a choledochal cyst being present.
References


33. Myburgh JA. The Hepp-Couinaud approach to strictures of

1. The pancreatic neck serves as a landmark for the origin of the transverse mesocolon and which one of the following?
   A. Middle colic artery arising from the superior mesenteric artery
   B. Middle colic artery arising from the inferior mesenteric artery
   C. Ileocolic artery arising from the superior mesenteric artery
   D. Ileocolic artery arising from the inferior mesenteric artery

   **Answer:** A.

2. The critical view of safety requires an anterior and a posterior view, including clearance of the hepatocystic triangle of fat and fibrous tissue and which one of the following?
   A. Two structures connected to the gallbladder and the lower half of the cystic plate elevated
   B. Two structures connected to the gallbladder and clearance of Calot's triangle
   C. Two structures connected to the gallbladder and the lower third of the cystic plate elevated
   D. Two structures connected to the gallbladder and identification of Calot's node

   **Answer:** C.

3. A 75-year-old female presents with painless jaundice. A CT scan demonstrates a 2.4 cm mass in the pancreatic head with dilation of the pancreatic duct to 5 mm and dilation of the common bile duct to 10 mm. A decision is made to take the patient to the operating room for a Whipple procedure. The operation is started by performing medialization of the duodenum (Kocher manoeuvre). Which one of the following is NOT a boundary for this manoeuvre?
A. Inferior vena cava
B. Origin of the superior mesenteric artery
C. Left renal vein
D. Superior mesenteric vein
E. Common bile duct

**Answer: B.**

4. In the same patient, a portal dissection is now being completed as part of the Whipple procedure. During dissection of the common bile duct, a pulsating vasculature structure is identified posterior to the duct and adjacent to the portal vein and the retroportal lymph nodes. Which one of the following vascular structures is this likely to represent?

A. Replaced left hepatic artery
B. Replaced right hepatic artery
C. Main posterior section branch of the proper hepatic artery
D. Perforating artery to the common bile duct

**Answer: B.**
Clinical cases

1. A 25-year-old male involved in a motor vehicle crash is hypotensive with a positive Focused Assessment with Sonography in Trauma (FAST) examination. He is taken to the operating theatre for exploratory laparotomy. When the abdomen is entered, a large volume of blood is encountered and all four quadrants of the abdomen are packed. The quadrants are examined systematically and the source seems to be coming from the right upper quadrant.

A. Which one of the following manoeuvres would be the most efficient for controlling haemorrhage temporarily?

A. Placement of an aortic clamp
B. Placement of a clamp around the portal vein
C. Placement of a clamp around the portal vein, hepatic artery and common bile duct
D. Packing the liver

Answer: C. Placement of a clamp around the portal vein, hepatic artery and common bile duct would be the most efficient.

B. You suspect an injury to the pancreas and elect to enter into the lesser sac. Describe the various approaches to entry into the lesser sac.

Entry into the lesser sac can be achieved through a variety of techniques. The most common method of entry is by division of the gastrocolic ligament, which serves as an avascular plane. Division of this ligament separates the stomach from the transverse colon and greater omentum, exposing the anterior wall of the pancreas and the posterior wall of the stomach. Access can also be achieved by division of the hepatoduodenal ligament (lesser omentum), exposing the superior border of the pancreas. Other methods of entry include an infracolic approach through the transverse mesocolon, entry from the epiploic foramen of Winslow or a transgastric approach.

C. You elect to enter the lesser sac through the gastrocolic ligament. On performing this manoeuvre, you encounter brisk bleeding. What is the cause of this bleeding?
The gastrocolic ligament separates the stomach superiorly from the transverse colon inferiorly. It generally lies inferior to the right gastro-epiploic pedicle (artery/vein). In obese individuals, for example, identification of this pedicle can be quite challenging and therefore it can be injured when an attempt is made to enter the lesser sac. Should this occur, the vascular structures should be controlled and ligated. Often, this manoeuvre has no long-term consequence for nearby organs due to the rich anastomotic network from the short gastric vessels, the left gastro-epiploic pedicle and the right and left gastric artery/vein.
The spleen is a large, encapsulated, complex mass of vascular and lymphoid tissue situated in the upper left quadrant of the abdominal cavity between the fundus of the stomach and the diaphragm (Fig. 64.1). For centuries, the spleen was thought to be the seat of melancholy. In 1521, the great German artist Albrecht Dürer (1471–1528) sent a sketch to his physician, requesting that his spleen be removed because he was depressed. It is clear from the sketch that Dürer knew the correct anatomical location of the spleen, although at that time its function was not understood. Henry Gray was 26 years old when he received the Astley Cooper Prize for his dissertation on the spleen\(^1\); in 1858, he published the first edition of the book that would eventually become known as *Gray’s Anatomy*.\(^2,3\)

<table>
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<th>Core Procedures</th>
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<td>• Open splenectomy</td>
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<td>• Laparoscopic splenectomy</td>
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<td>• Hand-assisted laparoscopic splenectomy</td>
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<td>• Partial splenectomy</td>
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<td>• Open/laparoscopic splenulectomy</td>
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The first report of splenectomy in the Western world is credited to Adriano Zaccaria (1549) for the treatment of splenomegaly secondary to malaria. The first ‘partial splenectomy’ was reported by Franciscus Rosetti in 1590. The first splenectomy for malignancy is credited to Karl Quittembaum (1826), although his patient did not survive. In 1895, Zikoff was the first to report operative repair, splenorrhaphy, of a lacerated spleen, and Campos Christo is credited with the first partial splenectomy. Splenectomy may be indicated in a very broad range of quite uncommon diagnoses (Table 64.1). Asplenic patients are at higher risk for infectious complications and at risk for overwhelming post-splenectomy infection (OPSI). Lifelong vigilance on the part of patient and caregivers allows the vast majority of splenectomized individuals to live for a normal lifespan.
Table 64.1
Indications for splenectomy

| Trauma iatrogenic                      | Hemicolectomy                         |
|                                     | Left nephrectomy                       |
|                                     | Procedures at the gastro-oesophageal junction |
| **Haematological conditions**        | Autoimmune Haemolytic Anaemia (AHA)   |
|                                     | Thrombotic Thrombocytopenic Purpura (TTP) |
|                                     | Immune Thrombocytopenic Purpura (ITP)  |
|                                     | Felty’s syndrome                       |
|                                     | Erythrocyte membrane disorders         |
|                                     | Hereditary spherocytosis and elliptocytosis |
| **Erythrocyte enzyme deficiencies** | Pyruvate kinase deficiency             |
|                                     | Glucose-6-phosphate dehydrogenase deficiency |
| **Haemoglobinopathies**              | Sickle cell disease                    |
|                                     | Thalassaemia                           |
|                                     | Primary hypersplenism                   |
| **Neoplastic diseases**              | Hodgkin’s lymphoma                     |
|                                     | Non-Hodgkin’s lymphoma                 |
|                                     | Chronic Myelogenous Leukaemia (CML)     |
|                                     | Chronic Lymphocytic Leukaemia (CLL)     |
| **Primary tumours**                  | Hamartomas                              |
|                                     | Lymphangiomas                           |
|                                     | Haemangioma                             |
|                                     | Littoral cell angiomas                  |
|                                     | Lipomas                                 |
|                                     | Angiomyolipomas                         |
|                                     | Haemangiosarcomas                       |
|                                     | Kaposi’s sarcoma                        |
|                                     | Primary lymphoma of the spleen          |
|                                     | Histiocytic tumours                     |
|                                     | Angiofollicular lymphoid hyperplasia (Castleman’s disease) |
| **Metastatic tumours**               | Melanoma                                |
|                                     | Breast adenocarcinoma                   |
|                                     | Lung cancer                             |
| **Non-malignant conditions**         | Gaucher’s disease                       |
|                                     | Wiskott-Aldric Syndrome                 |
|                                     | Chediak-Higashi Syndrome                |
|                                     | Splenic cysts                           |
|                                     | Splenic abscesses                       |
|                                     | Wandering Spleen and Splenic Torsion    |
**Embryology**

The developing spleen is first seen at the end of the fifth week post fertilization (stages 13–14) as local proliferations of the coelomic epithelium of the dorsal mesogastrium.\(^8\) The epithelium produces mesenchyme cells, which form condensed foci, vascularized by local angiogenic mesenchyme, and coalesce to constitute a lobulated spleen. By 8–9 weeks, the spleen contains thin-walled vascular loops and a vascular reticulum with immature reticulocytes.\(^9\) From week 11, erythrocyte precursors can be seen, followed by macrophages and lymphocytes. Primitive white pulp can be seen from 22 weeks, and by 24 weeks T and B lymphocytes become aggregated.

Movements of the dorsal mesogastrium, associated with the formation of the lesser sac, rotation of the stomach and development of its greater curvature, affect the position of the spleen. As it enlarges, it projects to the left (Fig. 64.2). The spleen remains connected to the dorsal abdominal wall by the splenorenal ligament and to the stomach by the gastrosplenic ligament. A number of congenital splenic anomalies may occur and these include agenesis, polysplenia, accessory spleens and persistent lobulation.\(^{10}\)
FIG. 64.2 The major developmental sequences of the subdiaphragmatic embryonic and fetal guts, together with their associated major glands, peritoneum and mesenteries: left anterolateral aspect. A–F, The development sequence spans 1.5 months to the perinatal period. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 60.6.)
Clinical anatomy

Vascular supply

The surgeon should be familiar with variations in the anatomy of the splenic blood vessels, specifically the splenic artery, left gastroepiploic artery and splenic vein.

Splenic artery

The splenic artery is the largest branch of the coeliac trunk. Occasionally, it arises directly from the abdominal aorta, and very rarely from the common hepatic or superior mesenteric artery. Its course is commonly suprapancreatic, but it may also be antero-, intra- or retropancreatic, and other rare variants have been described. An aberrant course related to the pancreas makes the splenic artery vulnerable to iatrogenic injury during pancreatic surgery.

The anatomy of the terminal branches of the splenic artery is of particular importance during splenectomy. Although the artery typically divides into two, more than six terminal branches have been described; it may pass through the splenic hilum without dividing at all. In a classic cadaveric study (n=100), Michaels described the splenic artery as having either a short trunk that divided into many long branches in a ‘magistral’ (bundled) distribution (30%), or a long trunk that divided near the hilum into as many as twelve branches in a ‘distributed’ arrangement (70%) (Fig. 64.3). Recognizing the pattern of terminal branching is important, especially if the surgeon dissects out and ligates each branch individually. Most surgeons performing contemporary splenectomy use an endovascular stapler, in which case such distinctions are less important (the hilar stapling technique is the author's preference).
The splenic vessels do not anastomose, which means that there are two or three distinct vascular segments; intersegmental planes are avascular and can be used to minimize blood loss during subtotal splenectomy. The splenic artery can be quite tortuous, a characteristic that seems to develop with age, since it is much more apparent in adults than in children.\(^{14}\) The artery can also be atherosclerotic in older patients, an important point to bear in mind when stapling the hilum because stapling may fail to control bleeding from an atherosclerotic splenic artery (see later).

**Left gastroepiploic artery**

The left gastroepiploic artery arises from the splenic artery proximal to the splenic hilum and anastomoses with the right gastroepiploic artery along the greater curvature of the stomach. A significant arterial branch may occasionally arise from the gastroepiploic arteries and supply the inferior pole of the spleen.

**Splenic vein**

Blood from the parenchyma of the spleen is collected by trabecular veins that merge to form the segmental veins that drain individual splenic segments. In general, there are no anastomoses between intrasegmental venous tributaries (Fig. 64.4). Segmental veins join to form two (superior and inferior) or three (superior, middle and inferior) ‘lobar’ veins that emerge
along the length of the splenic hilum, and unite either at, or within 2 cm of, the hilum to form the splenic vein within the splenorenal ligament; communicating veins may interconnect lobar veins. The splenic vein runs medially below the splenic artery, posterior to the tail and body of the pancreas. It crosses the posterior abdominal wall anterior to the left kidney, renal hilum and abdominal aorta, separated from the left sympathetic trunk and left crus of the diaphragm by the left renal vessels, and from the abdominal aorta by the superior mesenteric artery and left renal vein. It terminates posterior to the neck of the pancreas, where it joins the superior mesenteric vein and forms the portal vein. Along its course, it receives the short gastric veins, left gastroepiploic veins, retroperitoneal veins (Retzius's retroperitoneal venous plexus), pancreatic veins, posterior gastric vein, left gastric vein (occasionally) and the inferior mesenteric vein. Approximately 60% of portal vein blood flow is derived from the gut and the remainder from the spleen and pancreas.

**FIG. 64.4** The splenic vein and common variants. Abbreviations: LLV, lower lobar vein; LPSV, lower polar segmental vein; SV, splenic vein; ULV, upper lobar vein; UPSV, upper polar segmental vein. (Adapted from L. Gomez Pellico, J. Labrador Vallverdu, F.J. Fernandez Camachho, Venous segmentation of the spleen, Surg. Radiol. Anat. 16 (1994) 157–164.)
Preoperative planning

Immunizations

The primary purpose of immunizations for splenectomized patients is to provide better defence against encapsulated bacteria that cause pneumonia and meningitis, *Streptococcus pneumoniae* being the most common.\(^{16,17}\) It is recommended that vaccinations against pneumococci, *Haemophilus influenzae* type b, meningococci and influenza virus are also administered. For elective surgery, immunizations are started several weeks before splenectomy and continued at intervals postoperatively. Specific recommendations for immunization vary both with jurisdiction and over time. The availability of improved and broader vaccines means that the specific recommendations for pre- and postoperative immunization schedules may change. Annual vaccination against influenza virus is recommended because influenza infection confers a predisposition to bacterial pneumonia and sepsis caused by *S. pneumoniae* and *Staphylococcus aureus*.\(^ {18,19}\) The most recent immunization guidelines may be found at the national disease surveillance centre (for example, Centers for Disease Control and Prevention at [cdc.gov](http://cdc.gov)).

Blood transfusion

Blood products should always be available during splenectomy, for transfusion if required. For patients without thrombocytopaenia, at least 1 unit of packed red blood cells should be available before commencing surgery. For patients with a low platelet count, platelets should also be on standby for transfusion. In contrast to the classic teaching, which is to transfuse patients with immune thrombocytopaenic purpura (ITP) routinely once the splenic artery is taken, the authors do not transfuse blood products unless there is significant bleeding either during or after surgery; in their experience, the majority of ITP patients do not require blood products in the perioperative period.

Additional preoperative considerations

The surgical approach is dictated by the size of the spleen and, to a lesser extent, other patient factors such as obesity, previous surgery in the area, and the presence of prosthetic materials such as hernia meshes. Broad-spectrum intravenous antibiotics are given prior to the incision, but are not continued
postoperatively unless the patient requires them for other reasons. Venous thromboembolism (VTE) prophylaxis (subcutaneous heparin or equivalent) is given, except in circumstances where significant thrombocytopaenia is present; in these cases, VTE prophylaxis is initiated soon after the procedure is completed. There is no high-level evidence to support the use of pneumatic compression devices and the authors do not use them.¹⁹

A Foley catheter is placed, with its removal intended at the end of the operation. Before lateral positioning, an orogastric (OG) or nasogastric (NG) tube is put in position to permit decompression of the stomach. A gastric tube is far easier to place at the start of the procedure, before lateral positioning, rather than during the operation; an air-filled stomach can prevent adequate visualization and the authors argue that such a situation is less safe. The OG or NG tube is removed before the patient is woken.
Surgical approaches to splenectomy

In the earliest descriptions of laparoscopic splenectomy, the patient was placed supine.\textsuperscript{20–23} The authors prefer either the lateral or the 45° semi-lateral approach.\textsuperscript{24–27} The patient is placed in the full right lateral decubitus position when a normal-sized spleen is being operated on, or one preoperatively estimated to weigh 1 kg or less. For spleens of more than 1 kg, where a hand-assisted technique may be required, a 45° right lateral decubitus position is employed.

Splenomegaly

There are numerous definitions of splenomegaly, massive splenomegaly and super massive splenomegaly.\textsuperscript{28–30} The author (DK) contends that it is the mass of the spleen, rather than its length, that should dictate the surgical approach, and uses the following four-point scale: 1. Normal to somewhat enlarged spleens, up to 500 g, are almost always amenable to a standard three-port technique; occasionally, a fourth port is required, and conversion to an open approach is uncommon. 2. Enlarged spleens (500 g to 1 kg) can usually be removed with only three ports, although an additional port is often necessary and hand-assisted laparoscopic splenectomy (HALS) might also be required. 3. Massive spleens (over 1 kg but less than 2 kg) almost certainly require additional ports and/or HALS if the operation is to succeed. 4. Super massive spleens (over 2 kg) are quite likely to require HALS and conversion to an open approach; some surgeons prefer an open approach when removing super massive spleens.

Splenectomy

Splenectomy is an uncommon operation for which a large and heterogeneous number of diagnoses constitute the indication for surgery. Virtually all elective spleen operations, regardless of spleen size, can be approached laparoscopically (see Table 64.1). Even the largest of spleens is usually removable using the HALS technique. Open splenectomy is reserved for laparoscopic failures, or for trauma scenarios where the laparoscopic approach makes little sense in a haemodynamically unstable patient.

Laparoscopic splenectomy
Most spleens are of normal size and are readily extirpated with a fairly standard technique. The author (DK) places patients in a full right lateral decubitus position, with a kidney rest slightly elevated just cephalad to the iliac crest. The operating table is then flexed to gain better access to the left flank. All patients are supported with a suction beanbag apparatus. DK has performed over 300 splenectomies with this positioning system and has yet to see a pressure ulcer or nerve compression injury (Fig. 64.5). The initial entry port, 12–15 mm, is placed about two fingers’ breadths below the costal margin along the anterior axillary line. DK uses the open Hasson entry method exclusively31; other surgeons may use the Veress needle, and/or in cases of extreme obesity, may prefer to use an optical port or other entry technique. Pneumoperitoneum (to a pressure of 15 mmHg) is then established, and is followed by placement of two 5 mm ports, one on the left side of the epigastrium near the costal margin, and then another in the left flank a few fingers’ breadths below the costal margin, to allow for triangulation on the target organ (Fig. 64.6). A 30° 5 mm laparoscope is preferred because it can be placed in any of the ports. Generally, the camera is placed in the epigastric port, the spleen is retracted by the shaft of an atraumatic grasper, and the energy source (ultrasonic dissector, electrothermal vessel sealing system, or both) is placed in the third port.
FIG. 64.5  Right lateral decubitus. Prior to this positioning, with the patient supine, an indelible marker is used to indicate the midline in case of urgent conversion to an open approach. Beanbag support apparatus is used.

FIG. 64.6  The patient is positioned in right lateral decubitus and the initial 12–15 mm port inserted by the open Hasson technique. Two additional 5 mm cannulas are then established. These three ports are usually adequate for a spleen mass approaching 1 kg. (Adapted from D.T. Pointer, D.P. Slakey, Cysts and tumors of the spleen. In: C.J. Yeo (Ed), Shackelford’s Surgery of the Alimentary Tract, eighth ed., Elsevier, 2017, Ch. 142, Fig. 56.4.)

DK prefers to begin on the medial aspect of the spleen (Fig. 64.7) with the shaft of an atraumatic grasper in the right hand, levering the spleen laterally to expose the area better. The tip of this instrument should be placed against
the diaphragm, or used to grasp the diaphragm to reduce the risk of entering the parenchyma of the spleen. The electrothermal vessel-sealing device (and/or ultrasonic shears) is next directed from the inferior pole cephalad, dividing the short gastric vessels and then mobilizing the diaphragmatic attachments of the superior pole. It is advisable to stay about 1 cm from the splenic hilum, so that if any bleeding vessel retracts, it will still be controllable. It is not necessary to enter the lesser sac when dealing with a normal-sized spleen because the surgeon can stay close enough (but not too close) to the hilum. Next, the lateral attachments are mobilized and the spleen will often retract itself medially under its own weight. When approaching the upper pole, the surgeon should be mindful to stay close to the spleen because it is easy to wander erroneously along a peritoneal fold laterally toward the diaphragm. Adequate mobilization can be assessed by elevating the spleen with the shafts of two long graspers in a ‘chopstick manoeuvre’.

FIG. 64.7  Division of the medial attachments and short gastric vessels.

The endovascular stapler is then introduced and closed across the splenic hilum; several firings are frequently necessary. Once this has been applied, an interval of about 30 seconds is left, and the stapler is then fired;
impatience can be costly. As mentioned earlier, the splenic artery is prone to atherosclerosis; staples may be inadequate to control a vessel in these (typically elderly) patients. Therefore, the authors now oversew all staple lines with figure-of-eight 2-0 silk sutures, and occasionally also place metal clips. Since this strategy has been adopted, no cases have required reoperation for an early postoperative bleed.

The spleen can be retrieved utilizing a standard laparoscopic retrieval bag (Fig. 64.8). The neck of the bag is externalized through the original Hasson entry port and the spleen is morcellated to facilitate its removal. The incision may need to be extended. It will rarely be necessary to require an intact specimen, but a larger bag is sometimes needed and the surgeon must have these available for use. Drains are not used.

** FIG. 64.8  Spleen extraction.** The spleen is morcellated within a bag and extracted in a piecemeal fashion. Great care is taken to avoid spillage of splenic tissue.

**Hand-assisted laparoscopic splenectomy**

Hand-assisted laparoscopic splenectomy (HALS) was first described as an alternative to open procedures in cases of very large spleens in 1994 and was initially performed in the supine position. Hellman first described splenectomy in the right semi-lateral decubitus position and Kercher further refined the positioning. The right semi-lateral decubitus position is now used by most surgeons; DK has employed this technique since 2004 for removal of most spleens that exceed 1 kg. The patient is positioned on a
beanbag support in 45° right lateral decubitus. The usual three-port position is maintained but moved further from the costal margin to accommodate the large spleen. In non-obese patients, the hand-assist portal is usually placed from the umbilicus cephalad for 7–8 cm. DK currently uses the GelPort® (Applied Medical, Rancho Santa Margarita, California, USA). In patients with a high body mass index (BMI), the hand-assist port is placed within a subcostal incision, which may also be better when operating on very tall patients, where the hand-assist port at the umbilicus may not afford adequate reach within the abdomen.

The early surgical objective during splenectomy is to identify and occlude the splenic artery. Once all access ports are placed, the spleen is lifted and rotated laterally to expose its hilum better. The lesser sac is then entered near the inferior pole, several centimetres proximal to the hilum, with either ultrasonic shears or electrothermal vessel sealing. Once the lesser sac has been entered, the gastrosplenic ligament is then opened up to the short gastric vessels; if division is judged to be facile, these vessels are then divided. However, if the stomach is adherent to the spleen, or any other technical difficulties with the short gastric vessels are anticipated, their division is deferred until after the splenic artery has been occluded.

Next, the splenic artery is identified a few centimetres from the hilum, most often on the cephalad edge of the pancreas, and it is circumferentially dissected. Clips, either polymeric or metallic, or an endovascular stapler are/is then used to occlude the artery. Occlusion is sufficient at this point because the artery, or arteries, will be divided later with the endovascular stapler nearer the hilum. Occluding the artery makes the spleen softer and easier to manipulate. If the short gastric vessels remain, they are now divided, and the accessible superior pole attachments are thoroughly mobilized; caudal traction by the hand on the spleen is usually adequate to expose its superior pole. The attention is now turned to mobilizing the lateral peritoneal attachments. The hand is used to lever the spleen medially while the ultrasonic or electrothermal vessel-sealing device is used to mobilize the spleen fully on its hilum (Fig. 64.9). The hand is then used to guide the stapler across the hilum and fired after a 30 second pause. Several firings of the endovascular stapler may be necessary and any remaining attachments are then dealt with by ultrasonic or electrothermal sealing devices.
Once the spleen is free, it is captured in a retrieval bag. Purpose-made laparoscopic retrieval bags may not be large enough, and in these cases a large viscera bag with a drawstring is placed in the abdomen and opened. The spleen is placed in the bag, and the bag neck is brought out through the hand port. The spleen can now be broken into pieces for removal. A portion is typically sent fresh for lymphoma studies and the rest is placed in formalin for further pathological evaluation.

**Preoperative splenic artery embolization**

Preoperative splenic artery embolization has been described in the era of open splenectomy\(^3^4\) and for laparoscopic splenectomy when removing very large spleens (massive or super massive).\(^3^5\) The reported advantages are
shorter operative time, reduced blood loss and greater ease of surgery because the spleen is softer and more manageable.\textsuperscript{36–38}

**Partial splenectomy**

Partial splenectomy is the preferred operative approach for many children (when it should be pursued with alacrity) and for the treatment of certain conditions in adults. However, variations in the segmental blood supply of the spleen and in the arterial anastomoses within the parenchyma preclude the undertaking of partial resections based on vascular anatomy.\textsuperscript{14,39} The authors’ technique is initially to divide inferior pole vessels, if present, and then to mobilize the organ fully prior to any arterial transection(s). Once this has been accomplished, the remaining inferior pole vessels and the hilum are divided, leaving the short gastric arteries. The ischaemic spleen parenchyma is demarcated by a colour change, and the ultrasonic dissection shears and/or electrothermal vessel-sealing system are/is used to divide the parenchyma approximately 1 cm from this line of demarcation. Dissecting the parenchyma in this way remains imprecise; DK proposes to use indocyanine green immunofluorescence imaging in an effort to help find a preferable transection plane in future cases.\textsuperscript{40} With this operative strategy, the superior pole of the spleen remains viable. Operating instruments and laparoscope are also in direct line with the cut surface, facilitating haemostasis during transection of the parenchyma; the splenic pole remnant is against the diaphragm, and haemostasis agents can be deployed and direct pressure applied. This orientation also aids application of clips and suturing, so that haemostasis is easier to achieve. In the event of excessive bleeding, the surgeon can readily complete devascularization of the spleen and resort to splenectomy. This technique of leaving a splenic remnant supplied by the short gastric vessels should also maintain sufficient spleen function.

**Indications for conversion to open splenectomy**

The main indications for conversion to open surgery are: firstly, intolerance of pneumoperitoneum; secondly, failure to progress when laparoscopic methods have been exhausted; and thirdly, unacceptable bleeding that is occurring or that the surgeon feels will occur.

**Open splenectomy**
Open splenectomy is reserved for conversions from laparoscopic splenectomy and for trauma scenarios. Even though a literature on laparoscopy in the blunt trauma setting exists,\textsuperscript{41} the indications for a laparoscopic approach to blunt injuries are unclear.\textsuperscript{42,43} The authors have never utilized this approach. A midline trauma laparotomy is performed and the spleen is then medialized by sharp division of its lateral peritoneal attachments; the left hand cups the spleen and applies medial traction while scissors in the right hand cut these attachments. Great care must be taken not to injure the pancreas. The spleen is medialized by mobilizing it off the retroperitoneum in a plane that is located between the pancreas and the kidney and adrenal gland. In obese patients, where access and visualization can be difficult, the hilum can be stapled with an endovascular stapler as in a laparoscopic approach, and/or a laparoscopic clip applier can be used; conventional suture ligation is also adequate. The artery can be divided proximally before approaching the hilum.
Special surgical considerations

Cystic splenic lesions

There are numerous types of cystic splenic lesions (Table 64.2). Splenic cysts can be removed by partial splenectomy if the anatomy is favourable. Draining a large cyst first by fenestration may be very helpful in visualizing the surgical anatomy. Though splenic cysts may be treated by fenestration alone, no studies employing this technique have reported long-term follow-up; cysts can recur (DK has seen this happen twice). A recurrent cyst is also much more technically difficult to remove because of adhesions from the prior cyst fenestration. For this reason, if a cyst is in a central or hilar location, DK deals with these cases by performing a complete splenectomy.

Table 64.2

Potential causes of cystic lesions of the spleen (Adapted From41)

<table>
<thead>
<tr>
<th>Non-neoplastic</th>
<th>Neoplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post traumatic</td>
<td>Haemangioma</td>
</tr>
<tr>
<td>Inflammatory</td>
<td>Lymphangioma</td>
</tr>
<tr>
<td></td>
<td>Mucinous cystadenocarcinoma</td>
</tr>
<tr>
<td></td>
<td>Primary splenic lymphoma</td>
</tr>
<tr>
<td></td>
<td>Metastatic:</td>
</tr>
<tr>
<td></td>
<td>Melanoma</td>
</tr>
<tr>
<td></td>
<td>Breast, ovarian, gastric, colon and pancreatic cancers</td>
</tr>
</tbody>
</table>

Accessory spleens

The prevalence of accessory spleens (splenules, splenunculi or supernumerary spleens) varies across studies:46 a recent meta-analysis of over 22,000 patients reported an overall prevalence of just under 15%, with
most located in the splenic hilum (62%); other locations were suprahilar or infrahilar; pancreatic tail; retroperitoneum; greater omentum; greater curvature of stomach; splenic artery; gastrocolic, gastrosplenic and splenocolic ligaments; mesentery of small intestine; presacral area; uterine adnexa; and peritesticular region\(^47\) (Fig. 64.10).

**FIG. 64.10** Possible locations of accessory spleens. Key: 1, gastrosplenic ligament; 2, splenic hilum; 3, tail of the pancreas; 4, splenocolic ligament; 5, left transverse mesocolon; 6, greater omentum along the greater curvature of the stomach; 7, mesentery; 8, left mesocolon; 9, left ovary; 10, pouch of Douglas; 11, left testis. (From J.F. Gigot, B. Lengele, P. Gianello, et al., Present status of laparoscopic splenectomy for hematologic diseases: Certitudes and unresolved issues, Semin. Laparosc. Surg. 5 (1998) 147–167.)
Splenulectomy

A substantially active splenule occasionally remains after surgery for ITP and can be detected by CT scan, \(^{99}\)technetium-labelled heat-damaged red blood cell scan, or both. If not identified and removed at the index operation, an active splenule will usually be found in an unusual location. Its extirpation requires careful decision-making and risk–benefit discussions between patient, surgeon and haematologist. Removal can be carried out by the open approach or laparoscopically\(^{48}\) (Fig. 64.11). If surgery is undertaken, DK’s approach is to perform surgery in the afternoon; in the morning before surgery, labelled damaged red blood cells are administered by nuclear medicine, and a few millilitres of methylene blue are injected as near to the splenule as possible under CT guidance. At laparoscopy, the splenule is usually found by following a trail of blue dye. However, in some cases, this is not adequate and a gamma probe can be useful for locating the splenule\(^{49}\); the outcome of splenule removal is controversial\(^{50}\).

![Image of a supernumerary spleen located in the greater omentum](image)

FIG. 64.11 A supernumerary spleen located in the greater omentum (arrow). Supernumerary spleens are usually isolated and may be connected to the spleen or splenic pedicle by thin vessels. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 70.1.)
Complications of splenectomy

Overwhelming post-splenectomy infection

In 1952, King and Schumacker described increased susceptibility to severe infection in asplenic patients, especially children, a problem that subsequently became known as overwhelming post-splenectomy infection (OPSI). The incidence of OPSI in adults has been reported to range from 1.5% to 4% without preoperative immunizations; other reviews cite an incidence and mortality of 0.03 per 100 patient years. In a review of over 5000 splenectomized patients, the incidence of infection after splenectomy in children younger than 16 years was found to be 4.4%, with a mortality rate of 2.2%, compared with a 0.9% incidence and a 0.8% mortality in adults. It would be logical to assume that OPSI incidence and mortality should decrease with contemporary immunization protocols.

Splenic vein thrombosis and portal venous thrombosis

Splenic vein thrombosis (SVT) used to be considered uncommon but modern imaging techniques have confirmed that it occurs in 5–7% of patients. Portal venous thrombosis (PVT) has been found in a varying proportion of splenectomized patients, many of whom were asymptomatic. A splenic vein diameter of 8 mm or more, as measured on preoperative CT scan, was found to be predictive of postoperative PVT. Currently, no specific laboratory studies or physical findings can predict SVT or PVT; clinical suspicion of what appears to be a fairly common occurrence should spur the clinician to evaluate the patient further with intravenous contrast-enhanced CT or Doppler ultrasound.

Deep venous thrombosis and pulmonary embolism

Deep venous thrombosis (DVT) and pulmonary embolism (PE) are considerably less common than PVT. In a nationwide audit from Taiwan, splenic injury patients who had undergone splenectomy exhibited a 2.21-fold risk of venous thromboembolism (VTE), whereas those that did not require splenectomy exhibited a 1.71-fold risk of VTE. The overall incidence of VTE
was 1.97-fold higher in the splenic injury cohort than in the comparison cohort (95% CI, 1.38–2.81). Although splenectomy increased the risk of VTE 1.35-fold, compared with non-splenectomized patients, the difference was not statistically significant. However, in a large cohort study of patients in an intensive care unit, those who had undergone splenectomy had much higher rates of VTE than matched patients who had undergone other major abdominal operations (29.7% versus 12.1%, p < 0.01). After adjustment, splenectomy was found to be associated with a higher risk for VTE compared to the non-splenectomized group. Interestingly, reactive thrombocytosis did not predict the development of VTE, suggesting that, in the intensive care setting at least, splenectomized patients are at particular risk for VTE.

**Tips and Anatomical Hazards**

In very tall patients, the initial access port through which stapling and spleen removal are planned should be placed closer to the costal margin or there may be problems with instruments reaching the superior pole or even the hilum of the spleen.

In obese patients, especially in men with bulky mesenteries and omentum, a fourth 5 mm port is used to retract, and aid visualization of, the splenic hilum.

A disproportionately large left lobe of the liver can obstruct the surgeon's view of the spleen; a fourth 5 mm port may be useful to retract the left lobe in such cases.

To avoid an unsightly scar resulting from a haphazard incision made in haste, before positioning the patient in the right lateral decubitus position, draw ‘plan B’ (the midline traced with a marker) for use in cases that require urgent conversion to an open approach.

For a pure laparoscopic splenectomy (that is, not hand-assisted), attention to the superior pole and thorough mobilization will facilitate stapling of the splenic hilum. Inadequate superior pole mobilization will make stapling of the hilum more difficult.

Once the spleen is free, keep it firmly grasped and held in the left upper quadrant for capture within a bag. If the spleen falls into the pelvis on the contralateral side, it can be very difficult, and even hazardous, to retrieve.
Spleens are removed by morcellation, which DK carries out manually with a sponge forceps. Powered morcellators do exist; the proper bag must be used when they are employed or the morcellator could be broken.

With HALS and very large spleens, do not occlude the artery too close to the splenic hilum because this may interfere with subsequent use of the endoscopic stapler.

On occasion, HALS is hampered by numerous and dense adhesions to the diaphragm that may be difficult to access, especially superolaterally at the upper pole of the spleen. An additional 5 mm cannula placed just below the costal margin may allow instruments to access this area.

Large bags placed into the abdomen can be frustrating to work with. Pleating the bag, rather than rolling it up prior to insertion, allows for easier deployment.

Large spleens that are involved with lymphoma, leukemia, or infection, may have their hilum and the pancreatic tail crowded with enlarged lymph nodes, making clear anatomical distinctions difficult, if not impossible. A piece of the pancreatic tail may be divided in such cases; if this occurs, a closed suction drain should be placed.
References

24. Poulin EC, Thibault C, Mamazza J. Laparoscopic


28.


1. What percentage of people have an accessory spleen (splenule)?
   A. 50%
   B. 25%
   C. 15%
   D. 5%

   **Answer:** C. Multiple postmortem studies and surgical splenectomy series indicate that about 15% of people have an accessory spleen.

2. Which one of the following conditions is the most common complication of splenectomy?
   A. Pulmonary embolism
   B. Gastric stasis
   C. Postoperative bleeding
   D. Splenic vein and portal venous thrombosis

   **Answer:** D. Though splenic vein and portal venous thrombosis was once considered uncommon, recent published splenectomy series and high-quality imaging availability have facilitated this diagnosis, the most common postoperative complication; it exceeds pulmonary embolism, and far exceeds gastric stasis and significant postoperative bleeding.

3. With regard to the anatomy of the splenic artery, a ‘magistral’ distribution is found in approximately what percentage of people?
   A. 10%
   B. 30%
   C. 50%
Answer: B. Anatomical postmortem studies of the splenic artery demonstrate a ‘magistral’ or bundled distribution near the splenic hilum in approximately 30% of specimens.

4. Following complete splenectomy, which one of the following may be applied to a patient's lifetime risk of developing overwhelming post-splenectomy infection (OPSI)?

   A. <5%
   B. 10%
   C. 40%
   D. Almost all asplenic patients will develop OPSI at some point in their life

Answer: A. Following splenectomy, OPSI is rare, affecting approximately 1% of asplenic patients.
Clinical case

1. A 59-year-old male is being investigated for left upper quadrant abdominal pain. A CT scan of the abdomen is performed. Fig. 64.12 shows two representative images from the CT scan that were taken at different phases of the intravascular contrast injection. Radiology formally interprets these images as representing either a primary neoplasm of the spleen or a metastasis to the spleen. After an extensive work-up, no primary tumour is identified elsewhere.
A. Should a biopsy be performed?
A biopsy of a lesion in the spleen in this location is possible with percutaneous techniques. However, it is not without risk, particularly of haemorrhage, and may sometimes be non-diagnostic. As such, the next step should be to proceed with splenectomy unless the patient declines.

B. If this is an invasive primary tumour of the spleen, what organs/structures should be considered as potential sites of invasion?
A tumour in this location may potentially invade the diaphragm,
stomach, adrenal gland, kidney, left lateral lobe of the liver and/or the pancreas. Given its position closer to the upper pole, it is unlikely that this tumour would invade the colon.

C. What surgical approach should be employed?
Some surgeons would recommend an open splenectomy for solid tumours of the spleen; however, it is reasonable to place a laparoscope in order to assess for resectability. Even if adjacent organs require resection, the specific case may still lend itself to a laparoscopic approach. Conversion to open surgery in such circumstances is entirely reasonable and may be a safer surgical option.

In this particular case, the spleen is not found to be adherent to any adjacent organs and is quite amenable to laparoscopic resection. Once free, it is removed via placement in a retrieval bag and delivered intact through a Pfannenstiel incision. Alternative extraction sites, such as an extension of a subcostal incision or a peri-umbilical incision, are other possibilities. In these circumstances, the spleen should be sent to pathology intact and not morcellated (as is usually done during laparoscopic splenectomy).

The final pathology reports a sclerosing angiomatoid nodular tumour (SANT), a rare benign vascular tumour of the spleen that usually is only diagnosed postoperatively by pathological examination. Imaging criteria that characterize lesions of the spleen as being SANTs have been reported recently; the wide availability of high-resolution intra-abdominal imaging means that this diagnosis is likely to be made more frequently in the future. To date, there is no literature reporting on the strategy of watchful waiting if a SANT is diagnosed radiologically.
Adrenal glands

Kristin DeGirolamo, Adrienne L Melck

**Core Procedures**

- Open adrenalectomy
- Transperitoneal laparoscopic adrenalectomy
- Posterior retroperitoneoscopic adrenalectomy
Embryology

The adrenal (suprarenal) gland consists of two main parts, each with different embryonic origins. The inner part of the gland, the adrenal medulla, is originally derived from ectodermal neural crest cells. Also known as chromaffin cells for their staining properties, these cells migrate towards the adrenal cortex at approximately 7 weeks' gestation and gradually invade the cortex to achieve their ultimate central location.\(^1\) Many of these islands of chromaffin cells spontaneously regress, except for those that make up the glands of Zuckerkandl at the level of the inferior mesenteric artery just lateral to the aorta. This migration of chromaffin cells also explains the existence of heterotopic adrenal glands and paragangliomas, especially along the vertebral column anterior to the aorta. Indeed, 10% of phaeochromocytomas occur in an extra-adrenal location.

The outer adrenal cortex begins to form at approximately the fourth week of gestation from the urogenital ridge of mesenchyme. Mesonephric mesenchymal cells differentiate and proliferate to form the primitive steroid-producing cortex. By week 6, the fetal adrenal cortex is fully formed. As the fetus matures, the distinct cortical zones begin to differentiate. By birth, both the zona glomerulosa and zona fasciculata are present; the zona reticularis is not present until the third year of life. At birth, the adrenal glands are almost one-third of the size of the kidney but the cortex gradually shrinks in size, and the medulla grows only minimally after birth. This size regression continues into the second month, by which time the gland has reduced in size by almost 50%. From age 2 until puberty, the gland increases to its adult weight of approximately 5 g.

Adrenal rests represent accessory or ectopic islets of adrenal tissue. Those located close to the native adrenal gland are more likely to contain medullary tissue, while more distant rests typically contain only cortical tissue. They can be found anywhere but are most commonly located along the course of gonadal descent (that is, the spermatic cord or broad ligament). Most adrenal rests atrophy early in life and are clinically insignificant.\(^2\)
Surgical surface anatomy

The adrenal glands are located deep to the tenth and eleventh ribs, just lateral to either side of the vertebral column. Their position varies with respiration by approximately 3 cm with each movement of the diaphragm (Fig. 65.1).

**FIG. 65.1** The surface position of the spleen, kidneys and adrenal glands. Key: 1, spleen; sits deep to ribs 10–12 with the long axis aligned with rib 11; 2, supracristal plane. (Derived with permission from S.A. Mirjalili, S.L. McFadden, T. Buckenham, M.D. Stringer, A reappraisal of adult abdominal surface anatomy, Clin. Anat. 25 (2012) 844–50.)
Clinical anatomy

The adrenal glands are located in the retroperitoneum at the superomedial aspect of the kidneys (Fig. 65.2; Table 65.1). Each gland weighs 4–8 g (average 5 g, slightly larger in females), measures approximately $4 \times 3 \times 1$ cm, is enclosed in Gerota's fascia, and is surrounded by periaortic fat, except for a partition of connective tissue that separates it from the kidney. Both glands are firmly attached to the fascia of the abdominal wall and diaphragm by several vascular attachments and fibrous bands.
FIG. 65.2 Magnetic resonance imaging (MRI) of the adrenal glands. A, Axial T1
TABLE 65.1
Anatomical relations of the adrenal glands

<table>
<thead>
<tr>
<th>Boundaries</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>Bare area of liver</td>
<td>Stomach/ peritoneum</td>
</tr>
<tr>
<td>Inferior</td>
<td>First part of duodenum/ peritoneum</td>
<td>Tail of pancreas</td>
</tr>
<tr>
<td>Medial</td>
<td>Inferior vena cava</td>
<td>Left coeliac ganglion/ inferior phrenic artery</td>
</tr>
<tr>
<td>Lateral</td>
<td>Right lobe of liver</td>
<td>Superomedial aspect of spleen</td>
</tr>
<tr>
<td>Posterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>Diaphragm</td>
<td>Diaphragm</td>
</tr>
<tr>
<td>Inferior</td>
<td>Anteromedial aspect of right kidney</td>
<td>Tail of pancreas</td>
</tr>
<tr>
<td>Medial</td>
<td>Right coeliac ganglion/ inferior phrenic artery</td>
<td>Left crus of diaphragm</td>
</tr>
<tr>
<td>Lateral</td>
<td>Right lobe of liver</td>
<td>Medial aspect of left kidney</td>
</tr>
</tbody>
</table>

Right adrenal gland

The right adrenal gland lies posterior to the inferior vena cava (IVC), from which it is separated by a layer of fascia and connective tissue. It has a more pyramidal shape and is positioned higher on the kidney relative to the left gland. The two limbs of the right adrenal straddle the kidney. The right lobe of the liver is anterior and the right crus of the diaphragm is posterior. The anterior surface lies medial to the IVC, and the lateral side is in contact with the bare area of the liver. The lowest part of the gland may be covered by the peritoneal reflection of the inferior layer of the coronary ligament, in the upper recess of the hepatorenal pouch. The second part of the duodenum is just anterior and medial to the medial border of the gland. The posterior surface of the right adrenal is divided into upper and lower areas by a ridge; the large upper area is slightly convex and sits adjacent to the diaphragm, whereas the small lower area is concave and lies in contact with the right kidney. The right coeliac ganglion and right inferior phrenic artery are medial to the right adrenal gland.

Left adrenal gland

The left adrenal gland is crescent-shaped and lies along the anteromedial aspect of the upper pole of the left kidney. It has a close relationship with the
left crus of the diaphragm, from which it is separated by a thin layer of fascia. The upper part of its anterior surface is covered by the peritoneum of the posterior wall of the lesser sac, separating it from the stomach and spleen. A small portion of the lower anterior side of the gland is not covered by peritoneum and is adjacent to the pancreas and splenic artery. The posterior surface of the gland has relations similar to the right side, having a lateral area that adjoins the kidney, while the smaller medial area is in contact with the left crus of the diaphragm. The left coeliac ganglion and the left inferior phrenic and gastric arteries are medial to the medial border of the left adrenal gland.

**Vascular supply and lymphatic drainage**

The endocrine function of the adrenal glands mandates that they have an abundant blood supply. Per gram of tissue, the adrenals have one of the highest arterial flow rates of any gland or organ, up to 10 mL/min. The arterial supply is consistent on both sides and arises from three main sources (Fig. 65.3). The inferior phrenic artery gives rise to the superior adrenal artery before it supplies the diaphragm. The middle adrenal artery branches directly off the aorta above the origin of the renal artery. The inferior adrenal artery supplies the inferior aspect of the gland and is a branch of the renal artery.
Venous drainage of the adrenals is not consistent between sides. On the right, the adrenal vein is quite short, emerging from the adrenal hilum and draining directly into the IVC posteriorly; it may drain aberrantly into the right hepatic vein. The left adrenal vein emerges from the left adrenal hilum and runs inferomedially to drain into the left renal vein after joining the inferior phrenic vein; it is therefore substantially longer than the right adrenal vein.

The lymphatic drainage of the adrenals is to the renal hilar and lateral aortic nodes intra-abdominally, and to the posterior mediastinal nodes via the diaphragmatic orifices that accommodate the splanchnic nerves.

**Innervation**

The adrenal glands have a rich nerve supply that arises from the coeliac plexus and thoracic splanchnic nerves. The nerves are distributed throughout the gland and contribute to a greater autonomic supply than to any other organ. An adrenal plexus lies between the medial aspect of each gland and
the coeliac and aorticorenal ganglia. It contains predominantly preganglionic sympathetic fibres that originate in the lower thoracic spinal segments, reach the plexus via branches of the greater splanchnic nerves, and synapse on clusters of large medullary chromaffin cells (which can be regarded as homologous with postganglionic sympathetic neurones). A smaller proportion of postganglionic sympathetic nerve fibres innervate cortical blood vessels.\textsuperscript{2,3}

**Microstructure**

Each adrenal gland consists of two distinct areas, an outer cortex surrounding an inner medulla (\textbf{Fig. 65.4}). The lipid-rich cortex is yellow in colour and forms the main bulk of the gland. It contains three zones: an outer zona glomerulosa, a middle zona fasciculata and an inner zona reticularis. The zona glomerulosa is responsible for mineralocorticoid production and accounts for approximately 15% of the cortex. The zona fasciculata accounts for 75% of the cortex and is responsible for glucocorticoid production. The zona reticularis produces sex hormones (progesterone, oestrogens and androgens).\textsuperscript{4} The thinner medulla is typically dark red and makes up approximately 10% of the volume of the gland. It contains chromaffin cells, which are part of the neuroendocrine system and function similarly to postganglionic sympathetic neurones: they synthesize, store (as granules) and release catecholamines (noradrenaline/norepinephrine and adrenaline/epinephrine) into the venous sinusoids. Release is under preganglionic sympathetic control, mediated by the sympathetic neurones that occur either singly or in small groups in the medulla.
FIG. 65.4 The gross sectional appearance, microstructure, vasculature and ultrastructure of the adrenal gland. Brief functional summaries are included. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 71.4.)
Surgical approaches and considerations

In general, there are two indications for adrenalectomy. Either the adrenal gland is responsible for hormonal overproduction or there is a lesion within the gland that is worrisome for malignancy. Like many surgical procedures, the procedure of choice has evolved from ‘open’ surgery, with large incisions and the resultant significant potential associated morbidity, to more minimally invasive approaches with smaller incisions, less pain, fewer complications and shorter hospital lengths of stay. Perhaps the greatest ‘art of adrenalectomy’ relies not only on the safe performance of the operation itself, but also heavily on the careful work-up of the patient to arrive at a correct diagnosis, meticulous preoperative preparation, thoughtful decision-making regarding the most appropriate surgical approach that is individualized for each patient and their pathology, and attentive postoperative management based on knowledge of all potential complications.

Transperitoneal laparoscopic adrenalectomy

The most common approach to adrenal resection for non-malignant adrenal pathology is transperitoneal laparoscopic adrenalectomy (TLA; Table 65.2). While suspected metastases to the adrenal gland may also be approached endoscopically, lesions suspected to be adrenocortical carcinoma should be approached using an open technique. For TLA, patients are positioned in modified lateral decubitus position, at slightly less than a 90° angle (Fig. 65.5). A bean bag is utilized to maintain the positioning. The operating theatre table is then flexed to open up the space between the costal margin and the iliac crest, and also to elevate the adrenal gland. The patient must be secured to the table at multiple locations, and all pressure points must be adequately padded, including placement of an axillary roll. On the right side, four ports are required: one for the camera, one for the liver retractor and two working ports. On the left side, TLA may be accomplished with just three ports because liver retraction is not required and gravity aids medial retraction of the spleen and the tail of the pancreas. A combination of 5 mm, 10 mm and 12 mm ports may be used, placed approximately two fingers’ breadths below the costal margin from the mid-clavicular line to the mid-axillary line. Each port should be placed at least a hand's breadth away from neighbouring ports.
# TABLE 65.2

Core procedures, contraindications, advantages and disadvantages

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Positioning</th>
<th>Contraindications</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open adrenalectomy (OA)</td>
<td>Supine</td>
<td><strong>Absolute:</strong> None&lt;br&gt;&lt;br&gt;<strong>Relative:</strong> None</td>
<td>Excellent exposure&lt;br&gt;Allows <em>en bloc</em> resection of involved adjacent structures</td>
<td>More postoperative pain and ileus&lt;br&gt;Longer length of hospital stay</td>
</tr>
<tr>
<td>Transperitoneal laparoscopic adrenalectomy (TLA)</td>
<td>Modified lateral decubitus (80° angle)</td>
<td><strong>Absolute:</strong> Invasive adrenocortical carcinoma&lt;br&gt;Patent factors preventing toleration of pneumoperitoneum&lt;br&gt;Uncorrectable coagulopathy&lt;br&gt;&lt;br&gt;<strong>Relative:</strong> Large tumours (&gt;10 cm)</td>
<td>Familiar anatomy&lt;br&gt;Access to other intra-abdominal pathology&lt;br&gt;Less postoperative pain than with OA</td>
<td>Possible need to contend with adhesions&lt;br&gt;Repositioning for bilateral disease</td>
</tr>
<tr>
<td>Posterior retroperitoneoscopic adrenalectomy (PRA)</td>
<td>Prone jack-knife</td>
<td><strong>Absolute:</strong> Suspected adrenocortical carcinoma&lt;br&gt;Uncorrectable coagulopathy&lt;br&gt;&lt;br&gt;<strong>Relative:</strong> Body mass index &gt;45 kg/m²&lt;br&gt;Large tumours (&gt;8 cm)&lt;br&gt;Concomitant intra-abdominal pathology&lt;br&gt;History of renal surgery or pyelonephritis</td>
<td>No repositioning for bilateral cases&lt;br&gt;Direct access to adrenal gland&lt;br&gt;No need to contend with adhesions&lt;br&gt;Less postoperative pain than TLA&lt;br&gt;Shorter operative time</td>
<td>Unfamiliar anatomy&lt;br&gt;Inability to assess other intra-abdominal pathology</td>
</tr>
</tbody>
</table>
On the right side, dissection begins with taking down the triangular ligament and peritoneal attachments between the liver and the anterior surface of the adrenal gland to facilitate cephalad retraction of the liver and to expose the gland itself. Next, the medial border of the adrenal gland is mobilized away from the lateral border of the IVC until the adrenal vein is identified. The dissection is typically carried out with hook cautery or a vessel-sealing device. The vein is then ligated, leaving two clips on the IVC side. After vein ligation, mobilization of the gland continues from the superior pole of the kidney, moving in a medial to lateral direction.

On the left side, the dissection begins with mobilization of the splenic flexure of the colon, followed by mobilization and medial rotation of the spleen and pancreatic tail. Lateral splenic attachments are freed up to the level of the greater curvature of the stomach. Next, the left adrenal vein can be identified either by beginning inferiorly, identifying the renal hilum and following the renal vein medially to the adrenal vein take-off, or starting superomedially to identify the inferior phrenic vein and following it inferiorly until it joins the adrenal vein (Fig. 65.6). The adrenal vein is ligated, leaving two clips on the renal vein side (Fig. 65.7). Mobilization of the gland from inferior and posterior attachments continues in a manner that is similar to the dissection carried out on the right side.
FIG. 65.6 Transperitoneal laparoscopic adrenalectomy: exposure and dissection of the left renal vein and left adrenal vein. (From S.K. Lim, K.H. Rha, Surgery of the adrenal glands. In: A.J. Wein, L.R. Kavoussi, A.W. Partin, C.A. Peters, Campbell-Walsh Urology, eleventh ed. Copyright © 2016 by Elsevier, Inc. All rights reserved, pp. 1577–1595.e2, Fig. 66.20.)
The resected gland is placed in a retrieval bag prior to its removal from the abdominal cavity. For extraction, the largest port site is typically utilized. Either this can be enlarged or, for benign pathologies, the specimen can be morcellated in the retrieval bag before removal. The resection bed is irrigated and haemostasis is achieved.\(^5\)

During TLA, it is very important for the surgeon to be aware of aberrant venous anatomy. On the right side there can be multiple veins, or a single right adrenal vein may drain aberrantly into the renal vein or the right hepatic vein, rather than the IVC. The most crucial and delicate step in the dissection occurs along the lateral border of the IVC to identify the right adrenal vein, which can be easily avulsed. Additionally, the upper-pole branch of the right renal artery may adhere to the adrenal gland, be mistaken for the inferior adrenal artery, and be accidentally ligated when dissecting the inferomedial aspect of the gland away from the kidney.

On the left side, the inferior phrenic vein may not join the adrenal vein before it drains into the renal vein. Injuries to the spleen, the tail of the pancreas and the splenic flexure of the colon may occur when these
structures are being dissected in order to expose the gland: this dissection should therefore be carried out methodically and meticulously. Typically, bleeding from the liver or spleen can be controlled with direct pressure cautery, and the application of various haemostatic agents (Video 65.1).

**Posterior retroperitoneoscopic adrenalectomy**

Posterior retroperitoneoscopic adrenalectomy (PRA) is a newer surgical approach, and is reported to be faster and associated with less postoperative pain than other approaches (see Table 65.2). It also allows for performance of bilateral adrenalectomy without the need to reposition the patient, which can be time-consuming when employing the TLA approach and does not require the surgeon to contend with intra-abdominal adhesions. The lack of abdominal scars with the PRA approach may also appeal to many patients.

For PRA, patients are positioned in the prone position with their chest and hips supported, such that the abdomen falls away from the operative field. The hips are flexed to lengthen the working space and the operating table is adjusted to achieve a flat back. All pressure points are adequately padded. The first incision is made just below and beyond the tip of the twelfth rib. Dissection is carried down sharply to enter the retroperitoneal space (just below the rib), which is then opened bluntly with finger dissection. A second 5 or 10 mm port is then placed medial to the paraspinous muscles and a third 5 mm port is placed laterally beyond the tip of the eleventh rib. Care is taken to avoid the subcostal nerves. A pneumoretroperitoneum with pressures up to 25 mmHg is achieved and maintained to facilitate exposure.

A 30° endoscope is inserted into the middle port and a laparoscopic peanut dissector is used to develop the working space. The plane above the superior pole of the kidney is identified and the adrenal gland within its periadrenal fat is then mobilized from the kidney. The dissection generally starts inferolaterally and moves in a superomedial direction; it can largely be performed using a vessel-sealing device that also facilitates ligation of the adrenal arteries. The adrenal vein is ultimately identified and ligated with either clips or the vessel-sealing device. The remaining superior attachments of the gland to the diaphragm are then divided, and the freed gland is placed in a retrieval device and extracted through the middle port. The higher insufflation pressures used in PRA may mask venous bleeding, so prior to ending the procedure it is important to lower the pressure to 8–12 mmHg when evaluating for haemostasis.
**Tips and Anatomical Hazards**

Always leave periadrenal fat attached to the gland during dissection to avoid violating the adrenal capsule.

For left TLA, stay in the plane anterior to Gerota's fascia.

For left TLA, continue the cephalad dissection up to the level of the gastric fundus.

For left TLA, avoid early dissection along the lateral edge of the gland because this may lead to premature medial rotation of the gland, making it difficult to identify the vein.

Find the left adrenal vein by identifying and tracing the inferior phrenic vein caudally, or by identifying and tracing the left renal vein medially.

Higher insufflation pressures (up to 25 mmHg) are required to create a working space in the retroperitoneum for PRA.

Decrease insufflation pressures and check for haemostasis prior to ending the case (because higher insufflation pressures may tamponade venous bleeding, giving an incorrect impression regarding haemostasis).

For phaeochromocytomas, ligate the vein early to minimize haemodynamic lability with ongoing gland manipulation (even though the subsequent vascular congestion may theoretically cause more bleeding from the gland).

Consider a thoraco-abdominal approach for larger adrenal tumours, especially if en bloc resection of adjacent organs is required, as in adrenocortical carcinoma or malignant phaeochromocytoma.

For TLA, consider closing 10 and 12 mm port sites to avoid incisional hernia formation.
References


Single Best Answers

1. Which one of the following is NOT an advantage of the posterior retroperitoneoscopic approach to adrenalectomy?
   A. No repositioning for bilateral surgery
   B. Less postoperative pain
   C. Ability to access other intra-abdominal pathology
   D. No need to contend with adhesions from previous abdominal surgery

   **Answer:** C. A disadvantage of the posterior retroperitoneoscopic approach is the inability to assess the abdominal cavity for other pathology.

2. From which one of the following is the adrenal medulla derived?
   A. Ectoderm
   B. Mesenchyme
   C. Endoderm

   **Answer:** A. The adrenal medulla is derived from ectodermal neural crest cells while the adrenal cortex is derived from mesenchyme.

3. Into which one of the following vessels does the left adrenal vein drain?
   A. Inferior vena cava
   B. Left renal vein
   C. Left gonadal vein
   D. Inferior phrenic vein

   **Answer:** B. The left adrenal vein drains into the left renal vein after joining the inferior phrenic vein, while the right adrenal vein
typically drains directly into the inferior vena cava.

4. Mineralocorticoids are produced by which one of the following layers of the adrenal cortex?
   A. Zona glomerulosa
   B. Zona reticularis
   C. Zona fasciculata
   D. Zona medullaris

   **Answer: A.** Mineralocorticoids are produced in the zona glomerulosa, glucocorticoids in the zona fasciculata, sex hormones in the zona reticularis, and catecholamines in the adrenal medulla.

5. Which one of the following structures is NOT at risk of injury when dissecting out the left adrenal gland with a transperitoneal approach?
   A. Spleen
   B. Diaphragm
   C. Tail of pancreas
   D. Hepatic flexure of colon

   **Answer: D.** The splenic flexure of the colon must be mobilized during laparoscopic left adrenalectomy and is therefore at risk of injury.
Clinical cases

1. A 59-year-old female with a medical history of dyslipidaemia and migraine headaches presents to the accident and emergency department with visual changes. On presentation, her blood pressure is 230/110 mmHg. Ophthalmological examination reveals retinal haemorrhages, cotton-wool spots and macular oedema. On further questioning, the patient admits to palpitations but nothing else. She is admitted to hospital for blood pressure control and further work-up. Her 24-hour urine catecholamines and metanephrines are found to be markedly elevated (over 12 times normal), which is diagnostic of phaeochromocytoma. An abdominal MRI reveals a 3.7 cm left adrenal lesion with high T2 signal but no signal drop-out on the out-of-phase images. The right adrenal gland is normal.

A. What treatment should be offered?

The gold standard treatment for this patient would be a minimally invasive left adrenalectomy. Either a transperitoneal laparoscopic adrenalectomy or posterior retroperitoneoscopic adrenalectomy approach would be acceptable.

B. What are the important perioperative considerations?

Prior to surgery, the patient requires a cardiovascular assessment, which includes a 12-lead electrocardiogram at a minimum, and possibly an echocardiogram as well. In the 2 weeks preceding surgery, phaeochromocytoma patients should receive alpha blockade and fluid resuscitation in order to try to minimize the intraoperative fluctuations in blood pressure and heart rate that may occur with tumour manipulation. Beta blockade may also be added preoperatively if there is a persistent tachycardia. An experienced anaesthesia team and surgeon are vital for the safe and successful performance of this procedure. Arterial and central venous lines are required for continuous blood pressure monitoring, as well as the ability to administer vasoactive medications and resuscitative fluids rapidly. During the operation, the surgeon and anaesthesiologist must be in constant communication with each other regarding the patient’s haemodynamic status. In particular, the surgeon must tell the anaesthesia team when the adrenal vein is ligated so that they are prepared to manage the subsequent hypotension that typically ensues. The anaesthetist may also ask the surgeon to stop manipulation of the tumour at various points during
the operation in order to regain control over the patient's haemodynamics. Postoperatively, the patient should be kept in a monitored setting, such as a surgical step-down unit or an intensive care unit, for ongoing monitoring. In addition to haemodynamic status, blood glucose levels should also be monitored closely, as hypoglycaemia may occur with cure of catecholamine excess. In the long term, patients should undergo annual functional testing for phaeochromocytoma, as recurrence can occur, even though the majority of these tumours are benign.

2. A 36-year-old male presents to the emergency department with haematuria and flank pain. A CT of the kidneys, ureters and bladder is performed to evaluate for urolithiasis. Incidentally, a 2.5 cm right adrenal lesion is identified. On further questioning, the patient does not volunteer any symptoms consistent with a functional lesion; nor does his physical examination reveal any signs of such.

A. What, if any, further investigations are required?
An adrenal mass identified on imaging studies performed for another reason is referred to as an adrenal incidentaloma and requires evaluation if larger than 1 cm. The majority will be non-functional, benign adenomas. For a functional work-up, the patient needs screening for Cushing's syndrome and phaeochromocytoma. Acceptable screening tests for Cushing's syndrome include a low-dose dexamethasone suppression test or 24-hour urine free cortisol level. Plasma free metanephrines or 24-hour urine catecholamines and metanephrines may be used to screen for phaeochromocytoma. Screening is indicated for Conn's syndrome only if the patient has hypertension, which would consist of a plasma aldosterone concentration and plasma renin activity, in order to calculate the aldosterone-to-renin ratio. Sex hormone-producing tumours are extremely uncommon and so screening is not necessary unless virilizing or feminizing features are identified. In addition to functional testing, dedicated adrenal imaging (either CT or MRI) must be performed in order to determine if the lesion has benign or atypical features. Atypical features are suggestive of malignancy or phaeochromocytoma.¹⁰
Development and congenital anomalies of the gastrointestinal tract and its adnexae

Nathan E Wiseman

**Core Procedures**

- Duodenoplasty for type 1 duodenal atresia
- Diamond duodenoduodenostomy
- Duodenojejunostomy
- Tapering enteroplasty with end-to-back enteroanastomosis
- Ladd procedure for malrotation
- Meckel's diverticulectomy (open, laparoscopic)

Over the past quarter-century significant advances have occurred that have resulted in safer and more available surgical care of the neonate, infant and child. Neonatal surgery has evolved into a tertiary specialty carried out largely by paediatric surgeons. Intensive care nurseries have evolved with a body of expertise that has resulted in marked improvements in the care of the critically ill neonate. Fetal assessment has led to routine antenatal diagnoses in many, if not most, major congenital anomalies.\(^1\) This is well established with regard to anomalies arising within the abdomen. Earlier diagnoses with optimal antenatal maternal care and perinatal care, as well as carefully planned and timed neonatal interventions, have had a major impact upon the reduction in neonatal morbidity and mortality. With earlier diagnoses and earlier surgical intervention, many infants will now have better outcomes.

The common anomalies of the gastrointestinal tract have been known for many years. The investigation of these anomalies using modern imaging techniques has led to more precise anatomical diagnoses and an improved
awareness of the surgical anatomy and pathology. However, the surgeon still needs to unravel the very specific anatomical and pathological details encountered at the time of a surgical procedure because these dictate the precise method of surgical operative correction. Although many specific anomalies tend to occur at a relatively low frequency, there is now a vast body of surgical literature through which experience is communicated and shared. An increased awareness of even the rarest anomalies has produced a significant resource base to assist surgeons, even in the management of the least common surgical problems, and has resulted in an evidence-based approach to surgical management of both common and uncommon congenital anomalies. In addition, a standardized nomenclature, with studied classifications, for each anomaly has clarified the understanding of the anatomical variations that are encountered.²
Atresia of the intestine

Atresia of the gastrointestinal tract is known to occur at all levels, from the oesophagus to the rectum. In most instances, atresia may be understood from the perspective of developmental anatomy as a failure of normal developmental processes. Recent studies have identified a number of genes responsible for growth factors and their receptors in the gut during development. The interaction between the endodermal epithelium and underlying mesenchyme is particularly important for establishing normal gut structure, and disruption of these processes is thought to be an important contributing cause of atresia formation.

Atresias may occur as an isolated anomaly, in the context of multiple anomalies, and within a syndrome. They present with a range of severity (Fig. 66.1). Many patterns of anomaly association have been recognized. One example of a broad expression of anomalies is seen in the VACTERL association. The full expression of this clinical entity may include atresia of the oesophagus and rectum; duodenal atresia may also be a part of this spectrum. It is well established that Down's syndrome may include atresia of the duodenum. Atresia involving the jejunum and ileum, and the much less common atresia of the colon, appear to be the result of an insult that acts through the common pathway of ischaemia at the site of the atresia: this has been shown to occur after the intestine has developed. A well-known example of this phenomenon may be seen in the neonate who has suffered an antenatal volvulus, and then at birth is found to have deletion of a significant portion of the intestine. In the majority of atresias, a short segment of intestine is affected and often the remainder of the intestine is healthy, although multiple atresias are known to occur in about 10% of such patients. The appearance of an atresia at the time of surgical correction quickly reminds surgeons that the intestine does function in utero, and the atresia has resulted in an intestinal obstruction prior to the fetus reaching term. A variable expression of atresia is encountered in relation to the timing of an ischaemic insult. There may be evidence of the mechanism, such as an antenatal intussusception or segmental volvulus, if the event occurs close to term, and no such evidence if it has occurred much earlier in gestation. A secondary phenomenon that is observed in infants with intestinal atresia is related to the effect it may have on the peritoneal cavity. Intestine that has undergone infarction in utero will resorb, leaving behind remnants that suggest the timing of the event. When there has been spillage of intestinal
contents with perforation occurring in utero, fetal peritonitis will result, producing ascites and adhesions that increase the complexity of surgical repair (Fig. 66.2). In every instance of atresia, a significant discrepancy is found in the luminal size of the proximal dilated obstructed bowel and the distal collapsed defunctioned bowel. The bowel distal to the obstructing mechanism is described as microbowel, and the appearance at the time of a contrast enema very quickly brings the microcalibre of an unused colon to the surgeon's attention. This discrepancy in size, with a large dilated proximal bowel and a small collapsed distal bowel, adds to the challenge of restoring intestinal continuity: the luminal discrepancy ratio may be as much as 10 to 1. At the time of surgery there is a need to resect a portion of proximal bowel in order to reduce the luminal discrepancy, and to facilitate the re-establishment of intestinal continuity in order to optimize recovery of intestinal function. There is evidence that the proximal dilated bowel at the level of obstruction may have abnormal motility that is believed to be the result of the ischaemic insult and chronic dilation.12

FIG. 66.1  Jejunal atresia (type IIIa). Note the mesenteric defect between the proximal dilated bowel and distal collapsed bowel (arrow).
There are a number of less common and more severe anatomical patterns of atresia. These include a pattern of atresia following an ischaemic insult involving a major proximal branch of the superior mesenteric artery (type IIIb). This produces a long-segment deletion of bowel and an unusual retrograde pedunculated vascular supply to the remaining ileum, giving it a configuration that has been likened to an ‘apple peel’. This pattern of atresia poses significant challenges because the absence of a true mesentery supplying the remaining small bowel leaves it vulnerable to poor perfusion as well as potential volvulus. A second uncommon pattern of atresia, which may be diagnosed at the time of operation, is referred to as a ‘string of pearls’, where a string of atretic segments may extend along most, or all, of the small intestine, leaving the patient with very little functional small bowel. These patients may also have atresia involving the stomach, duodenum and colon. This pattern of atresia has been shown to be familial. Infants with either of these two patterns of atresia need to remain long-term in hospital, receiving supplemental parenteral nutrition and awaiting recovery of bowel function that will allow for enteral feeding. Fortunately, most intestinal atresias involve short segments; recovery following re-establishment of intestinal continuity is the rule, with preservation of adequate intestinal length.

Intestinal atresia at the level of the duodenum is not uncommon and is most often diagnosed antenatally. These fetuses will have developed a markedly enlarged duodenum; a large fluid-filled stomach and proximal duodenum, analogous to the classic double bubble seen on an abdominal X-
ray, will be seen on fetal assessment (Fig. 66.3). A clue to the presence of this anomaly is polyhydramnios, which is usually present and may be severe. At birth, these infants are found to have a markedly increased gastric capacity and have bilious emesis in the early hours of life. Prompt diagnosis, followed by nasogastric decompression of the stomach, will alleviate concerns regarding emesis and aspiration. The anomaly in this instance is usually ascribed to a failure of recanalization of the lumen of the proximal duodenum after a period of endodermal hyperplasia during the first trimester. The majority of these lesions will occur in the region of the second portion of the duodenum at the junction between foregut and midgut. The anomaly is in close proximity to the point of entry of the bile duct and pancreatic duct, and therefore is in an anatomical region where corrective surgery must avoid interference with drainage at the level of the ampulla. The pattern of atresia in the duodenum may be relatively simple, in that a diaphragm may account for the atresia, and in some instances there may even be continuity through a small opening that defines the lesion as a congenital stenosis. A diaphragmatic atresia lends itself to a repair that maintains duodenal continuity, and must be carried out with careful attention paid to the anatomical location of the ampulla. When there is a gap between the proximal and distal duodenum, the site of obstruction coincides with the region of the head of the pancreas. Pancreas is interposed between the two duodenal ends, making it seem as though pancreatic development interfered with duodenal development. It is believed that the atresia is primary, and that the prominence of the pancreas is secondary. When the anomaly is in close proximity to the pancreas, a carefully constructed duodenal anastomosis may be created, or alternatively it is possible to anastomose the proximal jejunum to the duodenum and avoid the risks of surgical manipulation in the region of the second part of the duodenum. Functional continuity of the bowel remains the objective. However, in the presence of a proximal megaduodenum, one can anticipate motor function to be somewhat delayed or to remain abnormal in the long term. The anatomical appearance of the duodenum even later in life may remain abnormal, with the proximal duodenum remaining large compared with the more distal duodenum.
Atresia of the small bowel distal to the duodenum may occur at any level of the jejunum or ileum but tends to be more common in the distal small bowel (Fig. 66.4). It is estimated that as many as 1 in 10 may be multiple and surgeons are therefore obliged to look carefully for a second level of atresia that can be hidden by a higher-level atresia because of the decompression of the distal bowel. Multiple anastomoses may be carried out in order to preserve a healthy segment of bowel interposed between two sites of atresia. This is done in order to adhere to the principle of preservation of maximum functional intestine. As with atresia at all levels of the intestine, the success in re-establishing continuity of bowel is dependent on achieving both anatomical and functional continuity. The bowel adjacent to a zone of atresia may have abnormal peristaltic activity and may also have a relatively poor blood supply, which may dictate the need to resect or taper the proximal blind-ending bowel. If bowel adjacent to the level of an anastomosis has poor perfusion, this may lead to stricture formation. Intestinal atresia involving the colon is uncommon (Fig. 66.5©). It occurs more frequently in the right-side colon; the relative competence of the ileocaecal valve means that an atresia of the ascending colon can result in a large dilated proximal bowel
that has the appearance of an enteric cyst.\textsuperscript{21}

\textbf{FIG. 66.4} Jejunal atresia (type I). Note the continuity of the bowel serosa and a sharp demarcation in calibre secondary to a diaphragmatic membrane at the level of the atresia.

\textbf{FIG. 66.5} Colonic atresia. This operative image shows atresia of a markedly dilated ascending colon. The distal microcolon is clearly seen on the right side of the image.

Atresia rarely involves the stomach, but when recognized, it often occurs in the region of the pylorus. It tends to arise in association with the dermal disease epidermolysis bullosa. Surgical restoration of continuity between stomach and duodenum may be accomplished, but these infants have
abnormal connective tissue and their ability to heal is often impaired.

Hirschsprung's disease should be considered in the differential diagnosis of a neonate or infant who presents with a low intestinal obstruction. It results from failure of enteric nerves to colonize the gut, leading to a portion of the gut having no enteric nervous system and being unable to generate peristaltic action. There is sustained contraction of the aganglionic portion of gut and distension of the proximal portion (megacolon). Affected neonates show delayed passage of meconium, constipation, vomiting and abdominal distension.\textsuperscript{22}
Remnants of the vitelline duct

The vitelline duct in the fetus extends from the midgut to the yolk sac. After the developing midgut returns to the peritoneal cavity, the vitelline duct undergoes involution, leaving no postnatal remnant. If complete involution of the duct fails, a variety of congenital anomalies may result and present clinically between the early neonatal period and adulthood.

The most frequently recognized remnant is a Meckel's diverticulum, which arises from the antimesenteric border of the distal ileum. It is present in approximately 2% of the normal population, usually contains enteric mucosa, and remains a benign and uncomplicated entity. The lining of the diverticulum may also include heterotopic gastric mucosa, which may cause significant complications. The most frequently identified clinical problem that confronts surgeons is severe lower gastrointestinal tract haemorrhage as a result of ulceration within the diverticulum. The pathological specimen will usually reveal an ulcer in the ileal mucosa that is adjacent to the ectopic gastric mucosa. Ulcer perforation may also occur, leading to severe peritonitis that may be confused with appendicitis. Radionuclide technetium pertechnetate scanning of the abdomen that identifies ectopic gastric mucosa in the lower abdomen will confirm the diagnosis. Such patients require urgent surgery: the problem is rectified by a diverticulectomy.

A Meckel's diverticulum may have a persistent connection to the region of the umbilicus through a fibrous band that represents an incompletely resorbed, involuted vitelline duct. Such a band is well known to predispose to intestinal obstruction. On occasion, the distal point of attachment of a band arising from the diverticulum may connect to the mesentery, again creating a risk of obstruction. The clinical presentation of a Meckel’s diverticulum may also include intussusception, which can occur in infancy or at an older age. This diagnosis is usually made only at the time of a surgical procedure carried out for treatment of a bowel obstruction. At the time of resection of a Meckel's diverticulum, the surgeon will recognize that its blood supply arises from the mesentery of the adjacent bowel. In this setting, a vessel is often visible as it passes around the bowel on the serosal surface: this vessel represents a vestige of the vitelline artery. The diverticulum may also, on occasion, be seen to be folded on to the mesentery, where it becomes adherent and may be difficult to detect. When the vitelline duct fails to involute at its distal end, it may leave a small island of intestinal mucosa at the level of the umbilicus. This mucosa is often mistaken for an umbilical
granuloma that has failed to heal; when it is excised, the pathologist will identify mucosa and facilitate diagnosis. A patent vitelline duct will present passage of enteric contents through the umbilicus of a neonate (Fig. 66.6). The anomaly is then acting as an external fistula or congenital stoma. Such lesions demand resection, which extends from the umbilicus to its point of attachment with the ileum. An isolated remnant of the mid zone of the vitelline duct may present as an enteric cyst. Since there is a communication neither internally nor externally, the lesion retains the products of its own mucosal lining; over time, it can grow to be of significant volume, and presents with abdominal discomfort or even a palpable abdominal mass. There are therefore many clinical presentations of the vitelline duct remnant, and awareness of this lesion and its many different modes of presentation is important. A rare occurrence is the association of a vitelline duct remnant with an omphalocele (Fig. 66.7).

FIG. 66.7 An omphalocele with a patent omphalomesenteric duct. Note the duct prolapsing through the wall of the omphalocele, with prolapse of both the afferent and the efferent limb of ileum.
FIG. 66.6  A patent omphalomesenteric duct. This operative image shows a loop of ileum mobilized through an umbilical incision, demonstrating the attached omphalomesenteric duct (indicated by arrow).
Anomalies of intestinal rotation

Malrotation of the midgut is an anomaly that is important from the perspective of both the paediatric surgeon and the surgeon who operates on adults.\textsuperscript{27} The conventional view is that the anomaly is the result of failure of normal intestinal rotation to occur during week 10 of embryogenesis at the time when the midgut returns to the abdominal cavity from the umbilicus.\textsuperscript{17} An alternative recent concept is that ‘non-rotation’ is a better descriptor and that the anomaly represents incomplete embryological development of the mesentery, resulting in the right colon and mesocolon being centrally located in the abdomen (Ch. 57). The term malrotation will be retained in this chapter: irrespective of the underlying mechanism(s), a number of very important anatomical anomalies result from this developmental failure.\textsuperscript{28} These include a markedly foreshortened attachment of the midgut mesentery to the dorsal abdominal wall that, in the extreme, becomes little more than an unsupported vascular pedicle containing the superior mesenteric vessels. A second anatomical anomaly ever present in malrotation is the orientation of the duodenum. The normal 270° anticlockwise rotation of the duodenum fails to occur and results in the duodenojejunal junction residing more inferiorly and towards the right side. In a patient with complete malrotation, the duodenum descends to the right side of the midline in a rather circuitous manner. The position of the colon in malrotation is also significantly altered. The right colon, including the caecum, ascending colon and the right portion of the transverse colon, are often leftward in their positioning and therefore the ileocaecal junction is frequently superiorly located in the epigastrium. It is most important to recognize that malrotation is variable from the perspective of the degree of failure of rotation and thus the intestinal anatomy encountered by the surgeon will differ from patient to patient.

Patients with incomplete rotation are noted to have their caecum in the right upper quadrant in close proximity to the liver, gallbladder and right kidney. When infants are born with complete malrotation, they are often asymptomatic initially; they may tolerate feeding and even appear to thrive. In fact, normal intestinal function may even persist throughout life. Alternatively, when malrotation results in extrinsic compression of the duodenum as a result of the peritoneal attachments of the right colon crossing the duodenum (Ladd’s bands), there may be a variable degree of extrinsic duodenal compression, and this may produce a picture of partial duodenal obstruction.\textsuperscript{29} The most serious consequence of malrotation
remains the risk of volvulus. With a narrow midgut vascular pedicle, the entire midgut may be suspended with very limited attachments and predispose to a volvulus that is based on the superior mesenteric vascular pedicle. This event may lead to a rapid compromise to the blood supply of the midgut. The clinical picture of such a patient in the early hours following volvulus will be that of high small bowel obstruction, characterized by bilious emesis often in the absence of abdominal distension. This will then progress to show evidence of bleeding into the bowel as a consequence of haemorrhagic infarction, and ultimately lead to hypovolaemic haemorrhagic shock. This is considered a surgical emergency, as it places at risk the viability of the entire midgut. Even though early surgical intervention may rescue the blood supply of the bowel, many patients will succumb to this intestinal catastrophe. The patient who survives but suffers the loss of a large portion of the midgut is inevitably faced with life-long intestinal morbidity due to extreme short gut syndrome. The clinical presentation in infancy of acute upper intestinal obstruction of an infant who appeared to have initially tolerated feedings is the hallmark of the diagnosis, and must lead to urgent surgical intervention. Whereas a complete volvulus may result in the rapid onset of intestinal ischaemic changes, a partial volvulus may spare the blood supply to the intestine. If a volvulus is treated early with timely detorsion, intestinal perfusion may be recovered. In the circumstance of a complete volvulus, the abdomen may in fact be airless, and the clinical picture may simulate obstruction at the level of the duodenum or proximal jejunum. Contrast images carried out through the stomach may reveal a corkscrew appearance of the duodenum, which is the classic appearance of a volvulus. The contrast will usually fail to progress beyond the duodenum and proximal jejunum. In the presence of volvulus, abdominal ultrasound may demonstrate inversion of the relative position of the superior mesenteric artery and vein, although this sign is variable. With complete non-rotation that is complicated by volvulus, urgent surgical intervention is undertaken in order to detort the volvulus and restore perfusion. Surgeons have long recognized that it is not possible to recreate normal intestinal anatomy. The objective of surgery is primarily to create a stable midgut anatomical configuration that reduces the potential for volvulus recurrence. An important anatomical feature of malrotation that must be addressed is the close binding together of the afferent duodenojejunal limb and the efferent right colon. These viscera are bound together and enveloped in bands of peritoneal attachments that must be
lysed in order to allow for maximum separation between the afferent and efferent bowel (Fig. 66.8). Extensive and complete lysis of these encasing bands will result in maximum separation between the duodenojejunum and the right colon. This procedure tends to broaden and stabilize the root of the midgut, and results in the duodenum descending to the right side of the midline, and the right colon residing on the left side. It is believed that, when these viscera are separated, the formation of adhesions helps to stabilize the midgut, and by this mechanism reduces the recurrence rate of volvulus. The bowel will thus, by necessity, remain in a non-rotated anatomical position. It is usually recommended that appendicectomy be performed at the time of surgery for malrotation because of the risk of an atypical clinical presentation, should appendicitis subsequently develop. The risk of volvulus in patients with a partial incomplete intestinal rotation appears to be significantly reduced. In such patients, it is often encountered as an incidental finding and raises a conundrum regarding management directives. Even with the lower risk of volvulus, some such patients may still undergo a surgical procedure in order to reduce their potential for volvulus, whereas others may just be followed clinically.

FIG. 66.8 Malrotation. This operative image depicts the appearance of the intestine after detorsion of a volvulus. Tight bands are encasing and tethering the duodenum and the right colon.

Malrotation may present as a chronic syndrome. Some patients will experience intermittent abdominal pain and vomiting that are felt to be related to a dynamic partial volvulus that may vary from time to time. Evidence for a partial volvulus may be found at the time of an ultrasound.
examination. Such patients may demonstrate lymphoid hyperplasia and thickening of their mesentery that result from partial lymphatic obstruction. They may also be found to have venous engorgement of the splanchnic circulation resulting from chronic non-strangulating partial obstruction of splanchnic venous return. Such findings mandate the need for surgical intervention. Malabsorption may also develop in patients with malrotation.

In patients with undiagnosed asymptomatic malrotation, the clinical presentation of the acute abdomen may be atypical. Appendicitis that is typically a right lower quadrant illness may appear in these patients as a pain focused in their right upper abdomen, or even in the epigastrium, and may be confused with such disease processes as cholecystitis, pancreatitis or even gastritis. In the spectrum of malrotation there exists the neonate who was noted antenatally to have a significant abnormal appearance to the abdomen. Fetal assessment may reveal the presence of ascites with an abnormal bowel that appears dilated and has a thickened wall. This finding may suggest the presence of an antenatal volvulus that at birth may present in an infant with bowel obstruction who is then found at surgery to have midgut infarction. From the surgeon's perspective, it is noteworthy that, at the time of surgery for malrotation, a significant anatomical variability is expected. Unravelling a volvulus and carrying out a definitive separation of the afferent and efferent limbs of the volvulus is the hallmark of successful surgical management.

Malrotation may also be an important part of other major anomalies. Such anomalies include omphalocele, gastroschisis and diaphragmatic hernia. In each of these anomalies, either the bowel has failed to return to the peritoneal cavity during normal midgut development, or it may have returned to the peritoneal cavity and subsequently extruded into an extra-abdominal space. In the patient with a diaphragmatic hernia, the bowel is malpositioned within the pleural cavity, and thus has not had an opportunity to become normally positioned within the abdomen. In the case of omphalocele, the bowel has not returned to the peritoneal cavity, and thus normal rotation has not occurred. Infants born with gastroschisis also have intestine that has not become fixed and is abnormally rotated; this bowel also has a significant risk for atresia. In all of these instances, the main focus is on the primary anomaly, which is managed in accordance with the principles of management of that particular anomaly. A secondary and significantly important surgical focus must also be placed on the potential role played by the associated malrotation.
**Intestinal duplication**

Intestinal duplication is a relatively uncommon anomaly of the gastrointestinal tract, resulting in a lesion that is in close proximity to normal bowel, and may arise anywhere from the oesophagus to the rectum. The anomaly presents in the form of either a cystic or a tubular mass that shares the wall of the adjacent intestine and is located on the mesenteric border. The surgeon must be aware that these lesions also share their vascular supply with the adjacent bowel. On resection of these lesions, it is most important for the surgeon to adhere to the principle of preservation of blood supply to the adjacent bowel.

A number of theories regarding the development of these anomalies have been proposed. Some may arise as a result of abnormal intestinal vacuolization, as parts of the bowel, such as the duodenum, undergo a transition from a solid to a luminal state. However, more complex embryological mechanisms are likely to be responsible, including the split notochord syndrome and even incomplete twinning. They may occur in association with other anomalies, including vertebral anomalies and duplications of the urogenital tract. The clinical problem posed by these lesions relates to their juxtaposition to normal bowel, which, in the case of a cystic lesion, may result in encroachment and lead to bowel obstruction. Often, lesions contain ectopic gastric mucosa; ulceration is known to occur and may result in gastrointestinal haemorrhage. Diagnostic imaging, including ultrasound, CT scans and MRI, will show the lesions as being unilocular and in very close proximity to the native intestine from which they arise. They are to be differentiated from choledochal cysts that arise from the extrahepatic biliary tree, and mesenteric cysts that arise in the mesentery. The latter are multilocular and more delicate in their anatomical configuration, lacking the characteristic intestinal wall layers that are noted to be present in all duplication cysts.
The principles of surgical management of such lesions demand firstly that close attention be paid to the blood supply of the normal bowel, and secondly that resection does not result in loss of long bowel segments.
Surgical management will often require a short segmental resection of the bowel along with the lesion. This is common when duplications arise in the small bowel. Enucleation of a duplication arising in the oesophagus, stomach and duodenum may often be accomplished with preservation of the blood supply to the normal bowel (Figs 66.11 and 66.12). Enteric duplication cysts have also been identified within the pancreas, where they may cause duct obstruction that leads to secondary pancreatitis. More complex tubular duplications are managed with an attempt to adhere to the principle of preservation of intestinal length. This may be achieved by creating a long communication between the duplication and the adjacent normal bowel. Alternatively, stripping its mucosal lining may obliterate the tubular duplication. Unusual clinical presentations of such lesions may include an antenatal fetal image of a cystic abdominal mass, a postnatal segmental volvulus or an intussusception (Fig. 66.13); rarely, they may present with haemoptysis or haematemesis. Resection of these lesions is usually curative. Duplication rarely occurs in the perirectal region (Figs 66.14 and 66.15).

FIG. 66.11 A large gastric duplication cyst located at the greater curvature of the body of the stomach (indicated by arrow).
**FIG. 66.12** Gastric duplication cyst operative resection. Note the shared serosal layer between the cyst and the adjacent gastric body. The cyst is being enucleated.

**FIG. 66.13** Ileal duplication causing intussusception. This operative image shows ileo-ileo-colic intussusception secondary to a duplication cyst.
FIG. 66.14 Rare rectal duplication presenting as a perianal bulging mass with unusual dermal buds, causing rectal compression and distortion.

FIG. 66.15 Resection of a rectal duplication cyst.

Tips and Anatomical Hazards

It is incumbent on the surgeon to be fully aware of the range of clinical problems that congenital anomalies of the gastrointestinal tract present with, and to be equally aware of the anatomical characteristics that will be encountered at the time of surgery.


10. Louw JH, Barnard CN. Congenital intestinal atresia:


**Single Best Answers**

1. Which one of the following statements concerning duodenal atresia is INCORRECT?

   A. In counselling parents antenatally, it is correct to inform them that the potential risk of Down's syndrome is approximately 1 in 3

   B. Duodenal atresia results from abnormal rotation of the ventral pancreatic bud occurring during the fifth week of embryogenesis

   C. The risk of a second intestinal atresia at another level of the bowel is infrequent enough to negate the need for the surgeon to explore for a second atresia

   D. The best surgical results following repair of duodenal atresia are achieved by carrying out a duodenoduodenostomy

   E. Air may be present in the intestine beyond the level of the atresia

   **Answer: B.** It is true that duodenal atresia occurs most frequently in the second part of the duodenum and, of necessity, this is adjacent to the developing pancreas. The atresia, however, results from abnormal vacuolization of the duodenum, which is a mechanism that is intrinsic to the development of the duodenum. Although the pancreas is present in close proximity to the region of a duodenal atresia, it is not considered to be implicated in the embryogenesis of the atresia. In counselling parents of a fetus that has been shown to have duodenal atresia, it is most important to make them fully aware of all of the issues that pertain to the anticipated infant's birth. Parents are usually given the option of having amniocentesis carried out in order to confirm the diagnosis of Down's syndrome. With respect to the risk of a second site of atresia, the duodenum carries an extremely low risk compared to the rest of the small bowel, where
the risk is as high as 10%. In recent years, surgeons have been encouraged to try to restore continuity of the duodenum by performing an anastomosis between the proximal and distal duodenum that bypasses the level of atresia. This procedure has been shown to be followed by a more rapid recovery of function and allows for earlier feeding and earlier hospital discharge. The presence of air in the bowel beyond the level of a duodenal atresia is explained by an associated duplex bile duct, with one duct entering the proximal duodenum and the other entering the distal duodenum. By this means, it is possible for air to circumvent the level of the atresia and enter the distal bowel. It is also not uncommon to see air in the biliary tree in infants with duodenal atresia.

2. Which one of the following statements concerning malrotation is correct?

A. The infant with a midgut volvulus will present early with abdominal distension

B. The diagnosis of malrotation will always be confirmed by an ultrasound demonstrating inversion of the superior mesenteric vessels

C. Gastrointestinal haemorrhage is a sign of haemorrhagic bowel infarction

D. Imaging investigations to confirm the diagnosis of volvulus are always necessary prior to undertaking surgery

E. All of the above

**Answer:** C. The evolution of midgut volvulus to the point when haemorrhagic infarction of the midgut occurs is heralded by the appearance of blood in the stool. This is a late and ominous sign and should lead to urgent surgery. Recognition of the fact that haemorrhage may occur prior to the onset of irreversible intestinal ischaemic infarction is of the utmost importance. It is
equally important for clinicians to be aware that the early appearance of the abdomen in the infant with a midgut volvulus is consistent with high intestinal obstruction and thus abdominal distension may well be absent. This reflects the anatomical fact that the afferent limb at the point of volvulus is the duodeno-jejunum and this marks the level of bowel obstruction. The presence of abdominal distension signifies that the midgut closed loop is filling with fluid and blood, and the bowel wall is becoming oedematous and haemorrhagic. It is important to note that the accuracy of ultrasound in diagnosing malrotation is below 80%. Although imaging modalities, such as an upper gastrointestinal contrast study, ultrasound and CT scan, are valuable in diagnosing malrotation, with volvulus the time lost in carrying out these investigations may be prohibitive with respect to proceeding with timely bowel-saving and potentially life-saving surgery.

3. Which one of the following clinical problems may arise as a result of a vitelline duct remnant and what is the pathogenesis of each of the clinical problems that may arise?
   A. Mechanical small bowel obstruction
   B. Acute gastrointestinal haemorrhage
   C. Peritonitis
   D. Abdominal mass
   E. All of the above

**Answer: E.** This confirms that each of the listed clinical problems may result from a remnant of the vitelline duct. Mechanical bowel obstruction may arise as the result of number of mechanisms. A remnant fibrous band can cause constriction or internal herniation. A Meckel's diverticulum can cause obstruction by the mechanism of intussusception. A large enteric cyst remnant can produce an extrinsic compression of bowel and
thereby cause bowel obstruction. The common mechanism of haemorrhage is well known to be ulceration arising in a diverticulum that contains gastric mucosa. Haemorrhage may also be part of the picture when an intussusception leads to haemorrhagic necrosis of the intussusceptum. A common cause of peritonitis is perforation of an ulcer within a diverticulum. Additionally, diverticulitis arising within the diverticulum can lead to peritonitis in a manner that is analogous to appendicitis. The abdominal mass that results from a vitelline remnant may be inflammatory, cystic or neoplastic. An inflammatory mass will result when a phlegmon occurs and may lead to abscess formation. A cystic mass will occur as a result of a non-communicating segment of a mucosa-bearing remnant: the resulting lesion is an enterocele. It is also important to note that a vitelline remnant may be the site of a neoplasm. Tumours arising within a Meckel's diverticulum are well described and include adenocarcinoma of either gastric or pancreatic origin. It is thus abundantly clear that a multitude of clinical problems may arise from a vitelline duct remnant.
Endoscopic anatomy of the gastrointestinal tract

Kyle J Fortinsky, Jason Samarasena, Adam V Weizman

Core procedures

- Oesophagogastroduodenoscopy (OGD)
- Push enteroscopy
- Capsule endoscopy
- Deep enteroscopy
- Endoscopic retrograde cholangiopancreatography
- Endoscopic ultrasound
- Colonoscopy
- Flexible and rigid sigmoidoscopy

Endoscopy is a critically important tool for both the diagnosis and the treatment of many different gastrointestinal disorders.\(^1\) With recent advances in endoscopy, the entire gastrointestinal tract can now be visualized. While there are potential risks of complications, endoscopic procedures are generally considered safe and usually do not require general anaesthesia.\(^2\) Each section of this chapter will provide an overview of endoscopic procedures, including procedural indications and risks. The endoscopic anatomy and potential pitfalls are also reviewed in the context of each procedure.
Oesophagogastroduodenoscopy (OGD) is used to investigate the oesophagus, stomach and duodenum. A gastroscope, which measures 9.9 mm in diameter and 100 cm in length, is most commonly used for the procedure. An accessory channel is available to place instruments, including biopsy forceps, clips and bipolar cautery probes, down through the scope.

The oesophagus is typically described as having three segments: cervical, thoracic and abdominal. It extends from the upper oesophageal sphincter at approximately 15 cm from the incisors to the lower oesophageal sphincter at 30–40 cm from the incisors (Fig. 67.1). The gastro-oesophageal junction is referred to as the Z line and can be identified as the transition from the paler, pearly-coloured oesophageal mucosa (squamous mucosa) to the pinker gastric mucosa (columnar epithelium) (Fig. 67.2). This landmark can sometimes be challenging to identify: for example, in patients with a hiatus hernia or a Barrett’s oesophagus. Other features that aid in identifying the gastro-oesophageal junction include the junction between the distal end of the oesophageal longitudinal vessels and the proximal end of the gastric longitudinal folds.
FIG. 67.1  Regions of the oesophagus. The cervical oesophagus extends from the upper oesophageal sphincter to the thoracic inlet; the upper thoracic oesophagus extends from the thoracic inlet to the azygos vein; the mid-thoracic oesophagus extends from the lower border of the azygos vein to the inferior pulmonary vein; and the lower thoracic oesophagus extends from the lower border of the inferior pulmonary vein to the gastro-oesophageal junction (GOJ). (From J.D. Spicer, R. Dhupar, J.Y. Kim, et al. Esophagus. In: Sabiston Textbook of Surgery, twentieth ed. Copyright © 2017 by Elsevier, Inc. All rights reserved, Fig. 41.13, pp. 1013–1042.)

FIG. 67.2  The normal gastro-oesophageal junction.

The stomach is divided into five sections extending from the cardia at the gastro-oesophageal junction to the fundus, body, antrum and the pylorus, which terminates at the duodenum.\(^5\) The cardia, fundus and body are usually characterized by prominent folds, or rugae, whereas the lining of the antrum is relatively flat (Fig. 67.3). When a patient is lying in the left lateral decubitus position, the gastric greater curvature is located at the bottom of the screen and the lesser curvature is located at the top of the screen\(^5\): this orientation is essential when reporting the location of gastric lesions. The pylorus is the short, circular channel that then leads into the first part of the duodenum, often referred to as the duodenal bulb. In most patients, the gastroscope may routinely be advanced into the second or third portion of the duodenum.
Common indications for OGD include upper gastrointestinal bleeding, dysphagia, early satiety, dyspepsia and reflux.\textsuperscript{7,8} OGD can be both diagnostic (for example, obtaining biopsies) and therapeutic (for example, endoscopic haemostasis for gastrointestinal bleeding). The risks associated with OGD include sedation-associated cardiopulmonary complications, bleeding, infection and perforation.\textsuperscript{9,10} During OGD, insufflation of CO\textsubscript{2} allows for visualization; photographs are taken routinely from specific locations throughout the oesophagus, stomach and duodenum in order to document a patient's anatomy and pathology.\textsuperscript{11}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{image}
\caption{A retroflexed view from the gastric antrum, looking at the fundus and body of the stomach.}
\end{figure}

\section*{Tips and Anatomical Hazards}

Barrett's oesophagus is often suspected endoscopically on the presence of pinkish gastric mucosa above the Z line, and is confirmed histologically by the replacement of the normal squamous oesophageal mucosa by specialized intestinal columnar epithelium (intestinal metaplasia). This lesion is a precursor to the development of malignancy and warrants ongoing endoscopic surveillance. The diagnostic accuracy for detecting \textit{Helicobacter pylori} infection is
improved when biopsies are obtained from both the gastric antrum and the body.
Push enteroscopy

Push enteroscopy allows access to distal duodenal or proximal jejunal lesions that are beyond the reach of a standard gastroscope. For this procedure, an endoscopist may use a paediatric colonoscope, which measures 9.7 mm in width and 160 cm in length; the extra length, when compared to a standard gastroscope, enables access to more distal regions of the lumen of the small intestine. This procedure is often performed for the investigation of iron deficiency anaemia or occult gastrointestinal bleeding.\textsuperscript{12} Another indication for push enteroscopy is access to more proximal small bowel lesions (tumours or angiodysplastic lesions) that have been localized by capsule endoscopy or another imaging modality.\textsuperscript{13} Small bowel tumours may be biopsied, and angiodysplastic lesions can be readily treated using argon plasma coagulation, through the accessory channel of the endoscope. The risks associated with the procedure are similar to those of OGD.
Capsule endoscopy

For capsule endoscopy, a patient swallows a small capsule that takes high-definition images throughout the gastrointestinal tract (Fig. 67.4). Common indications for the procedure include obscure gastrointestinal bleeding, iron deficiency anaemia or evaluation of small bowel Crohn's disease. Capsule endoscopy is especially helpful when routine endoscopic evaluation with gastroscopy and colonoscopy is not diagnostic and there is a suspected small bowel source of haemorrhage. Full bowel preparation is suggested prior to administering a capsule to improve visibility. Capsule endoscopy is only a diagnostic test; once a lesion has been identified, another procedure is required for either biopsy or therapy (see ‘Deep enteroscopy’). Notably, studies have shown that CT enterography is superior to capsule endoscopy for the diagnosis of small bowel tumours, whereas capsule endoscopy is superior to CT enterography for the evaluation of small bowel angiodyplastic lesions. The use of capsule endoscopy is contraindicated in the setting of a known small bowel stricture because the capsule could become lodged and surgery might be required for its removal. The major risks associated with capsule endoscopy are bowel obstruction and incomplete small bowel examination.
FIG. 67.4  Capsule endoscopy captured image showing a clean-based jejunal ulcer.
Deep enteroscopy

Once a small bowel lesion is identified, by either capsule endoscopy or other imaging test, there are several methods by which the lesion may be accessed for therapy. Balloon-assisted enteroscopy allows examination of the entire small bowel.\textsuperscript{22} The technique used to advance the enteroscope is a push-and-pull method, where inflation and deflation of balloons located along the scope allow the bowel to telescope on to an overtube, permitting longer endoscope advancement than is possible with conventional endoscopy. Balloon-assisted endoscopy can be performed either in an anterograde direction (via the mouth) or in a retrograde direction (via the anus).\textsuperscript{23,24} In certain circumstances, the endoscopist may wish to perform an entire enteroscopy, combining anterograde and retrograde approaches (rendezvous procedure). In these cases, a tattoo may be placed to ensure that the endoscopist has visualized the entire bowel. The advantages of balloon-assisted enteroscopy are that it permits therapeutic intervention and is less invasive than surgery. The major risks include sedation-associated cardiopulmonary complications, infection, bleeding, perforation, ileus and pancreatitis.\textsuperscript{25,26} This procedure can be considered an alternative to laparoscopic-assisted enteroscopy, where the surgeon makes an incision in the bowel wall to permit the passage of an endoscope.\textsuperscript{27}
Endoscopic retrograde cholangiopancreatography

Endoscopic retrograde cholangiopancreatography (ERCP) allows therapeutic intervention on the pancreaticobiliary tree. To gain access to the bile duct and pancreatic duct, a side-viewing duodenoscope permits direct visualization of, and access to, the ampulla of Vater, which is located in the second part of the duodenum. A duodenoscope measures 11.3 mm in diameter and 120 cm in length. It has an accessory channel available, which can be manipulated with an elevator to alter the angle and so permit the sphincterotome (a device used to cannulate the bile duct and pancreatic duct) to contact the ampulla of Vater, facilitating sphincterotomy and cannulation (Fig. 67.5). Indications for ERCP include common bile duct stones, pancreatic cancer causing biliary obstruction, symptomatic pancreatic stones and cholangiocarcinoma.

Given the risks associated with ERCP (sedation-associated cardiopulmonary complications, infection, perforation, post-sphincterotomy bleeding, cholangitis and pancreatitis), the procedure should be reserved for therapeutic purposes (such as brushings/biopsies, removal of stones or placement of stents); magnetic resonance cholangiopancreatography (MRCP) and/or endoscopic ultrasound are the preferred modalities for diagnostic evaluation.

During an ERCP, insufflation of CO₂ is used to enhance visualization and permit scope passage to the ampulla of Vater, at which point cannulation of the bile duct and/or pancreatic duct is performed using a sphincterotome and guide-wire technique. Both endoscopic views (to visualize the ampulla) and fluoroscopic images (to visualize the biliary and pancreatic ducts) are used simultaneously to guide the procedure. Routine endoscopic and fluoroscopic photographs are taken to document normal patient anatomy (Fig. 67.6); additional photos are captured of any abnormal or worrying pathology, and interventions may be performed if required.
FIG. 67.5  A, A normal appearing ampulla of Vater.  B, The ampulla immediately after sphincterotomy.
FIG. 67.6  A, The pancreaticobiliary tree. B, A fluoroscopic image of normal anatomy as seen on a cholangiogram obtained during endoscopic retrograde cholangiopancreatography.
Endoscopic ultrasound

Endoscopic ultrasound (EUS) combines endoscopy with high-resolution ultrasonography in order to obtain high-quality images of structures external to the lumen of the gastrointestinal tract. This procedure can be performed using a variety of different probes, including a radial endoscope, a through-the-scope EUS catheter probe and a linear endoscope. The endoscopic ultrasound probe measures 12.6 mm in diameter (14.6 mm at the distal tip) and 125 cm in length. Common diagnostic indications for this procedure include diagnosis and staging of malignancies (oesophagus, lung, stomach, small bowel, pancreas, liver, gallbladder, biliary tree, colon and rectum); characterization of submucosal lesions in the gastrointestinal tract; pancreatic cyst aspiration; and biopsy of lymph nodes.\textsuperscript{35–37} Any suspicious mass, lymph node or cyst can be biopsied or aspirated using a through-the-scope needle device.\textsuperscript{38} There is increasing utilization of EUS for therapeutic indications that include performing cystgastrostomy (drainage of a pancreatic pseudocyst) (Fig. 67.7), endoscopic pancreatic necrosectomy, coeliac plexus neurolysis, gastric variceal coiling and gluing, and biliary drainage, among others.\textsuperscript{39–41} The risks associated with EUS include those associated with sedation, bleeding, infection, perforation and pancreatitis (if performing biopsy of the pancreas).\textsuperscript{42–44}
Colonoscopy

Colonoscopy is used to investigate the rectum, colon and terminal ileum. The most common indication for the procedure is screening for colon cancer, and it is often used in the evaluation of lower gastrointestinal bleeding, iron deficiency anaemia and inflammatory bowel disease. A colonoscope measures 12.8 mm in diameter and 160 cm in length; an accessory channel is available to pass instruments down through the scope, including biopsy forceps, snares, clips and bipolar cautery probes. The anal canal is intubated and the colonoscope is advanced into the rectum (usually approximately 15 cm in length and typically described in proximal, mid and distal thirds). Retroflexion in the rectum is useful in the assessment of distal rectal lesions and haemorrhoids or rectal varices. Flexible sigmoidoscopy (examining distally up to the sigmoid colon) and anoscopy (examining only the rectum) can be performed in certain circumstances as an alternative to a full colonoscopy. The sigmoid colon often poses a technical challenge for endoscopists because of its tortuosity and it is a common location for scope looping to occur. Diverticuloses are most often found in the sigmoid colon in North American patients, although they may be located anywhere in the colon. The sigmoid and descending colons often have a circular shape, as compared to the transverse colon, where the haustra impose a triangular shape. The junction between the descending colon and the transverse colon is defined by the splenic flexure, which can be identified by the bluish blush of the spleen seen external to the transilluminated colon. The transverse colon terminates at the hepatic flexure, which is often identified by the transilluminated bluish blush of the liver. The ascending colon leads into the caecum; identification of caecal landmarks is critical to ensure that the entire colon has been traversed. The appendiceal orifice near the base of the caecum is usually a small, diverticular-like circular opening. The ileocaecal valve is usually a prominent bulbous fold located at the proximal end of the caecum. Intubating the valve is important to confirm that the colonoscopy is complete, and for the diagnosis and restaging of ileal inflammatory bowel disease. An endoscopist can usually examine the distal 10–20 cm of terminal ileum with a colonoscope.
To ensure adequate luminal visualization, a patient must complete bowel preparation in order to evacuate all stool from the colorectum prior to colonoscopy. The risks associated with colonoscopy include the risks of bowel preparation (aspiration, dehydration, electrolyte imbalances), sedation, bleeding, infection, perforation and missed lesions. During a colonoscopy, insufflation of CO$_2$ distends the bowel and allows for 360° visualization of the lumen of the distal small and entire large intestine. Routinely, photographs are taken from specific locations throughout the rectum, colon and distal small bowel in order to document patient anatomy and any abnormalities. Additional photographs are captured of any abnormal or worrisome pathology, and biopsies or other interventions may be performed as needed.

**Tips and Anatomical Hazards**

Photo-documentation of the caecal landmarks is considered an important quality indicator and should be performed during every colonoscopy, regardless of indication. Careful withdrawal of the scope, along with clockwise torque, can often help reduce colonoscope loops; these manœuvres can also assist with
further advancement of the colonoscope.
Polyps and cancers of the gastrointestinal tract

A variety of different types of polyp can develop throughout the gastrointestinal tract; they represent a spectrum of disease from benign to dysplastic to malignant. Polyps are routinely classified according to their appearance using the Paris classification system (Figs 67.9, 67.10).\textsuperscript{52–54}

Premalignant polyps can be removed by polypectomy or endoscopic mucosal resection (EMR). The technique of EMR can vary depending on the location of the polyp and the technical expertise of the endoscopist. Most often, a submucosal injection using methylene blue and normal saline is used to lift the polyp in preparation for its removal. This injection allows for the safe and complete removal of the polyp by reducing injury to underlying muscle.

Underwater EMR is an evolving procedure for polyp removal (Video 67.1). By filling the segment of colon with water (as opposed to air), the mucosa and submucosa separate, enabling safe and complete EMR without the use of an injection.\textsuperscript{55,56} In both cases, an endoscopic snare is used, with or without cautery, to remove the polyp. The major risks of polypectomy include infection, bleeding, perforation and leaving residual polyp \textit{in situ}.\textsuperscript{57–60}
FIG. 67.9 The Paris classification of polyps. Type I is elevated or polypoid; type Ip is polypoid/pedunculated; type Is is polypoid/sessile and broad-based. Type II is flat or superficial; type IIa is flat and elevated; type IIb is completely flat; type IIc is superficially depressed. These types often consist of mixed forms, such as type IIa+IIc, which is flat and elevated with a central depression. Type III (not shown) is excavated/ulcerated, without any further subgrouping. (From D.K. Rex, C. Hassan, M.J. Bourke, The colonoscopist’s guide to the vocabulary of colorectal neoplasia: histology, morphology, and management. Gastrointest. Endosc. 86 (2017) 253–263. © 2017, Fig. 6.)
Cancer may occur anywhere along the length of the gastrointestinal tract, from the oropharynx to the anus. Endoscopy has a role in both the diagnosis and the treatment of malignancy in a variety of different ways. Biopsies can be taken of the lesions to allow for the diagnosis of gastrointestinal cancer. Endoscopy also allows for the treatment of certain gastrointestinal cancer types; for example, oesophageal and gastric cancer can be managed using argon plasma coagulation or haemostatic sprays to treat haemorrhage; cryotherapy for tumour debulking; or stenting for oesophageal or gastric outlet obstruction.\textsuperscript{61,62} Oesophageal cancers may arise from the upper two-thirds of the oesophagus (squamous cell carcinoma) or from the lower third of the oesophagus (adenocarcinoma) (Fig. 67.11). ERCP is often used to relieve biliary obstruction caused by pancreatic cancer by placement of metal stents in preparation for either chemotherapy, radiation or surgery. Cancers of the gastrointestinal tract often present as large, mass-like lesions, and sometimes with ulceration and spontaneous haemorrhage (Fig. 67.12). Treatment of gastrointestinal malignancies requires a multidisciplinary approach involving gastroenterologists, surgeons, medical oncologists, radiation oncologists and other medical professionals.\textsuperscript{63,64}
FIG. 67.11  A, Squamous cell carcinoma at 26 cm in the mid oesophagus. B, Adenocarcinoma at 36 cm in the distal oesophagus.

**Tips and Anatomical Hazards**

All worrisome lesions should be carefully inspected under high definition white light endoscopy. The use of narrow band imaging can be helpful to determine the vascular pattern better; this may uncover the type of lesion. For ulcerated lesions, biopsies should always be taken from the edge of the ulcers since the base of the ulcer will often contain only necrotic tissue that is insufficient for diagnosis. Good bowel preparation is essential to detect colonic polyps and small cancers. Current guidelines advocate for split bowel preparation regimens, where the patient takes the bowel preparation the evening before, as well as the morning of the procedure; this regimen has been shown to improve the polyp detection rate.⁶⁵
References


41. Koo JE, Park DH, Oh J, et al. EUS-guided multitransgastric endoscopic necrosectomy for infected pancreatic necrosis with noncontagious retroperitoneal and peritoneal


Single Best Answers

1. Which one of the following is the most challenging segment of the colon for the novice endoscopist to navigate?
   A. Rectum
   B. Sigmoid colon
   C. Transverse colon
   D. Ascending colon
   E. Caecum

   **Answer: B.** The sigmoid colon poses a challenge for endoscopists due to its tortuous S-shape. It is a common location for looping during colonoscopy and requires careful technique to advance the scope safely. Diverticula are frequently encountered in this region, which also makes this segment challenging to navigate.

2. Which one of the following is a contraindication to performing capsule endoscopy?
   A. Coagulopathy
   B. Haemodynamic instability
   C. Stricture
   D. Cirrhosis

   **Answer: C.** Small bowel or colonic strictures can predispose to capsule retention and small bowel obstruction. This can be managed by endoscopic retrieval of the retained capsule, if possible; otherwise operative management is required.

3. A 62-year-old female presents to the Emergency department with a 1 month history of abdominal pain and weight loss. A CT scan of her abdomen reveals a 4 cm pancreatic head mass that is suspicious for malignancy. Which one of the following is the best
next test?
A. MRI abdomen
B. Endoscopic ultrasound
C. Gastroscopy
D. Abdominal ultrasound

**Answer: B.** This patient has had a CT, which raised concerns about a new diagnosis of pancreatic cancer. A biopsy is required to confirm the diagnosis. The best next test would be endoscopic ultrasound in order to obtain a fine needle aspiration to guide further treatment.

4. A 48-year-old male presents with painless jaundice. Magnetic resonance cholangiopancreatography (MRCP) is performed and reveals marked thickening of the distal common bile duct with upstream biliary dilation. A CT scan of the chest and abdomen shows metastatic lesions in the lung and liver. The patient complains of pruritus and fatigue. His liver enzymes and bilirubin are markedly elevated. Which one of the following is the best next test for this patient?
A. Repeat of liver enzymes in 1 week
B. Referral to Surgical Oncology
C. Endoscopic retrograde cholangiopancreatography (ERCP)
D. Lung function testing

**Answer: C.** This patient has obstructive jaundice, which is likely to be due to cholangiocarcinoma. Given the patient's jaundice and pruritus, the best next test would be an ERCP in order to obtain brushings and biopsies, in addition to providing endoscopic drainage and stent placement.

5. A 50-year-old female presents for a screening colonoscopy. She
has no significant past medical history and no family history of gastrointestinal malignancy or polyposis. Her colonoscopy reveals a 3 mm sessile polyp within the rectum, for which biopsies are consistent with a hyperplastic polyp. When do you recommend she undergoes her next colonoscopy?

A. 10 years
B. 5 years
C. 1 year
D. 6 months

**Answer: A.** This patient should undergo her next colonoscopy in 10 years. A single hyperplastic polyp does not change her risk of colorectal cancer and she would remain in the average risk category.
Clinical Cases

1. A 63-year-old male with longstanding heartburn undergoes a gastroscopy to investigate for possible Barrett's oesophagus.

   **A. How is the gastro-oesophageal junction identified endoscopically?**
   The gastro-oesophageal junction is often represented by the Z line, the transition from the pale, pearly-coloured oesophageal mucosa (squamous epithelium) to the pink-coloured gastric mucosa (columnar epithelium). Features to aid in locating the gastro-oesophageal junction include identifying the junction between the distal end of the oesophageal longitudinal vessels and proximal end of the gastric longitudinal folds.

   **B. How is a diagnosis of Barrett's oesophagus made?**
   Barrett's oesophagus is suspected endoscopically based on the presence of pink or salmon-coloured mucosa that is located above the gastro-oesophageal junction, and is confirmed histologically by biopsy from the replacement of the normal squamous epithelium by specialized intestinal columnar epithelium (intestinal metaplasia). This lesion is a precursor to the development of oesophageal adenocarcinoma and warrants ongoing endoscopic surveillance or ablative therapy.

   **C. Where should biopsies be taken in a patient with known or suspected Barrett's oesophagus?**
   Circumferential four-quadrant biopsies should be taken every 1 cm along the length of the segment. Any obvious lesions in the segment of Barrett's oesophagus should also be biopsied and submitted separately for histopathology.

2. A 71-year-old male undergoes a colonoscopy to work up rectal bleeding. The colonoscopy shows a 3.5 cm sessile polyp in the descending colon. Using the Paris classification, it is described as type IIb.

   **A. Describe how to remove this flat polyp.**
   Most often, a submucosal injection using methylene blue and normal saline is used to lift the polyp in preparation for removal. This injection allows for better characterization of the polyp margins and may also reduce the risk of colonic perforation.
B. The polyp is removed; however, the histology shows adenocarcinoma within the polyp. When should polypectomy be considered as adequate for resection of a malignant polyp?

Features that increase confidence that endoscopic polypectomy is adequate treatment for a malignant polyp and that a strategy of ongoing surveillance can be undertaken include: a pedunculated polyp, endoscopic confidence that polypectomy was complete, a well-differentiated cancer, at least a 2 mm resection margin, and no evidence of lymphovascular invasion.

C. Polypectomy is not deemed to be adequate management for this malignant polyp and the patient is referred for a right hemicolectomy. The patient does well postoperatively and the final staging of the patient is T1N0M0. When should this patient undergo his next colonoscopy?

The patient should undergo a surveillance colonoscopy 1 year after his hemicolectomy.
SECTION 8
Pelvic Viscera and Urogenital System

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Overview of pelvic viscera

Benjamin J Challacombe, Oussama Elhage

Core Procedures

- Radical cystectomy
- Radical prostatectomy
- Anterior resection of rectum
Surgical surface anatomy

The inguinal skin crease marks the junction of the anterior thigh with the anterior abdominal wall. It lies approximately 7 cm distal to the inguinal ligament. The anterior superior iliac spine (ASIS) lies superior to the lateral end of the crease; the iliac crest is palpable along its entire length from the ASIS. A line (Tuffier's) joining the most superior aspects of the iliac crests almost always crosses either the body of L4 or the L4/L5 intervertebral disc. The iliac crest terminates posteriorly as the posterior superior iliac spine (PSIS), which is marked superficially by the gluteal dimples. Palpation places the PSIS in the range L5/S1 to the spinous process of S2, whereas radiographic assessment places it at the level of S2. The ischial tuberosity is covered by gluteus maximus and is palpable during hip flexion. The coccyx is palpable in the superior part of the intergluteal cleft, the deep vertical groove between the buttocks extending to the S3–4 bony sacral segments. The sacral hiatus sits superior to the tip of the coccyx and is flanked by the raised palpable sacral cornua, which serve as reliable landmarks. The hiatus can also be located at the apex of an inverted equilateral triangle whose base is measured between the PSIS on either side.

The perineum is an approximately diamond-shaped region that lies below levator ani, between the inner aspects of the thighs and anterior to the sacrum and coccyx. It is usually described as if from the position of an individual lying supine with the hip joints in abduction and partial flexion. The surface projection of the perineum and the form of the skin covering it vary considerably, depending on the position of the thighs, whereas the deep tissues themselves occupy relatively fixed positions. The perineum is bounded anteriorly by the pubic symphysis and its arcuate ligament, posteriorly by the coccyx, anterolaterally by the ischiopubic rami and ischial tuberosities, and posterolaterally by the sacrotuberous ligaments. The deep limit of the perineum is the inferior surface of the pelvic diaphragm, and its superficial limit is the skin that is continuous with that over the medial aspect of the thighs and the lower abdominal wall. An arbitrary line joining the ischial tuberosities divides the perineum into an anterior urogenital triangle facing downwards and forwards, and a posterior anal triangle facing downwards and backwards at an approximate angle of 120° from the plane of the urogenital triangle. The male urogenital triangle contains the bulb and attachments of the penis, and the female urogenital triangle contains the mons pubis, labia majora and minora, clitoris and vaginal and urethral
orifices.
Clinical anatomy

Bony pelvis

The pelvis is divided anatomically into the false (greater) and true (lesser) pelvis. The true pelvis is a bowl-shaped structure formed by the sacrum, pubis, ilium, ischium, the ligaments that interconnect these bones, and the muscles that line their inner surfaces. It starts at the level of a plane passing through the promontory of the sacrum, the arcuate line on the ilium, the iliopubic line and the posterior surface of the pubic crest. This plane, or ‘inlet’, lies at an angle of between 35° and 50° up from the horizontal. Above this plane, the bony structures are sometimes referred to as the false pelvis; they form part of the walls of the lower abdomen. The outlet of the true pelvis is formed by the lower aspect of the pubic symphysis anteriorly; the ischiopubic rami running laterally and posteriorly; the ischial tuberosities and sacrotuberous ligaments laterally; and the tip of the coccyx and sacrospinous ligament posteriorly (Fig. 68.1).
Contents of the pelvic cavity

The pelvic cavity is a continuation of the abdominal cavity; the contents of the greater pelvis are usually part of the abdominal cavity and are draped by peritoneum. The right iliac fossa contains the caecum, appendix, and part of the ascending colon and the ileum. The left iliac fossa contains part of the descending colon and part of the sigmoid colon.

In the true pelvis, most of the organs are extraperitoneal but some are
covered by peritoneum. The rectum is posterior; only its upper part is covered with peritoneum anteriorly (Fig. 68.2). The most distal part of the rectum becomes the anal canal, which exits the pelvis at the anus.
The ureters are lateral to the rectum on each side. In males, the vasa deferentia and seminal vesicles lie medial to the ureters and posterior to the bladder; they remain mostly extraperitoneal structures. Anterior to the seminal vesicles and rectum, the bladder occupies most of the anterior true pelvis when full, pushing the small bowel and part of the sigmoid colon upwards. The dome of the bladder is covered by peritoneum; the close proximity of the small and large bowel renders them vulnerable to iatrogenic injury if the bladder is damaged during resection or during the insertion of suprapubic catheters.

In females the uterus, uterine tubes, ovaries and round ligament are all anterior to the rectum (see Fig. 68.2A). The uterus is covered with parietal peritoneum anteriorly and posteriorly: anteriorly, a reflection on to the bladder forms the vesico-uterine pouch, and posteriorly, a reflection on to the rectum forms the recto-uterine pouch.

The vagina lies behind the bladder and urethra, inferior and anterior to the rectum; it is extraperitoneal, except for its most posteromedial aspect at the recto-uterine reflection.

**Muscles and fasciae of the pelvis and perineum**

The parietal pelvic fascia (obturator fascia; fasciae over piriformis and levator ani and the presacral fascia) covers the pelvic muscles. The visceral pelvic fascia covers the pelvic organs and their neurovascular supply. The pelvic organs in both sexes are attached bilaterally to the pelvic walls by mesenteric condensations covered in fatty, loose connective tissue that extends to the midline, separating the bladder from the vagina, and the vagina from the rectum in the female, and separating the bladder, prostate and seminal vesicles from the rectum in the male. This tissue contains varying amounts of connective tissue and smooth muscle; where it is dense, it is conventionally called a ‘ligament’ (for example, cardinal and uterosacral ligaments; see Ch. 71).

The muscles arising within the pelvis form two groups. Piriformis and obturator internus form part of the walls of the pelvis but are considered primarily as muscles of the lower limb. Levator ani and ischiococcygeus form the pelvic diaphragm and delineate the lower limit of the true pelvis. The fasciae investing the muscles are continuous with visceral pelvic fascia above, perineal fascia below, and obturator fascia laterally.

Levator ani is a broad muscular sheet of variable thickness attached to the
internal surface of the pelvis, which forms a large portion of the pelvic floor and supports the pelvic viscera. It is subdivided into named portions according to their attachments and the pelvic viscera to which they are related (pubococcygeus, iliococcygeus and puborectalis) (Fig. 68.3). Although often referred to as separate muscles, the boundaries between each part cannot easily be distinguished (and they perform many similar physiological functions). Ischiococcygeus lies immediately cranial to levator ani and is contiguous with it. Pubococcygeus is often subdivided into separate parts (puboperinealis, puboprostaticus or pubovaginalis, puboanalis, puborectalis). Levator ani arises from each side of the walls of the pelvis along the condensation of the obturator fascia (the tendinous arch of levator ani). Fibres from ischiococcygeus are attached to the sacrum and coccyx, and converge in the midline. Fibres from iliococcygeus join by a partly fibrous intersection and form the iliococcygeal raphe posterior to the anorectal junction. Closer to the anorectal junction, and elsewhere in the pelvic floor, the muscle forms a sling (iliococcygeus, puborectalis).

The constant baseline activity of the levator muscles is similar to that of the anal sphincter, modulated to adjust to the loads placed on them. Pubococcygeus and puborectalis pull the pelvic and perineal structures ventrally and cranially, occluding the levator hiatus; they also reinforce the external anal sphincter, helping to create the anorectal angle. Iliococcygeus
and ischiococcygeus form a relatively horizontal diaphragm, especially in the dorsal half of the pelvis, which assists puborectalis in achieving anorectal and urinary continence. Levator ani must relax appropriately to permit expulsion of urine and, particularly, faeces; it contracts with the abdominal muscles and the respiratory diaphragm to raise intra-abdominal pressure.

**Vascular supply and lymphatic drainage**

The pelvis and its contents have a rich blood supply. This has important clinical consequences, especially when faced with trauma involving the pelvis. The strong bony frame makes it difficult to reach and control any internal bleeding, which means that postoperative or traumatic pelvic bleeding can quickly become life-threatening if not controlled swiftly.

**Arterial supply**

At the L4 vertebral level, the descending abdominal aorta bifurcates into left and right common iliac arteries. These vessels course laterally on each side, anterior to the sacroiliac joints at the level of the sacral promontory, and typically give no branches. The right common iliac artery is approximately 5 cm long. It passes obliquely across part of the bodies of L4 and L5, and is crossed anteriorly by the sympathetic rami to the pelvic plexus and, at its division into internal and external iliac arteries, by the ureter. It is covered by parietal peritoneum, separating it from coils of small intestine. Posteriorly, it is separated from the bodies of L4 and L5 and their intervening disc by the right sympathetic trunk, the terminal parts of the common iliac veins and the start of the inferior vena cava (IVC), the obturator nerve, lumbosacral trunk and iliolumbar artery. Laterally, the IVC and the right common iliac vein lie superiorly and the right psoas major lies inferiorly. The left common iliac vein is medial to the upper part of the right common iliac artery. The left common iliac artery is shorter than the right (approximately 4 cm long). The sympathetic rami to the pelvic plexus and the superior rectal artery are anterior relations; the sympathetic trunk, the bodies of L4 and L5 and their intervening disc, the obturator nerve, lumbosacral trunk and iliolumbar artery are all posterior. The left common iliac vein is posteromedial, and the left psoas major is lateral.

The common iliac arteries bifurcate into the external and internal iliac arteries. They are usually crossed by the ureter at their bifurcation: this is an important surgical landmark where, intraoperatively, the surgeon is able to
locate and identify the ureter. It is also a point where a ureteric calculus can be held up on its passage down the ureter.

The external iliac artery runs along the pelvic brim without entering the true pelvis. It gives off the inferior epigastric artery and the deep circumflex artery, which courses laterally along the inguinal ligament. As the external iliac artery passes beneath the inguinal ligament it becomes the femoral artery. The inferior epigastric artery can be damaged by the insertion of laparoscopic trocars that are placed too medially (less than 8 cm) from the midline or during an oblique incision in the iliac fossa, such as that for renal transplantation.

The internal iliac artery is the principle artery of the pelvis. Each artery, approximately 4 cm long, starts at the common iliac bifurcation, level with the lumbosacral intervertebral disc and anterior to the sacroiliac joint, and descends posteriorly to the superior margin of the greater sciatic foramen, where it divides into an anterior trunk, which continues in the same line towards the ischial spine, and a posterior trunk, which passes back to the greater sciatic foramen (Fig. 68.4).
The anterior trunk primarily supplies the pelvic organs via superior and inferior vesical, middle rectal, vaginal, obturator, uterine, internal pudendal and inferior gluteal arteries; it terminates as the internal pudendal and inferior gluteal arteries. Several of these branches are important to a surgeon operating in the pelvis. First to be encountered is the superior vesical artery arising from the proximal part of the obliterated umbilical artery. It courses medially and inferorly, and supplies the dome of the bladder and the distal part of the ureters before they enter the bladder posteriorly. In the male, it also supplies the vas deferens and the seminal vesicles. It must be ligated if performing a distal ureterectomy or mobilizing the bladder for a psoas hitch manoeuvre; this generally causes no sequelae because the bladder receives a bilateral arterial supply.

The obliterated umbilical artery is an important landmark. It travels along
the pelvic inlet anteriorly, raising the medial umbilical fold on the posterior aspect of the abdominal wall on each side parallel to the apex of the bladder, and coursing medially to converge on to the umbilicus. An additional landmark is the median umbilical fold (a remnant of the urachus) extending from the apex of the urinary bladder in the midline to the umbilicus. These landmarks help the laparoscopic/robotic surgeon to identify the dome of the bladder during prostate/bladder and inguinal hernia surgery. A careful dissection along the medial umbilical fold will lead the surgeon to the extraperitoneal space (cave of Retzius) and the superior vesical vessels.

The next branch of the anterior division of the internal iliac artery to be encountered is the obturator artery, which runs anteroinferiorly from the anterior trunk on the lateral pelvic wall to the upper part of the obturator foramen. In the pelvis, it is related laterally to the fascia over obturator internus and is crossed on its medial aspect by the ureter and, in the male, by the vas deferens. The obturator nerve runs above the artery, the obturator vein below it. The artery provides iliac branches to the iliac fossa, which supply the bone and iliacus, and anastomose with the iliolumbar artery. The obturator vessels and nerve leave the pelvis via the obturator canal; the obturator artery supplies the adductors of the thigh. During pelvic lymph node dissection, the obturator vessels and nerve should be formally identified and preserved prior to clipping the major lymphatics.

The inferior vesical artery lies deeper and more posteriorly in the pelvis. It supplies the distal part of the ureters and the inferior aspect of the bladder, the prostate and seminal vesicles (males), and the vagina (females). The prostatic branches can be specifically embolized to manage prostatic bleeding if other techniques fail or to treat extensive benign prostatic hypertrophy. The uterine artery is a large vessel that arises below the obturator artery on the lateral wall of the pelvis and runs inferomedially into the broad ligament of the uterus in females.

The middle rectal artery runs into the lateral fascial coverings of the mesorectum. It often consists of multiple branches, may be small, and occasionally arises either close to, or in common with, the origin of the inferior vesical artery in males. It anastomoses with the superior rectal artery (a branch of the inferior mesenteric artery) and the inferior rectal artery (a branch of the internal pudendal artery). The middle rectal artery primarily supplies the rectum. The internal pudendal artery runs inferiorly and leaves the pelvis near its origin through the greater sciatic foramen; it is the main artery supplying the perineal organs, including the penis and clitoris.
The inferior gluteal artery leaves the pelvis through the greater sciatic foramen and supplies the gluteal region and the hip joint. Most of the larger branches of the internal iliac artery show little variation. However, the blood supply to the prostate gland is highly variable. The prostatic artery may arise from the internal pudendal artery (56%); a direct branch from the anterior division of the internal iliac artery (28%); the obturator artery (12%); and the inferior gluteal artery (4%). A corkscrew pattern of the prostatic artery and multiple contralateral anastomoses between the prostatic arteries and the internal pudendal arteries are common. The artery may be more tortuous when supplying a large prostate.

**Venous drainage**

The true pelvis contains a large number of veins that drain the pelvic walls and most of the viscera contained within the pelvis, and also carry venous blood from the gluteal region, hip and thigh. The major veins frequently follow their named arterial counterparts, whereas the small tributaries exhibit considerable variation. The common iliac vein is formed by the union of the external and internal iliac veins, anterior to the sacroiliac joints. It ascends obliquely to end at the right side of the L5 vertebra, uniting at an acute angle with the contralateral vessel to form the IVC. The right common iliac vein is shorter and more nearly vertical, lying posterior, and then lateral, to its artery. The right obturator nerve passes posteriorly. The left common iliac vein is longer and more oblique, and lies first medial, then posterior, to its artery. It is crossed anteriorly by the attachment of the sigmoid mesocolon and superior rectal vessels. Each vein receives iliolumbar and, sometimes, lateral sacral veins. The left common iliac vein usually drains the median sacral vein.

The internal iliac vein is formed by the convergence of several veins above the greater sciatic foramen. It does not have the predictable trunks and branches of the internal iliac artery but its tributaries drain the same territories. It ascends posteromedial to the internal iliac artery to join the external iliac vein, forming the common iliac vein at the pelvic brim, anterior to the lower part of the sacroiliac joint. It is covered anteromedially by parietal peritoneum. Its tributaries are the gluteal, internal pudendal and obturator veins, which originate outside the pelvis; the lateral sacral veins, which run from the anterior surface of the sacrum; and the middle rectal, vesical, uterine and vaginal veins, which originate in the venous plexuses of the pelvic viscera.
The external iliac vein is the proximal continuation of the femoral vein and starts posterior to the inguinal ligament. It ascends along the pelvic brim and ends anterior to the sacroiliac joint by joining the internal iliac vein to form the common iliac vein. On the right, it lies medial to the external iliac artery, gradually inclining behind it as it ascends. On the left, it is wholly medial. Disease of the external iliac artery may cause it to adhere closely to the vein at the point where it is in contact, and, particularly on the right side, the walls of the vessels may become fused, making dissection hazardous. The external iliac vein is crossed medially by the ureter and internal iliac artery. In males, it is crossed by the vas deferens, in females by the round ligament and ovarian vessels. Psoas major lies laterally, except where the artery intervenes. The vein is usually valveless but may contain a single valve. Its tributaries are the inferior epigastric, deep circumflex iliac and pubic veins.

The pelvis is one of several sites where the portal venous system anastomoses with the systemic venous system. The superior rectal vein (portal system) drains blood from the upper part of the rectum and courses on the left side of the pelvis to drain into the inferior mesenteric vein. Tributaries from the superior rectal vein anastomose with tributaries of the middle and inferior rectal veins (caval system). Portal hypertension, for example as a result of liver cirrhosis, causes varicosities in the anorectal area around the sites of the anastomoses; surgical damage to these engorged veins can lead to torrential bleeding.

**Lymphatic drainage**

The lymph nodes in the pelvis are grouped around the common, external and internal iliac vessels, and are named accordingly (Fig. 68.5).
The common iliac nodes receive the entire lymphatic drainage from the lower limb because they drain both internal and external iliac nodes. They usually lie in medial, lateral and anterior chains around the common iliac artery, the lateral being the main route; one or two lie inferior to the aortic bifurcation and anterior to the L5 vertebra or sacral promontory. The common iliac nodes drain to the lateral aortic nodes.

The external iliac nodes usually form three subgroups, lateral, medial and anterior to the external iliac vessels. The medial nodes are considered the main channel of drainage, collecting lymph from the lower limb via the inguinal nodes, the deeper layers of the infra-umbilical abdominal wall, the adductor region of the thigh, the glans penis or clitoris, the membranous urethra, prostate, fundus of the bladder, uterine cervix and upper vagina. Their efferents pass to the common iliac nodes. The internal iliac nodes surround the branches of the internal iliac vessels. They collect lymph from most of the pelvic viscera (with the exception of the gonads and the majority of the rectum), the deeper parts of the perineum, and the gluteal and
posterior femoral muscles, and they drain to the common iliac nodes. There are frequent connections between the right and left groups, particularly when they lie close to the anterior and posterior midlines.

Lymph node dissection is an essential part of pelvic cancer surgery, especially for bladder and higher-risk prostate malignancies. Historically, the surgical definition of what constitutes a standard lymph node dissection in the pelvis has been inconsistent. Currently, the most commonly used template is the extended lymph node dissection template, which involves removing all pelvic lymph nodes up to the level of the bifurcation of the common iliac arteries; many surgeons extend this to include nodes up to the aortic bifurcation. Several studies suggest survival benefit for patients who undergo extended lymph node dissection.\(^3\),\(^4\)

**Innervation**

The pelvis contains the lumbosacral nerve trunk, the sacral and coccygeal plexuses, and the pelvic parts of the sympathetic and parasympathetic systems. Collectively, these nerves carry the somatic, autonomic and visceral afferent innervation to the majority of the pelvic visceral organs, and the muscles of the pelvic floor and perineum, the gluteal region and the lower limb.

The lumbar part of the lumbosacral trunk contains part of the fourth and all of the fifth lumbar ventral rami; it appears at the medial margin of psoas major and descends over the pelvic brim, anterior to the sacroiliac joint, to join the first sacral ramus. The greater part of the second and third sacral rami converge on the inferomedial aspect of the lumbosacral trunk in the greater sciatic foramen to form the sciatic nerve (Fig. 68.6).
The sacral and coccygeal plexuses are formed by the ventral rami of the sacral and coccygeal spinal nerves. The upper four sacral ventral rami enter the pelvis by the anterior sacral foramina, the fifth enters between the sacrum and coccyx, and the ventral ramus of the coccygeal nerve curves forwards below the rudimentary transverse process of the first coccygeal segment; each receives a grey ramus communicans from a corresponding sympathetic ganglion. The pelvic splanchnic nerves, preganglionic parasympathetic fibres from S2–4, run to minute ganglia in the walls of the pelvic viscera, where they synapse. The sacral plexus lies against the posterior pelvic wall anterior to piriformis, posterior to the internal iliac vessels and ureter, and behind the sigmoid colon on the left. The superior gluteal vessels run either between the lumbosacral trunk and first sacral
ventral ramus, or between the first and second sacral rami; the inferior gluteal vessels lie between either the first and second, or second and third, sacral rami.

The pudendal nerve arises from the ventral divisions of the second, third and fourth sacral ventral rami and is formed just above the superior border of the sacrotuberous ligament and the upper fibres of ischiococcygeus. It leaves the pelvis via the greater sciatic foramen between piriformis and ischiococcygeus, enters the gluteal region and passes dorsal to the sacrospinous ligament, close to its attachment to the ischial spine, where it lies medial to the internal pudendal vessels. It accompanies the internal pudendal artery through the lesser sciatic foramen into the pudendal (Alcock's) canal on the lateral wall of the ischio-anal fossa. In the posterior part of the canal, it gives rise to the inferior rectal and perineal nerves; the dorsal nerve of the penis or clitoris continues ventrally.

The obturator nerve originates from the lumbar plexus (L2–4) and enters the pelvis posteriorly near the sacroiliac joint. It courses laterally and anteriorly just under the pelvic inlet and over the insertion of obturator internus. It is joined by the obturator vessels before the neurovascular bundle exits the pelvis through the obturator canal. The obturator nerve is an important landmark during lymph node dissection because iatrogenic injury can affect adduction of the thigh. During endoscopic bladder surgery, diathermy to the lateral wall of the bladder posteriorly can stimulate the obturator nerve, resulting in a sudden adduction of the thigh and causing intraoperative perforation of the bladder. This can be avoided by anaesthetically induced paralysis of the adductors during this particular part of the operation.

The autonomic supply to the pelvic viscera is via the abdominopelvic part of the sympathetic trunk and the pelvic splanchnic nerves (parasympathetic) (Fig. 68.7).
The pelvic sympathetic trunk lies in extraperitoneal tissue anterior to the sacrum beneath the presacral fascia and medial or anterior to the anterior sacral foramina. It has four or five interconnected ganglia and is continuous above with the lumbar sympathetic trunk. The right and left trunks converge below the lowest ganglia and unite in the small ganglion impar anterior to the coccyx. Grey rami communicantes pass from the ganglia to sacral and coccygeal spinal nerves. Medial branches connect across the midline, and twigs from the first two ganglia join the inferior hypogastric plexus or the hypogastric ‘nerve’. Other branches form a plexus on the median sacral artery.

Parasympathetic pelvic splanchnic nerves travel initially in the ventral rami of S2–4. They leave these nerves as they exit the anterior sacral foramina and pass in the presacral tissue as a fine network of branches distributed to three principal destinations. Most pass anterolaterally into the inferior hypogastric plexus and then to the pelvic viscera. Others either join the hypogastric nerves and pass to the superior hypogastric plexus to be distributed with branches of the inferior mesenteric artery, or run superolaterally in the
presacral tissue, over the pelvic brim anterior to the left iliac vessels into the tissue of the retroperitoneum and the mesentery of the sigmoid and descending colon. The pelvic splanchnic nerves are motor to the smooth muscle of the hindgut and bladder wall, supply vasodilator fibres to the erectile tissue of the penis or clitoris, and are secretomotor to the hindgut. (For further details, see Chs 72–74.)

**Tips and Anatomical Hazards**

Vessels running in Scarpa's fascia can be controlled and tied during surgery with no clinical consequences. Infections that involve Scarpa's fascia can spread quickly but often do not involve deeper structures. The bladder is prone to injury during pelvic surgery. The dome of the bladder is covered with peritoneum and is in close proximity to loops of small bowel. When full, the bladder occupies most of the greater pelvis. A full bladder is required in order to insert a suprapubic catheter safely.

Iatrogenic injury to the inferior epigastric artery during surgery causes significant bleeding. Care must be taken when inserting laparoscopic trocars to avoid medial insertion (less than 8 cm from the midline). Medial umbilical folds provide important landmarks during laparoscopic surgery for the bladder, prostate and inguinal region. The pelvis contains rich plexuses of veins; injury and trauma to the pelvis can cause catastrophic bleeding if not swiftly controlled.
References

Further Further Reading

Kidneys and ureters

Benjamin Namdarian, Benjamin J Challacombe

Core Procedures

- Open nephrectomy
- Open partial nephrectomy
- Robotic/laparoscopic nephrectomy
- Robotic/laparoscopic partial nephrectomy
- Open nephro-ureterectomy
- Robotic/laparoscopic nephro-ureterectomy
- Robotic/laparoscopic pyeloplasty
- Percutaneous nephrolithotomy
- Nephrostomy
- Extracorporeal shock wave lithotripsy
- Ureteroscopy ± retrograde pyelogram/laser or lithoclast lithotripsy/biopsy/stent
- Pyeloscopy ± laser/biopsy/stent

This chapter contains an overview of the topographical and surface anatomy of the kidneys and ureters, and their relevance in common surgical procedures.

The kidneys have an essential physiological function in maintaining electrolyte and water balance while excreting the end-products of metabolism. They also have endocrine functions, producing and releasing erythropoietin, which affects red blood cell formation; renin, which influences blood pressure; and 1,25-dihydroxy cholecalciferol, the metabolically active form of vitamin D.

Common surgical pathologies that affect the kidneys vary from neoplastic growths requiring extirpation; obstruction requiring initial internal or
percutaneous drainage, with subsequent decompression if due to stones; excision if malignant; or rerouting if anatomically or functionally requiring an orthotopic reconstruction.
**Embryology**

The kidney is derived from the sequential development of the pronephros, mesonephros and, ultimately, the metanephros, forming the definitive kidney. The ureter is derived from the ureteric bud, which differentiates to form the pelvis, calyces and collecting ducts. Development is induced by metanephric mesenchyme, while a reciprocal induction leads to the metanephric mesenchyme forming nephrons. Any derangement of this relationship can result in embryological variants or absence, along with mesonephric (Wolffian) duct structures, the epididymis, vas deferens and seminal vesicles.

In the fetus and the newborn, the kidney normally has 12 lobules; in the adult, these lobules are fused to present a smooth surface, although traces of lobulation may remain and can mimic a renal mass on radiographic imaging. Horseshoe kidneys are found in 1 in 400 individuals. A transverse bridge of renal tissue, the isthmus, connects the two renal masses, usually lying between the inferior poles. Most commonly, it lies anterior to the great vessels and inferior to the inferior mesenteric artery, which obstructs its ascent during embryological development. The vascular supply is usually multiple and unpredictable; one vessel to each moiety is seen in only 30%, while the ureters curve anterior to the isthmus and often have a high insertion into the renal pelvis, where crossing vessels or de novo pelvi-ureteric junction obstruction causes hydronephrosis.

In a complete duplex system, the ureter from the upper pole of the kidney (the longer ureter) inserts more medially and caudally in the bladder than the ureter from the lower pole (Weigert–Meyer rule). This reflects the embryological development of the ureter: the ureteric bud that is initially more proximal on the mesonephric duct has a shorter time to be pulled cranially in the bladder and so it inserts more distally in the mature bladder. The clinical/surgical implication is that the upper moiety can obstruct while the lower moiety is often refluxing.

The urological surgeon should be aware that kidneys may be atypically located: they may be pelvic, ectopic or crossed fused ectopic, and may even be absent. Failure of the kidney to ascend into the renal fossa in utero results in renal ectopia. An ectopic kidney is found in the pelvis in 1 in 2500 live births; these kidneys often have associated malrotation anomalies and exhibit marked fetal lobulation. A single absent kidney resulting from the failure of the metanephric blastema to join a ureteric bud on the affected
side, is seen in 1 in 1200 individuals. There are no clinical sequelae, but the ipsilateral vas deferens and/or epididymis may also be absent and there may be other congenital anomalies.
Surgical surface anatomy of the kidney

Skeletal and cartilaginous landmarks

Anterior landmarks inform the placement of incisions or ports required for surgical access, typically through a transperitoneal route. From the midline, the xiphisternum denotes the apex, the costal margin forms the superior boundary, and the anterior superior iliac spine (ASIS), inguinal ligament and pubic symphysis denote the inferior abdominal boundary; the umbilicus, linea semilunaris and linea alba are all relevant surface markings. The transpyloric plane (defined by the intersection of the mid-clavicular line with the costal margin at around the ninth costal tip) is a reference point for various abdominal organs (Fig. 69.1).

Posterior landmarks inform surgical access either when the aim is to remain in the retroperitoneal space or when performing percutaneous stone surgery. The anterior, mid- and posterior axillary lines and the prominence of the eleventh and twelfth ribs should be noted. The posterior superior iliac spine (PSIS) and the sacroiliac joint are inferior fixed landmarks. Pleural
reflections are based on thirds along the twelfth rib; the lateral third is below the pleura, the mid third has a variable relationship to the pleura, and the medial third overlies the pleura. Psoas major is used as the most medial/posterior plane to establish retroperitoneal access. Quadratus lumborum lies lateral to psoas major.

The main renal vessels have surface markings along the transpyloric plane and hence most minimally invasive surgery will be mindful of this plane in planning access. The inferior epigastric vessels run craniocaudal 8 cm lateral to the midline and must be avoided when placing laparoscopic trocars.
Clinical anatomy of the kidney

In the fresh state, the kidneys are reddish brown and are situated posteriorly behind the peritoneum, on each side of the vertebral column. They are surrounded by adipose tissue of varying thickness and adherence. In adults, each kidney is typically 11 cm in length, 6 cm in breadth and 3 cm in anteroposterior dimension; male kidneys are slighter larger than female kidneys. Superiorly, the kidneys are level with the upper border of the twelfth thoracic vertebra, and inferiorly, with the third lumbar vertebra (Fig. 69.2). The right is usually slightly inferior to the left, reflecting its relationship to the liver. The left is a little longer and narrower than the right and lies nearer the median plane. The long axis of each kidney is directed inferolaterally and the transverse axis is directed posteromedially, which means that the anterior and posterior aspects, as usually described, are actually anterolateral and posteromedial. An appreciation of this orientation is important in percutaneous and endo-urological renal surgery.
Kidneys may be malrotated, duplicated, horseshoe or even absent, and retroperitoneal, pelvic or ectopic. Crossed ectopia is related to aberrant interaction between the mesonephros and ureteric bud during development.

**Vascular supply, lymphatic drainage and innervation**

**Renal arteries**

Renal vascular anatomy is important, particularly when undertaking partial nephrectomy.
The paired renal arteries take about 20% of the cardiac output. They branch laterally from the aorta, just below the origin of the superior mesenteric artery at vertebral level L2.

A single renal artery to each kidney is present in approximately 70% of individuals; the arteries vary in their level of origin, calibre, obliquity and relations. Each renal artery gives off one or more adrenal arteries, a branch to the ureter, and branches that supply perinephric tissue, the renal capsule and the pelvis. Near the renal hilum, the renal artery divides into anterior and posterior divisions that further divide into segmental arteries supplying the renal vascular segments (Fig. 69.3). Five arterial segments have been identified: apical, superior, middle and inferior segments anteriorly, and the whole posterior region between the apical and inferior segments posteriorly. While there can be considerable variation in this pattern, it is important to emphasize that vascular segments are supplied by virtual end arteries.

Brödel described a relatively avascular longitudinal zone (the ‘bloodless’ line of Brödel) along the convex renal border, which was proposed as the most suitable site for surgical incision to access the inner kidney. While, theoretically, this zone lies between the anterior and posterior segmental
divisions, in practice many vessels cross it, which means that planned radial or intersegmental incisions are preferable. The subdivisions of the renal arteries are described sequentially as segmental; lobar (one to each renal pyramid); interlobar (extending to the cortex around each pyramid); arcuate (forming at the corticomedullary junction); and interlobular arteries (extending radially into the cortex).

Accessory renal arteries occur in approximately 30% of individuals and are usually inferior to the main renal artery, where they may cause obstruction: for example, in cases of pelvi-ureteric junction obstruction.\textsuperscript{5}

**Renal veins**

The renal veins lie anterior to the renal arteries and open into the inferior vena cava (IVC) almost at right angles. The left is usually three times longer than the right (7.5 cm and 2.5 cm, respectively), and hence is usually the preferred side for live donor nephrectomy. Tributaries are variably received on the left from the adrenal, lumbar and left gonadal veins. The right renal vein typically drains directly into the IVC, as do the gonadal and adrenal veins.
Clinical anatomy of the ureter

The ureters are the muscular conduits through which urine is transferred to the bladder in peristaltic waves (vermication). Each ureter measures 25–30 cm in length and is thick-walled, narrow and continuous superiorly with the funnel-shaped renal pelvis. The ureters descend slightly medially, anterior to psoas major, and enter the pelvic cavity, where they curve initially laterally, then medially, before opening into the base of the urinary bladder at the lateral aspect of the trigone. On plain X-ray, the typical course of each ureter may be traced over the tips of the transverse processes of the lumbar vertebrae and the sacroiliac joint before turning medially at the ischial spine (Fig. 69.4). The diameter of each ureter is normally 3 mm but is slightly less at its junction with the renal pelvis, at the brim of the lesser pelvis near the medial border of psoas major while crossing the common iliac vessels, and where it runs within the wall of the urinary bladder, which is its narrowest part. These narrowings are the most common sites for renal stone impaction.
FIG. 69.4  The schematic course of the ureters appreciated on imaging or at surgery, descending from the pelvi-ureteric junction, over psoas major in line with the tips of the transverse processes of the lumbar vertebrae, then coursing over the sacroiliac joint before turning medially at the ischial spine to enter the bladder at the vesico-ureteric junction. Difficult retrograde access or sites of stone impaction may be anticipated at natural narrowings of the ureters at the vesico-ureteric junction, when crossing the pelvic brim and iliac vessels, and at the pelvi-ureteric junction.

Vascular supply and lymphatic drainage

The ureter is supplied by branches from the renal, gonadal, common iliac, internal iliac, vesical and uterine arteries, and the abdominal aorta. The pattern of distribution is subject to much variation. The abdominal ureter is supplied by vessels originating medial to the ureter; the pelvic ureter is supplied by vessels lateral to the ureter (Fig. 69.5). There is a good longitudinal anastomosis between these branches on the wall of the ureter,
which means that the ureter can be safely transected at any level intraoperatively, and a uretero-ureterostomy performed, without compromising its viability. The branches from the inferior vesical artery are constant in their occurrence and supply the lower part of the ureter, as well as a large part of the trigone of the bladder. The branch from the renal artery is also constant and is preserved whenever possible in renal transplantation to ensure good vascularity of the ureter.

**FIG. 69.5** The arterial supply of the left ureter: the proximal portion takes its blood supply medially, and the distal portion is supplied laterally. (With permission from P.C. Walsh, A.B. Retik, E.D. Vaughan, et al (eds), Campbell's Urology, eighth ed., Philadelphia: Saunders, 2002.)

The venous drainage of the ureters generally follows the arterial supply.
Lymph vessels draining the ureter begin in submucosal, intramuscular and adventitial plexuses, which all communicate. Collecting vessels from the upper abdominal ureter may join the renal collecting vessels or pass directly to the lateral aortic nodes near the origin of the gonadal artery; those from the lower abdominal ureter drain to the common iliac nodes; and those from the pelvic ureter drain to common, external or internal iliac nodes.

**Innervation**

The ureter is supplied from spinal segments T10–12, L1 and S2–4, by branches from the renal and aortic plexuses, and the superior and inferior hypogastric plexuses. The ureteric nerves consist of relatively large bundles of axons that form an irregular plexus in the adventitia of the ureter. The plexus receives branches from the renal and aortic plexuses (in its upper part); from the superior hypogastric plexus and hypogastric nerve (in its intermediate part); and from the hypogastric nerve and inferior hypogastric plexus (in its lower part). Numerous small branches penetrate the ureteric muscle coat; some of the adventitial nerves accompany the blood vessels and branch with them as they extend into the muscle layer; others are unrelated to the vascular supply and lie free in the adventitial connective tissue around the circumference of the ureter. The density of innervation increases gradually from the renal pelvis and upper ureter (where autonomic nerves are sparse) to a maximum density in the juxtavesical segment.

**Ureteric colic**

Excessive distension of the ureter or spasm of its muscular wall may be caused by a stone (calculus) or by stenting, and provokes severe spasmodic pain known as renal or ureteric colic. The pain is due to obstruction of urinary flow and the subsequent increase in tension in the ureteric wall. Rising pressure in the renal pelvis stimulates the local synthesis and release of prostaglandins, causing spasm of the ureteric smooth muscle and vasodilation, producing a diuresis that further increases intrarenal pressure. The visceral afferent fibres that carry nociceptive signals from the ureters terminate in spinal segments T11–L2; the pain is referred to the corresponding dermatomes (T11–L2) in a loin-to-groin distribution extending down to the scrotum or labium majus, potentially even into the anteromedial thigh via the genitofemoral nerve (L1,2).
Variants

(See Ch. 75 for further embryological details.)

Ureters may be bifid or duplex, where two ureters drain the renal pelvis on one side (1 in 125 cases), or bilateral duplex (1 in 800 cases). Duplication may be limited (partial) or total (complete). Ureters may be ectopic: single ureters and, more commonly, the longer ureter of a duplex system may insert more caudally and medially than normal. In males, this always occurs cranial to the external urethral sphincter, whereas in females it can be distal, causing persistent childhood incontinence. A congenital (primary) mega-ureter is an enlarged ureter where the aetiopathogenesis is intrinsic to the ureter; it may be obstructed, refluxing, or non-refluxing and unobstructed. A cystic dilation of the most distal portion of the ureter is a ureterocele and is usually congenital. A ureterocele typically presents radiologically as a ‘cobra-head’ halo around the ureteric orifice following administration of contrast on intravenous urography. Ureteroceles are often found in conjunction with a duplex system. A rare retrocaval ureter occurs when the posterior cardinal vein persists (1 in 1500 cases); clinical sequelae are rare, although the vein can obstruct the ureter.
Surgical approaches and considerations

Open renal surgery

Preoperative CT/MR angiography is useful to anticipate the vascular arrangement because 30% of patients have an accessory vessel accompanying the main renal vessel. Various approaches can be utilized, depending on the surgeon's experience, patient variables (previous surgery, habitus, comorbidities, complexity of vascular anatomy) and lesion characteristics (size; position – superior/inferior, anterior/posterior; chronic infection; previous drainage).

The main common access methods (Fig. 69.6) include a retroperitoneal flank incision sited at either a supra-eleventh or twelfth rib level, with or without rib excision. The transperitoneal route can employ a subcostal chevron/rooftop incision or a midline incision with or without a lateral extension.

Key points to consider in retroperitoneal access are identifying the peritoneum anteriorly and staying posterior to it; dissecting on top...
(superiorly) of each rib to avoid damaging the neurovascular bundles; and identifying and carefully mobilizing the diaphragm and pleura. The advantage of this approach is that it keeps the operative field or pathology away from peritoneal contents and the abdominal cavity, which may contain adhesions and be a hostile environment. The key point to consider in transperitoneal access is the fact that good retraction and effective mobilization of adjacent viscera (bowel/mesentery, liver, spleen and adrenal gland) are essential.

**Tips and Anatomical Hazards**

Trauma nephrectomy: immediate arterial control is key. Some authors advocate incising the mesentery onto the aorta, then gaining control; others suggest a standard colon/duodenal reflection before isolating and gaining control.

Xanthogranulomatous pyelonephritis kidney: the preference is often to pursue a retroperitoneal approach to contain the infective pathology but this may not always be possible. On occasion, either a dissection inside Gerota's fascia or within the renal capsule, or a wider dissection that may require adjacent organ resection (including spleen, bowel and psoas muscle), may be necessary to gain vascular control.

Careful consideration of the venous drainage is essential in cases of renal tumour with IVC thrombus. The ipsilateral and contralateral renal veins, adrenal veins, all lumbar veins, gonadal veins and the distal IVC must be isolated and controlled, as well as the infra- or suprahepatic IVC clamped above the liver. Complete dissection of the liver pedicle on the IVC may be required with ligation of caudate lobe vessels for adequate access.

If the surgeon is unable to locate the renal artery laterally on the right, there is significant venous bleeding or collateral vessels are present, it may be necessary to isolate the right renal artery in the inter-aortocaval groove.

Anticipate the location of vessels and the ureter at the hilum. Typically, the order from anterior to posterior is vein, artery and, most posteriorly, ureter. Recognizing this arrangement is key to transperitoneal and retroperitoneal approaches; in identifying vascular
structures during total or partial nephrectomy; and when transposing the ureter in a pyeloplasty around a crossing vessel. Consider vascular angiosomes, including Brödel’s avascular line, when making renal incisions.

Occasionally, direct polar compression manually or with bowel clamps is sufficient, rather than achieving complete renal ischaemia with vascular clamping.

Note the diaphragmatic fibres and pleural reflection in dissections of the ribs; reflection is variable along the twelfth rib. If the pleura is breached, attempt repair and close with a thoracic catheter at high positive ventilator pressure (Valsalva). Perform a chest X-ray in recovery to ensure that a pneumothorax is small (less than 15–20%); otherwise, a formal chest drain may be required. Be aware of the costal neurovascular bundle and ‘dissect above the rib below’.

**Minimally invasive renal surgery**

Surface markings for laparoscopic/robotic ports utilize common points of reference, including the xiphisternum, costal margin, umbilicus and ASIS, together with the likely location of the kidney and associated pathology relative to the transpyloric plane. Port location varies according to technique and technology, with triangulation for laparoscopic procedures and the older Si Robotic platform (to avoid external clashes), or a straight line for the Xi, reflecting its lower external profile ([Fig. 69.7](#)).
Retroperitoneal access is typically obtained at the most predictable location, which is just caudal to the tip of the twelfth rib. Here, dissection through the muscle layers and the two significant layers of fascia associated with the superficial musculature and the deeper lumbar fascia permits access to the potential retroperitoneal space adjacent to the kidney and Gerota's fascia. Identification of the correct space is confirmed by palpation of psoas major and ribs superiorly; visualization of psoas major as the horizontal landmark is reassuring.

Transperitoneal access is usually achieved with a standard Veress needle or Hasson open technique, being mindful of previous surgery, the location of the epigastric vessels and intra-abdominal structures.

A key area of progress in minimally invasive surgery is the use of technology to permit anatomical partial nephrectomy now that laparoscopic nephrectomy has become more standardized. The initial consideration is the vascular anatomy and isolating the correct arterial branch, whether primary, aberrant or segmental, in order to minimize parenchymal ischaemia. Next is the renorrhaphy, where understanding the vascular anatomy and parenchymal structure is important. The thin fibrous capsule composed of collagen-rich connective tissue provides a strong layer to tension sutures. An appreciation of the corticomedullary junction is useful because a dedicated vascular suture is often required deeper to the junction, and the arcuate vessels often punctuate this interface.
Similar anatomical considerations apply as for open renal surgery. Careful preservation of the peritoneal reflection in retroperitoneal surgery is preferable because a breach may lead to a compromised operative space.

Loss of haptics or arcing of energy from instruments may result in tissue/organ damage, such as an out-of-vision iatrogenic injury. An appreciation of the operative field anatomy is therefore essential. Minimally invasive surgery permits a potentially more refined and accurate approach to disease and organ anatomy while limiting surgical access morbidity.

Newer techniques of isolating the angiosome with indocyanine green and Firefly technology are increasingly becoming available (Video 69.1).

If laparoscopic access cannot be obtained in standard sites or sequence due to scar, adhesions or other intra-abdominal pathology, port placement or number may need to be modified.

**Percutaneous nephrolithotomy (prone or supine)**

An appreciation of calyceal anatomy is fundamental to percutaneous access. Given that the kidneys are rotated at roughly 30° in a posteromedial axis, on anteroposterior X-rays the anterior calyces are lateral while the posterior calyces are medial. Their number and orientation is highly variable, given that each minor calyx has developed to surround either a single papilla or, more rarely, groups of two or three papillae. The minor calyces unite with their neighbours to form two, or possibly three, larger chambers, the major calyces, which drain into infundibula. The renal pelvis is normally formed from the junction of two infundibula, one from the upper- and one from the lower-pole calyces; there may be a third, which drains the calyces in the mid portion of the kidney (Fig. 69.8).
Puncture landmarks reflect both general and patient-specific considerations. The position of the twelfth rib and the pleural reflections along the rib must be appreciated. The working area is limited inferiorly by the iliac crest and anterolaterally by the posterior axillary line, particularly in the supine procedure. The procedure typically involves either retrograde filling of the collecting system with contrast or ultrasound guidance for ease of identification and access. After either prone or supine positioning, and remaining posterior to the posterior axillary line, one of two methods is used to access the collecting system. The ‘bull’s-eye’ method employs direct visualization of the tract of the needle with the C-arm image intensifier parallel with the needle. The triangulation/two-plane/parallax technique uses two planes to triangulate the path to the relevant calyx (Fig. 69.9).
FIG. 69.9  Percutaneous access techniques. A, The ideal transverse route into the tip of the calyx. B, The ‘bull’s eye’ access technique with the image intensifier in the plane of the access needle directed into the end of the calyx. C, The ‘triangulation’ access technique with the image intensifier in oriented perpendicular and then rotated for two colocation angles with the access needle directed into the end of the calyx.

**Tips and Anatomical Hazards**

Preoperative imaging provides an awareness of adjacent anatomical structures, particularly the colon laterally, the lungs superiorly and intra-abdominal structures anterior to the kidneys, which may be at risk; always review the imaging in order to identify structures to avoid. Access may be difficult: an impacted stone and multiple previous punctures all increase the risk of an ongoing urine leak. There is a risk of pneumothorax with an upper-pole puncture, therefore puncture at full expiration. After the procedure, order a chest X-ray, and place a chest drain as needed.

**Ureteroscopy**

The key element of ureteroscopy is navigating the narrow parts of the ureter: namely, the pelvi-ureteric junction, vesico-ureteric junction, and the segment over the iliac vessels at the pelvic brim. Difficulties with access can be
overcome with prior stenting, access sheaths and even formal dilation, but care must be taken not to damage the ureter because strictures can ensue, with significant sequelae. Given the oblique angle of the ureteric orifice, inverting the scope is often advantageous. A flexible ureteroscope to decrease torque and displacement of the ureter may also be required.
References


Single best answers

1. Which one of the following best describes the order of arterial ramification after leaving the main renal artery?
   A. Segmental, lobar, interlobar, arcuate, interlobular
   B. Segmental, lobar, arcuate, lobular, interlobular
   C. Lobar, segmental, interlobar, arcuate, interlobular
   D. Lobar, arcuate, segmental, lobar, lobular, interlobular

   **Answer: A.** There are five arterial segments (anterior branches to the apical, superior, middle and inferior segments, and an additional posterior vessel). Subsequent ramifications progress as lobar (one to each renal pyramid); two or three interlobar arteries (extending towards the cortex around each pyramid) that divide into arcuate arteries at the corticomedullary junction; and interlobular arteries (ramify radially into the cortex).

2. Which one of the following best describes the order of structures at the hilum, from anterior to posterior?
   A. Artery, vein, ureter
   B. Vein, artery, ureter
   C. Ureter, artery, vein

   **Answer: B.** Typically, the order from anterior to posterior is vein, artery and ureter. This arrangement is important in both transperitoneal and retroperitoneal approaches; in identifying key vascular structures during total or partial nephrectomy; and when needing to transpose the ureter in a pyeloplasty around a crossing vessel.

3. What percentage of kidneys has an additional renal artery?
   A. 25%
B. 30%
C. 35%
D. 40%
E. 45%

**Answer: B.** Accessory renal arteries are noted in 30% of individuals, usually inferior to the main renal artery. Inferior vessels may cause obstruction, being noted in cases of pelvi-ureteric junction obstruction (30%).

4. Which one of the following statements is true?
   A. Posterior calyces are the most lateral
   B. Posterior calyces are the most inferior
   C. Inferior calyces are the most medial
   D. Anterior calyces are the most lateral
   E. Anterior calyces are the most medial

   **Answer: D.** Kidneys are rotated at roughly 30° in their posteromedial axis; thus, on anteroposterior X-rays, the anterior calyces are lateral while the posterior calyces are medial.

5. Which one of the following types of vessel typically drains into the right renal vein?
   A. Adrenal
   B. Gonadal
   C. Lumbar
   D. None of the above
   E. All of the above

   **Answer: D.** Renal venous drainage mirrors the arterial supply. Tributaries are variably received on the left from the adrenal,
lumbar and left gonadal veins. The right renal vein typically drains directly into the inferior vena cava, as do the gonadal, lumbar and adrenal veins.
Clinical cases

1. You need to perform a ureteroscopy for a proximal ureteric stone.  
   **A. Where might narrowing be anticipated in the ureter during access and how might these narrowings be overcome?**  
The known narrow points in the ureter include the pelvi-ureteric junction, vesico-ureteric junction and the point where the ureter crosses the iliac vessels. In addition, the site at which a stone is held up or impacted is likely to be inflamed and can also be a site of difficult passage. Techniques employed to navigate these sites during access procedures include (in no particular order): after initial wire placement, consideration of a second safety wire; a retrograde pyelogram prior to instrumentation to establish the site of impaction; inversion of the rigid scope at the vesico-ureteric junction because it has an oblique opening; use of a dilator, such as a Nottingham or balloon dilator, to access the ureter; use of an access sheath to dilate the ureter gently; placement of a stent and returning to access the ureter at another time.

2. A patient is booked for a supine percutaneous nephrolithotomy.  
   **A. What are the relevant surface anatomy considerations and what anatomical principles might be used in obtaining percutaneous access?**  
The key elements in percutaneous nephrolithotomy surgery are safe anatomical access and a controlled procedure that is cognisant of the relevant clinical anatomy and potential complications. Appreciation of the anatomy of an individual patient is vital. Cross-axial imaging is useful to guide the route of entry into the collecting system, as determined by patient-specific features such as habitus, previous surgery, collecting system orientation, stone location, upper- or lower-pole puncture, location of the lungs and pleural reflections. Positioning of the patient is key with the supine approach, where the patient needs to be slightly elevated from supine on the side of the puncture. The approach should routinely be behind the posterior axillary line, noting the imaging location of adjacent organs: colon, duodenum and lungs.

3. During an open partial nephrectomy, significant bleeding is encountered during the renorrhaphy.
A. What anatomical and surgical considerations are causative and what can be done to manage the bleeding?

Bleeding during the renorrhaphy can be due to multiple factors and each of these should be addressed or at least be considered. Is the bleeding arterial or venous? Is the bleeding from an accessory artery? The surgeon should review the imaging and ensure that there are no additional vessels. Each vessel should always be slung so that it can be clamped if necessary. The hilum should always be dissected out completely if there are any concerns. A segmental clamp may be inadequate. It may be necessary to clamp the main renal artery or additional artery. An artery may not be clamped adequately as a result of poor closing pressure of the bulldog/clamp or atherosclerosis; ensure that arterial clamps are used. Dissect out a good length of artery and make a trial closure before renorrhaphy. There may be a venous bleed, particularly if there is no venous clamp or if there is organ squeeze. Ensure appropriate placement of bowel clamps/hand pressure for haemostasis.

4. On the first day after laparoscopic partial nephrectomy, the patient is found to be pale, tachycardic and hypotensive.

A. What is the likely cause and what differentials are there? What is the immediate management?

Differentials in order of likelihood are: bleed; arteriovenous fistula; urine leak; sepsis; incarcerated hernia; bowel injury; deep venous thrombosis/pulmonary embolism. For the bleed scenario, resuscitation involves DR ABCDE (danger, response, airway, breathing, circulation, disability, everything else). If the bleed can be controlled, consider a CT angiogram and angio-embolization. If the bleed cannot be controlled, consider a return to theatre with an open approach or attendance for angio-embolization immediately. If the bleeding is not controlled and the patient is obtunded, attend theatre immediately and consider nephrectomy as appropriate, with necessary dissection.

5. A patient presents with flank pain and is diagnosed with a ureteric stone.

A. Describe the anatomical basis for the distribution of this pain.

Excessive distension of the ureter or spasm of its muscular wall may be caused by a stone (calculus) or by stenting, and provokes severe spasmodic pain known as ureteric colic. The pain is due to
obstruction of urinary flow and the subsequent increase in tension in the ureteric wall. Rising pressure in the renal pelvis stimulates the local synthesis and release of prostaglandins, causing spasm of the ureteric smooth muscle and vasodilation, producing a diuresis that further increases intrarenal pressure. The visceral afferent fibres that carry nociceptive signals from the ureters terminate in spinal segments T11–L2; the pain is referred to the corresponding dermatomes (T11–L2) in a loin-to-groin distribution, extending down to the scrotum or labium majus, and potentially even into the anteromedial thigh via the genitofemoral nerve (L1, 2).
Bladder and urethra

Ramesh Thurairaja, Brian A Parsons
Urinary bladder

Core Procedures

- Cystoscopy (endoscopic): diagnostic procedure
- Suprapubic catheterization (percutaneous, endoscopic): bladder drainage
- Cystoscopy and intravesical botulinum toxin injections (endoscopic): treatment of detrusor overactivity
- Transurethral resection of bladder tumour (endoscopic): diagnosis and treatment of bladder tumour
- Suprapubic cystostomy (open): removal of stones/foreign body
- Bladder augmentation (open): increase in bladder capacity
- Boari flap and psoas hitch (open): reconstruction of distal ureter and bladder
- Partial cystectomy/diverticulectomy (open, laparoscopic, robotic): partial excision of bladder
- Cystectomy (open, laparoscopic, robotic): radical treatment of cancer

The lower urinary tract consists of the urinary bladder and the urethra; in males it also includes the prostate (Ch. 73). The function of the urinary bladder is to store and periodically eliminate urine. It is a hollow muscular organ that acts as a compliant reservoir. The capacity of the normal adult bladder ranges between 300 and 600 mL; large volumes may be stored with little change in intravesical pressure, a physiological phenomenon known as accommodation or receptive relaxation.

Embryology

The urinary tract and reproductive systems develop from the intermediate mesoderm and are intimately associated with each other during the early stages of development. The cloaca divides into the urogenital sinus, into which the urinary and genital ducts empty, and a rectum, which discharges into the anal canal. The urinary bladder develops from the upper section of
the urogenital sinus and is continuous with the allantois above. Eventually, the allantois is obliterated, forming a fibrous cord (the urachus) that later becomes the median umbilical ligament. Failure of the lumen of the urachus to obliterate completely during normal gestational development can give rise to a fistula, cyst, sinus or diverticulum, depending on the extent and position of the residual patency. Urachal anomalies are uncommon (<1 in 5000 individuals) and are frequently asymptomatic, but can present with non-specific abdominal and urinary symptoms, and rarely malignant degeneration.\(^1\)

The mesonephric ducts (Wolffian ducts) open into the urogenital sinus early in development and the ureters develop as branches of the mesonephric ducts. The caudal end of the ureter and mesonephric duct becomes incorporated into the posterior wall of the sinus, allowing the ureters to gain separate orifices that access the developing bladder. The openings of the mesonephric ducts descend to open into the part of the urogenital sinus that becomes the prostatic urethra.

The triangular region created by absorption of the distal end of the mesonephric ducts into the bladder is termed the trigone (Lieutaud trigone) and is derived from the mesoderm. The remainder of the bladder has an endodermal origin and its epithelial lining is derived from hindgut endoderm. In the twelfth week of gestation, the connective tissue, smooth muscle and blood vessel components that coat the outer aspect of this endoderm are derived from the splanchnopleural mesoderm.

### Clinical anatomy of the bladder

The bladder is the most anterior organ in the pelvis, situated entirely in the lesser pelvis when empty and expanding superiorly into the abdominal cavity on filling (Videos 70.1 and 70.2). It is roughly spherical in shape when full but becomes tetrahedral in form as emptying occurs (Fig. 70.1). The bladder has an apex, a base and a superior and two inferolateral surfaces. The apex faces the upper part of the pubic symphysis and is attached by the median umbilical ligament to the umbilicus. The base is located posteroinferiorly and consists of the trigone and bladder neck (urethrovical junction). In females the bladder neck is closely related to the anterior vaginal wall, and in males it is separated from the rectum by the rectovesical pouch above and by the seminal vesicles, vas (ductus) deferens and Denonvilliers’ fascia below. The bladder neck is the lowest part of the bladder and lies 3–4 cm below and
behind the lower part of the pubic symphysis.

**FIG. 70.1** A schematic diagram of the posterolateral view of the bladder. The dashed line indicates the position of the prostate in males.

In children, the bladder lies in an abdominal position, reflecting their shallow true pelvis, and the internal urethral orifice is level with the superior border of the pubic symphysis. The paediatric bladder extends to approximately two-thirds of the distance towards the umbilicus, which means that aseptic urine samples may be obtained by suprapubic needle aspiration. The bladder progressively descends with growth, reaching its adult position shortly after puberty.

The bladder is an extraperitoneal organ: its superior surface is covered by peritoneum that extends anteriorly over the fibrous median umbilical ligament (obliterated fetal urachus), forming the median umbilical fold. In males, the peritoneum continues down over part of the bladder base and then runs posteriorly over the lower third of the rectum to form the rectovesical pouch. This is the lowest part of the peritoneal cavity and usually contains loops of terminal ileum or sigmoid colon (see Fig. 68.2B). In females, the peritoneum is reflected posteriorly on to the uterus at the level of the internal os of the cervix to form the vesico-uterine pouch (see Fig. 68.2A). A small area of the superior surface of the female bladder is devoid of peritoneum and is separated from the supravaginal cervix by fibroareolar
tissue.

The inferolateral surfaces are not covered by peritoneum and are cradled between the levator ani muscles of the pelvic floor and obturator internus above the attachment of the pelvic diaphragm. The anterior aspect of the bladder is separated from the transversalis fascia and the inner surface of the pubis by fat in the potential retropubic space of Retzius. This fat is more adherent to the bladder than to the anterior aspect of the prostate, aiding surgical identification of the bladder neck region. As the bladder fills, the parietal peritoneum overlying its superior surface is displaced away from the posterior abdominal wall for a variable distance (5–7 cm) above the pubic symphysis, depending on the degree of distension. This displacement allows surgical access to the bladder through the suprapubic region of the anterior abdominal wall without the risk of traversing the peritoneum.

The bladder neck and base are the most fixed parts of the urinary bladder and provide a stable structure against which the body of the bladder can contract during micturition. The bladder is anchored to the pubis and pelvic side walls by condensations of pelvic fascia or by fibrous bands mixed with smooth muscle fibres known as true ligaments. The medial and lateral pubovesical ligaments (puboprostatic ligaments in males) are stout bands of fibromuscular tissue extending from the bladder neck to the inferior aspect of the pubic bone. They form the floor of the space of Retzius and lie on each side of the midline, leaving a median hiatus traversed by numerous veins. The pubovesical/puboprostatic ligaments are derived from an extension of the detrusor apron, which in males overlies the anterior surface of the prostate. These ligaments are of surgical importance because of their intimate relation to the dorsal venous plexus. The lateral ligaments are formed by reflections of pelvic fascia between the inferolateral surface of the bladder and the tendinous arch of the pelvic side walls. The posterior ligaments are condensations of pelvic fascia that attach the neck and base of the bladder to the posterolateral pelvic wall along the internal iliac vein and contain the vesical venous plexus.

The peritoneum is carried off anteriorly from the superior surface of the bladder in a series of folds known as false ligaments. The median umbilical fold is created by the underlying median umbilical ligament. On each side, the medial umbilical folds are raised by the obliterated umbilical arteries, and more laterally, the peritoneum overlying the inferior epigastric vessels forms the lateral umbilical ligaments, which originate just medial to the deep inguinal ring and extend superiorly to the arcuate line on the posterior
abdominal wall (Fig. 70.2). Peritoneal folds also run posteriorly between the sides of the bladder and the sacrum, forming the sacrogenital folds, and demarcating the lateral boundaries of the rectovesical pouch in males.
During a partial cystectomy for a urachal tumour, the medial and median umbilical ligaments should be included within the resected specimen and
divided just caudal to the umbilicus to maximize the superior resection margin.

**Internal surface**

The urothelium of the bladder body and its associated basement membrane is folded and loosely attached to the subjacent detrusor muscle by the lamina propria. Bladder filling leads to an unfolding and flattening of the urothelium, a decrease in the coiled tortuosity of bladder wall collagen and a rearrangement of muscle bundles within the detrusor layer. Bladder outlet obstruction leads to a trabeculated appearance in which the muscle fasciculi hypertrophy and the mucosa between them bulges out to form sacculations and diverticula.

The trigone is the triangular area at the base of the bladder, demarcated internally by two slit-like ureteric orifices and the internal urethral meatus at its apex. The mucosa lining the trigone is smooth and is firmly attached to the underlying smooth muscle layer. In males, the elevation caused by the median lobe of the prostate (the vesical crest) means that the internal urethral orifice is not circular (Fig. 70.3). The ureters terminate by passing obliquely through the bladder wall for approximately 1.5 cm, forming the intramural ureters. The ureteric orifices are 2–3 cm apart in the empty bladder, connected by an interureteric bar of muscle formed by the continuation of the internal longitudinal muscle of the ureter. This ridge forms the superior boundary of the trigone and is easily identifiable endoscopically as a raised fold of bladder mucosa.
A duplex collecting system is a common congenital renal tract abnormality; it can be either partial or complete, and unilateral or bilateral. Embryologically, duplication occurs when two separate ureteric buds arise from a single mesonephric duct. The Weigert–Meyer rule describes the inverse relationship of the duplex ureteric orifices, in which the opening of the ureter associated with the upper moiety is caudal to that of the lower moiety (Ch. 69). Ectopic ureters, single or duplex, do not enter the trigone of the bladder (Fig. 70.4). In males, an ectopic ureter always enters the urogenital system above the external sphincter or pelvic floor, whereas in females the site of entry can be anywhere from the bladder neck to the perineum, and the ureter may empty into the vagina, uterus or rectum. A ureterocele is a cystic dilation of the distal end of the ureter that either is located within the bladder (intravesical) or spans the bladder neck and urethra (extravesical).
Vascular supply, lymphatic drainage and innervation

The arterial blood supply of the bladder is derived mainly from the anterior divisions of the internal iliac arteries. The superior vesical artery arises from the patent proximal part of the umbilical artery and gives off several branches that supply the bladder body and ureter. The inferior vesical artery supplies the base of the bladder and distal ureter, as well as the seminal vesicles and prostate in males. It is a direct branch from the internal iliac artery in males or from the vaginal artery (a branch of the uterine artery) in females. An extensive anastomosis develops between the superior and inferior vesical arteries, supplemented by branches from the obturator and inferior gluteal arteries.

The veins draining the bladder form a complex plexus on its inferolateral surfaces, passing backwards in the posterior ligaments of the bladder to form tributaries that drain into the internal iliac veins.

The urinary bladder is drained by mucosal, intermuscular and serosal lymphatic plexuses via one of three groups of lymphatic channels, most of which end in the external iliac lymph nodes. Vessels from the trigone emerge on the outer aspect of the bladder and run superolaterally. Vessels from the superior surface of the bladder converge towards the posterolateral angle and pass superolaterally to the external iliac lymph nodes, but some may drain into internal or common iliac groups. Vessels from the inferolateral
surfaces ascend to join those of the superior surface or drain to lymph nodes in the obturator fossa. Lymphatic trunks leading from the pelvic lymph nodes drain into more proximal common iliac lymph nodes and then to the aortocaval groups.

The bladder is innervated by sympathetic and parasympathetic fibres via the vesical plexus. Briefly, preganglionic sympathetic fibres converge on the superior hypogastric plexus lying in the midline at the level of the bifurcation of the aorta and above the sacral promontory. Along their course, the majority of these neurones synapse with their postganglionic sympathetic counterparts. They descend via their respective hypogastric nerve to the right and left inferior hypogastric (pelvic) plexuses, where they are joined by preganglionic parasympathetic fibres travelling via the pelvic splanchnic nerves. The inferior hypogastric (pelvic) plexus is a meshwork of efferent autonomic and visceral afferent fibres and ganglia lying lateral to the rectum: on each side, the inferior hypogastric (pelvic) plexus innervates the bladder, prostate/uterus and vagina, and rectum via the vesical, prostatic/uterovaginal and rectal plexuses, respectively (Fig. 70.5).³,⁴
The parasympathetic fibres arising from S2–4 sacral segments convey motor fibres to the detrusor muscle and cause bladder contraction, with the largest contribution afforded by the S3 segment. This makes the S3 foramen the preferred position for electrode lead placement in sacral nerve stimulation, as used to treat lower urinary tract dysfunction (see Fig. 71.3). Throughout bladder filling, the parasympathetic innervation of the detrusor is inhibited and the smooth and striated parts of the urethral sphincter are activated, preventing involuntary bladder emptying (the ‘guarding reflex’). The sympathetic fibres arising from thoracolumbar spinal segments T11–L2
provide excitatory innervation to the smooth muscle of the bladder neck and urethra, and cause relaxation of the detrusor muscle. Visceral afferent fibres transmitting sensory information from the bladder are carried predominantly by the parasympathetic nerves and consist primarily of small myelinated (Aδ) and unmyelinated (C) fibres that respond to chemical and mechanical stimuli. Normal sensations of bladder filling appear to be dependent on the integrity of the Aδ afferents; micturition is initiated by a supraspinal reflex pathway that passes through a centre in the brainstem and is triggered by these afferents. The more numerous C fibres are ‘silent’ under normal circumstances, but may be activated under pathological conditions and are of particular importance in bladder pain syndrome.

**Microstructure**

Bladder wall thickness ranges between 1.8 and 4.7 mm and tends to be greater in males than females; a small increase in thickness occurs in both genders with ageing. Histologically, the bladder wall is composed of four layers: urothelium, lamina propria, muscularis propria and adventitia or serosa. The urothelium is a transitional epithelium that forms the watertight interface between the bladder lumen and the underlying bladder wall. The lamina propria lies beneath the basement membrane of the urothelium and there is mounting evidence for its importance in bladder function. The lamina propria is composed of an extracellular matrix that contains numerous cell types, including fibroblasts, adipocytes, smooth muscle (muscularis mucosae) and interstitial cells, a rich vascular network, lymphatic channels, elastic fibres, and a variety of afferent and efferent nerve endings. The term mucosa is used to describe the combination of urothelium, its associated basement membrane and the lamina propria.

The muscularis propria consists of detrusor smooth muscle that is orientated in three layers: an inner and outer longitudinal layer with an intermediate circular layer. These layers are clearly distinct near the bladder neck, but are less easily discernible elsewhere as the longitudinal and circumferential layers mix freely without definite orientation. The detrusor muscle is better developed in males, as it needs to generate a greater pressure to overcome the outflow resistance related to the prostate and longer urethra. The serosa is the outermost layer that covers the superior urinary bladder, and beneath it there is a variable amount of vascularized adipose tissue. The other surfaces of the bladder are covered by a layer of...
connective tissue known as adventitia, which loosely connects the bladder to the surrounding tissues of the pelvis.

**Surgical approaches and considerations**

**Open bladder surgery**

A transperitoneal, retropubic (extraperitoneal) or combined approach can be used to expose the peritoneal and/or extraperitoneal surfaces of the bladder. To improve access and visibility, the patient should be positioned with the mid-table hinge at the level of the umbilicus and the table broken; the patient is placed in the slight head-down position. In women, placing the legs in stirrups in an abducted position (Lloyd-Davies position) allows access to the perineum and manipulation of the vaginal vault using a povidone–iodine-soaked swab on a Rampley sponge forceps placed in the vagina.

Radical cystectomy in the male includes the *en bloc* removal of the bladder, distal ureters, prostate, membranous urethra, seminal vesicles and distal vas deferens. A simultaneous total urethrectomy is rarely performed because of the increased morbidity and the low risk of subsequent urethral recurrence. An interval urethrectomy may be considered, based on adverse histological findings, but most patients undergo urethroscopic surveillance. In the female, radical cystectomy includes removal of the bladder, adjacent anterior vagina, urethra, uterus, Fallopian tubes, ovaries and distal round ligaments. Modified genital organ-sparing techniques can be considered in younger women to preserve sexual and reproductive function. Pelvic lymphadenectomy is routinely performed because the pelvic lymph nodes are the primary landing site for metastases, which tend to occur in an orderly progression. Urinary diversion with either an ileal conduit or construction of a continent reservoir is required.

The bladder pedicles can be separated into diverging lateral and posterior components for vascular control and division. During erectile-sparing surgery, it is important to preserve the posterior part because contributions from the inferior hypogastric plexus to the bladder and neurovascular bundles run inferomedial to the ureter within this pedicle towards the posterolateral edge of the seminal vesicles.

The optimal extent of lymph node dissection has yet to be established, but removal of at least ten lymph nodes in radical cystectomy for cancer is associated with improved overall survival in retrospective series. The surgical boundaries for standard lymphadenectomy in bladder cancer patients
involve removal of nodal tissue cranially up to the common iliac bifurcation, medially to the ureter, laterally to the genitofemoral nerve, distally to the circumflex iliac vein and lymph node of Cloquet, and posteriorly to the internal iliac vessels (Fig. 70.6). This should include the internal iliac, presacral, obturator fossa and external iliac groups of lymph nodes. During pelvic lymph node dissection, caution should be exercised in the obturator fossa to avoid injury to the obturator nerve. The genitofemoral nerve can also be damaged as it runs over the psoas muscle lateral to the external iliac vessels; care must be taken to try to preserve both its genital and femoral branches.

![FIG. 70.6](image)

**FIG. 70.6** A robotic assisted laparoscopic right-sided pelvic lymph node dissection. Key: A, obturator nerve; B, external iliac artery; C, external iliac vein; D, genitofemoral nerve.

During ureteric reimplantation, a psoas hitch to the tendon of psoas minor or psoas major fascia helps minimize tension at the uretero-neocystotomy anastomosis. Absorbable sutures are placed parallel to the external iliac vessels to avoid injury to the genitofemoral and femoral nerves. This can be combined with a Boari flap, in which an anterior bladder wall flap is used to compensate for a greater loss of distal ureteric length. The posteriorly based convex flap must be kept sufficiently broad to maintain adequate vascularization. The flap is tubularized and closed in continuity with bladder
closure. Ligation and division of the contralateral superior vesical artery (identifiable as it crosses the ureter) may be required to increase bladder mobility.

**Tips and Anatomical Hazards**

During pelvic lymphadenectomy, dissection lateral to the genitofemoral nerve is associated with an increased risk of lower limb lymphoedema. Open cystotomy is facilitated by prior placement of stay sutures because it aids retraction and defines the edges of the opening. Absorbable sutures must be used in lower urinary tract surgery because non-absorbable material becomes encrusted when exposed to urine, leading to stone formation and possibly becoming a nidus for infection. A pelvic drain is advisable following reconstructive surgery to help identify and manage urine leaks. Patients who have had prior lower abdominal surgery may have bowel interposed between the abdominal wall and the bladder, making supra-pubic catherization hazardous. The position of the right ureter is much more variable and often takes a lateral course over the external iliac vessels. Excessive proximal dissection and mobilization of the ureters during cystectomy can result in ischaemic strictures related to devascularization.

**Minimally invasive bladder surgery**

Surface markings for laparoscopic/robotic ports use common points of reference, including the umbilicus, pubic symphysis and anterior superior iliac spine. Port location varies according to technique and technology, with five or six ports sited in a fan-shaped pattern around the central camera port. Transperitoneal access is achieved using a standard Veress needle or preferably an open Hasson technique, being mindful of previous surgery. Subsequent ports are inserted under direct vision, taking care to avoid the epigastric vessels and intra-abdominal structures. Ports need to be placed high enough on the abdomen to allow dissection of the superior margin of
the bladder and an adequate pelvic lymphadenectomy.

**Tips and Anatomical Hazards**

Identify and retract the medial umbilical ligament to reduce the risk of an ipsilateral ureteric injury during dissection in the true pelvis because the ureter courses medial to the origin of the obliterated umbilical artery.

Avoid use of monopolar diathermy in the obturator fossa because stimulation of the obturator nerve may result in inadvertent damage to the external iliac vessels above.

In nerve-sparing cystectomy, use clips instead of diathermy or energy devices when dissecting and dividing the posterior component of the bladder pedicle.

Care must be taken when using the umbilicus as a midline anatomical landmark. It is normally located at the level of the intervertebral disc between the L3 and L4 vertebrae but its position is lower in children, obese patients and those with a pendulous abdomen. The vessels running within the medial umbilical ligaments are often not completely obliterated and can bleed when divided.

Loss of haptics or arcing of energy from instruments may result in tissue/organ damage: for example, an out-of-vision iatrogenic injury. An appreciation of the operative field anatomy is essential.

**Endoscopic bladder surgery**

The diagnostic inspection of the bladder is a key part of clinical evaluation for haematuria and complex lower urinary tract symptoms. The flexible or rigid cystoscope is passed through the urethra and up to the bladder neck. Once the scope is in the bladder, the trigone and ureteric orifices should be identified and good views of the whole bladder mucosa obtained to exclude a urothelial lesion. During rigid cystoscopy, a 30° scope is most commonly used, but a 70° scope may be required to examine recesses around the bladder neck.

Intravesical botulinum toxin injections using a flexible or rigid cystoscope can be used to treat neuropathic and refractory idiopathic overactive
bladders. The toxin is reconstituted with sterile saline and injected into the superficial layers of the bladder (traditionally trigone-sparing) at multiple sites (usually 10–20).

A suprapubic catheter can be inserted percutaneously into the bladder dome, under cystoscopic or transabdominal ultrasound guidance, to provide more comfortable bladder drainage in patients requiring an indwelling catheter. The bladder needs to be filled with more than 300 mL to be palpable. Suprapubic catheterization is best avoided in patients who have had lower abdominal surgery, are anticoagulated or present with clot retention.

The transurethral resection of a bladder tumour (TURBT) procedure involves endoscopic resection of a bladder lesion using a resectoscope and wire loop with either monopolar or bipolar current. A standard cystoscopy is performed prior to commencing resection; in multifocal disease, it is preferable to resect high-risk areas (bladder dome, area lateral to the ureteric orifices) last. Pathological evaluation of the specimen determines the depth of invasion and so it is important to include the muscularis propria in the resected specimen.

**Tips and Anatomical Hazards**

The interureteric bar provides a consistent guide to the position of the ureteric orifices.
For large tumours, a separate base specimen improves histological staging by maximizing the chances of including muscle within the specimen.
The risk of obturator kick can be reduced by:
  - emptying the bladder prior to resection in high-risk areas
  - reducing the diathermy current used during resection
  - using bipolar rather than monopolar diathermy
  - using neuromuscular blockade in intubated patients under general anaesthesia.
Neuromuscular blockade in intubated patients under general anaesthesia can make resection of tumours over the bladder dome safer in abdominal breathers.
In patients who have had prior lower abdominal surgery, review of the
available cross-sectional imaging can help in assessing the risk of a possible bowel injury during suprapubic catheterization. Bladder diverticula lack detrusor muscle (that is, they are not true diverticula), which means there is a higher risk of perforation during resection. Resection in the area above and lateral to the ureteric orifices is the common site for obturator nerve stimulation and adductor spasm. The superior surface of the bladder is covered with peritoneum and so intraperitoneal perforations can occur during resection over the posterior wall and bladder dome.
Urethra

Core Procedures

- Catheterization (percutaneous): bladder drainage/urine output monitoring
- Urethroscopy (endoscopic): diagnostic procedure
- Urethral dilation (endoscopic): treatment of urethral stricture
- Optical urethrotomy (endoscopic): treatment of urethral stricture
- Meatoplasty (open): treatment of meatal stenosis
- Urethroplasty (open): treatment of urethral stricture
- Urethrectomy (open): radical cancer treatment

The urethra is the fibromuscular tube that extends between the internal and external urethral openings and transports urine during micturition (males and females) and semen during ejaculation (males).

Embryology

The urethra is derived from hindgut endoderm as it develops from the lower part of the urogenital sinus between 8 and 20 weeks of gestation. In males, the prostatic urethra proximal to the orifice of the prostatic utricle is derived from the vesico-urethral part of the cloaca and the incorporated caudal ends of the mesonephric ducts. The remainder of the posterior urethra is derived from the urogenital sinus. The anterior urethra as far as the corona is formed by extension and tubularization of the urethral plate as the phallus grows. Secondary ingrowth of mesenchyme fuses the genital folds over the urethra. The short segment of anterior urethra within the glans develops in a proximal direction from ectodermal ingrowth and endodermal differentiation. The prepuce is formed at the same time as the urethra with circumferential growth of preputial folds that fuse with the glans. Abnormal urethral development impairs formation of the ventral prepuce. In females, the urethra is derived entirely from the vesico-urethral region of the cloaca, including the dorsal region derived from the mesonephric ducts; it is
homologous with the proximal part of the prostatic urethra in males.

The urethral sphincter develops as a mesenchymal condensation around the urethra after division of the cloaca. The mesenchyme proliferates in the area of the bladder neck with muscle fibre differentiation after 15 weeks’ gestation. In females, there is continuity between the smooth muscle of the proximal urethral wall and that of the bladder. In males, smooth muscle fibres are less abundant due to development of the prostate. Striated muscle fibres subsequently form around the smooth muscle of the anterior part of the urethra and eventually encircle it. The smooth and striated components of the urethral sphincter are closely related but mixing of fibres does not occur.

**Clinical anatomy of the male urethra**

The male urethra is 18–25 cm long with an average length of 22.3 cm. It is divided into anterior and posterior parts: this division is important both in terms of pathology and when imaging the urethra. On fluoroscopy, the anterior urethra can be visualized by performing an ascending (retrograde) urethrogram, and the posterior urethra with a descending or micturating (anterograde) urethrogram.

The anterior urethra runs from the inferior border of the perineal membrane, which lies at the lowest level of the pubic symphysis, to the external urethral meatus. It is approximately 16 cm long and consists of the bulbar urethra, the penile (pendulous) urethra and the navicular fossa (Guerin's sinus) distally. The lumen of the anterior urethra is a narrow transverse slit when empty, which dilates to approximately 6 mm when urine is passed. The external urethral meatus, the narrowest part of the urethra, is a sagittal slit bounded by a small labium on each side.
The bulbar urethra is the widest part of the urethra and lies within the urogenital triangle of the perineum surrounded by the bulbospongiosus muscles. The bulbourethral glands open on the lateral surfaces of the bulbar urethra approximately 2.5 cm below the urogenital diaphragm. The urethra then curves downwards as the penile urethra, extending from the penoscrotal junction to the base of the glans. This downward curve can act as a U-bend.
with pooling of urine that causes post-micturition dribbling. The penile urethra is surrounded by the corpus spongiosum throughout its length and stretches during penile tumescence. The periurethral tissues of the penile urethra contain numerous small mucus-secreting glands (of Littre) that discharge into recesses, the lacunae of Morgagni. The navicular fossa is the widened terminal part of the urethra that is invested in the spongy tissue of the glans; it contains a deep recess known as the lacuna magna. The navicular fossa is involved in rifling the urinary stream during voiding.

The posterior urethra extends from the internal urethral orifice at the bladder neck to the inferior fascia of the urogenital diaphragm and is divided into prostatic and membranous parts. The prostatic urethra is 3–4 cm long and tunnels through the prostate gland closer to its anterior than its posterior surface. In transverse section, the prostatic urethra is crescentic in shape, reflecting the presence of the urethral crest, a midline longitudinal ridge along most of the dorsal wall. The crest is bounded on each side by a shallow depression, the prostatic sinus, which is perforated by 15–20 prostatic ducts (Fig. 70.8). An eminence in the central part of the urethral crest, the verumontanum (colliculus seminalis), provides an indication of the position of the external urethral sphincter at endoscopy and is the point at which the urethra turns anteriorly by 35° before entering the bladder. It is an important surgical landmark during transurethral resection of the prostate because resection distal to it may result in incontinence. The verumontanum contains a slit-like opening that leads to the prostatic utricle, an epithelial-lined sac that is a Müllerian vestigial remnant of the fused paramesonephric ducts. The ejaculatory ducts empty into the prostatic urethra on either side of the verumontanum.
The membranous urethra is the shortest and least dilatable urethral segment. It is 1–2 cm long, extends from the prostatic apex to the bulb of the penis, and traverses the musculature of the external urethral sphincter and perineal membrane. The paired bulbourethral (Cowper’s) glands are located on the left and right sides of the membranous urethra but drain into the bulbar urethra.

The membranous urethra is prone to injury in pelvic fractures. The apex of the prostate gland is fixed to the bony pelvis by the puboprostatic ligaments: hence there may be shearing of the urethra when the pelvis is displaced. The bulbar urethra is the most common site of injury and is susceptible to blunt trauma (straddle-type injuries or kicks to the perineal area) because of its path along the perineum. The penile urethra is least likely to be injured by blunt trauma but iatrogenic injuries can occur during catheterization or urinary tract instrumentation. Penile fractures may also be associated with a urethral injury in 20% of cases.
**Vascular supply and lymphatic drainage**

The urethral artery arises from the internal pudendal artery or common penile artery just below the urogenital diaphragm and travels through the corpus spongiosum to reach the glans penis. It supplies the urethra and the erectile tissue that surrounds it. The urethra is also supplied bilaterally by circumflex branches of the dorsal penile artery and retrogradely from the glans by its terminal branches. The blood supply through the corpus spongiosum is so plentiful that the urethra can be divided at any point in its length without compromising the vascular supply distally.

The venous drainage of the posterior urethra is to the prostatic and vesical venous plexus that feeds into the internal iliac veins. The anterior urethra drains into the prostatic plexus indirectly through the deep dorsal veins of the penis and the internal pudendal veins.

Lymphatics draining the posterior urethra pass primarily to the internal iliac lymph nodes but some may drain to the external iliac group. Vessel from the anterior urethra pass to the deep inguinal nodes but some may drain into the superficial group of inguinal nodes.

**Clinical anatomy of the female urethra**

The female urethra is much shorter than that of the male and is approximately 4 cm in length. It lies directly behind the pubic symphysis, curves slightly forward during its course, and runs through the urogenital diaphragm to open in the vaginal vestibule. The urethra is suspended beneath the pubis by the posterior pubourethral ligaments and anteriorly by the suspensory ligaments of the clitoris. The external urethral meatus is a sagittal slit that is directly anterior to the vaginal introitus and 2–2.5 cm posterior to the glans clitoris. The walls of the urethra are in apposition, except during voiding.

A urethral diverticulum is a periurethral cystic structure that has a single discrete connection to the urethral lumen. The majority are acquired but congenital diverticula can occur. Clinical presentation is highly variable and does not correlate with diverticular size; classically, it causes dysuria, dyspareunia and post-micturition dribbling. Surgical excision can be offered to symptomatic patients but is associated with a risk of fistula or stricture formation.
The female urethra is supplied mainly by the vaginal artery but also receives blood from the inferior vesical artery. The venous plexus around the urethra drains into the vesical venous plexus around the bladder neck.

Lymphatics of the proximal urethra drain into the internal and external iliac groups of nodes. The distal urethral lymphatics communicate freely with lymphatics of the vulva and drain to the superficial inguinal lymph nodes.

**Microstructure**

The type of epithelium lining the urethra varies along its length. The male urethra is lined by transitional epithelium, except distally, where it becomes lined by non-keratinized stratified squamous epithelium. The urothelium is arranged in longitudinal folds that overlie a highly vascular suburothelial layer that encourages urethral wall coaptation, and this may have a role in maintaining continence, especially in females. Beneath this, the musculature is composed of an inner longitudinal and an outer circular layer of smooth muscle. At the level of the urogenital diaphragm, striated muscle intermingles with smooth muscle fibres to form the external urethral sphincter (rhabdosphincter). In females, the proximal third of the urethra is lined by urothelium and the remainder by non-keratinized stratified squamous epithelium that becomes keratinized at the external urethral meatus, where it is continuous with the skin of the vestibule.

**Innervation and urethral closure systems**

Voluntary control of the lower urinary tract depends on complex, tightly regulated interactions between somatic and autonomic efferent pathways. The nerve supply of the external urethral sphincter is generally believed to be supplied by neurones in Onuf’s nucleus and by perineal branches of the pudendal nerve lying on the perineal aspect of the pelvic floor; in both instances, the axons arise from somatic motor neurones in S2–4. A medially placed motor nucleus at the same spinal level supplies axons that innervate the muscles of the pelvic floor. Sympathetic innervation is derived from the pelvic plexus (see above) and preganglionic parasympathetic innervation originates in S2–4; visceral afferent axons from the lower urinary tract also travel in these nerves.

Continence is maintained by two sphincters: an internal urethral sphincter under autonomic nervous system control and a voluntary external urethral
sphincter under somatic control. The internal urethral sphincter consists of smooth muscle and lies at the junction of the urethra and bladder neck. It arises from a condensation of circular detrusor smooth muscle fibres that is continuous with the musculature of the proximal urethra and is arranged in a horseshoe shape. The ‘bladder neck’ sphincter is better developed in males, where it is important for preventing retrograde emission of semen during ejaculation. This function should be considered when prescribing alpha-blocker medication or when consenting patients for procedures such as a bladder neck incision and a transurethral resection of the prostate.

The external urethral sphincter is located around the middle third of the female urethra, and just distal to the prostate at the level of the membranous urethra in males. In this area, both sexes have an intramural layer of striated muscle that is fused to the underlying smooth muscle, but is separate from the periurethral skeletal muscle of the pelvic floor. The female distal urethral sphincter is more elaborate than the male equivalent, because it includes a more distal compressor urethrae muscle and the urethrovaginal sphincter; these intermingle ventrally to maintain urethral compression. Sling procedures provide mid-urethral support and have been the mainstay of the surgical treatment of stress urinary incontinence in females.

Surgical approaches and considerations

Open urethral surgery

Urethrectomy can be performed as part of a cystoprostatectomy or more commonly as an interval procedure in high-risk patients or those diagnosed with recurrence of a urethral cancer during endoscopic surveillance. The patient is placed in the lithotomy position and a urethral catheter is inserted and secured to the glans with a stitch. A midline, inverted U or Mercedes Benz-shaped perineal incision is made, with a ring retractor or stay sutures to optimize exposure. The corpus spongiosum is circumferentially released off the corpora cavernosa and this is continued distally to the base of the glans. A circumferential incision around the external urethral meatus is required to dissect the distal urethra free from the glans. The proximal urethra is traced back towards the urogenital diaphragm by dividing bulbocavernosus with diathermy. The urethral branches of the internal pudendal arteries enter at 4 and 8 o’clock, and need to be controlled and divided. The urethra is then disconnected carefully at the level of the urogenital diaphragm or delivered with the main specimen if performed at the time of the cystoprostatectomy.
Urethroplasty is the only curative option for the treatment of recurrent bulbar strictures and for all other anterior urethral strictures. Short bulbar urethra strictures are generally amenable to complete excision with primary end-to-end anastomosis. Long bulbar strictures and penile strictures of any length are best treated by stricture excision and a urethral substitution procedure incorporating an onlay graft or flap to replace the affected segment. Buccal mucosal graft is now routinely used in urethral reconstructive surgery.

**Tips and Anatomical Hazards**

After initial dissection, a vascular sloop can be placed around the urethra to facilitate retraction.
Dissection of the bulbar urethra becomes easier once the distal urethra has been divided.
Recurrent stricturing of the penile urethra is very common because its thinner corpus spongiosum means that its vascularity is more easily compromised.
The areas posterolateral to the bulb need to be dissected carefully to identify, expose and ligate the bulbar urethral arteries because inadvertent vessel avulsion can cause troublesome bleeding.
During an interval urethrectomy, care must be taken when traversing the urogenital diaphragm because loops of small bowel may be adherent to its superior surface.

**Endoscopic urethral surgery**

During urinary tract instrumentation, catheters and scopes should be introduced into the male urethra with the tip/beak pointing in a downward direction to avoid catching and damaging the lacuna magna in the navicular fossa. During male catheterization, an introducer may be used to guide the catheter tip anteriorly and negotiate the natural 35° angle as the posterior urethra slopes upwards from the verumontanum to the bladder neck. In postmenopausal women, the external urethral meatus can be difficult to locate due to intravaginal retraction, so catheterization may need to be performed more by feel than vision. Positioning a woman in the left lateral
position may improve visualization of the anterior vaginal wall and help identification of the meatus.

Endoscopic examination of the urethra, urethroscopy, should be performed with a 0° cystoscope. In a man with voiding symptoms, it can be used to confirm the presence of a stricture, but only an ascending and descending urethrogram can provide information about the exact position and length of the stricture.\textsuperscript{17}

Urethral dilation and optical urethrotomy are widely used minimally invasive options to manage urethral strictures, but they are potentially curative in only approximately 50% of cases when used for the first-time treatment of short (<1 cm) bulbar strictures.\textsuperscript{17} All other strictures inevitably recur with no evidence that optical urethrotomy is better than dilation.\textsuperscript{19} Optical urethrotomy or direct vision internal urethrotomy involves incising a stricture at the 12 o’clock position using a cold blade (most commonly) or a Ho:YAG laser. With urethral dilation, metal sounds or follow-on dilators (passed over a guidewire) of increasing calibre are inserted to dilate the urethra.

\textbf{Tips and Anatomical Hazards}

During difficult catheterizations, urethral bleeding is an indication of urethral trauma/creation of a false passage. Always pass a guidewire into the bladder before performing an optical urethrotomy. Leaving a catheter \textit{in situ} for 3 days following optical urethrotomy/urethral dilation reduces the risk of early postoperative urine extravasation and infective complications.\textsuperscript{20} Instrumentation-related strictures tend to occur at the external meatus, navicular fossa and penoscrotal junction, and in the region of the urethral sphincter because these are the narrowest parts of the urethra.\textsuperscript{21} In the bulbar urethra, the cavernosal nerves are found at the 1 and 11 o’clock positions so incision here may cause erectile dysfunction. Optical urethrotomy and urethral dilations need antibiotic cover; there is a high rate of procedure-related bacteraemias because the
subepithelial layer of the urethra is highly vascular.
References


Further Reading


Lewis SA. Everything you wanted to know about the bladder epithelium but were afraid to ask. *Am. J. Physiol. Renal Physiol.* 2000;278:F867–F874.


Single Best Answers

1. Which one of the following is the narrowest part of the male urethra?
   A. Bulbar urethra
   B. Penile urethra
   C. Membranous urethra
   D. External urethral meatus
   E. Prostatic urethra

   **Answer: D.** The narrowest part of the male urethra is the external urethral meatus and it may require dilation during endoscopic surgery. The membranous urethra has the second narrowest lumen and is the least dilatable segment of the urethra.

2. During a transurethral bladder tumour resection, which one of the following nerves must a surgeon be mindful of?
   A. Genitofemoral nerve
   B. Obturator nerve
   C. Ilioinguinal nerve
   D. Pudendal nerve
   E. Sciatic nerve

   **Answer: B.** The obturator nerve passes in close proximity to the inferolateral bladder wall, especially when the bladder is distended. During a transurethral operation, resection in this area may result in stimulation of the obturator nerve, causing violent adductor contraction and possible inadvertent extraperitoneal bladder perforation.

3. From proximal to distal, which one of the following groups is the
correct order of the four parts of the male urethra?
A. Membranous, prostatic, bulbar and penile
B. Bulbar, membranous, prostatic and penile
C. Penile, prostatic, bulbar and membranous
D. Prostatic, penile, membranous and bulbar
E. Prostatic, membranous, bulbar and penile

Answer: E. The male urethra is divided into posterior and anterior parts. The posterior urethra extends from the internal urethral orifice at the bladder neck to the inferior fascia of the urogenital diaphragm and is divided into prostatic and membranous parts. The anterior urethra runs from the inferior border of the perineal membrane to the external urethral meatus, and is divided into the bulbar and penile urethra.

4. Which one of the following urological organs most often suffers iatrogenic injuries?
A. Kidney
B. Testis
C. Bladder
D. Prostate
E. Ureter

Answer: C. External injury to the bladder, such as that related to gynaecological and colorectal surgery, is more common than internal injury associated with endoscopic surgery.

5. What percentage of penile fractures can be associated with a urethral injury?
A. 5%
B. 10%
C. 20%
D. 30%
E. 50%

**Answer:** C. Up to 20% of penile fractures are associated with urethral injury. Clinical features that suggest a urethral injury include blood at the external urethral meatus, haematuria and an inability to void following the injury. If an injury is suspected, a preoperative retrograde urethrograph or an on-table diagnostic flexible cystoscopy should be performed.
Clinical Cases

1. A 27-year-old male presents to the accident and emergency department, having noticed blood at his urethral meatus after landing on the crossbar of his pedal bike while braking suddenly. The patient has not passed urine since the incident.

A. Which part of the urethra is most likely to be damaged and how should this be managed initially?

Initial management of any trauma case should be in accordance with Advanced Trauma Life Support (ATLS) guidelines. A straddle or fall-astride injury leads to a crushing force on the bulbar urethra, resulting in an obliterative stricture with loss of normal urethral length. Potential examination findings include blood at the external urethral meatus, perineal bruising and a distended bladder on abdominal palpation, but their absence does not exclude an injury. A retrograde urethrogram should be performed to confirm injury and assess extent. Urinary diversion is then achieved by ultrasound-guided suprapubic catheter insertion or early endoscopic realignment with transurethral catheterization. In an unstable patient, a gentle attempt at urethral catheterization can be made in the presence of blood at the meatus and has been shown to be acceptable and successful in up to half of patients.

2. A 75-year-old male undergoing his first endoscopic resection for a 4 cm papillary tumour sustains a bladder perforation during the procedure.

A. How should this be managed?

Endoscopic bladder injuries are classified as either intraperitoneal or extraperitoneal. Once an injury has been recognized, the height of the irrigation fluid should be lowered, further tumour resection minimized and careful haemostasis undertaken. The histology specimen is retrieved by draining the bladder because use of the Ellik evacuator may worsen the perforation. Bladder irrigation should not be used; instead, the patient may be given furosemide to encourage a diuresis. For intraperitoneal perforations, the standard of care is surgical exploration with bladder repair; in the absence of peritonitis or ileus, selected cases may be managed with
continuous bladder drainage, antibiotic prophylaxis and a radiologically
guided insertion of an intraperitoneal drain. Extraperitoneal perforations are
managed conservatively with continuous bladder drainage, and antibiotic
prophylaxis may be considered. If perforation occurs during transurethral
resection of a bladder tumour, immediate intravesical instillation with
chemotherapeutic agents should not be performed.

3. An 82-year-old male presents to the surgical admissions ward with
painful retention at 02:00 in the morning. The patient has a past
medical history of urethral stricture disease, so urethral
catheterization is not possible. A suprapubic catheter is inserted
instead.

A. Discuss the anatomical considerations related to suprapublic
catheterization and the contraindications to the procedure.

At birth, the bladder is an abdominal organ that begins to descend into the
pelvis from the age of 6 years. In the adult, the empty bladder is an entirely
pelvic organ that rises into the abdomen as it fills beyond 300 mL. As the
bladder distends, the peritoneum overlying its superior surface is peeled off
the infra-umbilical abdominal wall, allowing an extraperitoneal approach for
suprapubic cystotomy. A non-distended bladder is an absolute
contraindication to suprapubic catheterization; anticoagulation or
coagulopathy, haematuria and previous pelvic or lower abdominal surgery
are all relative contraindications.
Pelvic inlet, pelvic floor and perineum

Arun Sahai, Rajesh Nair, Alexis Schizas

**Core Procedures**

- Pudendal nerve block/pudendal nerve stimulation
- Sacral nerve stimulation
- Cystocele repair
- Rectocele repair and levatoplasty
- Sacrospinous fixation
- Sacrocolpopexy
- Ventral mesh rectopexy
- Burch colposuspension
- Autologous fascial sling/pubovaginal sling
- Mid-urethral synthetic tapes
- Male sling
- Artificial urinary sphincter
Surgical surface anatomy

Perineum

The pudendal nerve supplies sensory fibres from the perineum (external genitalia and anal skin) and motor fibres to the pelvic floor muscles. It can be compressed and damaged in childbirth. It can be blocked with local anaesthetic or stimulated by an electrode, and can be accessed from either the posterior or the perineal approach. The injection needle for local anaesthesia is inserted perpendicular to the perineum between the ischial tuberosity and the anus (Fig. 71.1). The surgeon's finger is placed into the rectum or the vagina to guard against inadvertent bowel or vaginal puncture during needle insertion and is used to guide the needle to the ischial spine. The needle is then tilted medially and dorsally to reach the recto-ischial fossa until it is located below and behind the ischial spine in the pudendal canal (Alcock's canal)\(^1\). Always aspirate before injecting the anaesthetic agent to avoid direct vascular injection into the internal pudendal vessels that run in the pudendal canal.
During transobturator stress incontinence surgery in both males and females, it is useful to mark out surface anatomy in the perineum to aid trocar passage through the obturator foramen. With the patient in the lithotomy position, in either sex, a polypropylene mesh is typically inserted in either an out-to-in or in-to-out technique, depending on the product used. In men, the landmark for trocar placement in an out-to-in technique is two fingers’ breadths below the inferior border of adductor longus in the groin.
crease (Fig. 71.2). In women undergoing an in-to-out transobturator tape procedure, the markings of the exit position of the trocar are 2 cm above a line drawn parallel to the external urethral meatus and 2 cm lateral to the groin crease.

**FIG. 71.2** Surface markings for transobturator trocar passage (out to in) during male sling surgery to treat post-prostatectomy stress incontinence. The lines represent the inferior border of adductor longus and the groin crease. The incision and subsequent trocar passage are started one finger's breadth below adductor longus towards the groin crease when the patient is legs up in the lithotomy position.

**Sacrum**

The sacrum is made up by the fusion of five vertebrae and forms the posterosuperior wall of the pelvic cavity between the two iliac bones. The borders and anatomical landmarks of the sacrum can be identified by following the iliac crest medially and by palpating the sacrococcygeal articulation. The median sacral crest can be palpated in the dorsal midline. The sacral foramina are located approximately 2 cm lateral to the median
sacral crest. These landmarks are surgically relevant in sacral neuromodulation, a procedure originally described by Schmidt et al that involves stimulation of the S2–4 sacral nerve roots. The technique has been used to treat a variety of lower urinary tract and pelvic floor dysfunction disorders, such as urinary and faecal incontinence, overactive bladder, bladder/pelvic pain and urinary retention. The technique involves implantation of an electrode adjacent to the sacral nerve roots; the electrode is placed percutaneously with or without the use of X-ray guidance. When X-ray is not available, surface anatomy landmarks are critical for correct placement of leads into the S3 foramina. The patient is placed prone and a point identified 10 cm from the coccyx in the midline and 2 cm lateral and 3 cm superior to this point. The curvature of the sacrum means that the electrode must be inserted at an angle of 30–60° to facilitate entry into the S3 foramen (Fig. 71.3). Correct placement is confirmed by stimulating the S3 nerve root and observing a bellows contraction of the pelvic floor (an ‘anal wink’) and flexion of the great toe. Plantar flexion of the entire foot with heel rotation suggests stimulation of the S2 nerve root, and bellows contraction in isolation suggests S4 nerve root stimulation.
FIG. 71.3  Percutaneous access to S3 foramen during a sacral nerve stimulation procedure. A, The stylet of the foramen needle is removed and replaced with the
directional guide. B, Holding the directional guide in place, the foramen needle is gently removed. (From J. Wöllner, C. Hampel, T.M. Kessler, Surgery Illustrated – surgical atlas sacral neuromodulation, BJU Int. 110 (2012) 149.)
Clinical anatomy and surgical considerations: pelvis

Muscles and fasciae

The muscles within the pelvis form two groups: piriformis and obturator internus form part of the walls of the pelvis, and levator ani is the largest muscle of the pelvic floor. The fasciae investing the muscles are continuous with the obturator fascia laterally, perineal fascia inferiorly and visceral fascia superiorly. Obturator internus and the fasciae over its upper and inner surface form part of the anterolateral wall of the true pelvis and are attached to the structures surrounding the obturator foramen. Piriformis forms part of the posterolateral wall of the true pelvis and has attachments to the anterior surface of the sacrum, the gluteal surface of the ilium and the capsule of the adjacent sacroiliac joint. Levator ani is subdivided into pubococcygeus, iliococcygeus and puborectalis. Ischiococcygeus lies cranial to levator ani and is contiguous with it. These muscles act as the principal support mechanism of the pelvic floor and, through its attachments and relations around the vagina, prostate and rectum, play an important physiological role during micturition, defaecation and parturition.

Pelvic fasciae can be divided into parietal (coverings of the pelvic muscles) and visceral (coverings of the pelvic organs and their neurovascular supply). Parietal fasciae include obturator fascia, fascia over piriformis, fascia over levator ani (pelvic diaphragm) and presacral fascia. The visceral pelvic fascia connects the pelvic walls to the urogenital organs and is made up of neurovascular mesenteric condensations ensheathed by loose connective tissue and adipose tissue lying above the perineal membrane. The most lateral attachments constitute the endopelvic fascia. These attachments provide a course for neurovascular structures and also help to support and retain the pelvic organs in place. In females, loose connective tissue separates the bladder and vagina, and the vagina and rectum; in males, it separates the bladder, prostate and seminal vesicles from the rectum. There are important condensations of connective tissue within the endopelvic fascia. In the female, uterosacral ligaments pass from the posterolateral aspect of the cervix posteriorly flanking the rectum, and cardinal ligaments surround the cervicovaginal junction (parametrium), extending to mid-vaginal level where the vagina is attached to the tendinous arch of the pelvic fascia (paracolpium). Superiorly, this connective tissue is traversed by the
ureters. The pubocervical fascia extends forwards from the cardinal ligaments to the pubis on either side of the bladder. A layer of fascia between the rectum and seminal vesicles in the male, and the rectum and vagina in the female – the rectovesical or rectovaginal septum, respectively – is less prominent. Approximately 1 cm above and lateral to the inferior border of the pubic bone, the anterior end of the tendinous arch of the pelvic fascia is attached to the paravaginal or prostatic tissues. This band, sometimes referred to as the ‘white line’, extends to the superior margin of the ischial spine, lying on the superomedial aspect of the upper fascia covering levator ani. The attachment of the anterior vaginal wall to this tendinous arch of pelvic fascia helps to support the vagina, urethra and bladder.

Loss of the integrity of these structures can contribute to herniation of pelvic organs and prolapse into the vagina. The causes of pelvic organ prolapse (POP) are often multifactorial and defects may involve more than one compartment of the vagina (anterior, posterior and apical/vault). The paracolpium provides two levels of support\(^5\) (Fig. 71.4). Level I or upper support suspends the vagina via the uterosacral ligaments; damage will result in an enterocele or uterine prolapse, depending on whether the uterus is still present. Level II support is derived from the mid vagina; damage to either the pubocervical fascia or to the rectovaginal septum will result in anterior (cystocele) or posterior defects (rectocele), respectively. Surgery to correct POP aims to reconstruct these defects and restore normal anatomy. When considering transvaginal anterior compartment repairs, it is important to recognize that the defect may be midline sagittal, transverse, paravaginal (where the vagina is separated from its attachment to the arcus tendineus fasciae pelvis) or site-specific (Fig. 71.5). The surgeon must be able to recognize these defects at the time of surgery and tailor repair accordingly. The repair involves plication of the pubocervical fascia, which is repaired in the midline when there is a central defect, typically with interrupted delayed absorbable sutures. Apical support must be addressed to ensure a durable native tissue repair with incorporation of the fascial repair into the cervix or cardinal/uterosacral ligament complex. In paravaginal defects, the pubocervical fascia becomes separated in part from the arcus tendineus fasciae pelvis. The approach is identical initially to a central defect repair in terms of initial exposure, and concomitant central defects can be repaired. At the site of the defect, the bladder is retracted using a suitable retractor and the ‘white line’ of the arcus tendineus fasciae pelvis exposed. Four to five interrupted permanent sutures are then placed into the ‘white line’ and
aponeurosis of levator ani, from the bladder neck down to the ischial spine; at each level they are placed into the lateral aspect of the vaginal repair. Anterior compartment repairs can be augmented with the use of biological or synthetic material; however, their use is currently controversial and there is a move towards traditional native tissue repairs. Each case needs to be considered carefully on its merits. Augmentation with mesh or biological material is used following traditional repair; the implant is secured to firm structures such as the arcus tendineus fasciae pelvis and the sacrospinous ligaments.

**FIG. 71.4** Levels of vaginal support: level I (suspension) and level II (attachment). In level I, the paracolpium (uterosacral ligaments) suspends the vagina from the lateral pelvic walls. Fibres of level I extend both vertically and posteriorly toward the sacrum. In level II, the vagina is attached to the arcus tendineus fasciae pelvis and the superior fascia of levator ani. (From J.O.L. DeLancey, Anatomic aspects of vaginal eversion after hysterectomy, Am. J. Obstet. Gynecol. 166 (1992) 1717.)
Herniation of the rectum into the vaginal canal results in a rectocele. Correction can involve a transvaginal rectocele repair, where the posterior vaginal epithelium must be dissected from the rectum in the rectovaginal fascial plane. The rectovaginal fascial plane is thinned and the rectum will be bulging into the vagina; care must therefore be taken not to buttonhole the rectum. Dissection should be completed cranial to the defect; caution is required because if the patient has a concomitant enterocele (when the small bowel prolapses into the pouch of Douglas), there is a risk of small bowel injury. Lateral dissection should be completed to the lateral side wall (lateral vaginal sulcus) to expose the levators.

Weakness or damage to the cardinal and uterosacral ligaments can lead to apical/vault prolapse. Currently, one of the most common transvaginal procedures to repair post-hysterectomy vault prolapse or complete procidentia is sacrospinous fixation. Surgery involves posterior wall vaginal dissection and development of the pararectal space. Typically, two non-absorbable sutures are placed through the sacrospinous ligament on one side (although bilateral fixation is possible) and secured to the underside of the vaginal apex (Fig. 71.6). The first suture is placed 2 cm medial to the
ischial spine and the second suture 1 cm medial to the first. The sutures should be placed through the ligament and not around it, to avoid injury to the pudendal neurovascular bundle, which sits just behind the ligament.

The other common procedure to treat this condition is sacrocolpopexy, which uses an abdominal approach and can be performed open, laparoscopically or with robotic assistance; this also allows anterior and posterior repairs. Either biological or synthetic material is attached to the vaginal vault and to the longitudinal ligament overlying the sacrum distal to
the sacral promontory. Ventral mesh rectopexy utilizes the same approach as sacrocolpopexy but the dissection is focused on the posterior compartment through the pouch of Douglas, and the posterior vagina is dissected off the rectum in the rectovaginal fascial plane to a point just cranial to the anal sphincters (Fig. 71.7). Sacrocolpopexy and ventral mesh rectopexy can be combined for multicompartiment prolapse.

![A view of the pelvis during laparoscopic sacrocolpopexy demonstrating the rectovaginal space prior to biological mesh insertion.](image)

The pelvic inlet as viewed surgically from above is formed by the sacrum, pubis, ilium, ischium, the ligaments that interconnect these bones, and the muscles that line their inner surfaces (Fig. 71.8). The true pelvis is considered to start at the level of the plane passing through the promontory of the sacrum, the arcuate line on the ilium, the iliopectineal line and the posterior surface of the pubic crest. This plane, or ‘inlet’, lies at an angle of between 35° and 50° up from the horizontal. During sacrocolpopexy, the surgeon must be able to recognize the bifurcation of the aorta, the middle sacral vessels, the right ureter and the sigmoid colon. The dissection around the sacrum and initial anatomical exposure is particularly important and care must be taken to identify the major pelvic vessels (described below), right ureter and autonomic nerves. The presacral soft tissues are dissected to expose the vessels overlying the sacrum; care should be taken to avoid injuring these vessels and causing bleeding. Once the mesh is in place, the cul-de-sac posterior to this is often closed off to avoid enterocele formation.
During a vaginal hysterectomy, a McCall culdoplasty is typically performed at the end of the procedure to prevent vaginal vault prolapse. The goal is to appose the apical endopelvic fascia to the cardinal–uterosacral ligament complex at the apex. The uterosacral ligaments are tied in to the midline with intervening cul-de-sac peritoneum and full-thickness apical vaginal wall. When placing the sutures through the uterosacral ligaments, caution must be taken to avoid injury to the ureters, which lie 1–2 cm lateral at the level of the cervix.
Vascular supply, lymphatic drainage and innervation

Surgeons operating in the pelvis should be mindful of the important vascular structures (common, external and internal iliac arteries and veins and their branches; Fig. 71.9). Adequate exposure is critical to identify such areas of bleeding, and prompt repair of vascular defects is required without constricting the lumen. Arterial bleeding is often easier to identify and control, whereas the weaker walls of veins are prone to tear. In cases of significant uncontrollable bleeding, the use of vascular clamps on a temporary basis may be required to control haemorrhage so that adequate exposure and repair can be employed. The bifurcation of the common iliac vessels is often a reliable place for urologists to identify the ureter as it crosses the bifurcation to enter the pelvis. The ureter runs on the lateral wall of the pelvis and crosses the internal iliac artery before turning forwards and medially to enter the bladder.
The pelvic lymph node groups envelop the main arteries and are named accordingly (common, external, internal iliac and obturator nodal packets) (Ch. 68). Excision of these lymph node groups is of paramount importance during pelvic cancer surgery, particularly in patients undergoing cystectomy.
for bladder cancer, where removal is diagnostic, prognostic and therapeutic (Video 71.1). Standard lymphadenectomy involves removal of nodal tissue up to the common iliac bifurcation, with the ureter forming the medial border, and includes the internal iliac, presacral, obturator fossa and external iliac nodes. Extended lymphadenectomy involves removal of nodes up to the aortic bifurcation, including the presacral and common iliac regions medial to the ureters as well as the standard template. During obturator fossa lymph node dissection, the surgeon must identify and preserve the obturator nerve.
Clinical anatomy and surgical considerations: perineum

Ischio-anal fossa

The ischio-anal fossa is a horseshoe-shaped region filling the majority of the anal triangle. Although often referred to as a space, it is filled with loose adipose tissue and occasional blood vessels and nerves. The ‘arms’ of the horseshoe are triangular in cross-section because levator ani slopes medially from its lateral pelvic origin towards the anorectal junction. The anal canal and its sphincters lie in the centre of the horseshoe. Above them, the medial limit of the fossa is formed by the deep fascia over levator ani. The outer boundary of the fossa is formed anterolaterally by the fascia over obturator internus and the periosteum of the ischial tuberosities. Posterolaterally, the outer boundary is formed by the lower border of gluteus maximus and the sacrotuberous ligament.

An anterior recess of the ischio-anal fossa lies cranial to the perineal membrane and transverse perineal muscles. It extends anteriorly as far as the posterior surface of the pubis, below the attachment of levator ani. Posteriorly, the fossa contains the attachment of the external anal sphincter to the tip of the coccyx; above and below this, the adipose tissue of the fossa is uninterrupted across the midline. These continuations of the ischio-anal fossa mean that infections, tumours and fluid collections may not only enlarge relatively freely to the side of the anal canal, but also spread with little resistance to the contralateral side and deep to the perineal membrane. The internal pudendal vessels and accompanying nerves lie in the lateral wall of the ischio-anal fossa, enclosed in the fascia that forms the pudendal canal. The inferior rectal vessels and nerves cross the fossa from the pudendal canal and often branch within it. The ischio-anal fossa is an important surgical plane during resections of the anal canal and anorectal junction for malignancy. It provides an easy, relatively bloodless plane of dissection that encompasses all of the muscular structures of the anal canal and leads to the inferior surface of levator ani, through which the dissection is performed.

External anal sphincter

The external anal sphincter is a band of striated muscle that surrounds the lowest part of the anal canal. The uppermost (deepest) fibres blend with the
lowest fibres of puborectalis; the two are seen to be contiguous on endoanal ultrasound and MRI. Anteriorly, some of these upper fibres decussate into the superficial transverse perineal muscles. Posteriorly, fibres are attached to the anococcygeal raphe. The majority of the middle fibres of the external anal sphincter surround the lower part of the internal sphincter and are attached anteriorly in the perineal body, and posteriorly to the coccyx via the anococcygeal ligament. Some fibres from each side of the sphincter decussate in these areas to form a sort of commissure in the anterior and posterior midline. The anterior and posterior attachments of the external anal sphincter give the muscular tube an oval profile with its long axis lying anteroposteriorly. A subcutaneous portion encircles the anal verge and creates the radial skin creases surrounding the anus. The lower fibres lie below the level of the internal anal sphincter and are separated from the lowest anal epithelium by submucosa.

**Perineal body**

The perineal body is not a structure but an aggregation of fibromuscular tissue located in the midline at the junction between the anal and urogenital triangles, just ventral to the anal sphincter. It is attached to many structures in both the deep and the superficial urogenital spaces. Posteriorly, it merges with fibres from the middle part of the external anal sphincter and the conjoint longitudinal coat. Superiorly, it is continuous with the rectoprostatic or rectovaginal septum, including fibres from levator ani (puborectalis or pubovaginalis). Anteriorly, it receives a contribution from the deep and superficial transverse perineal muscles and bulbospongiosus. The perineal body is continuous with the perineal membrane and the superficial perineal fascia. Since the latter runs forwards into the skin of the perineum, the perineal body is tethered to the central perineal skin, which is often puckered over it. In males, this is continuous with the perineal raphe in the skin of the scrotum. In females, the perineal body lies directly posterior, and is attached, to the posterior commissure of the labia majora and the introitus of the vagina.

Spontaneous lacerations of the perineal body sustained during childbirth are often associated with damage to the anterior fibres of the external anal sphincter. The deliberate division of the perineal body to facilitate delivery (episiotomy) is sometimes angled laterally to avoid such sphincteric injuries.

Anal sphincter trauma is most commonly seen following obstetric anal
sphincter injury or iatrogenic injury. Following vaginal delivery a tear from the vagina through the perineal body may extend to involve the external anal sphincter (and possibly the internal anal sphincter). When the anal sphincters are being repaired, the levators are often recruited into the repair to give a longer length of sphincter, which gives improved function. The perineal body is often used to position radiological markers in the assessment of pelvic floor dysfunction.

Urethral sphincter mechanism

The urethral sphincter consists of both smooth and striated muscle. The smooth muscle has distinct layers, arranged so that a thicker inner longitudinal muscle is surrounded by a thinner circular layer.\textsuperscript{10} Striated muscle in the wall of the urethra, the rhabdosphincter, is a distinct structure and separate from the rest of the skeletal pelvic floor. Stress incontinence, defined as the involuntary loss of urine on exertion, coughing or sneezing in women, is multifactorial and related to increased urethral mobility and/or intrinsic sphincter deficiency.\textsuperscript{11} Urethral hypermobility is thought to arise as a result of loss of support for the proximal urethra and bladder neck by ligaments, fasciae and muscles. Usually, the bladder neck and proximal urethra are supported in a retropubic fashion that counteracts increases in intra-abdominal pressure. However, where there is urethral hypermobility, these structures may not remain intra-abdominal and so may be unresponsive to increased abdominal pressure; when this occurs, the urethral sphincteric mechanism may be overwhelmed.

Female incontinence

Burch colposuspension is an operation that aims to reposition the bladder neck and proximal urethra behind the anterior pubic bone by elevating the anterior vaginal wall and para-urethral tissues to the iliopectineal line of the pelvic side wall (Cooper's pectineal ligament), typically with two or three interrupted sutures on either side (\textbf{Fig. 71.10}). Suture placement is facilitated by the surgeon placing the middle finger of the non-dominant hand into the vagina and elevating the anterolateral vaginal wall while the bladder neck is retracted to the other side with the use of a swab on a stick. The bladder neck can easily be identified by the placement of a urethral catheter: the balloon of the catheter is readily palpable in the area. Sutures should be left so that the vaginal wall is approximated to the lateral pelvic wall and more loosely to the
iliopectineal line to prevent voiding dysfunction. The vaginal wall and pelvic side wall can be very vascular and are prone to bleeding, but this can be minimized with good exposure.

In patients with intrinsic sphincter deficiency, where there is partial or total loss of proximal urethral closure, stress incontinence can be severe. It may be congenital or associated, for example, with neurological lower urinary tract dysfunction, pelvic radiation or previous surgery to the bladder and
urethra. The use of a pubovaginal sling, utilizing autologous tissue such as rectus fascia or fascia lata for the sling material, has been shown to be effective (Fig. 71.11). The patient is placed supine with the legs up in the dorsal lithotomy position. The bladder is catheterized to ensure it is empty and to prevent injury with subsequent sling placement. Typically, an 8 × 1.5 cm rectus fascial sling is harvested through a transverse or Pfannenstiel incision. Suture material is applied to the sling ends on both sides (‘sling on a string’). The sling is then placed either retropubically via a vaginal incision or, less commonly, via a top-down approach. The anterior vaginal wall is grasped 1.5–2 cm from the external urethral meatus at approximately mid-urethral level. The vaginal mucosa at this level is dissected from the periurethral fascia and adequately mobilized to allow dissection with scissors to the retropubic space. Metzenbaum scissors are then placed on one side medial to the ischiopubic ramus and lateral to the urethra, and the endopelvic fascia is perforated in a superolateral direction with the tip of the scissors. The sling is then placed via the sutures mounted on curved forceps or modified Clutton sounds, or via plastic trocar devices. The process is repeated on the contralateral side. The sling traverses the periurethral fascia, infrapubic dissection plane, endopelvic fascia, retropubic dissection plane and, finally, the abdominal wall. The suture material is then tensioned over the rectus sheath; the amount of tension depends on the patient. It is left loose if there is evidence of urethral hypermobility and reasonable sphincter function, tight where there is intrinsic deficiency and tighter still if sphincteric function is very poor. Sling placement can lead to urethral, bladder, small bowel or vascular injury if not done correctly; to prevent injury to the bladder and other pelvic contents during sling placement, ensure that the bladder is empty and use a catheter with an introducer inside it to deviate the bladder from the side of sling placement. When placing the sling, try to feel the tip of the curved forceps or the device used to deploy the sling against the pubis. Hydrodissection with the use of normal saline injected into the infrapubic and retropubic spaces can be helpful in preventing iatrogenic bladder injury. When deploying the sling from the vagina to the retropubic space, ensure that the patient is head-down and aim in the line of the tip of the shoulder. Perform a cystoscopy after sling placement to assess for urethral and/or bladder injury.
The use of synthetic polypropylene monofilament mesh as the sling material, placed in a tension-free manner, is currently the most common procedure worldwide to treat stress incontinence in women. Petros and Ulmsten theorized that injury to the pubo-urethral ligaments and weakening of the pubococcygei at the level of the mid-urethra as a result of surgery, parturition, hormonal change or ageing would impair urethral function and anterior wall support. The introduction of synthetic tension-free vaginal tape (TVT), placed like the fascial sling from the mid-vagina upwards into the retropubic space, aimed to supplement the mid-urethral mechanism. It was assumed that the fibrosis resulting from the host's reaction to the synthetic tape would provide posterior support to the sphincter mechanism and allow
the sphincter to coapt against a ‘backboard’ again. The tape is tensioned over a metallic sound or Mayo scissors in a tension-free manner. The redundant tape is excised at the suprapublic skin level and the suprapublic punctures closed.\textsuperscript{14}

After the introduction of TVT, an obturator trocar passage was developed to avoid passage into the retropubic space and possible bladder injury; results were equally good.\textsuperscript{15} The technique used synthetic mesh placed tension-free. The transobturator tape may be passed from beneath the vaginal mucosa through the obturator foramen in an in-to-out fashion (TVT-O) or \textit{vice versa} in an out-to-in fashion (TOT). The relevant anatomy of the trocar passage includes the vaginal mucosa, superior surface of the perineal membrane, pubocervical fascia, and a 45° angle towards the medial edge of the obturator foramen (that is, the inferior pubic ramus in the dorsal lithotomy position); the path continues inferior to the origin of pubococcygeus and puborectalis, and below the arcus tendineus fasciae pelvis, levator ani, obturator internus, obturator membrane, obturator externus, superior end of adductor magnus, adductor brevis, upper edge of gracilis, fascia lata, subcutaneous fat and skin. Bleeding from accessory obturator vessels and bladder injury (rare) are potential hazards with trocar passages; surface markings help ensure the correct exit site with in-to-out obturator trocars (see \textit{‘Surgical surface anatomy’} above). If troublesome bleeding occurs from the trocar or guide insertion into the obturator membrane, direct bimanual compression is often helpful with pressure applied externally on to the obturator fossa and internally with the use of gauze transvaginally in the direction of the trocar passage. To avoid vaginal perforation, the surgeon's fingers placed in the vagina will guide the dissection with scissors, metal guide and subsequent trocar passage towards the obturator foramen, particularly in those patients with a high vaginal fornix.

The use of TVT, TOT and TVT-O can lead to mesh-specific complications in the minority, such as vaginal extrusion and urethral/bladder erosion, as well as dyspareunia, pelvic pain and, in the case of obturator tapes, groin pain. As a result, their use is currently highly controversial; it must be stated, however, that the majority have very good outcomes.\textsuperscript{6} Surgeons’ experience and knowledge of anatomy are paramount in preventing such complications.

\textbf{Male incontinence}
Male slings and artificial urinary sphincter insertion are used to treat bothersome post-prostatectomy incontinence in men. In such cases, stress incontinence is typically a result of radical prostatectomy, which causes intrinsic sphincter deficiency as a result of direct damage to supporting structures related to the external sphincter and to the sphincter or its neurovascular supply. Several sling designs are available commercially but in principle they all apply compression to, or reposition, the urethra utilizing mesh placed either above or below bulbospongiosus, with mesh arms typically tunnelled through the obturator foramen. For this type of surgery, the male urethra is approached through the perineum. In the dorsal lithotomy position, a 4–5 cm perineal incision is made in the midline. After the subcutaneous fat is gone through, bulbospongiosus is exposed and dissected in the midline to expose the corpus spongiosum and the bulbar urethra. One of the most commonly used slings works on the principle of relocating the urethra and providing a backboard for the urethral sphincter to coapt against (that is, replacing the structure and support that are lost through radical prostatectomy). Technically, this is not a compressive sling. When exposed, bulbospongiosus is released from the central tendon by which it is attached to the perineal body. This is a key part of the surgery because it allows the corpus spongiosum to become mobile and invaginate without obstructing the urethral lumen (Fig. 71.12). During trocar placement through the obturator foramen (out-to-in fashion), surface markings can be helpful (see ‘Surgical surface anatomy’ above). A finger in the wound displacing the urethra medially while the tip of the trocar is advanced into the surgical wound will help guide placement and avoid inadvertent injury to the urethra.
FIG. 71.12 The AdVance XP male sling (AdVance XP, Boston Scientific, USA). 

A. An anteroposterior view of the urethral bulb.

B. A lateral view of the bladder and urethra before tensioning of the sling.

C. A lateral view of the bladder and urethra with the sling tensioned. Note the invagination of the corpus spongiosum, allowing a backboard for the sphincter to coapt against and increasing the functional length of the urethral sphincter without causing obstruction to the urethral lumen. (From D. De Ridder, P. Rehder, The AdVance® male sling: anatomic features in relation to mode of action, Eur. Urol. Suppl. 10 (2011) 387. Copyright © 2011 European Association of...
The artificial urinary sphincter (AUS) is a three-piece mechanical device composed of a cuff, which is sized and placed around the urethra (typically, the bulbar urethra but it can be placed at the bladder neck), a balloon pressure reservoir and a pump (Fig. 71.13). Usually, the cuff is placed circumferentially around the bulbar urethra and a space is created preperitoneally or paravesically for the balloon reservoir through either a separate incision in the groin or a transverse incision over the lower rectus abdominis. The pump is placed in a subcutaneous or dartos pouch in the ipsilateral hemiscrotum through the same groin incision. The three components are then connected. The device is activated after a period of 6 weeks, resulting in normal saline from the reservoir filling the cuff. The pressure-regulating balloon maintains a pressure of around 61–70 cm H$_2$O, keeping the patient continent. When the bladder fills, the patient is able to empty his bladder by pressing the pump in the hemiscrotum, sending the fluid around and out of the cuff into the reservoir. After 2–3 minutes, the fluid relocates back into the cuff, maintaining continence. The urethra may be injured during dissection. When sizing the cuff around the urethra, the surgeon should always err on the side of caution, especially in a radiotherapy field. If in doubt and in between sizes, the larger cuff should be placed to avoid urethral erosion in the future.
**Tips and Anatomical Hazards**

When performing a pudendal nerve block, always aspirate before injecting an anaesthetic agent to avoid direct injection into the internal pudendal vessels as they run in the pudendal canal (Alcock’s canal). The surgeon’s finger should be placed into the rectum or the vagina to guard against inadvertently puncturing the bowel or vagina during needle insertion and to guide the needle to the ischial spine. The bifurcation of the common iliac vessels is often a reliable place for urologists to identify the ureter as it crosses the bifurcation to enter the pelvis. The ureter runs on the lateral wall of the pelvis and crosses the internal iliac artery before turning forwards and medially to enter the bladder.
During Burch colposuspension, suture placement is facilitated by the surgeon placing the middle finger of the non-dominant hand into the patient's vagina and elevating the anterolateral vaginal wall while the bladder neck is retracted to the other side with the use of a swab on a stick.

To prevent injury to the bladder and other pelvic contents during sling placement, ensure that the bladder is empty and use a catheter with an introducer inside it to deviate the bladder from the side of sling placement. Perform a cystoscopy after sling placement to assess for urethral and/or bladder injury.

During resections of the anal canal and anorectal junction for malignancy, the ischio-anal fossa provides an easy, relatively bloodless plane of dissection that encompasses all of the muscular structures of the anal canal and leads to the inferior surface of levator ani, through which the dissection is performed.

During trocar placement through the obturator foramen (out-to-in fashion), surface markings can be useful.

If troublesome bleeding occurs from the trocar or guide insertion into the obturator membrane, direct bimanual compression is often helpful, with pressure applied externally on to the obturator fossa and internally, and the use of gauze transvaginally in the direction of the trocar passage. To avoid vaginal perforation, the surgeon's fingers placed in the vagina will guide the dissection with scissors, metal guide and subsequent trocar passage towards the obturator foramen, particularly in those patients with a high vaginal fornix.

When sizing the cuff of an AUS around the urethra, always err on the side of caution, especially in a radiotherapy field. If in doubt and in between sizes, place the larger cuff to avoid future urethral erosion.

Care must be taken not to buttonhole the rectum when correcting a rectocele. In these cases, the rectovaginal fascial plane will be thinned and the rectum will be bulging into the vagina. Dissection should be completed cranial to the defect; there is a risk of small bowel injury if the patient has a concomitant enterocele.

In sacrospinous fixation, sutures should be placed through the sacrospinous ligament and not around it, in order to avoid injury to the pudendal neurovascular bundle (which lies just posterior to the ligament).

During sacrocolpopexy, the major pelvic vessels, right ureter and
autonomic nerves must be identified during anatomical dissection. When placing sutures through the uterosacral ligaments during a McCall culdoplasty, care must be taken to avoid injury to the ureters (which lie 1–2 cm lateral at the level of the cervix). During obturator fossa lymph node dissection, the obturator nerve must be identified and preserved. The risk of bleeding from the vaginal wall and pelvic side wall can be minimized with good exposure. Incorrect sling placement can lead to urethral, bladder, small bowel or vascular injury.
References


1. You are called to assist the gynaecological surgeons at the time of a total abdominal hysterectomy. They are concerned that the right ureter may be injured and have requested assistance in identifying and protecting the ureter. Which one of the following locations is the best place to identify the ureter?  
A. Lateral to the medial umbilical ligament  
B. At the bifurcation of the common iliac artery  
C. At the bifurcation of the abdominal aorta  
D. Traversing over the broad ligament in the female  

Answer: B. The ureteric course within the pelvis is a predictable one. In the region of the sacroiliac joints, the ureters cross the pelvic brim and enter the pelvic cavity. As they do so, they cross the bifurcation of the common iliac arteries. Within the pelvis, the ureters course down the lateral pelvic walls. At the level of the ischial spines, they turn medially, towards the bladder. The ureters are at risk of injury during urological, colorectal and gynaecological surgery; in females, the ureters are in close proximity to the ovaries and can be injured during ovarian artery ligation. During a hysterectomy, the uterine arteries run superior to the ureters, where they can be injured.

2. Which one of the following options describes the result of inadvertent damage to the obturator nerve during a radical cystectomy and extended pelvic lymph node dissection?  
A. Loss of adduction of the thigh muscles  
B. Loss of abduction of the thigh muscles  
C. Loss of internal (medial) rotation of the hip  
D. Loss of external (lateral) rotation of the hip
Answer: A. The obturator nerve is formed by the anterior divisions of the second, third and fourth lumbar nerves. It runs posterior to the iliac veins and laterally along the pelvic wall to the obturator foramen. It enters the thigh through the obturator canal and supplies the adductor compartment of the leg. The cutaneous branch of the obturator nerve supplies the skin of the medial thigh.

3. The first branch of the anterior division of the internal iliac artery is a useful anatomical landmark during open and robotic radical cystectomy, lateral to which is often an avascular plane to the pelvic floor. Which one of the following is the name of this branch?
   A. Superior vesical artery
   B. Inferior vesical artery
   C. Obliterated umbilical artery
   D. Middle rectal artery

   Answer: C. In the fetus, the umbilical artery is the first branch of the anterior trunk of the internal iliac artery and transports blood from the fetus to the placenta via the umbilical cord. After birth, the arteries obliterate from their distal ends until, by the end of the second or third postnatal month, involution has occurred at the level of the superior vesical arteries. The proximal parts of the obliterated vessels remain as the medial umbilical ligaments.

4. During an extended pelvic lymph node excision for a radical cystoprostatectomy, a patient complains of numbness to his upper scrotum and anterior thigh. Which one of the following nerves is most likely to have been injured?
   A. Obturator nerve
   B. Pudendal nerve
   C. Sciatic nerve
D. Genitofemoral nerve

**Answer: D.** The genitofemoral nerve marks the most lateral extent of dissection during a pelvic lymph node dissection. A branch of the lumbar plexus, it originates from L1–2 segments of the spinal cord and has two branches, genital and femoral. The genital branch supplies sensation to the upper anterior thigh and skin of the anterior scrotum in males and the mons pubis in females.

5. Correct placement of a tined lead electrode adjacent to the S3 nerve root during sacral nerve stimulation is confirmed by which one of the following motor responses?

A. Bellows contraction (anal wink) response in isolation
B. Hip flexion
C. Flexion of the great toe and bellows contraction (anal wink)
D. Plantar flexion of the foot

**Answer: C.** Correct placement is confirmed by stimulating the S3 nerve root and observing a bellows contraction of the pelvic floor (an ‘anal wink’) and flexion of the great toe. Plantar flexion of the entire foot with heel rotation suggests stimulation of the S2 nerve root, and bellows contraction in isolation suggests S4 nerve root stimulation.
Clinical Cases

1. A 63-year-old female presents with discomfort and a dragging sensation in her vagina and on occasion has noticed a bulge. She has had three children and a previous hysterectomy 20 years ago. On examination, she has evidence of multicompartment pelvic organ prolapse that appears to be predominantly related to the vault and anterior wall of the vagina.

A. Can you explain anatomically why this may have occurred?

The majority of women with pelvic organ prolapse have multicompartmental prolapse, as opposed to an isolated prolapse. As has happened in this case, anterior compartment and apical/vault prolapse often coexist. This has occurred as a consequence of the loss of integrity and support of the pelvic organs, which is most likely related to disruption of the pelvic floor as a result of pregnancy and childbirth, previous pelvic surgery (hysterectomy) and age. Pelvic organ prolapse is often multifactorial. In addition to the factors listed above, it can be linked to many others, including genetics, obesity, smoking, chronic cough, neurology, medication and hormonal status.

B. What levels of support in the pelvis are likely to have been affected, causing the prolapse in this case?

DeLancey described levels of support I–III. Level I support is provided by the paracolpium (uterosacral ligaments), which suspends the apex of the vagina from the lateral pelvic wall. Level II support attaches the vagina to the arcus tendineus fasciae pelvis and the fascia of levator ani by fascial condensations (pubocervical and endopelvic fascia). Level III support involves direct attachment of the vagina to adjacent structures, such as the urethra anteriorly and the perineal body posteriorly. In this case, the vault prolapse and cystocele are related to loss of levels I and II support, respectively.

C. The patient is unable to tolerate a ring vaginal pessary and subsequently opts to have a laparoscopic sacrocolpopexy. What important anatomical structures need to be visualized during the sacral dissection?

During sacrocolpopexy the surgeon must be able to recognize the bifurcation of the aorta, middle sacral vessels, the right ureter and the sigmoid colon.
2. A 57-year-old female presents to your clinic with bothersome mixed urinary incontinence. Stress urinary incontinence appears to concern her more than urgency incontinence, which is infrequent. She has had two children and is postmenopausal. She has already seen a physiotherapist and has spent the last 6 months doing pelvic floor muscle-strengthening exercises. She is very concerned because her symptoms are embarrassing and are now preventing her from socializing or taking long journeys out of the house. She needs four continence pads per day and has to carry a change of underwear wherever she goes.

A. What is the pathophysiology underlying stress incontinence?
Stress incontinence, defined as the involuntary loss of urine on exertion, coughing or sneezing in women, is multifactorial and related to urethral hypermobility and/or intrinsic sphincter deficiency. Urethral hypermobility is thought to arise as a result of loss of support for the proximal urethra and bladder neck by ligaments, fasciae and muscles. This is very common after pregnancy and childbirth. Usually, the bladder neck and proximal urethra are supported in a retropubic fashion, counteracting increases in intra-abdominal pressure. However, where there is urethral hypermobility, the bladder neck and proximal urethra may not remain intra-abdominal and so may be unresponsive to increased abdominal pressure; when this occurs, the urethral sphincteric mechanism may be overwhelmed. Direct damage to the external urethral sphincter or to its innervation/blood supply or supporting structures – for example, from pelvic surgery, childbirth or radiation injury – can lead to a reduction in sphincteric mass and function, and is termed intrinsic sphincter deficiency. Incontinence can often be a combination of both urethral hypermobility and intrinsic sphincter deficiency.

B. Following a thorough and informed decision-making process about stress incontinence surgery options, the patient opts to have a transobturator mid-urethral synthetic tape (TVT-O; in-to-out tape) procedure. What anatomical structures will the trocar device go through from the vagina to the perineal skin?
The relevant anatomy of the trocar passage includes the vaginal mucosa; the superior surface of the perineal membrane; the pubocervical fascia; and a 45° angle towards the medial edge of the obturator foramen (that is, the inferior pubic ramus in the dorsal lithotomy position). The path continues inferior to the origins of pubococcygeus and puborectalis, and below the
arcus tendineus fasciae pelvis, levator ani, obturator internus, obturator membrane, obturator externus, superior portion of adductor magnus, adductor brevis, upper edge of gracilis, fascia lata, subcutaneous fat and skin.
CHAPTER 72
Male reproductive system

Oliver Brunckhorst, Kamran Ahmed, Majed Shabbir

Core Procedures

- Scrotal exploration for torsion of the testis
- Inguinal orchidectomy
- Hydrocele repair (Jaboulay and Lord's repair)
- Circumcision
- Orchidopexy
- Vasectomy

The male reproductive system consists of several elements, focused on the effective formation and delivery of sperm. It has external components, such as the testes, involved in spermatogenesis and testosterone production, and the epididymis, where sperm is stored and matured. Deeper pelvic components include the prostate and seminal vesicles involved in the production of key elements of the seminal fluid. The spermatic cord, containing the vas (ductus) deferens, connects the pelvic and external components, acting as the conduit between the testis and the urethra. From here, the penis allows the delivery of sperm to its final destination. An understanding of the anatomy of the male reproductive system is vital to allow effective diagnosis and management of subfertility and other surgical issues that can affect this region.
Embryology
The development of the urogenital system is described in Chapter 75.
Clinical anatomy

External genitalia

Knowledge of the anatomy of the external genitalia is vital for conducting effective clinical examinations and for surgical procedures involving the male urinary tract and reproductive organs.

Penis

The penis consists of a root and a free body enveloped in skin that is thin, elastic and largely devoid of hair or glandular elements (Fig. 72.1). The root is attached to the inferior surface of the perineal membrane and consists of a central bulb and a laterally placed crus on either side, angled towards the ischiopubic ramus. The expanded terminal part of the penis is the glans, containing a rounded base, the corona, which separates it from the shaft. The glans is covered by the prepuce (foreskin), a loose fold of retractable skin attached to the ventral surface of the glans under the corona at the frenulum. The urethra opens at the apex of the glans: this is its narrowest point and is a common entry point for endo-urological procedures such as cystourethroscopey and ureteroscopy.
The penile shaft contains erectile columns. The crus continues forwards to become the paired corpora cavernosa and the bulb becomes the corpus spongiosum (Fig. 72.2). The corpora cavernosa lie side by side, separated by the spongiosum in the midline on the ventral surface of the penis. The corpus spongiosum contains the penile urethra throughout its entire length. It expands distally to form the glans penis, which sits over the tips of the corpora cavernosa over Buck's fascia. Appreciation of this anatomical plane led to the development of glansectomy rather than partial penectomy for penile cancers confined to the glans.
The deep dorsal vein lies in the dorsal groove between the two corpora cavernosa, flanked laterally by a pair of dorsal arteries. The branches of the dorsal nerves lie lateral to the arteries and fan out over the rest of the dorsal surface of the penis, extending laterally round to the ventral side. At its base, the penis is suspended by two ligaments (the fundiform and suspensory ligaments of the penis), which are continuous with Buck’s fascia of the penis and anchor it to the pubic symphysis. Rupture of the suspensory ligament can mimic a penile fracture but usually presents with more limited bruising and tenderness at the dorsal root of the penis, with a loss of stability of the penis in full erection and development of a ‘wandering’ penis.

The deep (Buck’s) fascia of the penis surrounds the three corpora. It is an extension of the deep perineal fascia, blending distally with the tunica and proximally becoming continuous with dartos and the deep perineal fascia, helping to fix the spongiosum and crura to the pelvic bones and perineal fascia. It is important to remember that Buck’s fascia lies immediately superficial to the dorsal neurovascular bundle, which directly overlies the tunica albuginea. The superficial dartos fascia, a continuation of Colles’ fascia of the perineum, lies more superficially. This layer contains all the superficial veins (including the superficial dorsal vein), arteries, nerves and lymphatics, and must be appreciated during penile surgery. Exposure of the entire penile shaft – for penile fracture repair, for example – is best achieved by degloving.
the penile shaft skin with the dartos fascia, by creating a plane under this fascia. It can be stripped back very readily over Buck's fascia, paying careful attention to the few communicating vessels running between the superficial and deep fascial layers. Mobilization of the penile skin with its dartos fascia ensures maintenance of the integrity and viability of the overlying skin and is also the basis for penile skin flaps used in some hypospadias repairs and other penile reconstructions. To achieve the best cosmetic and functional results, closure of any penile wound in two layers to re-establish a continuous dartos fascia as well as skin layer is advisable, especially in cases of revision surgery.

An understanding of the layers of the penis is also useful clinically in penile trauma. If Buck's fascia remains intact, urine or blood that is extravasated will be contained within the penile shaft (leading to the development of an ‘aubergine or eggplant penis’). However, disruption of Buck's fascia leads to extravasation into the superficial perineal pouch, causing a perineal haematoma in a butterfly distribution because the extent of spread is limited by an intact Colles’ fascia.¹ If Colles’ fascia is disrupted, urine and blood can spread into the abdominal wall and scrotum. When the penis is being operated on, closure of Buck's fascia, if opened, is good practice to assist with both haemostasis of the deeper structures and prevention of haematoma into the more superficial layers. While this should be readily achieved with elective operations, such as plication or plaque incision and graft operations for Peyronie's disease, it may not be possible in cases of penile trauma. Additional mobilization of Buck's fascia for a centimetre on either side of the incision will aid subsequent closure of this layer.

Within Buck’s fascia, the erectile columns are enveloped by a tough fibrous membrane, the tunica albuginea of the corpus (Fig. 72.3). This consists of an outer longitudinal layer and an inner circular layer enveloping the two corpora cavernosa.² Fibres extend from the circular layer to form a vertical septum separating the two cavernosa. Deposition of plaques of collagen and irregular fibrin can occur within the tunica albuginea, leading to the curvature seen in Peyronie's disease.³
Expansion of the sinusoidal spaces within the corpora during erection compresses subtunical and emissary veins against the tough tunica albuginea, which results in entrapment of blood in the corporal space and the rigidity of the erection. As the penis becomes erect, the tunica albuginea stretches and thins, increasing its susceptibility to injury/rupture in this state (penile fracture). The thinnest part of the tunica lies ventrally, beneath and adjacent to the corpus spongiosum, and is the area most vulnerable to rupture with a penile fracture. Direct closure and repair of the tunica can effectively restore its integrity to allow a return of normal erectile function. However, more extensive operations on the tunica, such as plaque incision and grafting operations in more significant cases of Peyronie's disease, can lead to erectile dysfunction as a result of impairment and disruption of the venous occlusive mechanism of the penis. The tunica albuginea surrounding the corpus spongiosum is considerably thinner and more elastic than that surrounding the cavernosa. This allows expansion of the urethra during
ejaculation and also means that the urethra and surrounding spongiosum are less prone to rupture during penile fracture. Urethral/spongiosal injury should always be suspected in cases where there is any frank haematuria/meatal bleeding after penile fracture, or when both corporal bodies have tunical disruption, because the tear often extends behind and through the corpus spongiosum.

**Vascular supply**

The arterial supply of the penis is derived from the internal pudendal artery, a branch of the internal iliac artery. The common penile artery supplies the deep structures of the penis via the bulbourethral artery, the dorsal artery of the penis and the deep cavernosal artery of the penis (Fig. 72.4). The bulbourethral artery enters the corpus spongiosum to supply the penile bulb, urethra and glans. The dorsal artery of the penis runs along the dorsal surface of the corporal bodies, as paired branches on either side of the dorsal penile vein. These vessels give off circumferential branches that supply the spongiosum and the urethra. The deep cavernosal arteries are paired and run along the centre of the corpora cavernosa towards the glans. The skin of the penis receives additional arterial supply via the external pudendal branches of the femoral arteries. It is important to be aware that the course, anastomoses and branching patterns of the penile arteries are highly variable. A single cavernosal artery may supply both corporal bodies or may be absent; an accessory pudendal artery may supplement or replace the branches of the common penile artery.\(^4\)
Some of the venous return from the corpora arises from deep veins accompanying the arteries, which go on to join the internal pudendal veins. Most of the venous blood is drained via the deep dorsal vein, which lies in the midline groove between the two corpora cavernosa (Fig. 72.5). It pierces the suspensory ligament, passing inferior to the pubic symphysis, and drains into the prostatic plexus. The superficial venous system on the dorsal and dorsolateral aspect of the penis drains the penile shaft and prepuce, forming a single superficial dorsal vein that drains into the great saphenous vein via the superficial external pudendal veins. The deep and superficial dorsal veins are the target of venous ligation surgery for erectile dysfunction due to ‘venous leak’; this surgery has very poor long-term outcomes, due to the highly developed collateral venous circulation of the penis.
Lymphatic drainage

The drainage of lymph from the penis follows a stepwise pattern to the inguinal and then pelvic regions. The penile skin lymphatics drain into the superficial inguinal lymph nodes. Lymphatics draining the glans pass to the deep inguinal and external iliac nodes, while lymph from erectile tissue and the penile urethra drains from the inguinal region to the internal iliac nodes. Knowledge of this more predictable and stepwise drainage allows the use of dynamic sentinel lymph node studies when assessing lymph node involvement and spread in cases of penile cancer.
Innervation

Paired dorsal nerves, branches of the pudendal nerve, provide a rich sensory innervation predominantly to the glans (Fig. 72.6). These nerves run with the dorsal vein and arteries, and give off ventral branches as they run along the shaft of the penis. Parasympathetic and sympathetic supply is through the cavernous nerves from the pelvic plexus, which enter the corpora cavernosa at the crus. Parasympathetic supply (S1–4) travels via the nervi erigentes in the pelvic splanchnic nerves to reach the pelvic plexus. Stimulation of these nerves causes vasodilation and leads to the development of an erection. Sympathetic supply (T11–L1) travels in the sympathetic trunk before reaching the pelvic plexus and is responsible for contraction of the seminal vesicles and prostate, and hence ejaculation, and also leads to detumescence. Bulbospongiosus and ischiocavernosus, two superficial perineal muscles that contract spasmodically during ejaculation, are supplied by the perineal nerve, which also arises from the pudendal nerve.
FIG. 72.6  The nerve supply to the penis. The corpus cavernosum of penis receives both a parasympathetic and a sympathetic innervation from the cavernous nerves. It is important to note that, in life, multiple cavernous nerves emanate from the prostatic plexus and intertwine with both dorsal sensory nerves. The afferent fibres from the glans pass via the dorsal nerves of the penis and via the pudendal nerve. (Adapted from R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray's Anatomy for Students, second ed., Elsevier, Churchill Livingstone. Copyright 2010.)

**Scrotum**

The scrotum is a sac of skin that contains the two testes. The skin is thin, pigmented and rich in sebaceous and sweat glands. A midline raphe extends from below the urethral meatus, down the ventral shaft of the penis and
scrotum to the anus. It represents the line of fusion of the genital tubercles and, being relatively avascular, is a common site of surgical incisions in scrotal surgery. Deep to the raphe, the scrotum is separated into two compartments by a septum composed of all the layers of the scrotal wall except the skin. The testes are suspended by the spermatic cords within these compartments.

Beneath the skin lie the dartos muscle and fascia, which are continuous with Colles’, Scarpa's and dartos fasciae of the penis (Fig. 72.7). Deeper still lie the external spermatic fascia, the cremasteric fascia and the internal spermatic fascia, which are continuous with the equivalent layers covering the spermatic cord and hence are derived from the aponeuroses of the external oblique and internal oblique and the transversalis fascia, respectively. The internal spermatic fascia is loosely attached to the parietal layer of the tunica vaginalis before reaching the visceral layer and subsequently the tunica albuginea of the testis. The parietal and visceral layers of the tunica vaginalis are derived from the peritoneum and become continuous with the posterolateral border of the testis at the point where it is fixed to the scrotal wall. The gubernaculum in the inferior pole of the testis also attaches the scrotal wall to the testis. A high insertion of the tunica vaginalis on to the spermatic cord allows a longer length of cord with the freedom to move and twist; when coupled with deficiencies in the gubernaculum, this anatomical variation can predispose to testicular torsion (a bell-clapper deformity).
**Vascular supply**

The rich arterial supply of the scrotum is derived from external pudendal branches of the femoral artery, scrotal branches of the internal pudendal artery and the cremasteric artery from the inferior epigastric. The anterior wall is supplied mainly by the external pudendal branches. The venous supply follows the arterial supply; there are extensive arteriovenous anastomoses. An important surgical consideration is that these vessels run along the rugae and do not cross the raphe, which means that a midline incision is mostly avascular.
Lymphatic drainage

Lymph vessels follow the blood supply of the scrotum and drain into the superficial inguinal lymph nodes. Importantly, the lymphatics do not cross the raphe but drain to ipsilateral nodes.

Innervation

The scrotum is densely innervated via the ilioinguinal nerve, the genital branch of the genitofemoral nerve, two posterior scrotal nerves from the perineal nerve (a branch of the pudendal nerve) and a branch of the posterior femoral cutaneous nerve. The anterior aspect of the scrotum is innervated by the ilioinguinal and genitofemoral nerves (L1), whereas the posterior aspect is innervated by the perineal and posterior femoral cutaneous nerves (S3). The nerve supply does not cross the raphe.

Testis

The left testis typically sits lower than the right. Each testis has a thick, fibrous white covering, the tunica albuginea, effectively acting as the testicular capsule (Fig. 72.8). The epididymis is attached to the posterolateral surface of the testis and the vas deferens arises from its lower pole, running up behind the testis. Anteriorly and laterally, the testis lies free in a thin, double-layered serous space created by the tunica vaginalis, a prolongation of the parietal peritoneum and the remnant of the fetal processus vaginalis. The two layers of the tunica vaginalis are continuous with each other, separated by a small space filled with a minimal volume of fluid. An increase in the amount of this fluid is known as a hydrocele. The visceral aspect of the tunica vaginalis also covers the anterolateral aspect of the epididymis; the small space in between the tunica and the testis is the sinus of the epididymis. A small, stalked cyst within the tunica, the appendix testis, usually lies at the upper pole of the testis and represents the remnants of the paramesonephric duct. It may undergo torsion, causing sudden testicular pain similar to that of torsion of the testis; occasionally, a ‘blue dot’ sign of the torted appendix is visible through the skin. Each testis, along with the epididymis and tunica, lies suspended in the scrotum by prolongations of the layers of the spermatic cord (internal spermatic fascia, cremasteric fascia, cremaster muscle and external spermatic fascia, from deep to superficial). The testes are also separated by the septum of the scrotum.
Each testis is divided into approximately 200–300 lobules by septa (see Fig. 72.8); each lobule contains 1–4 highly convoluted seminiferous tubules. Posteriorly, these open into a communicating plexus, the rete testis, lying in
the mediastinum testis. From here, 12–20 vasa efferentia (efferent ductules) form and pierce the tunica albuginea at the upper part of the testis to enter the head (caput) of the epididymis. These fuse to form one convoluted tube, making up the body and tail of the epididymis. Surgery at, or close to, this junction of rete testis carries an increased risk of testicular atrophy and obstruction.

**Vascular supply**

The testicular arteries arise from the abdominal aorta inferior to the origin of the renal artery, usually at L1 and occasionally at L2. As the right and left testicular arteries enter the pelvis, they lie anterior to the genitofemoral nerves, ureters and external iliac arteries. Both arteries then enter the deep internal inguinal ring and travel with the ipsilateral spermatic cord in the inguinal canal to the scrotum. In its course to the testis, the testicular artery gives off one or more internal spermatic arteries, an inferior testicular artery, and branches supplying the caput, corpus and cauda epididymis. At the level of the testis, branches of the testicular artery enter the tunica albuginea in the mediastinum testis and ramify in the tunica vasculosa before reaching their distribution. Ramification of the testicular arteries occurs primarily in the anterior, medial and lateral portions of the lower pole of the testis, and in the anterior segment of the upper pole. The testicular artery anastomoses with the artery to the vas (a branch of the superior vesical artery) and the cremasteric arteries (from the inferior epigastric artery), near the tail of the epididymis (Fig. 72.9). The testicular artery provides two-thirds of the testicular blood supply, with the remaining two arteries making up the remaining one-third. In cases of inadvertent testicular artery injury, the testis can still survive on this collateral circulation.
The venous drainage of the testis arises from the mediastinum testis, where several interconnecting veins pass superiorly around the testicular artery to form the pampiniform plexus (see Fig. 72.9). This vascular arrangement means that counterflowing arteries and veins are separated only by the thickness of their vascular walls, permitting the exchange of heat and small molecules, and facilitating the maintenance of lower testicular temperatures. Abnormal dilation of the pampiniform plexus due to incompetent venous valves is known as a varicocele, which can cause aching pains. The veins of the plexus join to become the testicular vein at the level of the internal inguinal ring, subsequently draining directly into the level of the inferior vena cava at L1 or L2 on the right side, and into the renal vein on the left side. There may additionally be some anastomoses of this system with the external pudendal, cremasteric and vasal veins, which may explain the recurrence of varicoceles after ablation procedures.

**Lymphatic drainage**
Lymphatic vessels follow the artery of the testis back to the para-aortic nodes, lying alongside the aorta at the origin of the testicular arteries, at the level of the renal vessels. There is free communication between the nodes, and subsequently with the intrathoracic para-aortic nodes and cervical nodes, as illustrated by the metastatic spread of testicular tumours to the para-aortic lymph nodes.

**Innervation**

The testis is innervated either by nerve fibres that arise from T10–11 via the renal and aortic plexuses and accompany the testicular vessels, or by fibres that arise from the pelvic plexus and accompany the vas deferens. Visceral afferent fibres travel with the sympathetic fibres, accounting for the referred pain of the testis lying in the lower abdomen.

**Epididymis and vas deferens**

The epididymis lies posterior to the testis and is divided anatomically into a head (caput), body and tail. It is invested by tunica vaginalis continuous with that investing the testis. The head lies superiorly and the tail points inferiorly. At its upper surface, the epididymis contains an appendix (hydatid of Morgagni), a remnant of the mesonephros that can also undergo torsion.

Between 8 and 12 efferent ductules from the superior pole of the testis drain into and form the caput epididymis. They coalesce into a single, highly convoluted tubule, 3–4 metres long, that forms the body of the epididymis (see Fig. 72.8). Distally, the cauda epididymis becomes continuous with the convoluted portion of the vas deferens. The tubule is surrounded by smooth muscle that pushes spermatozoa towards the tail. Obstruction of the tubule within the epididymis, causing infertility, can be treated by microsurgical epididymovasostomy, where a direct, usually end-to-side, anastomosis is created between an unobstructed vas and the distended epididymal tubule. The closer this anastomosis can be made to the tail of the epididymis, the greater the chance that repair will be successful. Cysts may arise in the epididymis and usually remain asymptomatic, but may become troublesome if they grow large. Any surgical procedure on the epididymis carries a risk of damaging the tubule and causing obstruction; non-essential surgery should be avoided in young men, especially if they have not completed their family.

The vas deferens arises from the tail of the epididymis, is roughly 45 cm in length and is responsible for the transport of sperm from the epididymis to
the urethra. In cross-section, it consists of an outer serosal sheath containing blood vessels and nerves; a thick, three-layered muscular wall of inner and outer longitudinal and middle circular smooth muscle; and an inner mucosal lining of pseudostratified columnar epithelium with non-motile cilia. The muscular layers effect the peristalsis required to propel sperm along the tract. When reconstructing an obstructed vas, a two-layer microsurgical approach has the advantage of using fine (9/0 or 10/0) mucosal sutures that minimize occlusion to the vasal lumen, coupled with serosal sutures (8/0) that strengthen the closure and detension the mucosal anastomosis.

The vas passes posterior and parallel to the vessels of the spermatic cord, through the superficial inguinal ring and inguinal canal, and emerging laterally to the inferior epigastric vessels. At the internal inguinal ring, it is important to consider that, laterally, the attachments of the intermediate stratum form the lateral spermatic fascia. This is of note during an orchidopexy, whereby these attachments can be removed to gain length to the cord. Additionally, at the internal ring, the vas separates from the vessels, passing below the peritoneum of the pelvic side wall, crossing the external iliac artery and vein, and the obturator nerve, artery and vein. It extends almost to the ischial tuberosity, turning medially and crossing the ureters to reach the posterior aspect of the prostate at its base. Here the vas dilates to form the ampullae, which lie parallel and medial to the seminal vesicles. The two then join to form the ejaculatory duct, opening into the prostatic urethra at the verumontanum.

**Vascular supply**

The testis and epididymis have a similar blood supply. The primary arterial supply arises from branches of the testicular artery with some anastomosis from the vasal and cremasteric artery. Venous drainage follows into the pampiniform plexus superiorly. The vas deferens is supplied by the artery to the vas (vasal artery), which usually arises from the superior vesical artery and occasionally from the inferior vesical artery. The venous drainage of the vas will travel into the pelvic venous plexus.

**Lymphatic drainage**

The epididymis will follow the same drainage as the testis back to the para-aortic lymph nodes, whereas the lymphatic vessels of the vas will drain towards the external and internal iliac lymph nodes.
**Innervation**

The epididymis receives postganglionic sympathetic innervation from the inferior mesenteric ganglion, from which the hypogastric nerve arises. This is primarily located in the distal regions of the epididymis. The smooth muscle of the vas deferens is innervated by an autonomic plexus, mostly postganglionic sympathetic fibres from the pelvic plexus.

**Seminal vesicles**

The seminal vesicles (glands) are two blind-ending, elongated sacs, which are responsible for the production of main bulk of seminal fluid (up to 65%). They are located at the posterior aspect of the base of the prostate, in between the bladder and rectum; the ureters are intimately related to them superiorly ([Fig. 72.10](#)). Each contains a coiled tube with several diverticula and an inferior pole, which joins the vas deferens to form the ejaculatory duct. This subsequently opens up at the verumontanum of the prostatic urethra.
Vascular supply
The arterial supply is derived from branches of the inferior vesical and middle rectal arteries. The venous drainage is mainly via the inferior vesical plexus.

Lymphatic drainage
The lymphatics follow the blood vessels, predominantly to the internal iliac nodes.

Innervation
The smooth muscle of the vesicles receives predominantly postganglionic sympathetic and some parasympathetic input from the hypogastric nerve, causing contraction and expulsion of stored secretions.
Scrotal exploration for torsion of the testis

A median raphe incision is most commonly used. Neurovascular structures do not cross the midline, allowing haemostatic access to the testis and exploration and fixation of the contralateral testis though the same incision. Dissection through the layers of the scrotum and testis (superficial to deep) includes the skin, dartos muscle and fascia, external spermatic fascia, cremaster muscle and fascia, internal spermatic fascia and the parietal tunica vaginalis. The testis is de-torted and examined for viability. If it is not viable, an orchidectomy is performed with ligation of the vas deferens and the vessels to the vas, separate to the rest of the spermatic cord, using transfixation sutures. If the testis is viable, an orchidopexy can be performed by suturing the tunica albuginea to the dartos layer at three separate points with a non-absorbable suture to allow complete stabilisation of the testis.

If torsion has occurred, the contralateral testis must then be explored though the same skin incision, and fixed in the same way to prevent future torsion.

Inguinal orchidectomy

Inguinal approach, with an oblique incision from over the external inguinal ring, running over the lie of the cord laterally towards the internal inguinal ring. This approach allows direct access to the spermatic cord for early clamping and avoids any theoretical scrotal skin contamination or seeding of the tumour (the scrotal skin has an inguinal lymphatic drainage, whereas the testis drains to the para-aortic nodes). The anatomical layers encountered during surgery are the skin, Scarpa's fascia, and the external oblique aponeurosis, which is opened from the external to the internal ring to open the inguinal canal. The spermatic cord is mobilised and clamped at the internal (deep) inguinal ring taking care to avoid the ilio-inguinal nerve. The testis is mobilised in the scrotum and delivered through the inguinal incision and the spermatic cord is divided over the clamp at the internal ring. The vas and the vessels to the vas are ligated separately to the rest of the spermatic cord using transfixation sutures at the internal ring, ensuring that the ilio-inguinal nerve is free and separate. The anterior wall of the inguinal canal (external oblique aponeurosis) is closed with a running strong absorbable suture (such as 0-vicryl). The surgeon should ensure that the ilio-inguinal
nerve does not get caught underneath during closure. Subcutaneous tissue and Scarpa's fascia are apposed with an absorbable 2/0 suture and the skin is closed with an absorbable continuous 3/0 monofilament suture.

**Hydrocele repair (Jaboulay and Lord's repair)**

A transverse scrotal or median raphe incision is performed. Dissection through the layers of scrotum includes the skin, dartos muscle and fascia, external spermatic fascia, cremaster muscle and fascia and the Internal spermatic fascia. In a Jaboulay repair (ideal for thicker walled hydrocele), the tunica vaginalis ‘sac’ is dissected free and delivered out of the scrotum with the testicle. The tunica vaginalis is incised and fluid is evacuated. An excessively thickened tunica vaginalis can be excised circumferentially to reduce bulkiness. The remaining cut edge of the tunica vaginalis should be oversewn with a locking continuous 4/0 absorbable suture to ensure haemostasis. The remnant of the divided and oversewn tunica vaginalis should be sutured to itself behind the cord, to ensure full exposure of the underlying testis, and avoid undue pressure on the cord (2/0 or 3/0 absorbable suture). In a Lord's repair (ideal for a thin walled hydrocele), the tunica vaginalis is incised and fluid evacuated and the tunica vaginalis is plicated by concertina over 3/0 absorbable sutures and secured to testiculo-epididymal laterally on both sides (usually 6 plication sutures required). The dartos is closed using a 2/0 absorbable suture and the skin is closed with a 3/0 absorbable suture.

**Circumcision**

A circumferential outer preputial incision is made along a line corresponding to the corona underneath: this is usually done with the prepuce in a resting position. A circumferential inner preputial incision is made along a line approximately 1cm below the coronal margin. The anatomical layers encountered are the skin and dartos fascia. Two layer closure involves reconstruction of the dartos fascia with 6-8 interrupted 4/0 absorbable suture and closure of the skin with an interrupted 5/0 absorbable suture with a frenular reconstruction as required.
A penile block before an incision is made can significantly reduce the pain associated with any surgery. Blockade of the neurovascular bundle at the dorsal root with a second injection at the ventral penoscrotal junction will ensure a complete 360° block.

A glans stitch can be useful to allow gentle stretch, stabilization and retraction of the penis during surgery (3/0 suture on a round-bodied needle).

It is important always to make sure of being below the dartos fascia (superficial Colles’ fascia) when degloving the penis. This ensures the integrity and viability of the overlying penile skin.

When closing a penile wound, aim to do so in two layers, reconstituting the dartos layer first to allow less tension on the skin, which can then be closed with a finer suture.

Careful dissection of Buck's fascia is important during Peyronie's surgery. Start the dissection on the ventral side para-urethrally. To ensure the correct plane under Buck's fascia, incise the layer through one of the crossing emissary veins. Dissecting beneath this vessel will ensure dissection in the correct plane. Using clips to hold the fascia up at 90° to the tunica albuginea, while asking your assistant to provide counter-traction on the corporal body, will allow easier sharp dissection of Buck's fascia using a number 15 blade.

Whenever plicating or closing a defect in the tunica albuginea of the corpus cavernosum, use a strong, interrupted, absorbable monofilament suture, as this has to withstand the forces of stretch during erections. Make sure that suture placement on either side of the tunical defect is even and just a few millimetres from the wound edge to avoid causing any secondary penile curvature or tilt from the closure.

Always aim to close Buck's fascia wherever possible. This can be aided by mobilizing both sides of it, where it has been opened, by about 1 cm, to allow an easier tension-free closure that will avoid tearing the fascia. A continuous locking (4/0 absorbable) suture is ideal, but suturing should be completed with the penis on full stretch to avoid contraction of the wound.
A penile tourniquet can be useful in difficult cases of penile trauma. By controlling blood flow from the opened tunica albuginea, it allows a better view of the anatomy during surgery. Use of a catheter can help identify the urethra during difficult penile surgery, especially after a fracture (with no concurrent urethral injury), where the swelling and haematoma in the superficial layers can make dissection difficult.

Compressive, but not occlusive, dressings have a key role in preventing postoperative oedema, haematoma and therefore infection. Early penile stretching after surgery is important for penile rehabilitation. Rather than erections being suppressed, they should be actively encouraged, although sexual activity should be avoided for 4–6 weeks, dependent on the nature of the penile surgery. Postoperative penile haematomas should be evacuated with a low threshold to prevent secondary penile shortening.

In revision penile surgery, the vital planes below the dartos fascia and Buck’s fascia can be more difficult to find, but are important to seek out and preserve to ensure the best outcomes. Avoid excessively tight, occlusive dressings, especially in diabetic patients. There is a higher risk of necrosis of the glans due to the compression of an already compromised circulation.

Always try to retract the foreskin or expose the glans before undertaking a circumcision to ensure that the anatomy of the glans is normal and to exclude undiagnosed hypospadias. Carefully mark skin during circumcision in the flaccid state to avoid excessive removal of skin. It is better to err on the side of removing too little rather than too much skin because it is easier to come back to revise a circumcision rather than have to reconstruct with grafts if too much skin is taken initially.

Avoid undertaking a redo circumcision in a patient with a buried penis without dealing with the fat pad at the same time; if this is not done, there will be further penile burying.

The skin at the penoscrotal junction is a ‘watershed area’, with a variable
but reduced blood supply, which means that there is an increased risk of wound dehiscence after surgery at this point.
Avoid monopolar diathermy on the penis.
Avoid undertaking cosmetic surgery in the penis for the wrong reasons!
Often a patient's vision of a desirable outcome is unobtainable and will only lead to more distress.

Tips and Anatomical Hazards

Scrotal Surgery

A midline scrotal approach gives good exposure to both hemiscrotums and has excellent cosmetic results.
Meticulous haemostasis is vital in scrotal surgery due to the large number of vessels encountered during dissection and the expansible nature of the scrotal sac, which can accommodate large haematomas before tamponade.
Always ensure that patients’ blood pressure is back to within 10% of their pre-anaesthetic baseline or that the systolic pressure is at least 90 mmHg before closing the scrotum, to be sure that the haemostasis you see is genuine.
A good occlusive/pressure dressing and scrotal support can significantly reduce the risk of haematoma formation. Ensure these are fully in place before patients wake and take their first cough, as at this moment their systolic blood pressure rises sharply and increases the risk of haematoma formation.
Avoid operating on the epididymis in young men because it can impair fertility.
Exploration of the scrotum in revision surgery can be extremely difficult because the dartos layer adheres like glue to the tunica albuginea. Keep in mind the possible impaired landmarks and anatomy, and always strive to identify and preserve the cord structures first to avoid inadvertent injury.
Be mindful of the ilioinguinal nerve during closure of a groin wound in order to avoid nerve injury or suture entrapment of the nerve, which can cause paraesthesia and pain.
Whenever microscopic surgery on the cord is being undertaken, a Doppler probe or papaverine can be used to help identify the arterial vessels.

Be wary of extensive venous ligation of varicoceles in patients after a previous vasectomy because there will be an increased risk of developing venous ischaemia of the testis.

Be cautious about undertaking scrotal surgery for chronic scrotal pain; selected procedures in the right setting may be beneficial but careful case selection is vital.
References

Single Best Answers

1. To which one of the following structures does the lymphatic drainage of the testis predominantly occur?
   A. External inguinal nodes
   B. Internal inguinal nodes
   C. External iliac nodes
   D. Para-aortic nodes

   **Answer:** D. Testicular lymphatic flow follows the general retroperitoneal scheme of vertical drainage, with lateral flow from right to left. Lymphatic vessels from the right testis drain primarily into the inter-aortocaval nodes and paracaval nodes, with some drainage into the left para-aortic nodes. Lymphatic vessels from the left testis drain into the left para-aortic and inter-aortocaval nodes.

2. Which one of the following structures anchors the testis to the scrotum?
   A. Spermatic cord
   B. Gubernaculum
   C. Tunica vaginalis
   D. Tunica albuginea

   **Answer:** B. The gubernaculum is formed as part of the development of the testis as a condensation of the mesenchymal cells that attaches the inferior pole of the testis to the scrotum. After descent of the testis, the gubernaculum continues to fix the inferior pole to the wall of the scrotum; its abnormal development predisposes to testicular torsion, such as that seen in bell-clapper deformity.

3. Via which one of the following structures does the venous
drainage of the penis predominantly occur?
A. Internal pudendal veins
B. Bulbourethral vein
C. Deep dorsal vein
D. Superficial dorsal vein

Answer: C. Venous drainage occurs via several sources, however the majority of it is through the deep dorsal vein which lies in the midline groove between the two corpora cavernosa, immediately deep to Buck's fascia. The deep dorsal vein subsequently passes through the suspensory ligament and inferior to the pubic symphysis before draining into the prostatic plexus.

4. Via which one of the following structures does the nerve supply responsible for penile erection arise?
A. Pudendal nerve
B. Nervi erigentes in the pelvic splanchnic nerves
C. Perineal nerve
D. Sympathetic trunk

Answer: B. The pudendal nerve is responsible for the sensory innervation of the penis, while the perineal nerve, a branch of the pudendal nerve, is responsible for contraction of bulbocavernosus and ischiocavernosus during ejaculation. The sympathetic system is responsible for ejaculation via the penis through the sympathetic trunk (T11–L1). The parasympathetic system is responsible for the initiation of an erection via the nervi erigentes in the pelvic splanchnic nerves (S1–4). This vital innervation can be remembered by the phrase ‘point (parasympathetic responsible for erection) and shoot (sympathetic responsible for ejaculation)’. 
5. Which one of the following structures is NOT involved in the sensory innervation of the scrotum?
   A. Ilioinguinal nerve
   B. Genital branch of the genitofemoral nerve
   C. Posterior scrotal nerves
   D. Anterior femoral cutaneous nerve

**Answer:** D. A branch of the posterior femoral cutaneous nerve is involved in sensory innervation, along with the posterior scrotal nerves. The ilioinguinal nerve and genital branch of the genitofemoral nerve (L1, 2) innervate the anterior scrotum. The posterior scrotal nerves innervate the posterior aspect of the scrotum (S3). An important clinical point is that neither lumbar nor sacral nerves cross the raphe at the midline.
Clinical Cases

1. A 32-year-old male presents to the emergency department after the acute onset of penile pain with an acutely swollen penis after acute trauma during sexual intercourse. On examination there is swelling and bruising limited to the penis with an aubergine (eggplant) deformity (swelling, discoloration and deviation); a diagnosis of penile fracture is made.

A. Describe the blood supply to the penis.

The arterial supply of the penis is derived from the internal pudendal artery. The common penile artery supplies the deep structures through the bulbourethral artery (corpus spongiosum and glans), deep cavernosal artery (corpora cavernosa) and the dorsal artery of the penis. Blood leaving the penis is drained by one of three venous systems: superficial, intermediate or deep. The superficial veins are contained within the dartos fascia on the dorsolateral surface of the penis. They receive blood from the penile shaft skin and prepuce, and coalesce at the base of the penis to form a single superficial dorsal vein that drains into the great saphenous vein via the superficial external pudendal veins. The intermediate drainage system contains the circumflex and deep dorsal veins, which lie within and beneath Buck’s fascia. Deep venous drainage occurs via the crural and cavernous (deep, cavernosal) veins, which receive blood from the proximal third of the penis. Crural veins arise in the midline, in the space between the crura, and join the cavernous veins at the hilum of the penis, ultimately draining into the internal pudendal vein.

B. Describe the layers involved in a penile fracture and the distribution of swelling that may be seen.

A penile fracture refers to a tear in the tunica albuginea, the outer sheath of the corpora cavernosa. Distribution of the swelling can highlight other layers that may be involved. The classic aubergine (eggplant) deformity, whereby swelling is limited to the penile shaft, suggests that the deep Buck’s fascia remains intact. If this is disrupted, the bruising will extend to the perineum, with a butterfly distribution because spread is limited by an intact Colles’ fascia. Disruption of Colles’ fascia results in spread of bruising into the abdominal wall and scrotum.

C. How would you repair this injury? Describe the anatomical approach.
If the point of fracture cannot be felt, it can be located using imaging. The most likely site is the ventral side of the penis, by the penoscrotal junction. An incision over the midline raphe at this point will allow good exposure. Dissection down to Buck's fascia can be difficult and a catheter is useful to identify and avoid the urethra (if there is no concurrent urethral injury). The focal haematoma at the point of tunical breach will provide a guide to the point of fracture. The urethra and contralateral corporal body should be inspected to ensure that there is no other injury. A tourniquet can help visualize the anatomy if there is excessive bleeding. The tunical defect is closed with a strong monofilament buried interrupted suture (such as 0-PDS). Buck's fascia is closed, if amenable, then the dartos fascia and skin are closed with appropriate absorbable sutures.

D. **What is the sensory innervation of the penis?**

The sensory innervation of the penis is mediated via the paired dorsal nerves, which arise from the pudendal nerve. These run as a pair on the dorsal aspect of the penis, deep to Buck's fascia and lateral to the paired dorsal arteries and the deep dorsal vein. The nerves give off ventral branches circumferentially as they travel towards the richly innervated glans and are the clinical target when introducing a penile ring block as an anaesthetic.

2. A 13-year-old boy complains of acute-onset left testicular pain while playing football. He states that he has had some previous episodes of pain that have resolved spontaneously. On examination, his left testis is high-lying and extremely tender; there is an absent cremasteric reflex. He is taken immediately for scrotal exploration.

A. **Describe the blood supply of the testis.**

The testicular arteries arise on both sides of the aorta near the level of the renal arteries. Each testicular artery travels in the spermatic cord to reach the posterior testis, where it gives off medial and lateral branches. On either side, the testicular artery anastomoses with the artery to the vas artery (from the superior vesical artery) and cremasteric arteries (from the inferior epigastric artery). The venous drainage is via the pampiniform plexus of veins that join to become the testicular vein, which subsequently joins the inferior vena cava on the right or the renal vein on the left.

B. **Describe the layers encountered during scrotal exploration surgery.**

In order from superficial to deep, the layers that a surgeon will go through are: skin, dartos muscle and fascia, external spermatic fascia, cremaster
C. **How would you perform an orchidectomy if the testis was non-viable?**

If the testis was non-viable, an orchidectomy should be performed, ligating the vas and the vessels to the vas independently of the other contents of the spermatic cord using transfixation sutures. The contralateral testis must then be explored, and additionally fixed (orchidopexy) by suturing the tunica albuginea to the dartos layer at three separate points with a non-absorbable suture to allow complete stabilization of the testis. During closure, the tunica vaginalis is not reconstructed to allow adhesion between the testis and surrounding dartos. The dartos and skin are closed using an appropriate absorbable suture.

D. **Describe the course of the vas deferens from the testis to the urethra.**

The vas deferens arises from the tail of the epididymis, passing posterior and parallel to the vessels in the spermatic cord. It traverses the inguinal canal and, at the internal ring, separates from the vessels to pass below the peritoneum of the pelvic side wall. Here it crosses the external iliac artery and vein, and the obturator nerve, artery and vein, and extends almost to the ischial tuberosity, where it turns medially. It crosses the ureters to reach the posterior aspect of the prostate at its base. Here it dilates to form the ampullae, which join the seminal vesicles to form the ejaculatory duct that opens on to the prostatic urethra.

3. A 34-year-old male presents with a slowly developing testicular swelling. On examination, the enlargement is smooth and tense but it is possible to get above it. It also transilluminates brilliantly when a torch is applied to it. On ultrasound, a hydrocele is diagnosed with no clear underlying cause.

A. **What is a hydrocele and what anatomical layer does it affect?**

A hydrocele is a build-up of fluid within the layers of the tunica vaginalis surrounding the testis. It can be differentiated from a hernia because the surgeon is able to get above the mass and the swelling has brilliant transillumination. Hydroceles can be caused by infection, tumours and inflammation; they may also be primary or congenital due to a patent processus vaginalis.

B. **What is a patent processus vaginalis?**

As the testis descends during development via the path of the
gubernaculum, it passes from the abdomen into the scrotum via the processus vaginalis, an outpouching of peritoneum. This normally closes during development, but may remain open in some individuals, predisposing them to indirect inguinal hernias and hydroceles, where the fluid tracks from the peritoneum into the scrotum.

C. How does a hydrocele differ from a varicocele?

A varicocele is caused by an abnormal dilation of the testicular venous plexus within the scrotum, usually causing a painless swelling or a dull ache. It may be primary in some individuals and is more common on the left, where the left testicular vein enters the left renal vein at a right angle, encountering a higher-pressured system than the inferior vena cava (which receives the right testicular vein). A varicocele may also be caused by venous outflow obstruction, such as that caused by a new renal cancer.

D. What are the types of hydrocele repair and how would you do them?

Describe the anatomical layers.

A midline scrotal or transverse scrotal approach involves dissection through the layers of the scrotum, including skin, dartos muscle and fascia, external spermatic fascia, cremaster muscle and fascia, and internal spermatic fascia. Either a Jaboulay repair (ideal for a thicker-walled hydrocele) or a Lord’s plication (ideal for a thin-walled hydrocele) may then be performed. In a Jaboulay repair, the tunica vaginalis ‘sac’ is dissected free; any excess thickened tunica vaginalis can be excised, and the remaining cut edge oversewn and sutured to itself behind the cord, to ensure full exposure of the underlying testis. In a Lord’s repair, the tunica vaginalis is plicated with absorbable sutures and secured to the testiculo-epididymal junction laterally on both sides (usually six plication sutures are required). The dartos and skin layers are then closed with absorbable sutures.
Prostate

Rick Catterwell, Benjamin J Challacombe

Core Procedures

- Transurethral resection of the prostate (TURP)
- Photo-selective vaporization of the prostate (PVP)
- Holmium laser enucleation of the prostate (HoLEP)
- Open simple prostatectomy
- Transrectal prostate biopsy
- Transperineal prostate biopsy
- Radical prostatectomy (open/laparoscopic/robotic-assisted)

The prostate is a walnut-sized accessory male sexual organ composed of a mixture of glandular and fibromuscular tissue, located inferior to the bladder and directly above the superior fascia of the urogenital diaphragm. It lies within the pelvic cavity, below the lower part of the symphysis pubis and anterior to the rectum, through which it may be palpated. The primary function of this small gland is the production, secretion and storage of alkaline prostatic fluid. The fibromuscular component of the gland plays a pivotal role in bladder neck closure and semen propulsion during ejaculation.¹

Pathology of the prostate is extremely common: benign enlargement and malignant involvement both increase in prevalence with age. Consideration of the anatomical structure and relations of the gland is essential in the management of both of these conditions. This chapter contains an overview of the anatomy of the prostate and its relevance in the contemporary surgical procedures utilized in the management of benign prostatic hyperplasia (BPH) and prostate cancer.²
Embryology

The fetal genital system remains undifferentiated until the seventh week of embryogenesis, at which time the sex-determining region on the Y chromosome (SRY) induces a male phenotype through hormonal influences. In particular, the potent androgen, dihydrotestosterone, stimulates development of the fetal prostate and external genitalia. Towards the end of the first trimester, an outgrowth of epithelial buds from the posterior urogenital sinus epithelium into the surrounding urogenital sinus mesenchyme marks the preliminary event in prostate morphogenesis. Prostatic glandular epithelium develops from cells with endodermal origins, while the stroma and smooth muscle elements develop from cells of mesenchymal origin. Under the influence of androgenic hormones, the prostatic buds continue to multiply and form specific arrangements of epithelial cell cords within the mesenchyme, resulting in the lobar divisions of the prostate.\textsuperscript{3} The differing origins of the glands of the inner and outer regions of the prostate may account for the variations in incidence of prostate cancer. Acinar glands of the peripheral zone arise from the buds from the pelvic part of the urogenital sinus, while glands of the central and transition zones form from buds of the urogenital sinus above the level of the mesonephric ducts. In the male, the merging of the urinary and reproductive systems occurs in the prostatic part of the urethra, with implications for several surgical procedures.
Clinical anatomy

The prostate is located entirely within the true pelvis, posterior to the inferior aspect of the pubic symphysis and anterior to the rectum (see Fig. 68.2B). It can be assessed via anterior palpation during rectal examination, where the degree of enlargement and changes associated with malignancy, such as firm nodularity, loss of the median sulcus and extension of cancer into the seminal vesicles, can be appreciated. Although digital rectal examination is a rather unsophisticated and imprecise estimation of these parameters, it continues to play a role in the contemporary evaluation of the prostate for both size and malignancy.

The prostate is a pale, pyramidal fibromuscular gland surrounding the proximal male urethra. Superiorly, the flat base of the prostate is directed upward and is applied to the inferior surface of the bladder. The majority of the superior surface is directly continuous with the bladder wall. The urethra penetrates it closer to its anterior than its posterior aspect and typically traverses the gland along the junction of its anterior with its middle third. The apex is directed downward and is in contact with the superior fascia of the urogenital diaphragm, which invests the prostate and the membranous portion of the urethra and is intimately related to the external urethral sphincter.

The non-enlarged prostate measures approximately 4 cm transversely at its base, 2 cm in its anteroposterior diameter and 3 cm in its vertical diameter. It weighs 10–20 g and is supported by the superior fascia of the urogenital diaphragm, the puboprostatic ligaments and the anterior portions of levator ani.

The urethra and the ejaculatory ducts perforate the prostate. The ducts pass obliquely downward and forward through the posterior part of the gland and open into the prostatic portion of the urethra on the lateral aspects of the verumontanum (seminal colliculus), a rounded eminence of the urethral ridge on the floor of the prostatic urethra (Fig. 73.1). The prostatic utricle, a small blind-ended pouch, opens into the midline of the seminal colliculus; numerous prostatic ducts drain into the prostatic sinuses that flank the colliculus. In clinical practice, the verumontanum is a crucial anatomical landmark because it indicates the proximal border of the striated external urinary sphincter during endoscopic procedures involving the prostate, and so marks the most distal limitation of intervention that will avoid surgical complications (Fig. 73.2).
**Fascial relationships**

The prostate is surrounded by periprostatic fascia. The true capsule is a thin layer of connective tissue. The pseudocapsule is superficial to the anterior, posterior and lateral surfaces of the true capsule and consists of two fascial layers. The cavernosal nerves course between these layers, predominantly over the posterolateral aspect of the gland.2

The posterior surface is flattened from side to side and is slightly convex from above downward. The two ejaculatory ducts enter the prostate at a medial depression near its upper border that serves to divide the posterior surface into a larger lower and a smaller upper portion. The latter constitutes the middle lobe of the prostate and intervenes between the ejaculatory ducts and the urethra; it varies considerably in size. The lower portion commonly features a shallow median depression or sulcus that imperfectly separates it into right and left lateral lobes, which constitute the main mass of the gland and are directly continuous with each other behind the urethra. Anterior to the urethra, the lateral lobes are connected by a band of fibromuscular stroma that is devoid of glandular substance. The rectoprostatic fascia, also known as Denonvilliers’ fascia, is a fibromuscular structure consisting of
several fused layers that separate the retroprostatic and prerectal spaces (Fig. 73.3). It inhibits the local invasion of prostate cancer posteriorly into the rectum and is a landmark during radical prostatectomy to gauge the proximity to the prostate for nerve sparing.

The anterior surface is narrow, measuring approximately 2.5 cm in craniocaudal length, and is convex from side to side. It lies 2 cm behind the inferior third of the pubic symphysis, from which it is separated by the extraperitoneal fat of the retropubic space (space of Retzius) which contains the periprostatic plexus of veins. The puboprostatic ligaments attach the anterior aspect of the apex of the gland to the pubis. The urethra emerges from the anterior surface a little above and in front of the apex.²

The concave lateral surfaces are covered by three layers of fascia, a plexus of periprostatic veins and the anterior portions of levator ani. The preservation of these anterior muscular fibres during surgical treatment of prostate cancer with radical prostatectomy is an important factor in the preservation of continence.⁴,⁵ Although the majority of cavernosal nerves lie within the fascial layers covering the posterolateral aspect of the gland, the

![Diagram of the rectoprostatic fascia (Denonvilliers' fascia) separating the retroprostatic and prerectal spaces.](image)
extent to which they wrap anteriorly within the fascial layers on the lateral surface varies. This means that the anterior or ‘high’ release of this fascia during radical prostatectomy may preserve a significantly increased proportion of nerves in some individuals and thus influence postsurgical potency.

Zonal anatomy

In most animals, including some primates, the various prostatic lobes remain distinguishable throughout life. In the adult human, the lobes are fused, cannot be defined by dissection and are indistinct histologically.

The contemporary nomenclature most commonly used to describe the structure of the human prostate was first described by McNeal, who divided the prostate into areas that are histologically distinct and anatomically separate. His description included the non-glandular fibromuscular stroma surrounding the organ and two glandular regions with histologically distinct ductal systems termed peripheral and central zones (Fig. 73.4). The peripheral zone surrounds most of the central zone and extends caudally to surround the distal portion of the urethra partially. The central zone is a wedge of glandular tissue surrounding the ejaculatory ducts, constituting most of the base of the prostate. McNeal also identified the transition zone, a smaller, glandular region that surrounds the prostatic urethra.
The peripheral zone ducts exit directly lateral from the posterolateral recesses of the urethral wall. The system consists of long, narrow ducts surrounded by a stroma of loose muscle bundles. This area is the principal site of carcinoma of the prostate and is not involved in BPH. Hence early prostate cancer usually causes no symptoms as it grows in the zone well away from the urethra.

The central zone ducts run predominantly proximally following the ejaculatory ducts. They are much larger and of irregular contour, and the muscular stroma is more compact than in the peripheral zone. The central zone has a low incidence of disease.\(^3\)

The transition zone surrounds the proximal segment of the urethra between the bladder and the verumontanum. The principal feature of this region is the internal urinary or preprostatic sphincter, a cylindrical sleeve of smooth muscle. Although it contributes only 5% of the volume in the normal prostate, the transition zone is the principal site of BPH (Fig. 73.5). Nodular expansion of this region results in compression of the urethra and varying degrees of bladder outlet obstruction. As a result, voiding urinary symptoms are usually due to BPH expansion of the transition zone rather than prostate cancer.
FIG. 73.5  A, The axial MRI appearance of a normal prostate. B, A prostate with significant benign prostatic hypertrophy. Note the gross enlargement of the transition zone (TZ indicated by dashed orange line) and compression of the peripheral zone (PZ indicated by blue dashed line).

**Vascular supply**

The arterial supply of the prostate is predominantly from the prostatic artery, a branch of the inferior vesical artery from the internal iliac artery, which enters the prostate from either side of the gland at the posterolateral aspect of the base. The prostatic artery divides into urethral and capsular groups of arteries. Additional arterial supply can be derived from the middle rectal and pudendal arteries.

The venous system forms the prostatic plexus (Santorini's plexus), which receives the deep dorsal vein of the penis and drains into the internal iliac vein. The communication between the internal iliac vein and the vertebral venous plexus is the proposed pathway for the propensity for axial skeletal metastases that are seen in prostate cancer.

**Lymphatic drainage**

Lymph from the prostate drains to the obturator and internal iliac lymph nodes. There is also communication to the external iliac, presacral and paraaortic lymph nodes. Lymphatic metastasis of prostate cancer commonly involves these sites.
Innervation

The prostate receives an abundant nerve supply from the inferior hypogastric (pelvic) plexus (see Fig. 68.7). The prostatic capsule is covered by numerous nerve fibres and ganglia posterolaterally, forming a crescentic periprostatic nerve plexus. The greatest density of nerves is found in the preprostatic sphincter; fewer fibres are found in the anterior fibromuscular stroma, and the peripheral zone is the least densely innervated. Parasympathetic fibres (S2–4; pelvic splanchnic nerves; erector nerves of Eckhard) pass along the prostate from base to apex within the prostatic fascial layers and terminate around the acinar cells; they stimulate prostatic secretion. Iatrogenic damage to the cavernosal nerves during radical prostatectomy is related to postsurgical erectile dysfunction. Sympathetic drive (T12–L2) produces contraction of the smooth muscle of the prostatic capsule and stroma. The pudendal nerve innervates the striated external sphincter.
**Transurethral resection of the prostate**

Benign prostatic enlargement (BPE) is a result of an imbalance between cellular division and apoptosis within the transition zone of the gland. The result is an increase in the number of cells in this region (hyperplasia, BPH) and not an increase in cell size (hypertrophy). Both stromal and epithelial components enlarge, with bladder outlet obstruction (BOO) resulting from a combination of static and dynamic factors. Static obstruction is secondary to the bulk enlargement of the prostate encroaching on the prostatic urethra whereas dynamic obstruction is related to prostate smooth muscle tension. Surgical interventions for BPH primarily treat the static cause of obstruction by removing mass from the enlarged transition zone.

Although the first transurethral resection of the prostate (TURP) was performed in the early twentieth century, it was several decades before endoscopic management replaced open surgery as the predominant technique. Subsequently, advances have resulted in two distinct techniques of endoscopic management of BPH: enucleating and non-enucleating.

Initial endoscopic management was via TURP utilizing monopolar diathermy and this remains the most common approach. This technique requires the use of a poorly conducting irrigation fluid – typically, glycine or water – to facilitate electrocautery being directed into the tissue and prevent dissipation into the fluid. During TURP, absorption of the irrigant is related to the duration of resection. Water and glycine are both hypotonic, which means that a prolonged resection with significant fluid absorption can result in a dilutional hyponatraemia, a potentially catastrophic complication. Resection with monopolar TURP is therefore limited to 1 hour, and consequently the technique is appropriate only for glands up to a certain size.

The use of bipolar electrocautery in TURP permits isotonic fluid irrigation and greatly reduces the risk of prolonged surgery. Despite this, technical challenges mean that the technique remains relatively contraindicated for massively enlarged prostates over 100 ml in size. Both monopolar and bipolar TURP are non-enucleating techniques involving the removal of transition zone tissue in multiple fragments, each fragment from an individual pass of an electrocautery loop (Fig. 73.6). Tissue can be sent for histological analysis (Video 73.1).
**FIG. 73.6** Transurethral resection of the prostate (TURP). An endoscopic view taken as the diathermy loop is resecting an adenoma.

**Tips and Anatomical Hazards**

Consideration of the anatomical relations of the prostate is essential. Loop resection must not extend beyond the transition zone, as defined by the bladder neck proximally and verumontanum distally, compressed peripheral zones and capsule posterolaterally, and fibromuscular stroma anteriorly.

Extension of resection beyond the prostatic utricle risks damage to the external urinary sphincter and subsequent incontinence.

At the proximal (cranial) limit of resection, the location of the ureteric orifices should be noted and their resection avoided, particularly with large middle lobes. Anatomical variation in the location of the ureteric orifices in relation to the bladder neck is common.

The urethra is located at the junction of the anterior and middle thirds of the prostate; minimal anterior resection is therefore required.

During resection, the transition zone and compressed peripheral zone have distinct appearances. Resection to the border between the adenoma and compressed peripheral zone facilitates haemostasis because the perforating arteries are perpendicular to this surface.

Prolonged monopolar TURP is associated with dilutional hyponatraemia.

The urethral group of arteries, derived from the prostatic artery, supply
the transition zone. In particular, Flocks' arteries approach the bladder neck at 1 and 11 o'clock, and Badenoch's arteries approach the neck at 5 and 7 o'clock, and are all potential sites of significant bleeding. These areas should be carefully assessed for adequate haemostasis.

Considered in the sagittal plane, the oblique orientation of the external urinary sphincter is such that it is more cranially located on the anterior aspect of the prostate. This should be considered during the distal anterior resection.

Perforation of the prostate capsule during resection can involve the periprostatic venous plexus and greatly increase absorption of the irrigating fluid.
Photo-selective vaporization of the prostate

PVP is a non-enucleating technique used in the surgical treatment of BPH. By coupling a neodymium:yttrium–aluminium–garnet (Nd:YAG) laser with a potassium–titanyl–phosphate (KTP) crystal, a laser with 532 nm wavelength is produced. This wavelength is within the visible green spectrum and hence this technique is also called a ‘GreenLight’ laser. The wavelength of a laser determines its properties when used on tissue. This particular wavelength vaporizes tissue and is highly absorbed by haemoglobin, which potentiates haemostasis.\textsuperscript{13,14}

Unlike TURP, where tissue is removed with passes of the electrocautery loop, in PVP the tissue is vaporized rather than resected/removed. The procedure is performed with saline irrigation to minimize the risk of absorption. Superior haemostasis can facilitate day surgery treatment.\textsuperscript{1,13}

The GreenLight laser can be transmitted through both water and air. This necessitates consideration of inadvertent injury to the patient (iatrogenic injury to the bladder) and to surgical staff (corneal/retinal injuries with laser fibre fracture).\textsuperscript{14}

### Tips and Anatomical Hazards

Vaporization at the bladder neck should be performed cautiously to avoid damage to the ureteric orifices. The GreenLight laser is not absorbed by water and so there is a risk of posterior bladder wall injury when vaporizing at the bladder neck (as a result of errant aiming of the laser beam). This is especially relevant with an enlarged intravesical median lobe. Careful attention to technique and reduction in the power settings of the laser are required.

The verumontanum is used as a marker distally to avoid damage to the external urinary sphincter.

The urethra is located at the junction of the anterior and middle thirds of the prostate and therefore anterior resection should be minimal.
Holmium laser enucleation of the prostate

Holmium laser enucleation of the prostate (HoLEP) is a transurethral surgical technique for the treatment of BPH. It is an enucleating technique and is most comparable to open surgical techniques (Millin's/Freyer's/simple prostatectomy). The holmium:YAG laser has a wavelength of 2140 nm and is ideal for cleanly ablating without charring or overheating adjacent tissue. In contrast to the KTP GreenLight laser, the holmium wavelength is highly absorbed by saline or water. With separation from fibre to tissue of 4 mm, less than 1% of energy reaches the tissue, greatly reducing the risk of unintended vaporization of distant tissue such as the posterior bladder wall or trigone. The risk of post-resection absorption syndrome is negligible because laser enucleation is undertaken with saline irrigation and avoids dissection into prostatic venous channels. There is no limit to the size of prostate that can be approached; HoLEP is therefore an excellent option for surgical management of prostates greater than 100 ml: it is regarded as the contemporary gold standard technique for massively enlarged prostates (Video 73.2).

The expanding transition zone adenoma in BPH results in a defined tissue plane between the adenoma and the peripheral zone (Fig. 73.7). This plane is utilized to enucleate the tissue, which is dissected free into the bladder and then removed piecemeal from the bladder with a morcellation device. A combination of laser incision and manipulation by the beak of the resectoscope facilitates dissection of the adenoma away from the peripheral zone. The bladder is distended with continuous irrigation during this process; attention to surgical technique is key to avoid iatrogenic bladder wall injury. Utilization of this anatomical plane has benefits with regard to haemostasis and superior adenoma clearance. The verumontanum is used as a clinical landmark for the location of the external urinary sphincter: dissection of the apical extent of the adenoma must consider the location of the verumontanum and external urinary sphincter and laser incisions in this region must be made in an anterograde direction to avoid iatrogenic injury.
**FIG. 73.7** An endoscopic view during holmium laser enucleation of the prostate (HoLEP). The adenoma (A) is being distracted by the scope, revealing the plane (dashed line B) between it and the compressed peripheral zone (C).
Open simple retropubic (millin's) prostatectomy

Open approaches were the mainstay of BPH intervention prior to the development of endoscopic techniques. The limitations of TURP in the management of massively enlarged prostates mean that these approaches continue to have a role in BPH management. Recent advances in technology and technique have seen open simple prostatectomy superseded in environments where the equipment and expertise are available for HoLEP or a robotic-assisted simple prostatectomy approach.

Open simple prostatectomy differs significantly from radical prostatectomy. The aim of treatment in simple prostatectomy is to alleviate bladder outlet obstruction from BPH, the peripheral zone of the prostate remains in situ and reconstruction only involves closure of the prostatic capsulotomy. In radical prostatectomy, the entire prostate is removed along with the seminal vesicles as the surgical treatment for prostate cancer. The reconstruction following radical prostatectomy involves making an anastomosis between the urethra and bladder. Open simple prostatectomy utilizes an extraperitoneal approach via a lower midline or Pfannenstiel incision. The retropubic space (space of Retzius) is then developed, exposing the anterior surface of the prostate. A transverse incision is made in the anterior prostate capsule between rows of haemostatic sutures. These sutures ligate the branches of the prostatic venous plexus and minimize bleeding during capsulotomy. The plane between the adenomatous transition zone and the peripheral zone is bluntly dissected, initially with scissors and then with the surgeon's finger. The adenoma is removed en bloc via the capsulotomy and haemostatic sutures are placed through the capsulotomy into the adenoma cavity. The 5 and 7 o'clock positions are likely to contain the prostatic arteries and should be addressed first.

Tips and Anatomical Hazards

Knowledge of the vascular anatomy of the prostate is essential because there is a significant risk of bleeding during surgery. Some surgeons advocate suture ligation at the posterolateral aspect of the base of the
prostate prior to capsulotomy, aiming to ligate the prostatic arteries. Sharp dissection of the apical extent of the adenoma is advised to reduce the risk of damage to the external urinary sphincter and subsequent incontinence.¹⁸
Transrectal/transperineal prostate biopsies

The clinical detection of prostate cancer involves a combination of digital rectal examination, serum PSA evaluation and MRI. Findings from one or a combination of these tests may indicate that a prostate biopsy is warranted to confirm and grade prostate cancer. Biopsies of the prostate are performed using transrectal ultrasound guidance with cores of prostate tissue taken through either the rectum or the perineal skin; a systematic template of biopsies is taken of the prostate (Fig. 73.8). The anterior region of the prostate (anterior horns of the peripheral zone and transition zone) and apical areas are poorly sampled by transrectal biopsies, which may produce false negative results or understaging. Focal abnormalities on MRI may indicate the need for additional targeted biopsies. To reduce discomfort, transrectal biopsies should be taken so that the biopsy needle passes through the wall of the rectum above the dentate line. Biopsies should focus on targeting the peripheral zone of the prostate, reflecting the prevalence of prostate cancer in this area. The incidence of post-biopsy sepsis is higher following transrectal biopsies.\textsuperscript{19} The location of the urethra in the midline at the junction between the anterior and middle thirds of the prostate should be considered to avoid iatrogenic injury.

\textbf{FIG. 73.8} A transperineal prostate biopsy. The needle is passed via the perineum under ultrasound guidance and directed biopsies are taken from the prostate.
Radical prostatectomy

Radical prostatectomy involves the surgical excision of the entire prostate and seminal vesicles as a potentially curative procedure for localized prostate cancer. Pelvic lymph node dissection is also performed in intermediate to high-risk patients. Over the past two decades, minimally invasive surgical techniques for radical prostatectomy have been increasingly adopted, in particular robotic-assisted radical prostatectomy. The attributes of the robotic surgical platform, such as stable magnified vision, improved instrument dexterity and advantages of pneumoperitoneum in limiting venous bleeding, are well suited to radical prostatectomy. Even so, the dorsal venous complex drains the deep dorsal vein of the penis into the prostatic venous plexus and can be a source of significant bleeding during open or robotic radical prostatectomy.

With the adoption of this new technology has come a new understanding of the anatomy of the prostate, especially its fascial coverings and the distribution of the cavernosal nerves that transverse its surface. Three-dimensional, magnified vision and precision instruments have facilitated increasingly detailed dissection of the fascial layers with the aim of preserving these nerves, which are critical for erectile function (Fig. 73.9, Videos 73.3 and 73.4). The bladder is released from the anterior abdominal wall via peritoneal incisions lateral to the medial umbilical ligaments (remnants of the obliterated umbilical arteries).
The parasympathetic cavernosal nerves transverse the prostate from base to apex. The distribution of these nerves has significant variation but is predominantly in the posterolateral aspect between the anterior extension of Denonvilliers’ fascia and the lateral prostatic fascia. Nerve sparing during robotic prostatectomy involves the identification and dissection of an intrafascial, interfascial or extrafascial plane (Fig. 73.10). The closer the chosen plane is to the prostate, the greater the number of nerves that are preserved, but this is also closer to the capsule of the prostate and potentially prostate cancer. Deciding which plane to dissect is dependent on preoperative imaging and biopsy findings. The surgeon considers the likelihood of extraprostatic cancer extension that could result in a positive margin with an aggressive nerve spare; the aspired level of nerve spare is commonly different on one side to the other. The degree of nerve spare attempted should be decided with consideration of imaging and biopsy results, along with patient and surgeon preference. All imaging should be contemporary and reviewed. A positive margin at the site of an aggressive nerve spare is a poor outcome.
FIG. 73.10 Levels of nerve spare: intrafascial within the thin layer of the true prostatic capsule (A); interfascial between the true capsule and the anterior extension of Denonvilliers’ fascia (B); extrafascial partial nerve spare (C). A wide excision sacrifices the lateral neurovascular bundle (D).

Preservation of the peri-urethral structures and maximization of urethral length may lead to improved early continence.\(^5\) Preservation of the fibres of levator ani sitting in close proximity to the lateral aspect of the prostate apex is important for continence. Post-biopsy inflammation can affect the retroprostatic and prerectal spaces, causing the rectum to adhere to the posterior prostate, with an increased risk of iatrogenic bowel injury. To reduce the incidence of such cases, adequate time between biopsy and definitive surgery should be allowed (at least 4–6 weeks).
References


Single Best Answers

1. Which one of the following best describes the transition zone of the prostate?
   A. It is the region of the prostate that is most commonly affected by prostate cancer
   B. It contributes 20% of the volume of a normal prostate gland
   C. It surrounds the proximal segment of the urethra between the bladder and the verumontanum
   D. It follows the course of the ejaculatory ducts

   **Answer: C.** The transition zone surrounds the proximal urethral segment between the bladder neck and verumontanum. The zone accounts for only 5% of the volume in the normal prostate and is the principal site of benign prostatic hypertrophy.

2. Which one of the following best describes venous drainage of the prostate?
   A. It occurs directly via the prostatic vein
   B. It involves communication with the vertebral plexus
   C. It receives tributaries from the testicular vein
   D. It has no role in the spread of prostate cancer

   **Answer: B.** The prostatic plexus receives the deep dorsal vein and drains into the internal iliac vein. The internal iliac vein communicates with the vertebral venous plexus and this pathway is the proposed origin of axial skeletal metastases seen in prostate cancer.

3. Which of the following is a reliable landmark to assess the location of the striated/external urinary sphincter during endoscopic surgery?
A. The caudal extent of the protruding prostatic lateral lobes
B. A point 4 cm proximal to the bulbar urethra
C. The lateral urethral sinus
D. The verumontanum (seminal colliculus)

**Answer: D.** The verumontanum, also known as the seminal colliculus, is a raised midline crest within the prostatic segment of the urethra. It is a remnant of the Müllerian ducts and so it must be located proximal to the striated/external sphincter. During endoscopic resection of the prostate for benign prostatic hypertrophy, the verumontanum is used a marker for the safe distal extent of resection.

4. Which one of the following statements about the parasympathetic cavernosal nerves innervating the prostate is true?
A. They course outside the lateral fascia of the prostate
B. They transverse the prostate from base to apex within the true capsule
C. They have a highly predictable distribution and location
D. They transverse the prostate from base to apex within the fascial layers covering the gland

**Answer: D.** The parasympathetic cavernosal nerves are invested in the fascial layers of the prostate, mainly on its posterolateral aspect. They are important in erectile function.

5. Which one of the following statements about the internal urinary sphincter is true?
A. It is routinely non-functional following transurethral resection of the prostate (TURP)
B. It is a striated muscle sphincter under voluntary control
Answer: **A.** The internal urinary sphincter is related to the transition zone and has an autonomic innervation. During micturition, parasympathetic stimulation induces relaxation and detrusor contraction. Sympathetic stimulation during male orgasm closes the sphincter, resulting in closure of the bladder neck and ensuring passage of the ejaculate distally. The bladder neck or internal urethral meatus is resected during transurethral resection, rendering the sphincter non-functional; retrograde ejaculation is therefore an expected side-effect of this operation.
Clinical Cases

1. You are performing a transurethral resection of the prostate.

A. What are the anatomical landmarks that define the limits of your resection?
   The bladder neck and verumontanum should be carefully defined. The bladder neck fibres are circular and care should be taken not to undermine the bladder neck.

B. What are the structures beyond these landmarks that must be avoided?
   The ureteric orifices on the trigone of the bladder and external urethral sphincter are the key structures to be avoided.

2. While performing a robotic prostatectomy, you plan an interfascial nerve spare on one side and an extrafascial non-nerve spare on the contralateral side.

A. Discuss the relevant fascial dissection.
   Once the posterior plane has been dissected and the seminal vesicles and vasa elevated, the nerve-sparing plane should be entered. On the extrafascial side, the fat anterior to the rectum should be seen posteriorly to ensure an adequate distance from the prostate. The prostatic pedicles should be divided with sufficient distance away from the prostate capsule to ensure cancer clearance. The nerve bundles are then clipped and excised several millimetres away from the capsule and mobilized to the apex. On the contralateral interfascial nerve-sparing side, the interfascial plane should be identified and mobilized either anterogradely or retrogradely and the bundle released. The pedicle is then clipped and divided close to the capsule to ensure maximal nerve preservation.

3. Holmium laser enucleation of the prostate requires the utilization of a particular anatomical plane.

A. Where is this plane?
   HoLEP requires identification and dissection in the plane between the adenoma/transition zone and the capsule/peripheral zone.

B. How is prostate tissue extracted?
The prostatic tissue is extracted using an endoscopic morcellator through a nephroscope.

C. What is the significant risk during this extraction?
The significant risk of this procedure is iatrogenic bladder injury, which can be mucosal only or up to full thickness with bladder perforation.

4. During a transurethral resection of the prostate there is significant bleeding following the passage of the diathermy loop, resulting in a ‘red-out’ of vision.

A. How would you manage this?
A loss of vision with a ‘red-out’ usually means that a cut arterial vessel is spurting towards the camera. It is important to ensure the irrigation is flowing well and to consider raising or squeezing the irrigation bags temporarily. In changing the position and angle of the scope, it is important to identify the source of the bleeding and to press on it with sustained pressure and coagulation diathermy.

B. What is the blood supply to the transition zone of the prostate?
The blood supply to the transition zone is from the urethral group of arteries, derived from the prostatic artery.

C. Where are these vessels located in relation to the prostatic urethra?
Flocks’ arteries approach the bladder neck at 1 and 11 o'clock and Badenoch’s arteries approach the neck at 5 and 7 o'clock; they are all potential sites of significant bleeding.
Female reproductive system

Tom Holland, Ahmad Sayasneh

Core procedures

Vulva

- Bartholin's cyst marsupialization
- Drainage of labial abscess
- Wide local excision
- Radical and simple vulvectomy

Vagina

- Anterior and posterior vaginal repair
- Vaginectomy

Uterine Cervix

- Large loop (needle) excision of the transformation zone (LLETZ/NETZ)
- Trachelectomy

Uterus

- Total/subtotal/radical hysterectomy
- Myomectomy

Uterine (Fallopian) Tubes
• Tubal ligation
• Salpingectomy

**Ovaries**

• Ovarian cystectomy
• Oophorectomy
• Salpingoophorectomy

In order to operate successfully in the pelvis at a high level it is essential to have a thorough knowledge of the three-dimensional organization of the pelvic viscera and their associated ligaments and neurovascular supply, and of the anatomy of the retroperitoneal side wall of the pelvis, regional potential spaces and relevant avascular planes.
Clinical anatomy of the vulva

The female external genitalia or vulva include the mons pubis, labia majora, labia minora, clitoris, vestibule, vestibular bulbs and the greater vestibular glands (Fig. 74.1). The appearance of these structures changes throughout the female reproductive cycle from infancy through puberty, pregnancy and the menopause.1

![Vulval anatomy. Key: a, labium minus; b, glans clitoris; c, fourchette; d, vaginal opening; e, prepuce of clitoris; f, mons pubis; g, opening of Skene's glands; h, frenulum; i, vestibule; j, carunculae hymenales (myrtiformes); k, urethral opening; l, labium majus; m, site of the opening duct of Bartholin's gland.](image)

The mons pubis is the rounded, hair-bearing area of skin and adipose tissue over the pubic symphysis and adjacent pubic bone. Before puberty, it is relatively flat and hairless; through adolescence and into adult life, it becomes prominent with coarse hair; and after menopause, it atrophies slightly. The labia majora are two folds of skin that extend from the mons pubis to the perineum, forming the lateral boundaries of the vulva. Each labium has an external surface covered with hairs and a smooth, pink internal surface that contains large sebaceous follicles. The labia minora are thin folds of skin, devoid of fat, that extend from the clitoris anteriorly to the fourchette posteriorly. The anterior parts of each lip meet above the clitoris to
form the clitoral hood or prepuce, and the lower parts pass below the clitoris
to form the frenulum of the clitoris. The space between the labia minora is
the vestibule; it contains the openings of the vagina, the external urethra, the
greater vestibular glands (Bartholin's glands) and the para-urethral glands
(Skene's glands). The urethra opens 2.5 cm below the clitoris at the urethral
meatus. The openings of Skene's glands are located on each side of the
urethral meatus.

**Surgical approaches and considerations**

The surgeon must recognize the anatomical landmarks of the vulva when
planning surgery. The main arterial blood supply comes from the internal
pudendal artery (a branch of the anterior division of the internal iliac artery)
and the external pudendal artery (a branch of the femoral artery). The
internal pudendal branches enter the vulva from the lateral posterior angles.
During radical total vulvectomy, these branches should be ligated at 5 and 7
o'clock, 3–4 cm lateral to the introitus, at the margins of the vulvectomy.

Adhesions between the labia minora are common in prepubertal girls; rarely, they may occur in postmenopausal women due to lack of oestrogen or
skin inflammation, and may predispose to urinary infections (Fig. 74.2). In
girls born with imperforate anus, the posterior vestibule is a common site for
a rectovaginal fistula opening. The hair-bearing skin of the outer aspects of
the labia majora and the mons pubis are common sites of folliculitis or
abscesses, whereas sebaceous cysts may occur in the non-hair-bearing skin of
the labia minora.
The bulbs of the vestibule are two masses of erectile tissue around the vaginal opening that are in contact with Bartholin's glands posteriorly and the clitoris anteriorly (Fig. 74.3). Bartholin's glands are normally located at 5 and 7 o'clock in the vestibule. A Bartholin's cyst is a common cause for gynaecological emergency admission and may require surgical intervention. During marsupialization of a Bartholin's cyst, a 2–3 cm semilunar or cross incision is made at the internal surface of the cyst. The bulb of the vestibule should be avoided when making the incision to minimize blood loss; after the incision is made, the cyst is kept open by suturing the cyst wall to the vulval skin.
The clitoris is an erectile mass that consists of a gland, body (two corpora cavernosa) and root, where the crus of the corpora cavernosa is attached to the ischiopubic ramus on each side. During radical vulvectomy, the dorsal clitoral blood supply should be ligated via the corpora cavernosa; the defect should be closed by primary closure after careful assessment of the surrounding tissue to confirm minimal tissue damage (Fig. 74.4).\textsuperscript{5,6}
FIG. 74.4  Primary closure of the vulva after radical total vulvectomy.
Clinical anatomy of the vagina

The vagina is a fibromuscular tube lined by non-keratinized stratified epithelium that extends from the vestibule to the uterus. It widens and is typically directed posteriorly as it ascends from the introitus. The upper end of the vagina surrounds the vaginal projection of the uterine cervix; the anular recess so created between the cervix and vagina is the fornix. Although the different parts of the fornix are given separate names – anterior, posterior, and right and left lateral – they are continuous. The posterior fornix is the largest part and lies below the recto-uterine pouch (pouch of Douglas) in the peritoneal cavity. The recto-uterine pouch is the lowest peritoneal pocket and is an important area to assess during gynaecological imaging because it is the first site to show fluid collection in pelvic disorders such as ectopic pregnancy, pelvic inflammatory disease and ruptured ovarian cysts.

The fibromuscular anterior wall of the vagina supports the base of the bladder in its middle and upper portions, and the urethra (which is embedded in it) inferiorly. The fibromuscular posterior wall of the vagina supports the rectum. The upper quarter of the posterior vagina is separated from the rectum by the peritoneum of the recto-uterine pouch, and by moderately dense fibromuscular tissue (Denonvilliers’ fascia) in its middle half. In its lower quarter, it is separated from the anal canal by the fibromuscular perineal body. The upper part of the vagina is supported laterally by levator ani, and the transverse cervical, pubocervical and uterosacral ligaments. Pubovaginalis provides a U-shaped muscular sling around the mid vagina. The lower vagina is surrounded by bulbospongiosus.5

The vagina opens externally via a sagittal introitus positioned below the urethral meatus. The hymen is a thin fold of mucous membrane situated just within the vaginal orifice. The internal surfaces of the fold are normally in contact with each other and the vaginal opening appears as a cleft between them. The hymen varies greatly in shape and dimensions. The hymenal ring normally ruptures after first sexual intercourse, but can rupture earlier during non-sexual physical activity. Small, round remnants of the ring, carunculae hymenales (carunculae myrtiformes) persist after it has been ruptured. The hymen may be imperforate, a condition that is usually detected in adolescence.

Surgical approaches and considerations
Cusco's speculum is a self-retaining speculum used to examine the anterior and posterior vaginal walls and the cervix; it has two valves that can be retained open using a screw (Fig. 74.5). Sims’ speculum is used to assess vaginal pelvic prolapse (Figs 74.6, 74.7). The fascial support of the vagina may change as a consequence of childbearing and age, and this may result in anterior vaginal prolapse (cystocele), posterior vaginal prolapse (rectocele) and/or posterior fornix prolapse (enterocele). Uterine prolapse into the vagina may occur when uterine fascial and ligamentous support is weakened. Anterior and posterior longitudinal midline vaginal incisions can provide access to plicate the vaginal fascia adjacent to the bladder and rectum to treat cystocele and rectocele, respectively. Blunt and sharp dissection of the vesicovaginal and rectovaginal spaces is usually bloodless and easy to perform when identifying the avascular tissue in these planes. Care should be taken to avoid iatrogenic injury to the bladder and/or rectum. Posterior colpotomy or entry to the vaginal posterior fornix via a transverse or cruciate cut between the uterosacral ligaments of the uterus may be performed vaginally or laparoscopically, and can facilitate surgical procedures such as hysterectomy or laparoscopic procedures to retrieve excised samples (ovarian cysts, fibroids or other solid benign tumours).
FIG. 74.5 Using a Cusco's speculum to examine the vagina. Key: a, cervical external os; b, ectocervix; c, lateral vaginal fornix; d, posterior vaginal fornix; e, anterior vaginal fornix; f, lateral vaginal wall.
FIG. 74.6  Using a Sims’ speculum to examine the posterior vaginal wall.

FIG. 74.7  Using a Sims’ speculum to examine the anterior vaginal wall.
Clinical anatomy of the uterus

The uterus is a thick-walled, muscular organ situated in the pelvis posterior to the bladder and uterovesical space, and anterior to the rectum and recto-uterine pouch. It is mobile, which means that its position varies with distension of the bladder and rectum. The uterus is divided structurally and functionally into two main regions: the pear-shaped muscular body (corpus uteri) forms the upper two-thirds, and the fibrous cervix (cervix uteri) forms the lower third.

The uterine tubes enter the uterus at the uterine cornua; the part of the tube that passes through the myometrium (uterine muscle) is its interstitial (intramural) portion. The dome-like fundus is superior to the entry points of the uterine tubes and is covered by peritoneum that separates it from coils of small intestine and, occasionally, distended sigmoid colon. The lateral margins of the body are convex; on each side, their peritoneum is reflected laterally to form the broad ligament, which extends as a flat sheet to the pelvic wall. The anterior surface of the uterine body is covered by peritoneum reflected on to the bladder at the uterovesical fold; this normally occurs at the level of the internal os, which is the most inferior part of the body of the uterus. The vesico-uterine pouch, between the bladder and uterus, is obliterated when the bladder is distended, but may be occupied by small intestine when the bladder is empty. The posterior surface of the uterus is convex transversely; its peritoneal covering continues down to the cervix and upper vagina, and is then reflected back to the rectum along the surface of the recto-uterine pouch. The sigmoid colon and, occasionally, the terminal ileum lie posterior to the uterus.

The cavity of the uterine body is flat in its anteroposterior plane and triangular in coronal section, being broad above where the two uterine tubes join the uterus, and narrow below at the internal os of the cervix (Figs 74.8, 74.9).
Uterine cervix

The adult, non-pregnant cervix is narrower and more cylindrical than the body of the uterus and is typically 2.5 cm long. The upper end communicates with the uterine body via the internal os, and the lower end opens into the vagina at the external os. In nulliparous females, the external os is usually a circular aperture, whereas it is a transverse slit after childbirth. Two
longitudinal ridges, one each on its anterior and posterior walls, give off small, oblique, palmate folds that ascend laterally like the branches of a tree (arbor vitae uteri); the folds on opposing walls interdigitate to close the canal. The external end of the cervix enters the upper end of the vagina, dividing the cervix into supravaginal and vaginal parts. The supravaginal part is separated anteriorly from the bladder by cellular connective tissue, the parametrium, which also passes to the sides of the cervix and laterally between the two layers of the broad ligaments. In the adult nulliparous state, the cervix usually tilts forwards relative to the axis of the vagina (anteversion), and the body of the uterus tilts forwards relative to the cervix (anteflexion).

Procedures involving the cervix are usually undertaken using a colposcope. At appropriate magnification, the transformation zone of the cervix can be better visualized. This is the central area at the level of the cervical os where the columnar epithelium of the cervical canal is replaced by metaplastic squamous epithelium, and is the area where cancerous and precancerous lesions usually begin.

**Peritoneal folds and ligaments of the pelvis**

The uterus is connected to a number of ‘ligaments’. Some are true ligaments, in that they have a fibrous composition and provide support to the uterus; some provide no support to the uterus; and others are simply folds of peritoneum.

The uterosacral, cardinal (transverse cervical, ligaments of Mackenrodt) and pubocervical ligaments are condensations of the visceral or endopelvic connective tissues that connect the pelvic viscera to the side wall of the pelvis; they radiate like the spokes of a wheel around the hub of the cervix, providing it with considerable support (Fig. 74.10). The uterosacral ligaments contain fibrous tissue and smooth muscle. They pass back from the cervix and uterine body on both sides of the rectum, and are attached to the anterior aspect of the sacrum. They can be palpated laterally on rectal examination and can be felt as thick bands of tissue passing downwards on both sides of the posterior fornix on vaginal examination. The cardinal ligaments extend from the sides of the cervix and lateral fornices of the vagina, and are attached extensively on the pelvic wall. The lower parts of the ureters and pelvic blood vessels traverse the transverse cervical ligaments. Fibres of the pubocervical ligament pass forwards from the anterior aspect of the cervix and upper vagina to diverge around the urethra, and are attached
to the posterior aspect of the pubic bones. In order to complete a total hysterectomy, all of these supports to the uterus must be cut (Fig. 74.11). However, in order to prevent vaginal vault prolapse, as many as possible of the ligamentous connections to the vagina should be retained.

*FIG. 74.10* The supporting ligaments of the pelvis, showing the transverse cervical ligaments. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)
The round ligament is a narrow fibromuscular band, 10–12 cm long, extending bilaterally from the lateral cornu of the uterus through the broad ligament to enter the deep inguinal ring lateral to the inferior epigastric artery (Video 74.1). Near the uterus, the round ligament contains a considerable amount of smooth muscle but this gradually diminishes and the terminal portion is purely fibrous. The round ligament also contains striated muscle, blood vessels, nerves and lymphatics that drain the uterine region around the entry of the uterine tube to the superficial inguinal lymph nodes.

The broad ligaments extend bilaterally from the uterus to the lateral pelvic walls. The upper border is free and the lower border is continuous with the peritoneum over the bladder, rectum and side wall of the pelvis. The borders are continuous with each other at the free edge via the uterine fundus, and diverge below near the superior surfaces of levatores ani. A uterine tube lies in the upper free border on either side. The broad ligament is divided into an upper mesosalpinx, a posterior mesovarium and an inferior mesometrium.

The parietal peritoneum is reflected over the upper genital tract to produce
anterior (uterovesical), posterior (rectovaginal) and lateral peritoneal folds. The uterovesical fold consists of peritoneum reflected on to the bladder from the uterus at the junction of the cervix and the body. The rectovaginal fold extends lower than the anterior fold and consists of peritoneum reflected from the posterior vaginal fornix on to the anterior surface of the rectum, creating the deep recto-uterine pouch. The recto-uterine pouch is bounded anteriorly by the uterus, supravaginal cervix and posterior vaginal fornix; posteriorly by the rectum; and laterally by the uterosacral ligaments. The connective tissue lateral to the uterus and the cervix, the parametrium, continues down along the vagina as the paracolpium.

Vascular supply, lymphatic drainage and innervation

The uterine artery arises from the anterior division of the internal iliac artery, runs superiorly to the ureter (‘water under the bridge’) and bifurcates at the level of the internal os to supply the body of the uterus and the upper vagina and cervix (Fig. 74.12). The superior branch often anastomoses with the ovarian artery. The veins follow the course of the arteries (Fig. 74.13).

FIG. 74.12  The normal arterial supply to the uterus and ovary. (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban & Fischer. Copyright 2013.)
Uterine lymphatics from the body of the uterus and cervix pass laterally in the parametrium to three main groups of lymph nodes: the external and internal iliac and the obturator nodes. Lymph vessels from the fundus of the uterus and the uterine tubes may pass to para-aortic nodes. Some drainage from the uterine tube may drain along the round ligament to the superficial inguinal nodes.

The nerve supply to the uterus is predominantly from the inferior hypogastric plexus. Efferent preganglionic sympathetic fibres arise from T12/L1, and preganglionic parasympathetic fibres arise from S2–4 (Fig. 74.14).
Surgical approaches and considerations

At hysterectomy, it is important to recognize the two important high-risk sites of potential ureteric injury. The first occurs at the time of infundibulopelvic ligament ligation, where the ovarian blood supply is parallel and superior to the ureter (Fig. 74.15). The second is at the level of
the entry of the uterine artery into the uterine side wall, before it gives off ascending and descending branches; at this level the uterine artery forms a vascular bridge above the ureteric tunnel (Figs 74.16, 74.17).

**FIG. 74.15** Left side. The relationship of the infundibulopelvic ligament (a) and the ureter (b). Note that a window has been created to separate the two structures and to perform a safe ligation of the infundibulopelvic ligament.
FIG. 74.16 Ascending branches of the uterine arteries (arrows) just before ligation. The bladder has been reflected caudally to allow safe clamping of the vessels.
FIG. 74.17 The broad ligament and blood supply to the ovaries, uterus and relations of the ureter. (With permission from R.L. Drake, A.W. Vogl, A. Mitchell, R. Tibbitts, P. Richardson (eds), Gray's Atlas of Anatomy, Elsevier, Churchill Livingstone. Copyright 2008.)
Clinical anatomy of the ovaries

In the adult, non-pregnant state, the ovaries are small, dull-white organs that lie on each side of the uterus close to the lateral pelvic wall. Their size and appearance change with the stages of the menstrual cycle and with the stages of female maturation: they are smaller before puberty and after the menopause. Each ovary is attached to the lateral angle of the uterus by the ovarian ligament and to the back of the broad ligament by the mesovarium, a short, double fold of peritoneum. The infundibulopelvic ligament, attached to the upper part of the lateral surface of the ovary, contains the ovarian vessels and nerves.

Vascular supply, lymphatic drainage and innervation

The ovarian arteries are branches of the abdominal aorta and originate below the renal arteries. Each descends behind the peritoneum and, at the brim of the pelvis, crosses the external iliac artery and vein, genitofemoral nerve and the ureter to enter the true pelvic cavity. Here, the artery turns medially in the ovarian suspensory ligament and splits into a branch to the mesovarium that supplies the ovary, and a branch that continues into the uterine broad ligament, below the uterine tube, and supplies the tube (see Figs 74.12, 74.17). On each side, a branch passes lateral to the uterus to unite with the uterine artery. Other branches accompany the round ligaments through the inguinal canal to the skin of the labium majus and the inguinal region.

The ovarian veins emerge from the ovary as a plexus (pampiniform plexus) in the mesovarium and suspensory ligament. Two veins emerge from the plexus and ascend with the ovarian artery; they usually merge into a single vessel before entering either the inferior vena cava on the right side or the renal vein on the left side.

The main lymphatic drainage of the ovaries is to para-aortic nodes, but drainage may also occur via pelvic nodes into lower para-aortic nodes and, rarely, may follow the round ligament to the inguinal nodes.

Ovarian innervation is derived from autonomic plexuses. The upper part of the ovarian plexus is formed from branches of the renal and aortic plexuses, and the lower part is reinforced from the superior and inferior hypogastric plexuses.
Surgical approaches and considerations

In ovarian cancer, sufficient access via a midline incision is usually required to deliver the mass intact and to facilitate cancer staging (Fig. 74.18); spillage of the ovarian contents would potentially upstage the tumour. The right ovarian vein is a landmark that facilitates para-aortic lymphadenectomy because it can be used to identify the lymphadenectomy borders (Fig. 74.19).

FIG. 74.18  A large borderline ovarian tumour.
Ureterolysis, rather than simple identification of the ureter by eye, is usually required when the ovarian fossa is obliterated as a result of adhesions, cancer or endometriosis. This can be achieved by opening the retroperitoneum at the posterior leaflet of the broad ligament lateral to the ovarian pedicle and posterior to the round ligament, or alternatively by opening the peritoneum just under the infundibulopelvic ligament and after it has passed over the bifurcation of the iliac vessels.
Avascular planes of dissection in the female pelvis

The para-rectal, rectovaginal and para-vesical planes are important avascular planes of dissection in the female pelvis.

The para-rectal space lies lateral to the rectum, medial to the pelvic side wall and inferior to the cardinal ligaments.\(^{10}\) The uterosacral ligaments run through the space as they pass round the rectum towards the sacrum. This space can be accessed by opening the peritoneum medial and inferior to the uterosacral ligament and is useful to access the rectovaginal space, especially in surgery for severe endometriosis, where the rectum is often adherent to the posterior aspect of the uterus. The rectovaginal space lies between the rectum and vaginal fascia caudal to the torus uterinus (a small transverse thickening on the posterior cervix marking the origin of the uterosacral ligaments). The para-vesical space is bordered laterally by the fascia over obturator internus, anteriorly by the broad ligament, and medially by the bladder. It opens into the space of Retzius (Ch. 70) and is separated from the para-rectal space by the uterine arteries and cardinal ligaments.

**Tips and Anatomical Hazards**

Vulval anatomy can become significantly distorted by many pathologies such as trauma (Fig. 74.20) or malignancy (Fig. 74.21).
FIG. 74.20  A right labial haematoma after vulval blunt trauma. A skin marker was used to mark the upper border of the haematoma.

FIG. 74.21  Vulval cancer necrosis and fistulation (rectovaginal).

To minimize the risk of recto-anal injury when planning posterior vulval surgery, it is important to note the distance between the posterior vulva and the anus (normally 2.5–3 cm across the gynaecological perineum).

The valves of a Cusco's speculum can mask the vaginal walls and prevent visualization of pathology. New versions of the speculum are made of translucent plastic, which means that the vaginal walls behind the valves of the speculum can be examined for epithelial changes such as
vaginal intraepithelial neoplasia (VAIN) or small tumours. Acetic acid 3–5% and Lugol's iodine solution can be used to visualize abnormal areas of VAIN during colposcopy.

The blood supply of the uterus increases in benign tumours such as leiomyomas (fibroids) and malignancies such as sarcomas. In these conditions, special attention should be paid to the uterine blood supply. During hysterectomy, sufficient reflection of the bladder should be performed before ligating the uterine arteries. Bladder reflection can be achieved by identifying the avascular vesico-uterine plane and bladder pillars (Fig. 74.22).

When performing salpingectomy (removal of the uterine tube: for example, in the treatment of tubal ectopic pregnancy), it is important to note the proximity of the distal uterine tube to the ovarian vessels. Compromise of the ovarian blood supply may cause loss of ovarian function (Video 74.2).

During cervical dilation before endometrial sampling, careful assessment of the cervical canal should be performed. Cervical stenosis can happen after surgical intervention such as large loop
excision of the transformation zone (LLETZ), or in postmenopausal women. Cervical dilation in these patients is a common reason for uterine perforation. In these cases, the authors recommend cervical dilation under direct vision (using a hysteroscope) (Fig. 74.23) or under ultrasound guidance.

![Fig. 74.23 The cervical canal at hysteroscopy.](image)

In ovarian cystectomy, it is important to minimize the use of diathermy to preserve residual ovarian function in premenopausal women. The key is to identify the ovarian cyst wall and carefully separate the cyst wall from the surrounding ovarian tissue. Traction, counter-traction and dissection are necessary for this process. It is important to identify the uterine ovarian ligament and to remember the vascular anastomosis through this pedicle. Occasional late postoperative haemorrhage from the uterine ovarian ligament may occur after salpingoophorectomy.
References

Further Reading

Single best answers

1. Which one of the following procedures does the sample shown in Fig. 74.24 best represent?

   ![FIG. 74.24 Single Best Answer Question 1.](image)

   A. A subtotal hysterectomy with bilateral salpingoophorectomy  
   B. A radical hysterectomy with bilateral salpingoophorectomy  
   C. A total hysterectomy with bilateral salpingoophorectomy  
   D. A total hysterectomy with bilateral salpingectomy  
   E. A total hysterectomy with bilateral oophorectomy

   **Answer:** B. Fig. 74.24 shows a uterus, cervix, uterine tubes and both ovaries with associated parametrium and vaginal cuff.

2. In the vulval image shown in Fig. 74.25, A is the labium majus and B is the labium minus. Which one of the following is structure C?
A. A vaginal wall prolapse; it is not possible to decide which part of the wall has prolapsed until a Sims’ speculum examination is performed
B. Enterocele
C. Rectocele
D. Fourchette

**Answer:** A. This is a large cystocele, however, a Sim’s speculum examination is necessary to confirm this (Fig. 74.26).
3. **Fig. 74.27** illustrates the uterine cervix after which one of the following surgical procedures?
A. Vaginal trachelectomy
B. Vaginal hysterectomy
C. Cervical polypectomy
D. Cervical dilation
E. Large loop excision of the transformation zone of the cervix (LLETZ)

Answer: E. LLETZ is used to excise high-grade lesions (cervical intra-epithelial neoplasia (CIN) 2, CIN3 and early invasive cancers) of the cervix. The principle is based on the thermal cutting effect generated by a diathermy loop to excise the transformation zone of the cervix that contains the lesion.

4. **Fig. 74.28** is a view obtained during total abdominal hysterectomy: ‘a’ is the left infundibulopelvic ligament. Which one of the following options is structure ‘b’?
A. Left ovarian vein
B. Meckel's diverticulum
C. Left ureter
D. Round ligament of the uterus
E. Internal iliac artery

**Answer:** C. Left ureter.

5. **Fig. 74.29** is a hysteroscopic view of the uterine cavity. If this is the correct orientation and (b) is the ostium of the left uterine tube, which one of the following is the correct location of the endometrial polyp (a)?
A. Anterior uterine wall
B. Posterior uterine wall
C. Right uterine wall
D. Left uterine wall
E. Fundus

Answer: A. Anterior uterine wall.
Clinical Cases

1. A 24-year-old female comes to the Accident and Emergency department with right ovarian torsion.

   A. Describe the affected ovarian vasculature and the effects of the ovarian tissue.
   When an ovary twists on its pedicle, the infundibulopelvic ligament and associated blood supply and the ovarian ligament and associated blood supply will rotate around one another. The tube and the mesosalpinx, which is in close relation to the ovary, will often be taken into the rotation. Initially, the venous system (which is at a lower pressure) will be partially occluded, causing ovarian oedema and enlargement. With increased tension on the torted pedicle, capillary blood pressure is increased, leading to capillary rupture and haemorrhage into the tissues. Eventually, complete occlusion of the venous system results in ischaemia and ultimately necrosis.

   B. The patient is referred for a transvaginal ultrasound scan. How do you expect this to help in diagnosis?
   Although diagnosis is based on history and clinical examination, imaging is helpful to confirm but not exclude the diagnosis. Transvaginal ultrasound may show signs of ovarian torsion, which can include ovarian enlargement; stromal oedema; peripherally spaced follicles; increased ratio of stroma to follicular volume; unusual location of the ovary (anterior to the uterus); presence of an ovarian cyst; free fluid in the pouch of Douglas; decreased vascularity on colour Doppler in comparison with the contralateral ovary (although vascularity may be equal); and the ‘whirlpool’ sign (twisted vascular pedicle on its longitudinal access, which looks like a whirlpool). When the clinical picture is suggestive of torsion, such as lateralizing, sudden-onset pain with vomiting only, a completely normal ovary in terms of both morphology and size is reassuring. All other features as described above should increase the suspicion of torsion and be acted on to reduce the swelling, preserve ovarian function and reduce pain.

2. A 52-year-old female is having a total abdominal hysterectomy and bilateral salpingoophorectomy.

   A. Which pedicles, including their anatomical structures, are normally cut and ligated, and in which order?
First, the round ligaments. Second, the infundibulopelvic ligaments. Third, the anterior leaf of both broad ligaments: the incision is connected across the front of the uterus by lifting and cutting the peritoneum of the uterovesical fold, enabling reflection of the bladder off the anterior uterus and vagina. Fourth, the posterior leaf of the broad ligament is dissected to identify the uterine arteries close to the uterus where they can be ligated, taking care to identify and avoid the ureters, which will be close to the uterine arteries at this point. Fifth, the cardinal ligaments towards the side of the cervix. Sixth, the uterosacral ligaments are cut and ligated close to the uterine cervix; they can be taken at the same time as the vaginal circumferential incision is made.

B. What are the possible danger areas during this operation?
Special caution is required to avoid injuring the ureter at the inferior lateral border of the infundibulopelvic ligament and at the inferior border of the uterine artery when it enters the side wall of the uterus at the level of the uterocervical isthmus. The rectosigmoid is at risk of injury at the time of incision of the uterosacral ligaments and opening of the vaginal wall, especially if there is rectovaginal tethering as a result of previous endometriosis or pelvic inflammatory disease. The bladder is at risk at the time of opening the vesico-uterine peritoneum and reflecting the bladder, and again at the time of opening the anterior vagina if insufficiently reflected.
Development and congenital anomalies of the urogenital system

Arash K Taghizadeh, Clare Skerritt

Core procedures

- Orchidopexy
- Hypospadias repair
- Procedures relating to the kidney e.g. nephrectomy, pyeloplasty
- Resection of posterior urethral valves
Embryology

The urogenital system develops from intermediate mesenchyme extending longitudinally in the trunk, subjacent to the somites, and through reciprocal interactions with the coelomic epithelium lining the intraembryonic coelom. Pronephric and mesonephric kidneys are seen early in development, with the definitive metanephric kidney arising later. Reproductive ducts, mesonephric and paramesonephric, are present early and will become male or female duct systems, depending on the genetic sex of the embryo.

Kidney

The pronephros is a transitory structure at the level of the developing heart. A primary excretory duct can be seen in stage 11 embryos (29–30 days post fertilization). The mesonephros extends from somite 8–20 and forms nephrons that connect to the excretory duct (now termed mesonephric duct) sequentially in a rostrocaudal manner. The organ produces amniotic fluid by stage 17 (39–41 days post fertilization). The cranial end of the mesonephros atrophies; in the male, the nephrons in the mid portion become the efferent ductules of the testis (see later).

The mesonephric duct connects with the urogenital sinus, an endodermal diverticulum derived from the allantois that is confluent with the enteric hindgut at the cloaca. The permanent kidneys develop from an outgrowth of the lowest part of the mesonephric duct, the ureteric bud (stage 16, 37–38 days post fertilization). This interacts with surrounding metanephric mesenchyme, which forms metanephric nephrons; angiogenic mesenchyme migrates into the developing metanephros later to form the glomeruli and vasa recta, adjacent to the loops of Henle. Metanephric nephrons start forming from stage 21 (50–52 days post fertilization) and contribute to amniotic fluid production from week nine. The metanephric kidneys are initially sacral but with differential growth of the embryo they ascend cephalically to the level of the second lumbar vertebra, gaining sequential arterial blood supplies during their ascent; the definitive renal artery is recognizable by the beginning of the third month.

Bladder

The primitive hindgut, the cloaca, is formed by an enteric portion and the
allantois, a blind-ending diverticulum that projects into the connective stalk between the umbilical blood vessels. The cloaca will form the anorectal canal, urethra and bladder, and the vagina in females\(^2,3\); perturbations of its development may give rise to complex cloacal malformations.\(^4,5\)

The urinary and enteric portions of the cloaca become separated by the growth of the urorectal septum, endodermal epithelium and underlying mesenchyme (Fig. 75.1). This creates the anorectum dorsally and the urogenital sinus ventrally. The superior extension of the urogenital sinus, the allantois, narrows, forming the urachus, which ultimately becomes the median umbilical ligament. The ureters extend from the ureteric bud and open separately into the dorsal wall of the urogenital sinus, lateral to the openings of the paramesonephric and mesonephric ducts. These orifices become further separated as the bladder enlarges, so that the ureters open laterally into the superior part of the trigone, whereas (in the male) the mesonephric ducts move caudally to open into the future prostatic urethra (Fig. 75.2). The internal, endodermal, epithelium of the bladder differentiates into transitional epithelium. The outer lamina propria, muscularis and adventitia derive from the surrounding splanchnopleuric mesenchyme. In the neonate, the superior half of the bladder is above the pubic symphysis and does not gain its adult position until 6 years.
FIG. 75.1 The division of the hindgut into urinary and enteric parts: left ventrolateral view of the intraembryonic coelom and corresponding midsagittal sections. A, The early cloaca. B, Proliferation of the urorectal septum. C, Complete separation of the urethra and anal canal, and position of the perineal body. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 72.4.)
Reproductive ducts

The mesonephric (Wolffian) duct develops as the excretory duct of each mesonephros. The mesonephric nephrons become the efferent ductules of the testis, and the mesonephric duct forms the epididymis, vas (ductus) deferens, seminal vesicles and ejaculatory ducts (Fig. 75.3). Paramesonephric (Müllerian) ducts, first seen from 35 days post fertilization, invaginate from the coelomic epithelium into the dorsal wall of the peritoneal cavity bilaterally and extend caudally, lateral to each mesonephric duct. At the
caudal end of the mesonephros each duct turns medially, crossing ventral to the mesonephric duct, then continues growing caudally in close contact, and ultimately fusing, with the contralateral duct. The paramesonephric ducts become the uterine tubes, the body of the uterus and uterine cervix (see Fig. 75.3). The two ducts enter the dorsal wall of the urogenital sinus, producing an elevation, the Müllerian or sinus tubercle, which induces vaginal development. Failure of fusion of the two paramesonephric ducts can result in a range of uterovaginal anomalies, including uterus didelphys and double vagina.

Gonadal tissue develops on the surface of each mesonephros, within a genital ridge of proliferating coelomic epithelium interacting with the underlying mesonephric mesenchyme. Primordial germ cells migrate from an early extraembryonic site close to the cloaca and enter the genital ridge from stage 15 (35–36 days post fertilization). They become incorporated into

**FIG. 75.3**  A, The indifferent or ambisexual stage of development. B, Male. The mesonephric ducts are retained (left) and the paramesonephric ducts involute (right). C, Female. The paramesonephric (Müllerian) ducts are retained (right) and the mesonephric ducts involute (left). (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 72.13.)
the proliferating coelomic epithelium, close to the mesonephric nephrons.

**Male**

Possession of a Y chromosome and its sex-determining region (*SRY*) gene initiates a male reproductive programme. The coelomic epithelial cells become Sertoli cells, which surround the primordial germ cells. Sertoli cells secrete anti-Müllerian hormone (AMH), also known as Müllerian inhibiting substance (MIS), which promotes mesonephric duct growth and paramesonephric duct apoptosis. Mesonephric mesenchymal cells become the cells of Leydig, which secrete testosterone.

The testes move relatively lower in the body as the remaining mesonephros involutes. A condensation of mesenchyme from the lower end of the gonad, the gubernaculum, connects the testis to the anterior abdominal wall at the site of the future inguinal canal. The gubernaculum enlarges and a crescentic column of peritoneum, the processus vaginalis, extends into it (*Fig. 75.4*). The testis is in apposition with the deep inguinal ring during the fourth to sixth months. Testis descent into the scrotum occurs relatively rapidly during the seventh month, the left testis descending ahead of the right. The layers of processus vaginalis involute proximally, remaining around the vas deferens and the testis as the tunica vaginalis. Layers of the anterior abdominal wall form the layers of the spermatic cord as the testis passes along the inguinal canal and into the scrotum.
The descent of the testis. The testis is retroperitoneal throughout development. It becomes obliquely orientated during abdominal descent. A, The gubernaculum attached to the lower part of the testis has an abdominal part covered with developing peritoneum, an interstitial part and a distal end embedded in the anterior abdominal wall at the site of the future inguinal canal. B, The gubernaculum swells, becoming similar in width to the testis. The distalmost portion of the gubernaculum bulges into abdominal wall muscles and grows 3–5 cm over the superior pubic ramus and into the scrotum. A crescentic column of peritoneum, the processus vaginalis, develops in the expanding gubernaculum. C, The testis gains a crescentic covering of visceral and parietal peritoneum (which forms the tunica vaginalis) and muscle and connective tissue layers as it passes through the deep and superficial inguinal rings. The coverings remain around the vas (ductus) deferens, whereas the proximal processus vaginalis normally becomes obliterated by 3 weeks after birth. (Based on H. Tuchmann-Duplessis, P. Haegel P, Illustrated Human Embryology, Vol. 2 Organogenesis, London, Chapman and Hall, 1972. With kind permission of Springer Science+Business Media. From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 72.17.)

Female

Absence of a Y chromosome initiates a female development pathway. The coelomic epithelial cells cluster around each primordial germ cell and become granulosa (follicular) cells, which form primordial ovarian follicles. The mesonephric mesenchyme becomes the connective tissue cells of the ovarian stroma. The mesonephric duct involutes but vestiges may remain: cranially, as the epoophoron between the uterine tube and ovary; as the
paroophoron in the broad ligament; and as Gartner's duct in the lateral wall of the vagina.

The ovaries descend from their original position (the ovarian artery arises from the aorta below the renal arteries) into the pelvis as the embryo/fetus grows. The gubernaculum ovarii develops as fibrous bands from the lower pole of the ovary, ending close to the external inguinal ring. On each side, the gubernaculum becomes the ovarian ligament cranially and the round ligament caudally. A saccus vaginalis may be present and extend into the inguinal canal (canal of Nuck): this is normally obliterated but may remain patent and provide a sac for potential indirect inguinal hernia.

**External genital development**

External genitalia are initially similar in both sexes and early external determination of sex is difficult. A midline genital tubercle appears at the cranial end of the urogenital membrane with two lateral ridges, the genital (urethral) folds. Elongation of these protuberances produces a primitive phallus. Lateral folds (scrotal or labial) develop later ([Fig. 75.5](#)). When the urogenital membrane breaks down, the internal, endodermal, portion of the urogenital sinus is open to the amniotic cavity.
In females, the genital folds remain separated as labia minora. In rare disorders of sex development, fetuses that are XY but lack testosterone receptors become phenotypically female. In males, the genital folds fuse with each other to form the bulb of the urethra and the greater part of the spongiosum urethra. The penile urethra is completed by an ingrowth of ectodermal epithelium from the distal tip (glans) of the penis. In males, failure of fusion of the genital folds, or of the canalization of the ectodermal and endodermal parts of the urethra, results in hypospadias.

An ectodermal fold, containing mesenchyme, grows over the glans of the penis, forming the prepuce. Abnormal urethral development impairs formation of a ventral prepuce. The preputial sac may not be complete until 6–12 months or more after birth; thus at birth it is usually not possible to retract the foreskin. This is because the opening to the prepuce is too narrow and inelastic, and also because the inner prepuce is adherent to the glans. Over time, the preputial opening becomes wider and more elastic, and the preputial adhesions separate. Although many boys will be able to retract their foreskin by the time they reach school, it is very common for the process not to be complete until a boy reaches puberty.
Surgical surface anatomy

In general, the surface anatomy of the urogenital system in infants is similar to that of adults. The most important difference is that the abdominal cavity is proportionately wider than it is long in infants. Superiorly, the abdominal cavity does not extend deeply under the ribs, and inferiorly, the pelvic cavity is not as deep. In practice, this results in the lower pole of the kidneys extending under the lower margin of the ribs, and the bladder tending to rise above the level of the pubic symphysis when full. It is therefore possible to palpate an infant's kidney if there is significant enlargement, e.g. pelvicalyceal dilation. This difference between infant and adult anatomy has practical consequences when surgery is being performed. For a laparotomy there is better access to the abdominal cavity through a transverse rather than a longitudinal midline incision. In addition, access to the kidneys and bladder is easier because they are not tucked in too deeply above the ribs or in the deep pelvic cavity, respectively. As a child approaches school age, the proportions of the abdominal cavity become more similar to those of the adult cavity: by the age of 7 years, the kidneys lie under the ribs and the cavity of the pelvis is much deeper.

The anatomy of the inguinal canal follows the pattern in adults: the inguinal ligament runs from the anterior superior iliac spine to the pubic tubercle, and the external ring of the inguinal canal is located just above and lateral to the pubic tubercle. In young infants, however, the inguinal canal is much shorter and it is possible to perform a hernia repair without opening the external oblique aponeurosis to enter the inguinal canal until 1 year of age.7

The prepuce is significantly different in boys compared to adults (see earlier).
Clinical anatomy of congenital anomalies of the urogenital system

An exhaustive description of all possible congenital anomalies of the urogenital system is beyond the scope of this book. Instead, there will be an account of the more common conditions and those conditions where interpretation of the final anomaly requires a firm understanding of the normal developmental anatomy.

Duplex kidneys

A duplex kidney has two separate pelvicalyceal systems. Complete duplication happens when there are double ureters draining separately into the bladder. The incidence of partial duplex kidneys in postmortem series is approximately 1%, bilateral in approximately 20%. The incidence of complete duplex kidneys is lower, at 1 in 1000. Duplex kidneys arise from premature branching of the ureteric bud; if more than one bud develops from the mesonephric duct, two separate ureters will form, resulting in a complete duplex. The more cranial ureteric bud connects to the upper pole of the kidney, but as the ureteric bud and metanephric ducts incorporate into the bladder, the upper-pole ureteric bud rotates and migrates to a more caudal position than the lower-pole ureteric bud. This results in the upper-pole ureter having an opening that is more caudal than the lower-pole ureter: the Weigert–Meyer Law.

Duplex kidneys can sometimes give rise to problems. Pelviureteric junction obstruction can occasionally affect the lower pole, but otherwise the pathology relates to how the ureter enters the lower urinary tract.

The insertion of the upper-pole ureter can be normal, ectopic or related to a ureterocele.

Ectopic ureters are rare. In girls, an ectopic ureter would insert into derivatives of the urogenital sinus, which include the urethra and vagina. Insertion of the ureter below the sphincter in a girl will result in continuous urinary incontinence. In a boy, the urogenital sinus does not extend below the sphincter and so incontinence is not a problem, but the ureter may insert into mesonephric duct derivatives, e.g. the vas, resulting in epididymitis. The more abnormal the origin of the ureteric bud from the mesonephric duct, the more abnormal its insertion into the metanephros, resulting in impeded
reciprocal induction and dysplastic kidney.\textsuperscript{15}

A ureterocele is a cystic dilation of the distal ureter as it inserts into the lower urinary tract. It may impair drainage of the ureter that it drains and even affect the bladder outlet. Ureteroceles are sometimes present in duplex kidneys.\textsuperscript{14,16}

The insertion of the lower-pole ureter can be normal or associated with reflux. The more cranial insertion of the lower-pole ureter into the bladder results in a more perpendicular and less oblique intramural tunnel that is more susceptible to reflux. The proportion of children with duplex kidneys with reflux ranges from 36\% to 76\%.\textsuperscript{14,16}

**Horseshoe kidney and crossed fused renal ectopia**

Horseshoe kidney occurs in 1 in 400 births with a 2 : 1 male predominance.\textsuperscript{17} They arise as a result of fusion of the kidneys during their ascent from the pelvis to their normal positions. The developing kidneys probably fuse when they come into close proximity, possibly as they pass through an arterial fork (aortic bifurcation or umbilical arteries) or as a result of flexion or rotation of the fetus.

The anatomy and relations of a horseshoe kidney reflect its embryology, its ascent and the site at which the kidneys meet. The isthmus, which is the point at which the kidneys meet, is almost always composed of functioning renal tissue. The isthmus of a horseshoe kidney is almost always at the lower pole. Generally, the isthmus lies anterior to the great vessels and the ureters pass anterior to the isthmus, but this is not always the case. Horseshoe kidneys usually have a more inferior position. Sometimes, the isthmus lies immediately below the inferior mesenteric artery at L3, giving rise to the suggestion that the kidney is held back by this artery. Horseshoe kidneys sometimes lie within the pelvis. As part of their normal ascent, kidneys rotate so that the hilum moves from an anterior to a medial position; in horseshoe kidneys, rotation is often abnormal and a more anterior pelvis is common. The orientation of normal kidneys follows that of psoas major, so that the lower poles are more lateral than the upper poles. The absence of this normal orientation on imaging is a useful indicator for the presence of a horseshoe kidney.

The blood supply of a horseshoe kidney is highly variable. The vascular anatomy is understood by remembering that the kidney migrates from the pelvis to the abdomen, and as it moves up it will develop and then lose its
supply from nearby major vessels, beginning at the median sacral artery and then sequentially involving the internal iliac artery, external iliac artery, common iliac artery and aorta. The most common origin of the renal artery in horseshoe kidneys is the aorta, but other origins include the common iliac artery (40%), median sacral artery (3%), lumbar artery (3%), internal iliac artery (2%), external iliac artery (1%) and even phrenic artery (1%).

Most horseshoe kidneys will have more than one renal artery supplying a renal unit, since a horseshoe kidney is comprised of two renal units. However, it is common for there to be a normal segmental vascular pattern. There may be an additional supply to the isthmus.

Horseshoe kidneys are commonly associated with other coexisting anomalies. In one series of symptomatic patients with horseshoe kidneys, 6.8% had ureteral duplication, 18.2% had vesicoureteric reflux and 15.9% had pelviureteric junction obstruction.

Crossed fused renal ectopia is a related renal perfusion anomaly that occurs when one kidney (usually the left) crosses the midline during ascent and fuses with the lower pole of the contralateral kidney. It is more common in boys and has an estimated incidence of 1 in 1000–7500.

Pelviureteric obstruction

Impairment of urine flow from the renal pelvis into the ureter results in pelviureteric junction obstruction (PUJ obstruction), which causes dilation of the pelvicalyceal system above the level of the obstruction: this can cause symptoms of pain or urinary tract infection, or reduction of renal function. The most common cause of PUJ obstruction is an intrinsic narrowing of the lumen at the level of the obstruction. In children, the problem is most commonly detected as a result of finding renal dilation on routine prenatal scanning; the condition is frequently corrected surgically before the infant develops symptoms.

PUJ obstruction may also result from extrinsic compression due to the lower-pole segmental renal vessels. This finding is more commonly seen in older children and adults who present with renal pain from their PUJ obstruction. Characteristically, pain is triggered by diuresis, e.g. after a large drink. The lower-pole vessels run anteriorly across the PUJ.

The same operation, pyeloplasty, is performed to treat PUJ obstruction from intrinsic and extrinsic compression. The pelvis and ureters are exposed. When there is intrinsic obstruction, the narrowed segment is excised and the
ureter is spatulated and anastomosed to the open pelvis. When there is extrinsic obstruction, the renal pelvis and ureter are disconnected (dismembered) and the spatulated ureter is anastomosed to the pelvis, so that the crossing vessels lie posterior to the anastomosis: this reconfiguration prevents subsequent obstruction by the lower-pole vessels.

**Urachal remnants**

The urachus is the fibrous remnant of the allantois. It lies outside the peritoneum and runs from the dome of the bladder into the umbilicus. Failure of this tract to obliterate results in epithelial lined urachal remnants. The most common anomaly is a urachal cyst, followed by urachal sinus, patent urachus and vesico-urachal diverticulum. These are rare anomalies with an incidence of around 1 in 7500. Urachal remnants are frequently asymptomatic but may cause infection or discharge from the umbilicus. Historically, asymptomatic urachal anomalies have been excised because of concern about malignant potential but this is no longer justified.

**Persistent cloaca**

Persistent cloaca is a severe form of anorectal malformation seen in girls, with an incidence of approximately 1 in 20,000–25,000. The distal rectum, vagina and urethra open into a single common channel (*cloaca* means drain in Latin). It is clinically obvious because of the presence of a single perineal opening. There is a spectrum of severity: the longer the common channel, the more difficult the operative repair. Common channel cloacas of <3 cm are more straightforward to repair and have a better outlook for the development of urinary and faecal continence. Some 40% of patients have obstructed drainage of the vagina, which can be detected antenatally as hydrocolpos. Often, the very distended vagina compresses the bladder and ureters posteriorly, leading to hydronephrosis. The initial treatment is to decompress the vagina with a vaginostomy rather than performing a vesicostomy.

Cloaca patients often have associated anomalies of the genital system, including vaginal septum and uterus didelphys.

**Posterior urethral valves**

Posterior urethral valves are caused by a membrane at the level of the distal
verumontanum running obliquely anteriorly and distally. They have an incidence of 1 in 5000 and are the most common cause of congenital bladder outlet obstruction. The presence of severe bladder outlet obstruction during the development of the urinary tract of the fetus impacts on the long-term function of the bladder and kidney: urinary symptoms are common in boys with posterior urethral valves and one-third of them will develop renal failure in childhood.\textsuperscript{25} Despite the importance of this condition, its origin and embryology are uncertain. The problem occurs at an embryologically interesting site: the distal limit of the urogenital canal, the insertion of the mesonephric ducts into the urethra and the proximal end of the urethral plate origin of the anterior urethra. One suggestion is that the valves are the result of a failure to canalize. Other possibilities are that the valves represent an exaggeration of folds that are present during normal development, or that as the ejaculatory ducts enter the urethra they heap up transitional epithelium in the posterior urethra, giving rise to the valves.\textsuperscript{26} Boys who are born with posterior urethral valves will have a lumen through this membrane: complete obstruction of the urethra is not easily survived. Posterior urethral valves impair bladder emptying, which accounts for the other features seen in this condition, namely, a dilated prostatic urethra, a thickened and trabeculated bladder with a hypertrophied bladder neck, vesicoureteric reflux and renal pelviccalyceal dilation (\textbf{Fig. 75.6}).
Inguinal hernia

During testicular descent, the testis travels across the peritoneum to move down the inguinal canal into the scrotum. The processus vaginalis is a channel that provides continuity between the peritoneal cavity and the tunica vaginalis. It usually obliterates but this is not always the case. If the channel is small, it will allow fluid passage, causing a hydrocele, a fluid collection around the testis. A more widely patent processus vaginalis will allow viscera to travel down the inguinal canal, giving rise to an inguinal hernia. Most inguinal hernias in children are of the indirect variety; treatment requires control and ligation of the neck of the hernial sac, but the posterior wall of the inguinal canal does not require reinforcement, as is the case in adults. With the increasing use of laparoscopy it has been recognized that the incidence of a patent processus vaginalis is very high and exceeds the incidence of hydrocele or hernia.

Undescended testis

Undescended testis is the most common congenital anomaly of the urogenital system in boys. The testis does not complete its descent to the
fundus of the scrotum and may be located anywhere along the path of its normal descent. The most common location is just outside the external ring of the inguinal canal, lying slightly laterally in a space sometimes called the superficial inguinal pouch. The frequency of an inguinal position in undescended testis would suggest that the problem is a failure of the second stage of the descent of the testis, a suggestion supported by the observation of an increased incidence of undescended testis in premature infants. However, it is interesting to note that, during orchidopexy, traction on the gubernaculum of an undescended testis indicates that the distal gubernaculum is not attached at the base of the scrotum, as would normally be the case, but is attached at a more proximal location, e.g. at the neck of the scrotum. Rarely, testes lie ectopically outside the normal path of descent of the testes. Ectopic testes may be femoral, or perineal at the base of the penis, or may even lie in the contralateral groin; it is possible that the abnormal location is the result of an abnormally lying genitofemoral nerve.

**Hypospadias**

Hypospadias consists of a triad of features: an abnormally ventrally sited urethral meatus, a ventral curvature to the penis (chordee) and an incomplete or hooded foreskin. The more proximal the urethral meatus, the more severe the hypospadias is considered to be (Fig. 75.7). Particularly severe hypospadias with proximal openings on the proximal penis, scrotum or even perineum is associated with more marked curvature. In severe hypospadias there may be a failure of the scrotal folds to meet fully, resulting in a cleft scrotum. Hypospadias represents a failure of development of the ventral tissues of the penis. Dissection of a penis with hypospadias will demonstrate poor ventral tissues, especially distally; the skin may be thin, dartos layers deficient, corpus spongiosum absent and the urethra thinned. The severity of these features is generally worse with a more proximal hypospadias. However, they can be found even when the urethral meatus is distal, and it can be striking to see the markings of a catheter through the near-translucent urethra and skin in what at first appeared to be a mild hypospadias.
FIG. 75.7 Hypospadias. **A**, Ventral view of penis and scrotum. **B**, Close-up ventral view of distal penis showing hooded foreskin, urethral groove on the glans and the urethral meatus at the level of the corona. **C**, Lateral view showing ventral curve and hooded foreskin.

**Tips and Anatomical Hazards**

The most important difference between operating on an adult and operating on an infant or child is the difference in their physiology: they have a higher surface area to size ratio, are more susceptible to cold, and will become proportionately more fluid-depleted for any given loss in fluid or blood.

Anatomical relations in children are similar to those of adults. The pitfalls and danger areas arise due to the variations caused by congenital anomalies.

Horseshoe kidneys and those in ectopic locations, such as pelvic kidneys, are at a higher risk of trauma than orthotopically located kidneys because they do not have the protection of the ribcage.

Hydronephrotic kidneys are also more susceptible to trauma. Signs and symptoms may appear to be out of proportion to the severity of the injury. It is important to bear in mind that there may be underlying congenital anomalies when signs do not fit with the mechanism of injury.
Defining vascular anatomy provides a significant challenge. Preoperative vascular imaging in the form of angiography and MRI can be difficult in practice in children because they require general anaesthetic procedures. When duplex kidneys are being operated on, the absence of preoperative vascular imaging is not usually a problem because there is an expectation of early branching of the renal artery. If a heminephrectomy is being performed, vessels are divided close to the renal parenchyma of the moiety being removed. Identification of vessels is part of renal pelvic surgery and is easily done in children. More care is required when operating on horseshoe kidneys, however. When dividing the isthmus or removing part of the horseshoe, preoperative vascular imaging is more important because the variability of renal anatomy means that encountered vessels may potentially supply an unexpectedly large proportion of part of both kidneys.

In duplex kidneys, the ureters can be separated and mobilized as separate structures. Care should be taken when performing heminephro-ureterectomy to ensure that the healthy ureter is not devascularized as the abnormal ureter is being removed. This is done by keeping dissection as close as possible to the abnormal ureter and, as far as is feasible, staying away from the adventitia and connective tissues of the normal ureter. Duplex ureters enter the bladder through a common sheath. If surgery is planned to reimplant a duplex ureter, then both of the duplex ureters will need to be mobilized en masse and both reimplanted.

Undescended testes are at a higher risk of torsion, and account for ≤5% of torsions. The presentation may be confused with an incarcerated inguinal hernia, especially when there is an inflammatory response in the surrounding tissues. It is crucial to check that there is a normal testis palpable in the scrotum when patients present with groin swelling and pain, to ensure that this diagnosis is not missed.

In operating on a penis with hypospadias, the surgeon should be alert to the possibility of unexpectedly thin ventral tissue. If not anticipated, it can be easy to injure the urethra when operating on ventral skin in males with hypospadias.

Weigert–Meyer Law: the ureter of the upper pole of the kidney enters the bladder more caudally than the ureter of the lower pole of the duplex kidney.
Hypospadias describes a triad of an abnormally proximally and ventrally sited external urethral meatus, hooded foreskin and ventral curvature of the penis. It is best thought of as an underdevelopment or dysplasia of the ventral tissues of the penis.
References


Further Reading


1. A renal stone is identified on CT scan in the lower pole of the right kidney. When the images are reviewed with the radiologist, you are both certain that the kidney is duplex. The plan is to treat the stone by passing a flexible ureteroscope to it. At operation, two ureteric orifices are seen in the right side of the bladder. Which of the following statements is correct?

A. The more cranial right ureteric orifice will lead to the lower pole of the right kidney
B. The more caudal right ureteric orifice will lead to the lower pole of the right kidney
C. It is not possible to predict which of the ureteric orifices will connect to the lower pole of the right kidney
D. It does not matter which ureteric opening is selected, as both will lead into a common collecting system
E. Ureteroscopy should not be performed in patients with duplex systems

**Answer:** A. The Weigert-Mayer Law reliably predicts that the lower-pole collecting system is accessed from the more cranial ureteric orifice in the bladder. The upper and lower pole collecting systems of a complete duplex kidney do not communicate until the ureters open into the bladder. In the case of a partial duplex, the two pelvises or ureters meet before reaching the bladder and so will have only a single ureteric opening in the bladder.

2. Which one of the following structures does NOT take its origin from the mesonephric duct?

A. Hydatid of Morgagni
B. Vas deferens
C. Ejaculatory ducts
D. Seminal vesicles
E. Gartner's duct

**Answer: A.** Hydatid of Morgagni is sometimes called the appendix of the testis and is derived from the paramesonephric (Müllerian) ducts. The paramesonephric duct forms the uterus and upper two-thirds of the vagina.

3. Below the level of which one of the following vessels does the isthmus of a horseshoe kidney frequently lie?
   A. Median sacral artery
   B. Bifurcation of the aorta
   C. Renal artery
   D. Inferior mesenteric artery
   E. Division of the common iliac into the internal and external iliac arteries

   **Answer: D.** The isthmus commonly lies below the inferior mesenteric artery. It is sometimes thought that the inferior mesenteric artery prevents the isthmus migrating cranially and stops the horseshoe kidney reaching its normal site.

4. Which one of the following phenomena is NOT seen in hypospadias?
   A. Absence of the corpus spongiosum over the urethra
   B. Curvature of the corpora cavernosa
   C. Dorsal curvature of the penis
   D. Spraying urinary stream
   E. Adherence of the prepuce to the glans

   **Answer: C.** The prepuce is adherent to the glans in all newborn
boys, whether they have hypospadias or not. In hypospadias, any of the ventral tissues can be deficient. It is common to see the most distal section of the urethra without a layer of corpus spongiosum. The curvature of the penis seen in hypospadias is ventral. The penile urethra is flattened in an anterior–posterior direction but in the glans the slit-like opening is directed anterior to posterior: this change in orientation of the urethra is thought to result in rifling of the urinary stream. As this change in orientation of the urethra is not present in boys with hypospadias, their urinary stream tends to spray and be a little less easy to direct.

5. A mother reports that she has never seen the left testis in the scrotum of her 6-month-old son. Which one of the following statements is correct?

A. It is worth waiting until the boy is 1 year old before doing anything
B. Ultrasound can reliably identify an undescended testis in the superficial inguinal pouch
C. It is possible to palpate an intra-abdominal testis easily
D. Palpation is helpful in determining the location of the testis
E. A testis lying in the groin will require orchidopexy, even if it can be easily milked into the scrotum without tension

**Answer: D.** A testis that has not come down by 3 months of age is unlikely to descend further. Although ultrasound can identify testes in the groin, it will not distinguish an undescended from a retractile testis. It should not be possible to palpate an intra-abdominal testis. Clinical examination, mainly palpation, can identify whether an undescended testis is in the groin or ectopic, and provides the basis of clinical decision-making in undescended testis. A testis that can be brought easily into the scrotum without tension or pain is a retractile testis that does not
require surgery.
Clinical Cases

1. You are asked to see a boy on the neonatal unit. Prenatal ultrasound scans have demonstrated that he has pelvicalyceal and ureteric dilation affecting both kidneys, and that his bladder is large and thick-walled. The midwives have seen him pass urine with only a very poor stream. When you see him, he has a palpable bladder.

A. What is the most common cause of congenital bladder outlet obstruction?
   Posterior urethral valves.

B. You are asked to catheterize him. As you do so, you feel the tip of the catheter pass easily through his sphincter as he relaxes. Shortly beyond that, the catheter is obstructed. Where might the tip of the catheter be?
   The posterior urethral valves are at the level of the verumontanum, just above the external sphincter, and they do not present resistance to catheterization. However, the posterior urethra can be very dilated and the bladder neck may be so hypertrophied that a lip is formed, making catheterization difficult.

C. How might this problem be overcome?
   Sometimes, inserting a finger into the rectum and pushing anteriorly will redirect the catheter over the lip of the bladder neck and into the bladder.

D. How are posterior urethral valves diagnosed?
   Postnatal ultrasound scanning can be used to confirm renal pelvicalyceal and ureteric dilation. It is sometimes possible to see the dilated posterior urethra on an ultrasound scan. The diagnostic test is a micturating cystourethrogram: contrast is passed through the catheter under X-ray screening.

E. What are the features of posterior urethral valve seen during a micturating cystourethrogram?
   There is a step between the dilated posterior urethra and the thinner anterior urethra. The bladder neck is hypertrophied. There may be trabeculation of the bladder and vesicoureteric reflux.

2. You are a urologist seeing a 5-year-old girl who has primary urinary incontinence. She has continuous dribbling urine leakage, although she is also able to say when she needs to pass urine and passes
reasonable volumes, according to her parents. Reviewing her notes, you see that she had unilateral antenatal hydronephrosis and her follow-up ultrasound scan at birth showed a possible duplex kidney with no evidence of pelvicalyceal dilation.

A. What is the likely diagnosis?
This patient may well have an ectopic ureter. It is usually the ureter from the upper moiety of a duplex kidney that inserts distally, following the Weigert–Meyer rule.

B. What surgical options should be considered and why?
It is important to determine how much the upper moiety contributes to the overall function of the duplex kidney. This can be assessed with a DMSA scan (a radionuclide scan that uses dimercaptosuccinic acid) or functional MRI. If the kidney has poor function, then a heminephrectomy would be the treatment of choice. If it contributes more than 40% of function, options include reimplantation of the ureter into the bladder or an end-to-side ureteroureterostomy.

3. An 8-year-old boy presents to the accident and emergency department with severe right loin pain and vomiting. He has had several similar episodes in the past. An urgent ultrasound shows a very dilated pelvicalyceal system in the right kidney with no ureteric dilation and no evidence of a renal calculus.

A. What further investigations will help plan further management?
This is most likely to be an obstruction of the pelviureteric junction. It will be important to determine the function of the kidney and it is also helpful to explore the anatomy of the renal vessels. A mercaptoacetyltriglycine (MAG-3) scan will show differential function and drainage of the kidney; however, a functional MRI will supply this information and also provide cross-sectional imaging of the anatomy, which may reveal a lower pole crossing vessel.

B. What are the surgical approaches for a pyeloplasty?
The most commonly performed pyeloplasty is the Anderson–Hynes dismembered pyeloplasty. This can be performed via an open or a laparoscopic approach. The open approach to the kidney is by a retroperitoneal dissection. In the laparoscopic operation, the surgeon can either approach the kidney via the retroperitoneum or take a transperitoneal approach anteriorly. If there is good evidence that the pelviureteric junction
obstruction is caused exclusively by extrinsic vascular compression, then a vascular hitch can be performed.
SECTION 9
Bony Pelvis and Lower Limb

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This chapter presents an overview of the general morphology of the pelvis and lower limb. The main junctional region of the body contains not only the articulation of the femur to the pelvis, i.e. the hip joint, but also the major neurovascular pathways between the abdominopelvic cavity and the lower limb. Posteriorly, the gluteal (buttocks) region and its relationships to the greater and lesser sciatic foramina are important in this transmission of structures; the significance of the former foramen is evident in its nickname, the ‘Gibraltar’ or porta of the gluteal region. Anteriorly, the inguinal region includes the transitional zones between the lower limb and the abdominal cavity via the myopectineal orifice (the gap between the inguinal ligament and anterior thigh), which provides a gateway for the passage of various structures. Similarly, the obturator nerve and vessels traverse between pelvis and thigh via the obturator canal.
Skin and fascia

Pelvis

In the young adult, and as an adaptation to weight-bearing, the skin of the lower limb is generally stronger and thicker than that of the upper limb. The soft tissues of the sole of the foot are particularly thickened in order to support weight during standing. The skin of the buttocks and posterior thigh bears weight in the sitting position, and consequently is relatively thick. The skin over the anteromedial aspect of the leg is particularly fragile and vulnerable in the elderly.

The pelvic girdle represents a crossroads of various fascial specializations. The superficial fascia (tela subcutanea) of the buttock is continuous superiorly with that over the lower back and contains a variable quantity of fat. The aponeurosis of erector spinae is attached to the posterior sacrum and iliac crest; the lower part of the thoracodorsal fascia (posterior laminae) is attached posterior to this aponeurosis and to these same bones. The deep fascia (fascia musculorum) covering the gluteal muscles varies in thickness. Over gluteus maximus it is thin, but over the anterior two-thirds of gluteus medius it forms the thick, strong gluteal aponeurosis, which is attached to the lateral border of the iliac crest superiorly, and splits anteriorly to enclose tensor fasciae latae and posteriorly to enclose gluteus maximus.

Iliac fascia

The thin iliac fascia covers psoas and iliacus. The external iliac vessels are anterior to the fascia but the branches of the lumbar plexus are posterior to it. Lateral to the femoral vessels, the iliac fascia is continuous with the posterior margin of the inguinal ligament and the transversalis fascia. Medially, it passes behind the femoral vessels to become the pectineal ligament, attached to the pecten pubis. At the junction between its lateral and medial parts it is attached to the iliopubic ramus and the capsule of the hip joint. It thus forms a septum between the inguinal ligament and the hip bone, dividing the space here into a lateral part – the muscular space – which contains psoas major and iliacus and the femoral nerve, and a medial part – the vascular space – which transmits the femoral vessels. The iliac fascia continues downwards to form the posterior wall of the femoral sheath.

Obturator membrane
The obturator membrane is a thin aponeurosis that closes most of the obturator foramen, leaving a superolateral aperture, the obturator canal, through which the obturator vessels and nerve leave the pelvis and enter the thigh. The outer and inner surfaces of the obturator membrane provide attachments for obturator externus and internus, respectively. Some fibres of the pubofemoral ligament of the hip joint are attached to its outer surface.

**Lower limb**

**Fascia lata**

The fascia lata, the wide fascia musculorum of the thigh, is thicker in the proximal and lateral parts of the thigh, where tensor fasciae latae and an expansion from gluteus maximus are attached to it. It is attached superiorly and posteriorly to the back of the sacrum and coccyx, laterally to the outer margin of the iliac crest, anteriorly to the inguinal ligament and superior ramus of the pubis, and medially to the inferior ramus of the pubis, the ramus and tuberosity of the ischium, and the lower border of the sacrotuberous ligament. From the iliac crest it descends as a dense layer over gluteus medius to the upper border of gluteus maximus, where it splits into two layers, one passing superficial and the other deep to the muscle. These layers reunite at the lower border of the muscle.

**Iliotibial tract**

Over the lateral surface of the thigh, the fascia lata thickens to form a strong band, the iliotibial tract, the superior end of which splits into two layers. These enclose and anchor tensor fasciae latae and receive, posteriorly, most of the tendon of gluteus maximus. The superficial layer ascends lateral to tensor fasciae latae to the iliac crest; the deeper layer passes upwards and medially deep to the muscle, and blends with the lateral part of the hip joint capsule. Distally, the iliotibial tract is attached via its tubercle (Gerdy's tubercle) to the anterolateral aspect of the lateral condyle of the tibia.

**Intermuscular septa**

The deep surface of the fascia lata yields two intermuscular septa, which are attached to the whole of the linea aspera and to its proximal and distal prolongations. The lateral septum extends from the attachment of gluteus maximus to the lateral femoral condyle; it lies between vastus lateralis
anteriorly and the short head of biceps femoris posteriorly, and provides a partial attachment for them. The medial septum lies between vastus medialis and the adductors and pectineus. Numerous smaller septa, such as that separating the thigh adductors and flexors, pass between the individual muscles, ensheathing them and sometimes providing partial attachments for their fibres.

**Tela subcutanea and fascia musculorum**

The more superficial fascia of the lower limb (tela subcutanea) becomes thinner peripherally. In the thigh, as elsewhere in the limbs, it is made of loose areolar tissue containing fat. It participates in the integrity of the skin and provides support for subcutaneous structures such as cutaneous nerves and superficial veins. It prevents the superficial veins from being displaced during limb movement by virtue of its connections to their adventitia.

The deeper fascia of the lower limb (fascia musculorum) is a well-defined aponeurotic fascia that constrains the musculature. Septa pass from its deep surface to the bones within, confining the functional muscle groups within osteofascial compartments. It is sufficiently tough to provide additional areas of muscle attachment and ensure maximal function. Elsewhere, thickenings in the fascial skeleton form the fibrous retinacula, where tendons cross joints. This pattern of soft tissue organization has a bearing on the physiological effects of the muscles and is crucial for efficient venous return from the limb. The fascial planes also control and direct the spread of pathological fluids within the limb and are important determinants of the degree and direction of displacement seen in long-bone fractures.

The fascia musculorum of the leg (crural fascia) is continuous with the fascia lata. Below, it is continuous with the extensor and flexor retinacula. Laterally, it is continuous with the anterior and posterior crural intermuscular septa, which are attached to the anterior and posterior borders of the fibula, respectively. A broad sheet of fascia, the transverse intermuscular septum (deep transverse fascia) of the leg, passes between the superficial and deep parts of the posterior compartment of the leg.

The plantar aponeurosis on the sole of the foot consists of densely compacted collagen fibres orientated longitudinally and transversely. It runs anteriorly from the calcaneus, and at the heads of the metatarsals it divides into five bands, one extending out to each digit.
Bones and joints

Pelvis

The left and right pelvic bones, with the sacrum interposed posteriorly and the pubic symphysis anteriorly, form the pelvic girdle. The sacroiliac joints have both syndesmonic and synovial parts and are slightly mobile, especially during childbirth. The sacrum is formed by fusion of the five sacral vertebrae, which taper in size in a cranial to caudal direction, the fifth articulating with the rudimentary coccyx at the sacrococcygeal joint. The design of the sacrum positions it as the keystone of the pelvic girdle, so the weight of the body is transferred from the first sacral vertebra along the hip bones and down into the lower limbs.

Each pelvic bone is composed of three separate bones (ilium, pubis and ischium). Between the sixteenth and eighteenth years of life, these three fuse together in the depths of the acetabulum, which faces inferolaterally and serves as a receptacle for the head of the femur, forming the robust hip joint and uniting the lower limb to the spine via the pelvis.

A line connecting the anterior superior iliac spine to the ischial tuberosity passes across the summit of the greater trochanter and is known as Nélaton's line. Anteriorly, the pelvic girdle articulates with the contralateral girdle at the pubic symphysis, a secondary cartilaginous joint that can exhibit slight mobility during hip and sacroiliac movement and during childbirth. Strong ligaments (e.g. the sacroiliac, sacrotuberous and sacrospinous) unite the sacrum to the hip bones (Fig. 76.1).
The pelvis can be arbitrarily divided into lesser and greater parts by an oblique plane travelling through the sacral promontory and the lineae terminales. There are many sex differences but the female pelvis is larger, has a smaller acetabulum, and has a less acute pubic arch at 80–85°.

Lower limb
The bones of the lower limb include the femur (thigh) and patella (kneecap), the tibia and fibula (leg), and the tarsus, metatarsus, phalanges and sesamoid bones (foot). The fabella and cyamella are sesamoid bone variants found in the tendons of the lateral head of gastrocnemius and popliteus, respectively.

The hip joint is robust and heavily overlaid by strong ligaments. These include the posteriorly placed ischiofemoral and the anteriorly positioned pubofemoral ligaments, both of which resist abduction of the hip joint, and the iliofemoral ligament, which resists hyperextension of the hip. The latter is considered the strongest ligament in the body and has an inverted Y-shape. Internally, along its rim the acetabulum is lined with the acetabular labrum, which increases the contact area of the head of the femur, thereby reducing contact stress.

The knee joint, formed mainly between the femur and the tibia, also includes the articulation between the patella and the femur. Strong internal ligaments, such as the anterior and posterior cruciate ligaments, and external ligaments, such as the fibular and tibial collateral ligaments, maintain joint stability. Internally, the medial and lateral menisci interface between the articular surfaces of the distal femur and proximal tibia. The tibia and fibula articulate with each other at the superior (plane synovial) and inferior tibiofibular (fibrous) joints. The interosseous membrane that connects the adjacent borders of these two bones is continuous distally with the interosseous ligament of the distal tibiofibular joint. It is interposed between the anterior and posterior groups of crural muscles and gives attachment to some members of each of these muscle groups.

The ankle (talocrural) joint is formed by the distal ends of the tibia and fibula flanking either side of the talus, and allows dorsiflexion and plantar flexion. This joint is located about 1 cm superior to the inferior extent of the medial malleolus. There are multiple joints in the foot that can be classified topographically on the basis of their location in the hindfoot, midfoot or forefoot.
Muscles

The muscles of the lower limb can be subdivided into those of the iliac and gluteal regions and those of the thigh, leg and foot (Fig. 76.2).
**Pelvic girdle**

The main muscles of the posterior abdomino-pelvic region are psoas major and iliacus (together called iliopsoas), which attach distally to the lesser trochanter of the femur and are the strongest flexors of the hip. A small psoas minor (when present) runs from the lumbar spine to the pubis. The rectangular quadratus lumborum unites the twelfth rib to the iliac crest.

The muscles of the gluteal region include the three named gluteal muscles and the deeper short lateral (external) rotators of the hip joint. Gluteus maximus lies most superficially, running from the posterior pelvis to the proximal femur and fascia lata. It is a powerful extensor of the hip joint, acting more often to extend the trunk on the femur than to extend the limb on the trunk. Glutei medius and minimus, attached proximally to the outer surface of the ilium and distally to the greater trochanter of the femur, are abductors of the hip, although their most important action is to stabilize the pelvis on the femur during locomotion. They are helped in this function by tensor fasciae latae, a more anteriorly placed muscle that arises from the anterolateral ilium and inserts via the iliotibial tract on to the proximal tibia. Two of the short lateral rotators of the hip – piriformis and obturator internus – arise from within the pelvis, whereas the others – obturator externus, superior and inferior gemelli and quadratus femoris – are attached externally. All of these muscles are attached distally to the proximal femur.

**Lower limb**

**Thigh**

The muscles of the thigh can be grouped into three functional compartments: anterior (extensor), posterior (flexor) and medial (adductor). In the leg, fascial septations create the anterior (extensor), posterior (flexor) and lateral (evertor) compartments.

The anterior or extensor compartment includes sartorius and quadriceps femoris (vastus lateralis, vastus medialis and vastus intermedius). Sartorius and rectus femoris are attached proximally to the pelvis and can therefore act on the hip joint as well as the knee, whereas the vasti are attached proximally to the femoral shaft and distally, via the patellar ligament, to the tibia and are therefore powerful knee extensors. The attachment of the patellar ligament to the tibial tuberosity can be palpated about 5 cm inferior to the patella in
the sitting position. Articularis genus is a deep slip from vastus intermedius and attaches to the suprapatellar bursa. The medial or adductor compartment contains the named adductor muscles (longus, brevis, magnus) and gracilis; pectineus can also be included. These muscles are attached proximally to the anterior aspect of the pelvis and distally to the femur; gracilis has no femoral attachment, however, being attached distally to the proximal tibia, while part of adductor magnus has a proximal attachment to the ischial tuberosity.

The posterior compartment of the thigh includes, at midthigh from medial to lateral, semimembranosus, semitendinosus and biceps femoris. These muscles are attached proximally to the ischial tuberosity and act both to extend the trunk on the femur and to flex and rotate the knee.

**Leg and foot**

The anterior or extensor compartment includes tibialis anterior (the main foot dorsiflexor), extensor digitorum longus, extensor hallucis longus and, most laterally, fibularis tertius, a dorsiflexor, which also everts the foot. The posterior or flexor (plantar flexor) compartment has superficial and deep components. The former contains gastrocnemius and soleus and the small plantaris with its long slender tendon. Gastrocnemius and soleus are attached distally to the foot via the calcaneal (Achilles) tendon. The deep component of the flexor compartment contains popliteus, the extrinsic flexors of the toes (flexor digitorum longus and flexor hallucis longus) and tibialis posterior, an invertor of the foot. The lateral compartment contains the main evertors of the foot, fibularis longus and brevis; both muscles are also plantar flexors of the foot. Gastrocnemius and plantaris, when present, are attached proximally to the femur and distally to the calcaneus. The intrinsic muscles of the sole of the foot are arranged in four layers and serve primarily to move the digits.
Vascular supply and lymphatic drainage

**Arterial supply**

At the L4 vertebral level, the descending abdominal aorta bifurcates into left and right common iliac arteries. These vessels course inferiorly towards the pelvis and soon split into the external and internal iliac arteries, the latter principally supplying the internal aspect of the pelvis and the former continuing into the thigh to become the primary blood supply of the lower limb (Fig. 76.3).
External iliac artery
Distal to the inguinal ligament, the external iliac artery becomes the femoral artery, which is the main blood supply to the lower limb. It enters the thigh midway between the anterior superior iliac spine and pubic symphysis, enters the femoral triangle lateral to the femoral vein, and courses within the adductor canal, which is located on the anteromedial aspect of the thigh. It passes through the adductor hiatus to become the popliteal artery and soon thereafter divides into the anterior and posterior tibial arteries, which form a
collateral network in the foot.

**Internal iliac artery**
The internal iliac artery gives rise to many branches derived from its anterior and posterior divisions. The posterior division gives three somatic vessels: the iliolumbar, lateral sacral and superior gluteal arteries.\(^8,9\) Branches to the lower limb from the anterior division include the inferior gluteal and obturator arteries.

**Venous drainage**
The veins of the lower limb can be subdivided into superficial and deep groups.\(^10\) The superficial veins are subcutaneous and lie in the tela subcutanea, and the deep veins are deep to the fascia musculorum. The two principal superficial veins are the long and short saphenous veins, which have numerous tributaries (see Figs 77.5 and 77.6).

The deep veins of the lower limbs accompany the arteries and their branches.

**Lymphatic drainage**
The lymphatic drainage of the lower limb begins on the dorsal and plantar surfaces of the foot and continues around the leg and thigh. Along these pathways, major lymph nodes are found in the popliteal fossa and inguinal region. The inguinal lymph nodes lie superficial and deep to the fascia musculorum. The superficial inguinal nodes, which drain into the deep inguinal nodes, are related to the proximal part of the long saphenous vein and are parallel to and below the inguinal ligament.\(^11\) The vessels along the medial surface of the lower limb are larger and more numerous, and these drain into the distal superficial inguinal nodes. The lateral vessels from the dorsum of the foot cross anteromedially in the leg to join the medial vessels and so pass to the distal superficial inguinal nodes, while others accompany the short saphenous vein and drain into the popliteal nodes.

Superficial lymph vessels from the gluteal region run anteriorly to the superficial inguinal nodes. The deep lymph vessels accompany regional blood vessels and drain into the popliteal nodes, and those from the thigh travelling medial to the femoral vein pass to the deep inguinal nodes, then to the external and common iliac nodes, and ultimately to the lateral aortic
nodes.
Innervation

**Lumbar plexus**

The upper four lumbar ventral rami form the lumbar plexus, which gives rise to the iliohypogastric (L1), ilioinguinal (L1), genitofemoral (L1, L2), lateral femoral cutaneous (L2, L3), femoral (L2–L4) and obturator (L2–L4) nerves (Fig. 76.4). Occasionally, an accessory obturator nerve is present and leaves the pelvis by passing over the pubis, primarily to supply pectineus.
The main motor outflow of the lumbar plexus is via the femoral and obturator nerves, which are the primary nerves of the anterior and medial compartments of the thigh, respectively. The cutaneous distribution of the lumbar plexus is illustrated in Fig. 76.5.
Sacral plexus

Branches of the sacral plexus (see Fig. 76.4) to the pelvic girdle and lower limb include nerves to quadratus femoris (L4, 5; S1), obturator internus (L5; S1, 2) and piriformis (S2); the superior gluteal (L4, 5; S1), inferior gluteal (L5; S1, 2) and posterior femoral cutaneous (S1–S3) nerves; and the sciatic nerve
with its two parts – the medially placed tibial (L4, 5; S1–S3) and the laterally placed common fibular (L4, 5; S1, 2) nerves.\textsuperscript{14,15}

The main motor outflow from the sacral plexus, which is joined to the lumbar plexus via the lumbosacral trunk (L4, 5) to form the so-called lumbosacral plexus, comprises the gluteal and sciatic nerves. The inferior gluteal nerve innervates gluteus maximus, and the superior gluteal nerve innervates glutei medius and minimus and tensor fasciae latae. The tibial nerve innervates most of the posterior thigh muscles and all the posterior leg muscles. The common fibular nerve innervates the anterior and the lateral compartments of the leg via its deep and superficial branches, respectively.\textsuperscript{16}

The cutaneous distribution of the sacral plexus is seen in Fig. 76.5.\textsuperscript{17}

**Reflexes**

Clinically significant spinal reflexes of the lower limb include the patellar, calcaneal and plantar reflexes. The knee reflex tests spinal levels L2–L4 and the ankle and plantar reflexes test spinal levels S1–S2. The plantar reflex is elicited by stroking the outer edge of the plantar surface of the foot with a blunt object, such as the tip of a percussion hammer handle. In the absence of upper motor neurone disease, the toes will flex; in pathological states, the great toe will extend (Babinski’s sign).

**Autonomic nerves**

The autonomic nerve supply to the limbs is exclusively sympathetic. The preganglionic sympathetic fibres to the lower limb are derived from neurones in the lateral horn of the T10–L2 spinal cord segments. Fibres pass in white rami communicantes to the sympathetic trunk and synapse in the lumbar and sacral sympathetic ganglia. Postganglionic fibres pass in grey rami communicantes to enter the lumbar and sacral plexuses, and many are distributed to the skin via the cutaneous branches of the nerves derived from those plexuses. The blood vessels to the lower limb receive their sympathetic nerve supply via adjacent peripheral nerves.
Embryology

The early limb bud develops through a series of tissue interactions between the lateral body wall surface ectoderm and underlying somatopleuric mesenchyme. An imaginary axial line defines the proximodistal axis of the limb bud, with preaxial and postaxial borders defined as cranial or caudal to the axial line. Dorsal and ventral ectodermal surfaces give rise to the region-specific adult posterior and anterior epidermal structures. As the limb bud lengthens, the somatopleuric mesenchyme forms cartilaginous skeletal elements, joints and associated ligaments; it also generates signals for the organization of limb muscles that arise from the dermomyotome of the somites and migrate into the limb as dorsal and ventral premuscle masses. Motor nerves enter the limb ahead of sensory nerves. Embryonic and fetal movements are necessary for the normal development of limb tissue and the overlying skin.

The lower limb initially grows laterally, with the dorsal aspect of the limb growing faster than the ventral aspect, causing the limb bud to curve around the body wall. By stage 17 (39–41 days post fertilization), a hip region can be identified but not a knee, and the foot plate is flattened. In stage 18 (42–44 days post fertilization), the lower limb appears flexed and abducted at the hip, with a bent knee facing laterally and the ventral surface of the foot plate facing the umbilical cord. The feet, still with digital rays, can touch at stage 21 (50–52 days post fertilization), when the umbilical cord is proportionally smaller and the embryo larger. Toes are clearly defined by stage 23 (53–58 days post fertilization).

The origins and development of the arteries in the lower limb are complex. The axial artery is derived from the lateral branch of the fifth lumbar intersegmental artery, which arises from the dorsal root of the umbilical artery passing to the placenta. New vessels arise, some of them temporarily, during development; the mature vascular pattern is established by the end of the embryonic period. The superficial veins of the lower limb are derived from the marginal vein running along the periphery of the extending limb bud beneath the pre- and postaxial limb borders: the preaxial vein becomes the long saphenous vein, and the postaxial vein becomes the short saphenous vein. The lower limb is relatively underdeveloped at birth compared to the upper limb, with the lower leg proportionally shorter than the thigh. The tibia and fibula are straight but the slightly more advanced development of the lateral head of gastrocnemius compared to the medial
head gives the illusion of bow legs. The morphological changes in the embryonic lower limb from stage 18 continue during fetal development, and in the neonate the legs are usually retained in a flexed position and the feet inverted. When infants start walking, the lower limb is further medially rotated and extended, with the dorsal (extensor) portion of the limb directed ventrally. This rotation is reflected in the innervation patterns of the lower limb, where quadriceps femoris, although derived from the dorsal muscle mass and innervated by the femoral nerve, is a muscle of the anterior thigh.
References


1. During harvest of a piece of fascia lata to be used for cranial duraplasty following a large skull fracture due to trauma, the surgeon notices several nerve fibres superficial to the fascia and travelling to the skin of the lateral thigh. The skin incision site was made approximately 12 cm distal to the anterior superior iliac spine. The graft measured 4 × 4 cm. Branches to the underlying musculature were not apparent. Which of the following nerves do these fibres most likely represent?
A. Femoral branches of the genitofemoral nerve
B. Cutaneous branches of the obturator nerve
C. Cutaneous branches of the ilio-inguinal nerve
D. Branches of the lateral femoral cutaneous nerve
E. Branches of the superior clunial nerves

**Answer: D.** The lateral femoral cutaneous nerve, a branch of the lumbar plexus, leaves the pelvis usually just medial to the anterior superior iliac spine. It descends into the thigh and supplies the skin of the anterolateral thigh variably down to the knee. Injury to the nerve can result in decreased sensation or paraesthesias in this distribution. Chronic irritation or compression of the nerve is the aetiology of meralgia paraesthetica.
Clinical Case

A two-year-old boy presented to the neurosurgical clinic with a six-month history of dragging his right leg. The parents denied a history of birth trauma or other injury to the lower limb. He began walking at 14 months of age. Nerve conduction studies were performed. Sural nerve sensory response was normal. Superficial fibular nerve sensory response was absent. Common fibular motor studies (recorded from extensor digitorum brevis and tibialis anterior) showed decreased amplitudes. Tibial nerve motor study was normal. MRI identified two intraneuronal common fibular nerve lesions in the thigh (Fig. 76.6). Surgical excision of the distal neuroma was performed. Pathological evaluation of the mass revealed a perineuroma.

FIG. 76.6 Parasagittal MRI of the distal thigh and proximal leg of the patient presented in the Clinical Case and demonstrating the articulation between the femur and tibia. The arrows point to two masses involving the common fibular nerve component of the sciatic nerve with the inferior mass arising from the common fibular nerve as it diverged from the sciatic nerve in the superior aspect of the popliteal fossa.
A. In its pathway from the thigh to the leg, the common fibular nerve curves around which of the following structures: medial condyle of the femur, neck of the fibula, medial condyle of the tibia, interosseous membrane or Gerdy's tubercle?

As the common fibular nerve enters the leg, it passes lateral to the neck of the fibula. This very superficial location of the nerve places it in danger of injury.
**Core Procedures**

- Access to the distal aorta and iliac vessels
- Exposure of the femoral vessels
- Access to the proximal popliteal artery
- Access to the distal popliteal artery
- Approach to the anterior tibial artery
- Access to the posterior tibial artery
- Access to the fibular artery
- Long saphenous vein harvest
- Lower limb four-compartment fasciotomies
- Varicose vein surgery
Embryology

The common iliac arteries develop from the union of the umbilical arteries and fifth lumbar dorsal intersegmental arteries during early gestation. The internal iliac arteries are derived from the fifth lumbar ventral segmental artery. The blood supply to the lower limb is initially via the sciatic artery, which forms as a branch of the umbilical artery. A second system develops in the lower limb at 6 weeks’ gestation, when the common iliac artery gives rise to the external iliac artery. The sciatic artery almost completely regresses, although portions persist to form the popliteal and fibular arteries, and the inferior and superior gluteal arteries.
Surgical surface anatomy

Arteries

The femoral artery is located roughly along an imaginary line drawn from the mid-inguinal region to the adductor tubercle and within the femoral triangle proximally (Video 77.1). The femoral triangle (Scarpa’s triangle) is located between sartorius, the medial border of adductor longus and the inguinal ligament (Fig. 77.1). The floor of the triangle is composed of iliopsoas and pectineus, and the fascia lata forms its roof. From lateral to medial, the triangle contains the femoral nerve, femoral artery, femoral vein and femoral canal; the femoral sheath surrounds the artery, vein and canal but not the nerve. The femoral canal contains lymphatics and a lymph node (of Cloquet); it can allow the passage of abdominal contents as a femoral hernia, which is visible inferolateral to the pubic tubercle.
The subsartorial (Hunter's) canal extends from the apex of the femoral...
triangle to the adductor hiatus. It is bordered by sartorius anteriorly, vastus medialis laterally and adductors longus and magnus posteriorly, and contains the femoral artery and vein, the saphenous nerve and the nerve to vastus medialis. The femoral artery becomes the popliteal artery as it exits the canal. The popliteal artery is located initially along an imaginary line drawn from the lateral margin of semimembranosus obliquely downward to the centre of the popliteal fossa, and then along a line drawn through the lower part of the tibial tuberosity, running vertically for 2.5 cm.

The anterior tibial artery arises about 3 cm inferior to the head of the fibula and runs along an imaginary line from the medial side of the head of the fibula to midway between the malleoli, where it becomes superficial at the ankle and palpable as the dorsalis pedis pulse between the tendons of extensor digitorum longus and extensor hallucis longus. The posterior tibial artery travels along a line from the termination of the popliteal artery to the medial malleolus, where it becomes superficial at the ankle and palpable posterior to the medial malleolus. The fibular artery (peroneal artery) arises 7–8 cm inferior to the knee and follows the line of the fibula distally to its lateral malleolus.

Veins

The saphenous opening is a defect in the fascia lata inferior to the medial part of the inguinal ligament and inferolateral to the pubic tubercle. The opening is occupied by cribriform fascia (Hesselbach’s fascia). The long saphenous vein and lymphatics from the superficial lymph nodes pass through the saphenous opening and cribriform fascia to enter the femoral vein and the deep inguinal nodes, respectively.

The long saphenous vein arises at the dorsum of foot, passes 2 cm anterior to the medial malleolus (it can be approached for a long saphenous vein cut-down at this point), ascends the medial leg, passes immediately posterior to the medial femoral condyle (a hand’s breadth posterior to the patella), then passes up the medial thigh to drain into the femoral vein. The junction of the long saphenous vein with the femoral vein typically lies 2.5–4.0 cm inferolateral to the pubic tubercle, but can be closer to the pubic tubercle in women.

The short saphenous vein passes posterior to the lateral malleolus and ascends the posterior aspect of the calf to enter the popliteal vein behind the knee.
Clinical anatomy

Arteries

The aorta bifurcates at the L4 vertebral level into the common iliac arteries, which cross the linea terminalis, lying inferolaterally along the medial border of psoas major, and divide into the external and internal iliac arteries at the linea terminalis anterior to the sacro-iliac joint. The right common iliac artery can compress the left common iliac vein against the lumbar spine as the vein crosses from left to right to enter the inferior vena cava. This can cause left lower limb swelling and deep vein thrombosis (May–Thurner syndrome), which is more common in females than males and tends to present in the second to fourth decades of life.1 May–Thurner syndrome rarely involves the right common iliac vein.

The internal iliac arteries predominantly supply the structures of the pelvis and muscles of the thigh and gluteal region, whereas the external iliac arteries are the main suppliers of blood to the lower limb (Fig. 77.2).
**Internal iliac artery**

The exact configuration of the internal iliac artery is variable but it usually divides into anterior and posterior divisions.

**Anterior division**

The obturator artery distributes blood predominantly outside of the pelvis,
where it divides into anterior and posterior branches. It supplies muscles of the medial compartment of the thigh and muscles attached to the ischial tuberosity and the head of the femur. There is a risk of significant bleeding in obturator artery bypass that is difficult to control, and occasionally this artery arises from the inferior epigastric artery. The inferior gluteal artery descends on the medial side of the sciatic nerve and is involved in the cruciate anastomosis. It supplies gluteus maximus, obturator internus, quadratus femoris and the proximal attachments of the hamstrings.

The inferior vesical artery supplies the urinary bladder and prostate in males (Ch. 70). The middle rectal artery supplies the rectum. The internal pudendal artery passes out of the greater sciatic foramen to enter the lesser sciatic foramen, where it is distributed to the perineum. Other branches include the umbilical artery and uterine and vaginal arteries in females (Ch. 74).

**Posterior division**

The posterior division gives rise to the iliolumbar, lateral sacral and superior gluteal arteries. The superior gluteal artery divides into deep and superficial branches and supplies the gluteal muscles and tensor fasciae latae; it anastomoses with the inferior gluteal and medial circumflex femoral arteries.

Occlusive disease of the internal iliac artery can cause symptoms of claudication in areas supplied by the vessel, particularly the buttocks. Sacrifice of the internal iliac artery is sometimes required during aortic surgical procedures and this can result in buttock ischaemia. Control of bleeding from the internal iliac vessels can be challenging owing to their depth in the pelvis; it can be difficult to clamp a bleeding internal iliac artery, and insertion of a catheter as an occlusion device in an emergency situation can help to control the haemorrhage temporarily.²

**External iliac artery**

Near the anterior abdominal wall, the external iliac artery gives rise to the inferior epigastric and deep circumflex iliac arteries, which supply the lower anterior abdominal wall. As the external iliac artery passes inferior to the inguinal ligament it becomes the femoral artery. The external iliac artery is the usual site of anastomosis for a donor renal artery during renal transplantation.
**Femoral artery**

The femoral artery gives rise to the superficial circumflex iliac and superficial epigastric arteries, the superficial and deep external pudendal arteries, and the deep femoral artery (profunda femoris artery). Distal to the deep femoral artery origin, it is known clinically as the superficial femoral artery and it gives off the descending genicular artery near its entrance into the adductor canal.

The deep femoral artery lies posterior to the femoral artery and vein on the medial side of the femur, exiting the triangle between pectineus and adductor longus. It gives rise to numerous perforating arteries that supply adductor magnus, hamstrings and vastus lateralis, and to the circumflex femoral arteries (which can occasionally arise from the femoral artery), which supply the thigh muscles and proximal femur (Fig. 77.3).
Most of the blood supply to the head of the femur is derived from the medial circumflex femoral artery (a branch of the deep femoral artery), supplemented by the lateral circumflex femoral artery, which also supplies muscles of the lateral thigh. Following trauma or hip fracture, the head of the femur is at risk of avascular necrosis because the blood supply is relatively fixed at the neck of the femur and therefore easily impaired by trauma. Important collaterals between the gluteal arteries provide continued
blood supply when the femoral artery is occluded.

The femoral artery (clinically referred to as the common femoral artery proximal to its deep femoral branch) is the most common site of proximal anastomosis in lower limb bypass surgery, though a ‘distal’ origin graft (from either the distal femoral artery – clinically, the superficial femoral artery – or proximal popliteal artery) can be used to reduce the length of conduit required and to spare the patient an inguinal incision, which entails an increased risk of wound complications. This is particularly pertinent for patients with diabetes, who tend to have relative sparing of the proximal femoral vessels and are at increased risk of wound infections. However, the patency of the deep femoral artery must be confirmed or established, as this is an important source of collateral blood flow in the event of subsequent occlusion, and patch angioplasty of the origin of the deep femoral artery may be required to optimize this vessel.4

The patency of the deep femoral artery must also be ensured when a gracilis flap mobilization is undertaken to cover an infected inguinal region wound, because the medial circumflex femoral artery is the sole artery supplying gracilis. Sartorius has a segmental blood supply making it an alternative muscle to use as a rotational flap to treat inguinal infection, although this is prone to seroma formation. Rectus femoris can also be used for a muscle flap by making an incision vertically down the leg, mobilizing the muscle and rolling it back up to the inguinal region to cover the wound. This is particularly useful in exposed femoral–femoral crossover or axillo-femoral grafts because the muscle can be pushed right up above the inguinal ligament.

The femoral artery distal to the origin of the deep femoral artery is most commonly affected in peripheral artery disease. It descends along the anteromedial aspect of the thigh through the adductor canal and becomes the popliteal artery as it passes through the adductor hiatus.

**Popliteal artery**

The popliteal artery is the most anterior structure in the popliteal fossa and ends at the lower border of popliteus. It gives off five genicular branches that supply the knee joint and form part of the genicular anastomosis, which is a source of collateral supply when the popliteal artery is kinked in full knee flexion. The popliteal artery above and below the knee can be used for bypass. It divides into the anterior tibial and posterior tibial arteries.
Anterior tibial artery
The anterior tibial artery supplies the anterior compartment of the leg and the dorsum of the foot as the dorsalis pedis artery. It passes anterior to popliteus, through the interosseous membrane between the tibia and fibula, and descends to the dorsal aspect of the foot between tibialis anterior and extensor digitorum longus. It is vulnerable to injury in trauma to the fibula as it passes medial to its neck.

Posterior tibial and fibular arteries
The posterior tibial artery gives rise to the fibular artery and then continues distally it supplies the posterior compartment of the leg and the plantar aspect of the foot. At the ankle, it lies deep to the flexor retinaculum and terminates by dividing into the medial and lateral plantar arteries.

The fibular artery supplies the lateral compartment of the leg, while continuing in the deep posterior compartment towards the medial malleolus and into the foot. Its terminal branch is the lateral calcaneal artery.

The angiosome concept
An angiosome is a three-dimensional functional unit of tissue fed by source arteries; the concept was initially coined by plastic surgeons concerned with optimizing skin flap viability.\textsuperscript{5} In vascular surgery, it has recently been proposed that revascularization should follow the ‘angiosome concept’, whereby the artery supplying an area of tissue loss should be the main target for endovascular treatment or distal anastomosis in bypass, rather than the traditional ‘best vessel’ approach. This allows blood flow to be delivered to the affected tissue, optimizing the chances of wound healing. There is conflicting evidence about its efficacy.

There are six angiosomes in the foot (Fig. 77.4) originating from the three major arteries and their branches: the anterior tibial artery becomes the dorsalis pedis, which supplies the dorsum of the foot; the posterior tibial artery feeds the plantar surface of the foot; and the fibular artery supplies the lateral ankle and heel. However, there are arterial–arterial interconnections between angiosomes, and wounds can also be healed by an indirect approach by revascularizing a connecting artery to an affected angiosome.
Veins

The venous system of the lower limb (Fig. 77.5) promotes the anti-gravity flow of blood back to the right side of the heart, facilitated by one-way valves. The superficial and deep veins are connected via perforating veins that penetrate the deep fascia.
FIG. 77.5 An overview of the veins of the anterior aspect of the lower limb. (From
The superficial venous system is variable in its configuration but it always includes the long and short saphenous veins lying in the subcutaneous tissues of the lower limb. There is free communication among the superficial veins. The deep venous system lies deep to the deep fascia; deep veins have more valves than superficial veins.

**Superficial veins**

The long saphenous vein passes anterior to the medial malleolus (where it can be accessed via a venous cut-down in an emergency) and up the medial side of the leg. It traverses the posterior border of the medial epicondyle of the femur at the knee, then runs anteriorly over the thigh and enters the saphenous opening in the fascia lata to join the femoral vein at the saphenofemoral junction (Fig. 77.6).
The long saphenous vein anastomoses freely with the short saphenous vein. The latter ascends posterior to the lateral malleolus, passes along the lateral border of the calcaneal tendon, inclines to the midline, penetrates the deep fascia between the heads of gastrocnemius and empties into the popliteal vein in the popliteal fossa (see Fig. 77.6). However, the short saphenous vein can extend into the posterior thigh as a distinct tributary that enters the long saphenous vein in the upper thigh; this is known as the Giacomini vein and it can contribute to chronic venous insufficiency.

Valvular insufficiency of the superficial system (most commonly at the saphenofemoral junction) can lead to venous hypertension and primary varicose veins. Deep venous thrombosis can also lead to (secondary) varicose veins due to chronic obstruction or insufficiency. This ‘post-thrombotic syndrome’ is associated with oedema, ulceration and lipodermatosclerosis. Secondary varicose veins can also result from trauma and pregnancy.

**Deep veins**

The dorsal venous arch of the foot gives rise to the anterior tibial vein, while the medial and plantar veins arise on the plantar aspect of the foot. These veins combine to form the posterior tibial and fibular veins, which accompany their named arteries in the leg. The anterior tibial, posterior tibial and fibular veins unite to form the popliteal vein on the posterior surface of the knee. The popliteal vein crosses posterior and lateral to the popliteal artery as it ascends through the popliteal fossa, enters the thigh with the popliteal artery via the adductor canal and becomes the femoral vein. The deep femoral vein drains the thigh muscles and related perforating veins, and then joins the femoral vein, which runs deep to the inguinal ligament (medial to the femoral artery) to become the external iliac vein. The external iliac vein joins the internal iliac vein to form the common iliac vein, which unites with its contralateral equivalent to form the inferior vena cava at the L5 vertebral level.

**Lymphatic drainage**
The distribution of lymphatic vessels in the lower limb is similar to that of the veins. The superficial lymphatics are arranged into medial and lateral groups. The medial lymphatics originate on the dorsum of the foot and follow the course of the long saphenous vein and drain into the inguinal nodes. The lateral lymphatics originate from the lateral surface of the foot and accompany the short saphenous vein; they either enter the popliteal nodes or join the medial lymphatics just inferior to the knee.

There are fewer deep lymphatics than superficial ones, and they accompany the deep veins of the leg. The flow of lymph from the legs towards the heart is aided by the calf muscle pump, which facilitates compression of the lymphatic vessels during contraction of the calf muscles. On muscle relaxation, lymphatic vessel valves close to prevent the retrograde flow of lymph.

The superficial and deep inguinal nodes are found in the femoral triangle, separated by the fascia lata. The superficial nodes form a T shape at the upper end of the long saphenous vein and are parallel with, and slightly inferior to, the inguinal ligament. They receive drainage from the legs, buttocks, lower abdominal wall and perineum, and can therefore be enlarged if any of these areas are affected by infection or malignancy. The superficial inguinal nodes drain into the deep inguinal nodes medial to the femoral vein and through the femoral canal into the external iliac nodes.

The deep inguinal nodes are found on the medial aspect of the femoral vein and drain the deep lower limb and the penis or clitoris. They send drainage to the superficial system via small lymph vessels.

In the popliteal fossa, the lymphatics accompanying the short saphenous vein enter the popliteal lymph nodes, which surround the popliteal vein. Lymph from the popliteal nodes ascends alongside the femoral vessels to empty into the deep inguinal nodes. Some lymph channels from the popliteal nodes accompany the long saphenous vein.
Surgical approaches and considerations

Core procedures and their common clinical use in the lower limb are summarized in Table 77.1.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Common clinical use</th>
<th>Overview of procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to the distal aorta and iliac vessels</td>
<td>Iliac artery aneurysms, vascular occlusive disease</td>
<td>Midline or transverse supraumbilical transperitoneal or retroperitoneal approach; no consensus as to which is better&lt;sup&gt;2,3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Exposure of the femoral vessels</td>
<td>Access to femoral vessels for vessel bypass surgery, endarterectomy, endovascular aneurysm repair, trauma</td>
<td>Vertical incision over palpable pulse (or at anatomical location of femoral artery). Alternative use of transverse or oblique incisions (particularly in obese patients) allows the femoral sheath to be accessed by sweeping fat medially and proximally. A transverse incision sits naturally in the inguinal crease and may be less vulnerable to wound breakdown; note that transverse and oblique incisions do not allow cranial or caudal extension if required. Once the femoral sheath is exposed, continue with vertical dissection to avoid the lymphatics. The deep femoral artery (profunda femoris artery) and femoral artery can be accessed via the subsartorial (Hunter’s) canal, which is useful in trauma, distal origin bypasses or popliteal artery aneurysm bypass requiring a more proximal origin</td>
</tr>
<tr>
<td>Access to the proximal popliteal artery</td>
<td>Lower limb arterial bypass; popliteal artery exclusion bypass</td>
<td>Incision on medial aspect of thigh, anterior to sartorius and medial to vastus medialis. Continue through the subcutaneous tissue and fascia, taking care to avoid the long saphenous vein and saphenous nerve, then incise the deep fascia longitudinally above sartorius to enter the popliteal fossa. The pulse of the popliteal artery is palpated against the posterior surface of the femur.</td>
</tr>
<tr>
<td>Access to the distal popliteal artery</td>
<td>Lower limb arterial bypass; popliteal artery exclusion bypass</td>
<td>Incision at the level of the tibial tuberosity, posterior to the medial border of the tibia; retract the medial head of gastrocnemius posteriorly to reveal the neurovascular bundle – the deepest structure is the popliteal artery</td>
</tr>
<tr>
<td>Approach to the anterior tibial artery</td>
<td>Lower limb arterial bypass</td>
<td>Usually, a lateral approach with a vertical incision midway between the tibia and fibula (one to two fingers’ breadths lateral to the tibia), down to the crural fascia and along the lateral border of tibialis anterior to enter the anterior compartment. The vessel lies immediately above the interosseous membrane</td>
</tr>
<tr>
<td>Access to the posterior tibial artery</td>
<td>Lower limb arterial bypass</td>
<td>Proximal access in the leg: a medial skin incision is made along the posterior edge of the tibia, then dissection carried out down through the superficial posterior compartment to retract the medial head of gastrocnemius posteriorly, followed by dissection of soleus and division of the posterior fascia. Follow the common trunk giving rise to the fibular artery distally to find the posterior tibial vessels between flexor digitorum longus and flexor hallucis longus in the deep posterior compartment of the leg. Beware of the venae comitantes that accompany the artery, as they can cause troublesome bleeding if not adequately controlled. Access in the distal leg: longitudinal incision posterior to the medial malleolus. Extend distally to access the plantar arteries</td>
</tr>
</tbody>
</table>
**Access to the fibular artery**

- **Lower limb arterial bypass**
  - Medial or lateral approach; medial approach can be difficult in large patients. A fibula-sparing lateral approach is possible using a lateral incision 2 cm behind the posterior margin of the middle third of the fibula, mobilizing the muscles of the lateral compartment, and retracting posteriorly to access the deep posterior compartment containing the vessels. Alternatively, resection of a segment of fibula may be required. Again, beware of the accompanying venae comitantes.

**Long saphenous vein harvest**

- **Conduit for lower limb arterial bypass**
  - When harvesting for lower limb or coronary artery bypass, the vein is usually marked preoperatively with duplex ultrasound. Where relevant, access the saphenofemoral junction through the incision already made to expose the femoral artery. Sequential bridging or continuous skin incisions are made directly over the course of the vein, ligating tributaries and leaving short stumps to avoid narrowing of the vein.

**Lower limb four-compartment fasciotomies**

- **Prevention or treatment of acute compartment syndrome**
  - Incisions should be at least 15–20 cm long. Anterolateral incision: to decompress the anterior and lateral compartments of the leg, the incision is made 3 cm distal to the tibial tuberosity, centred between the anterior border of the tibia and the body of the fibula, and extending to the lateral malleolus. Dissect to between the anterior and lateral compartments, then make a small incision in the fascia and extend into both the anterior and lateral compartments. Beware the superficial fibular nerve in the lateral compartment before releasing the fascia. Release the compartments, aiming for the lateral border of the patella and the centre of the ankle for the anterior compartment; aim for 5 cm distal to the head of the fibula and distally almost to the lateral malleolus for the lateral compartment. Posteromedial skin incision: used to decompress the superficial part of the posterior and deep part of the posterior compartments of the leg. It is begun one finger’s breadth posterior to the posteromedial border of the tibia. Identify and protect the long saphenous vein and saphenous nerve in the subcutaneous tissue near the anteromedial border of the tibia. Incise the fascia overlying gastrocnemius to access the superficial posterior compartment of the leg, extending the whole length of gastrocnemius and soleus. After dissecting the superficial part of the posterior compartment attachment off the tibia, identify the deep part of the posterior compartment distally in the calf, where flexor digitorum longus is found just posterior to the tibia. Incise along the entire length of the muscle, protecting the posterior tibial neurovascular bundle.

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**Tips and Anatomical Hazards**

Always ensure that a vein being harvested for bypass is marked using duplex ultrasound preoperatively before scrubbing. This will allow its suitability, location and course to be confirmed when the patient is anaesthetized and the leg is positioned appropriately for the procedure.

Fixed fascial compartments in the calf ensure that the deep veins are compressed during muscle contraction, aiding venous return to the
heart. However, injury to lower limb bones or muscles can cause swelling within the fixed compartments, raising the compartmental pressure and reducing muscle perfusion (acute compartment syndrome).

The saphenous nerve lies alongside the long saphenous vein and is at risk of injury during thermal ablation, stripping (particularly below the knee – the long saphenous vein should not be stripped distal to the knee) or venous cut-down. The short saphenous vein should not be stripped because the sural nerve is close to it and therefore at risk of iatrogenic injury.

Beware of lymph nodes when dissecting the proximal femoral artery and its branches because inadvertent disruption can cause lymphorrhoea or a lymphocele; vertical inguinal incisions cut through adipose tissue and lymphatics, and can encourage the formation of seroma or infection. There is almost always a vein crossing the femoral artery high in the inguinal region, just inferior to the inguinal ligament (deep circumflex iliac vein). This can be inadvertently avulsed during exposure of the femoral vessels by over-enthusiastic retraction, blind dissection, or tunnelling of prosthetic grafts deep to the inguinal ligament.

When the long saphenous vein is harvested for use as a bypass conduit, it is imperative to ensure that all of its tributaries are carefully ligated at the time of harvest. This can be challenging at flexion points such as the knee joint, or between skin bridges, as it can be difficult to identify and access small tributaries. However, bleeding from the tunnel following advancement of the graft (either from untied tributaries or from the vein graft itself) can be difficult to resolve, and can even remain unrecognized until the patient is extubated and regains a normal blood pressure.
References


Further Reading


Single Best Answers

1. A 50-year old female presents with a swelling in the left buttock, which she has had for the past 2 years, and with buttock pain of 6 months’ duration. Physical examination reveals a large, visibly pulsatile swelling in the left gluteal region, with an absent femoral artery pulse but a normal popliteal artery pulse. Which one of the following is the most likely diagnosis?

A. Schwannoma of the sciatic nerve
B. Subgluteal abscess
C. Persistent sciatic artery
D. Accessory gluteal muscle
E. Deep vein thrombosis of the inferior gluteal vein

**Answer: C.** In approximately 0.05% of the population, a persistent sciatic artery results from failure of the iliofemoral system to develop. The sciatic artery can be completely persistent from its origin at the internal iliac artery to the popliteal artery, or incomplete, with persistent collaterals to the internal iliac artery or popliteal artery. This can manifest as an absent femoral artery pulse with normal popliteal artery pulses, and can lead to atherosclerosis and aneurysm formation in the buttocks due to repeated trauma from sitting. Subsequent compression of the sciatic nerve (which is located adjacent to a persistent sciatic artery) can cause neurological symptoms.

2. A 23-year-old athlete presents with progressive pain and paraesthesia of her right calf when walking short distances. Physical examination reveals fullness of the right calf and the muscles appear hypertrophic. There is marked tenderness on palpation. A Buerger's test of the foot is positive with absent pulses. Which one of the following is the diagnosis?

A. Popliteal entrapment syndrome
B. Hypertrophy of the short head of biceps femoris
C. Popliteal artery aneurysm
D. Popliteal vein aneurysm
E. Schwannoma of the tibial nerve

**Answer: A.** Popliteal entrapment syndrome is a group of conditions that lead to compression of the popliteal artery, vein or tibial nerve in the popliteal fossa by surrounding musculoskeletal structures. It can be functional (when the medial head of gastrocnemius enlarges and compresses the structures) or anatomical (types I–V), resulting from anomalous development such as misplacement of the popliteal artery medial to the medial head of gastrocnemius (type 1) or other variants. Normally, the popliteal artery is formed and established in its anatomical location prior to attachment of the medial head of gastrocnemius to the medial femoral epicondyle (with the lateral head already attached to the lateral epicondyle). However, late development of the artery or early migration of the medial head of the muscle can result in the popliteal artery being impinged against the femur, causing ischaemic symptoms and/or a popliteal artery aneurysm. This tends to present much earlier in life than internal vascular disease.
Clinical Cases

1. A 27-year-old male is admitted with a painful pulsatile swelling in the left groin, with overlying skin compromise. He has a history of recent intravenous drug use in the left groin. A CT angiogram demonstrates a large pseudoaneurysm arising from the proximal common femoral artery, with active extravasation of contrast. He requires urgent haemorrhage control and will likely require a muscle flap to cover the skin defect.

A. Describe the anatomy of the femoral triangle and its relevance to this case.

The boundaries of the femoral triangle are:

- superior – inguinal ligament
- medial – medial border of adductor longus
- lateral – medial border of sartorius

The femoral triangle contains (from lateral to medial), the lateral cutaneous nerve of the thigh, femoral nerve, femoral sheath. The femoral sheath contains (from lateral to medial), the femoral branch of the genitofemoral nerve, the femoral artery, the femoral vein and the deep inguinal lymph nodes. The femoral vein may be a target for intravenous drug use, but its position immediately adjacent to the femoral artery leaves the artery vulnerable to inadvertent injury. This may result in a femoral artery pseudoaneurysm or, rarely, an arteriovenous fistula.

B. Describe the approach to gaining proximal and distal control.

Given that the pseudoaneurysm arises from the proximal common femoral artery, proximal control may best be achieved by isolating the external iliac artery in the pelvis via an extraperitoneal approach. This can include the extension of a standard vertical groin incision into a Rutherford Morrison incision:

- Make a vertical incision at the midpoint of the inguinal ligament (proximal to the pulsatile mass)
and extend this cranially to allow more proximal control, as a ‘hockey stick’ oblique curvilinear muscle-splitting incision.
• Extend the incision proximally and curve it laterally if it extends above the iliac crest.
• Continue dissection down to external abdominal oblique and divide it in this plane, along with internal abdominal oblique, transversus abdominis and rectus abdominis.
• Protect the peritoneal contents by manually elevating the anterior abdominal wall.
• Ensure that your plane lies lateral to the internal inguinal ring, in order to avoid spermatic cord structures.
• Sweep the peritoneum and its contents medially to expose the iliac vessels and control them with slings. Pass a curved forceps, such as a Lahey, from medial to lateral to avoid inadvertently damaging the vein. The external iliac artery may now be controlled with a vascular clamp.
• Beware of the ureter, which lies anterior to the internal iliac artery in the pelvis.

Distal control could include either the common femoral artery distal to the pseudoaneurysm, if there is sufficient length of undamaged artery or, more likely, will require isolation and control of the superficial femoral artery and deep femoral (profunda femoris) artery:

• Continue your vertical incision caudally until the
common femoral artery is identified distal to the pseudoaneurysm.
• Pass a curved forceps (e.g. Lahey) from medial to lateral and control the common femoral artery with a vessel loop.
• If required, continue the dissection distally to expose the superficial femoral artery and the deep femoral artery, controlling any branches with heavy silk ties and the major arteries with slings.

C. Describe the anatomy of the sartorius muscle and outline the use of sartorius myoplasty or transposition to cover an infected groin.

Sartorius is the longest muscle in the body and is an important flexor and rotator of the thigh at the hip joint. It arises from the anterior superior iliac spine and descends obliquely across the hip joint and thigh, running medially and inferiorly towards the medial aspect of the knee. It is inserted on the pes anserinus on the medial aspect of the tibial tuberosity. Sartorius is innervated by the femoral nerve (L2–4). It receives segmental blood supply from branches of the superficial circumflex iliac, lateral femoral, profunda femoris, descending geniculate and superficial femoral arteries. Many branches enter the muscle at its posteromedial aspect, and therefore care must be taken during full transposition.

Myoplasty is the simpler of the muscle flap techniques, but is not suitable for wounds requiring major debridement or coverage up to the inguinal ligament. A transposition should be used instead: this technique includes a risk of muscle ischaemia due to disruption to the arterial branches that supply the muscle from its posteriomedial aspect.

Myoplasty: divide the enveloping fascia of sartorius longitudinally and allow herniation of its muscle fibres. Mobilize the muscle to the medial aspect of the femoral triangle and secure it with interrupted sutures.

Transposition: detach sartorius from its origin at the anterior superior iliac spine and transpose the muscle medially to cover the entire groin. Secure it with interrupted sutures.
2. A 39-year-old female suffers blunt trauma to the right popliteal fossa. Her right leg is cold, pale, pulseless and paralysed. There is no sign of active bleeding but you suspect an arterial injury and take her to theatre.

A. Describe the anatomy of the popliteal fossa.
The boundaries of the popliteal fossa are:

- Superomedial: semimembranosus and semitendinosus
- Lateral: biceps femoris
- Inferior: medial and lateral heads of gastrocnemius

Contents (from superficial to deep), are the tibial nerve, common fibular nerve, popliteal vein, popliteal artery, small saphenous vein, lymph nodes.  
B. Describe the posterior approach to popliteal artery exploration.

- With patient supine, externally rotate the leg and flex the knee to 30°.
- Make a medial longitudinal incision starting at the anterior border of sartorius in the medial distal thigh and extend it posteriorly to the posterior knee joint, finishing approximately 1 cm behind the posterior border of the proximal tibia.
- Avoid the great saphenous vein in the distal third of the incision.
- Retract sartorius and gracilis posteriorly and vastus medialis anteriorly to expose the proximal popliteal vessels.
- The popliteal artery will be found deep to the nerves and the popliteal vein.
Innervation of the lower limb and nerve blockade techniques

Andrew C Vivas, Juan S Uribe

Core procedures

Nerve Blockade

Lateral Hip Exposure

- Hip arthroscopy
- Hip arthroplasty

Knee Surgery

- Knee arthroscopy
- Knee arthroplasty
- ACL repair

Foot and Ankle Surgery
Surgical surface anatomy

Nerve blockades best illustrate important surgical landmarks of the lumbosacral plexus (LSP) and its branches. Lumbar plexus and sciatic nerve blockade can be used to achieve near-total anaesthesia of the lower limb, either via a single injection or through placement of catheters for continuous, prolonged analgesia. Anaesthetic blockade can be initiated at the level of the lumbar plexus, the level of gluteus maximus, inferior to gluteus maximus, within the popliteal fossa, or at the ankle.

Lateral retroperitoneal approach

The LSP is housed within psoas major in the retroperitoneal space. The retroperitoneum is usually entered from a lateral or ventrolateral approach (Fig. 78.1), though it can also be entered through a transperitoneal approach or, rarely, through a prone dorsal approach. The surface boundaries of the lateral approach include the twelfth rib superiorly, the iliac crest inferiorly, the edge of erector spinae dorsally and the lateral edge of rectus abdominis (linea semilunaris) ventrally (Fig. 78.2).
FIG. 78.1 Imaging of the lumbar spine. **A**, A lateral MRI. **B**, A corresponding axial T2-weighted MRI. The yellow arrow shows the operative trajectory that is typical for oblique lumbar interbody fusion, between the great vessels and psoas major. The teal arrow shows the trajectory of the transpsoas approach to the spine, which traverses psoas major and the lumbosacral plexus (LSP). The pink arrow demonstrates the trajectory of posterior or posterolateral approaches to the retroperitoneum and LSP. This is also the trajectory of the needle for lumbar plexus blockade. The green asterisk shows one of the branches of the lumbar plexus in the axial plane as it courses through psoas major.
FIG. 78.2 A lateral view showing the pertinent superficial landmarks for lateral retroperitoneal exposure of the lumbosacral plexus. The boundaries of the lateral approach are the twelfth rib superiorly, the linea semilunaris ventrally, erector spinae posteriorly, and the iliac crest inferiorly. Note that retroperitoneal surgical exposure is typically performed posterior to the anterior axillary line.

Lumbar plexus anaesthetic blockade surface landmarks

Psoas major can be targeted from a posterior trajectory with the patient in a
lateral decubitus position to achieve lumbar plexus nerve blockade (Fig. 78.3). The pertinent landmarks are the spinous processes of the lumbar spine, which mark the midline of the patient, and the iliac crest. A line drawn 4 cm lateral to the intersection of the iliac crest and the midline spinous process marks the needle insertion site; nerve-stimulating needles are inserted perpendicular to the skin plane and advanced until quadriceps femoris contracts (stimulation of the femoral nerve). If the transverse process is contacted *en route*, the needle can be ‘walked off’ either superiorly or inferiorly, approximately 2 cm deeper, to enter psoas major.
FIG. 78.3  A posterior view of the back, showing the surface landmarks for lumbar plexus blockade. The entry point is approximately 3–4 cm off the midline, perpendicular to a line connecting the iliac crest and the spinous processes of the lumbar spine. This is generally in the same plane as the posterior superior iliac spine from a medial to lateral standpoint.

**Femoral nerve blockade**

The femoral nerve lies lateral to the femoral artery, superficially within the inguinal crease. An anterior branch of the femoral nerve, which innervates
sartorius, is encountered first. Stimulation elicits contraction of sartorius along the medial aspect of the thigh. To achieve anaesthesia throughout the femoral nerve distribution, the needle should be redirected laterally without withdrawal and advanced until the patella twitches, indicating stimulation of the muscular branches that innervate the quadriceps femoris.

Sciatic nerve blockade

The sciatic nerve can be blocked at several levels, depending on the distribution of required anaesthesia. A traditional sciatic blockade (classic approach of Labat) blocks the nerve as it exits the greater sciatic foramen inferior to piriformis and begins its descent between the greater trochanter and ischial tuberosity. This is achieved from a posterior transgluteal approach and is based on the relationship of the posterior superior iliac spine to the greater trochanter with the patient in a modified Sims’ position. The sciatic nerve can also be accessed from a supine subgluteal or an anterior approach. Popliteal sciatic, lateral popliteal and ankle blockades allow more specific lower-extremity regional anaesthesia to be achieved.
Clinical anatomy

Nerves of the lumbosacral plexus and innervation of the lower limb

The LSP innervates the muscles of the pelvic girdle and gives rise to the sciatic nerve, the largest nerve supplying the lower limb (Fig. 78.4; Ch. 76). Most of the nerves that form the LSP are mixed motor and sensory nerves. The intrinsic motor branches to psoas major are motor nerves, while the lateral femoral cutaneous nerve is a cutaneous nerve (Videos 78.1–78.3).
Exposure and protection of the lumbosacral plexus en route to the lateral lumbosacral spine

The most direct approach to psoas major (and the LSP) is laterally via a retroperitoneal approach. The retroperitoneum is entered by traversing the
lateral abdominal wall musculature (from superficial to deep, this is formed by the external and internal abdominal oblique muscles and transversus abdominis) and the transversalis fascia. Care is needed when these layers are surgically dissected because nerves, some of which are derived from the lumbar plexus, course between the internal abdominal oblique and transversus abdominis. Once the transversalis fascia is opened, the retroperitoneal space is encountered.

Within the retroperitoneal space, quadratus lumborum can be palpated posterolaterally and can be followed medially until the transverse processes of the lumbar vertebrae are encountered. Ventrally, the peritoneal cavity can be retracted forward. Anteromedial to quadratus lumborum lies psoas major, overlying the lumbar portion of the LSP.

**Psoas major**

Psoas major originates from the anterolateral aspect of the lumbar vertebral bodies, their transverse processes and their intervening disc spaces. It descends anterolaterally, deep to the inguinal ligament and anterior to the capsule of the hip joint, and converges to a tendon that, having received nearly all the fibres of iliacus on its lateral side, inserts on to the lesser trochanter of the femur.

**Lumbar plexus within psoas major and the ‘safe working zone’**

The LSP lies posterior to, and many of its branches course within, psoas major. It is most dorsally positioned at the posterior end-plate of L1/2 with a general trend towards progressive ventral migration down to the level of L4/5. The vertebral body can be divided into four zones when approached through psoas major. Safe anatomical zones for avoiding nerve injury when psoas major is dissected can be found at each level (Fig. 78.5). The genitofemoral nerve pierces psoas major and then travels along its ventral surface. The femoral nerve is most at risk in the lower dorsal portions of the muscle (particularly at the L3–4 and L4–5 disc levels). Fig. 78.6 illustrates the position of the nerves within psoas major with the muscle removed.
FIG. 78.5 Safe anatomical zones within psoas major. There are four quartiles, I–IV, from anterior to posterior. The open circles indicate a ‘safe zone’ for placement of the surgical retractor and for subsequent exposure. From L1/2 to L3/4, the posterior third is generally safe. At L4/5, placement at the midpoint between zones II and III is generally safe since this will decrease the risk of injuring the femoral nerve.
Anatomical variants

The lumbar plexus is generally formed from T12 (often) to L4, but there are prefixed and postfixed variants that begin more cephalad or caudad,
respectively. In these cases, the furcal nerve originates higher or lower than expected.

**Tips and Anatomical Hazards**

Anatomical hazards include the ureter, genitofemoral nerve, femoral nerve, sympathetic trunk, inferior vena cava, abdominal aorta, and iliac arteries and vein.

Avoid monopolar diathermy during the retroperitoneal approach to the lumbar spine, as this can injure distal peripheral branches of the lumbar plexus coursing through the abdominal wall.

Minimize compression, tension and retraction of psoas major and the LSP to avoid neural injury.

The lumbar sympathetic trunk is found at the ventral aspect of the lumbar spine lateral to the great vessels. Injury to the sympathetic trunk can lead to retrograde ejaculation.

**Proper positioning to prevent iatrogenic injury to the LSP**

When positioning patients prone or decubitus, operators should adequately pad and offload pressure from the anterior superior iliac crests. The lateral femoral cutaneous nerve can otherwise be compressed, leading to meralgia paraesthetica.

Avoid placing the patient in lateral flexion (that is, ‘breaking the table’), which stretches the ipsilateral psoas major and LSP, and can lead to injury.

**Preserving neural elements during approach**

Use of blunt dissection to traverse the lateral abdominal wall, as opposed to monopolar diathermy, can prevent injury to the nerve branches that course between the internal oblique and transversus abdominis. Branches encountered during dissection can be mobilized without causing direct injury.\(^6\)

The lumbar sympathetic trunk, found on the anterolateral aspects of the
lumbar vertebrae along the medial margin of psoas major, passes posterior to the common iliac vessels. On the right side, it is posterior to the inferior vena cava, while on the left, it is posterior to the lateral aortic nodes. These structures must be preserved, as injury to the sympathetic trunk can lead to retrograde ejaculation.

**Mobilizing LSP and psoas major**

When psoas major or the nerves of the LSP are mobilized, retraction dorsally (in the direction of the contributory nerve roots) is better tolerated than mobilization in the ventral direction. Over-distraction of retractors, or translation of retractors anteriorly while within psoas major, can lead to avulsion or traction injuries of the LSP. Compression or retraction of the nerves should be minimized: there is a direct correlation between the amount of time the nerve is under tension and the incidence of neurological injury.
References


Single Best Answers

1. Which one of the following nerves of the lumbosacral plexus courses over the anterior (ventral) aspect of psoas major?
   A. Ilio-inguinal nerve
   B. Iliohypogastric nerve
   C. Femoral nerve
   D. Sciatic nerve
   E. Genitofemoral nerve

   Answer: E. The genitofemoral nerve is the only branch of the lumbar plexus to course over the anterior (ventral) surface of psoas major.

2. Which one of the following options best describes the relationship of the femoral nerve to the femoral artery and vein from lateral to medial in the femoral triangle?
   A. Nerve, artery, vein
   B. Nerve, vein, artery
   C. Vein, nerve, artery
   D. Vein, artery, nerve
   E. Artery, nerve, vein

   Answer: A. In the femoral triangle, the femoral nerve is lateral to the femoral artery and the femoral artery is lateral to the femoral vein.

3. Which one of the following is the only pure motor nerve of the lumbosacral plexus?
   A. Femoral nerve
   B. Lateral femoral cutaneous nerve
   C. Sciatic nerve
D. Psoas major motor branches
E. Common fibular nerve

**Answer: D.** Direct branches of the lumbar plexus that innervate psoas major are motor only.

4. Which one of the following nerve blockades is commonly used to achieve near-total anaesthesia of the lower limb?
   A. Lumbar plexus blockade
   B. Femoral nerve blockade
   C. Sciatic nerve blockade
   D. Tibial nerve blockade
   E. Both A and C

**Answer: E.** In order to achieve complete anaesthetic blockade of the lower limb, a lumbar plexus and a sciatic nerve anaesthetic must be administered.
Clinical Case

1. A 53-year-old male undergoes lateral retroperitoneal exposure for lumbar interbody fusion. Postoperatively, he wakes up with numbness and paraesthesia along the anterior and anterolateral aspects of his thigh. Physical examination reveals pain and limitation in hip flexion. Knee flexion, knee extension, plantar flexion, dorsiflexion and great toe extension are all full strength. Sensation is otherwise intact.

   A. Given the distribution of the sensory deficit, what is the likely nerve injury?
      Lateral femoral cutaneous nerve injury. Injury to any other branch of the lumbar plexus would result in muscle weakness on physical examination.

   B. What is the course of the lateral femoral cutaneous nerve within the pelvis after it exits the lateral border of psoas major?
      After emerging from the lateral border of psoas major at approximately L4, the nerve courses obliquely across iliacus toward the anterior superior iliac spine. Within the iliac fossa, the right lateral femoral cutaneous nerve passes posterolateral to the caecum, while the left lateral femoral cutaneous nerve passes posterior to the descending colon. Both nerves then course either through or below the inguinal ligament, approximately 1 cm medial to the anterior superior iliac spine.

   C. What motor deficit would be expected if the patient suffered from a femoral nerve injury?
      Isolated femoral nerve injury would present with profound deficits in knee extension. There would be some weakness with hip flexion and a diminished knee jerk reflex would be expected.
# Pelvic girdle

*R Shane Tubbs, Jens Chapman*

## Core Procedures

- Femoral hernia repair
- Saphenofemoral exposure for endarterectomy, embolectomy, bypass, and endovascular repair of aneurysms
- Exposure/puncture of femoral artery/vein
- Open reduction internal fixation for fractured acetabulum/femur
- Above-knee amputation
- Gluteal approach for hip replacement
Pelvis and gluteal region

Surgical surface anatomy

The summit of the iliac crest is level with the fourth lumbar vertebral body in adults and with the fifth vertebral body in children aged up to 10 years. The sciatic nerve is more or less at the midpoint between the ischial tuberosity and the greater trochanter of the femur (Fig. 79.1). The proximal border of the greater trochanter lies approximately a hand's breadth below the iliac tubercle, level with the centre of the head of the femur. The femoral artery is at a mid-inguinal position between the anterior superior iliac spine and pubic tubercle; the femoral nerve and femoral vein lie lateral and medial to this vessel, respectively (see Fig. 79.3). The lateral femoral cutaneous nerve most commonly travels a finger's breadth medial to the anterior superior iliac spine.
Clinical anatomy

The pelvic girdle consists of the paired hip bones, which articulate anteriorly at the pubic symphysis and posteriorly at the sacro-iliac joint. The gluteal region is demarcated by the gluteal fold inferiorly, a line joining the greater
trochanter to the anterior superior iliac spine laterally, the iliac crest superiorly and the midline medially. It contains a large skeletal muscle mass that covers several vulnerable neurovascular structures and incorporates junctional zones between the lower limb, pelvis and perineum at the sciatic foramina. Surgery to this region can injure the sciatic nerve and the gluteal nerves and vessels (see Fig. 79.1; Video 79.1); a posterior (gluteal) approach is commonly used to operate on the hip joint.²

**Sciatic foramina**

Knowledge of the sciatic foramina is key to understanding the gluteal region and, in particular, its neurovascular supply. These foramina lie deep to gluteus maximus, which some have viewed as the ‘pelvic deltoid’. The greater sciatic foramen is bounded anterosuperiorly by the greater sciatic notch, posteriorly by the sacrotuberous ligament and inferiorly by the sacrospinous ligament and ischial spine. It is partly filled by the emerging piriformis (see Fig. 79.1), above which the superior gluteal vessels and nerve leave the pelvis. The inferior gluteal vessels and nerve, internal pudendal vessels and pudendal nerve, sciatic and posterior femoral cutaneous nerves, and the nerves to obturator internus and quadratus femoris all leave the pelvis below it.³ The undivided sciatic nerve can emerge above or through piriformis. The major divisions of this nerve can lie on either side of the muscle, or (the most common variant) one division passes between the heads of the divided muscle and the other either above or below it.

The lesser sciatic foramen is bounded anteriorly by the body of the ischium, superiorly by its spine and sacrospinous ligament, and posteriorly by the sacrotuberous ligament. It transmits the tendon and the nerve to obturator internus, the internal pudendal vessels and the pudendal nerve.

**Perforators and skin flaps**

The gluteal region has an average of 21 perforators, which arise from three main source arteries: the superior and inferior gluteal and the internal pudendal.³ The flaps based on these perforators can be used as free flaps for breast reconstruction and as local flaps for covering defects in the sacral and perineal regions.
Tips and Anatomical Hazards

Any surgery to the hip region in children can injure the growth plate, resulting in abnormal proximal femoral development. If there are fractures involving the epiphysis, expeditious restoration of normal bony alignment is essential in order to minimize the risk of subsequent abnormal growth.

The blood supply to the head of the femur is derived from an arterial ring around the neck, just outside the attachment of the fibrous capsule, comprising the medial and lateral circumflex femoral arteries with minor contributions from the superior and inferior gluteal vessels. From this ring, ascending branches pierce the capsule to ascend the neck beneath the reflected synovial membrane (Fig. 79.2). These vessels become the retinacular arteries and form a subsynovial intracapsular anastomosis. Here they are at risk from a displaced fracture of the neck of the femur. If the fracture is intracapsular, not only is the intraosseous blood supply disrupted but also the retinacular vessels are vulnerable. If the fracture is extracapsular, the retinacular vessels will remain intact and avascular necrosis of the head of the femur is much less likely.

Thigh

Clinical anatomy

Perforators and skin flaps

The hip and thigh regions have six source arteries and an average of 50 arterial perforators. The thigh can be divided into four areas: anteromedial; anterolateral and trochanteric; posteromedial; and posterolateral. The perforators that supply the anteromedial thigh are derived from the femoral artery and those for the anterolateral thigh from branches of the lateral circumflex femoral artery. Perforators that supply the skin over the posteromedial and posterolateral thigh regions are derived from the deep artery of the thigh and the popliteal artery.

Skin flaps based on the superficial circumflex iliac, superficial external pudendal and superficial inferior epigastric arteries have been used as local flaps, tube pedicles and free tissue transfers (see Fig. 79.3). Other popular skin flaps are tensor fasciae latae (TFL) perforator flaps, anterolateral thigh (ALT) and anteromedial thigh (AMT) flaps, the gracilis perforator flap and posterior thigh flaps.  

Muscles

There are three functional groups of muscle in the thigh: anterior (extensor), posterior (flexor) and medial (adductor). Apart from the adductor muscles, these groups are separate osteofascial compartments limited peripherally by the fascia lata and separated from each other by the femur and the medial and lateral intermuscular septa. Adductor magnus, adductor longus and pectineus could each be considered constituents of two compartments: adductor magnus in the posterior and medial compartments, and adductor longus and pectineus in the anterior and medial compartments.

Femoral sheath and related structures

Key to repairing femoral hernias is knowledge of the femoral sheath, a funnel-shaped distal prolongation of the extraperitoneal fascia, formed from the transversalis fascia anterior to the femoral vessels and from the iliac fascia posteriorly (Fig. 79.3). It is wider proximally and its tapered distal end fuses with the vascular adventitia 3–4 cm distal to the inguinal ligament. It is shorter at birth. The medial wall slopes laterally and is pierced by the long
saphenous vein and lymphatic vessels.

**FIG. 79.3** A, An anterior view of the proximal thigh and pelvic girdle. The fascia lata inferior to the inguinal ligament is cut and reflected to illustrate the continuation of the iliac fascia. A window has been opened in the iliac fascia so that the femoral nerve is seen. The femoral triangle is outlined. B, Following dissection into the femoral sheath, its contents are seen. (From K.L. Moore, A.F. Dalley, A.M.R. Agur, Clinically Oriented Anatomy, seventh ed. Lippincott Williams and Wilkins, 2013, Fig. 5.28A and B, p. 552.)

Three compartments are described: a lateral one containing the femoral artery, an intermediate one for the femoral vein, and a medial compartment, the femoral canal, which contains lymph vessels and an occasional lymph node embedded in areolar tissue (see Fig. 79.3). The canal is conical and approximately 1.25 cm long. Its proximal (wider) end, termed the femoral ring, is bounded in front by the inguinal ligament, behind by pectineus and its fascia and the pectineal ligament, medially by the crescentic, lateral edge of the lacunar ligament, and laterally by the femoral vein. The spermatic cord, or the round ligament of the uterus, is just above its anterior margin, while the inferior epigastric vessels are near its anterolateral rim. The ring is filled with condensed extraperitoneal tissue, the femoral septum, which is
covered on its proximal aspect by the parietal peritoneum.

**Vascular supply and innervation**

The nerve supplies to the compartments of the thigh more or less follow the ‘one compartment – one nerve’ principle. Thus, the femoral nerve supplies the muscles in the anterior compartment, the obturator nerve those in the medial compartment, and the sciatic nerve those in the posterior compartment (tibial nerve to the hamstring muscles less the short head of biceps femoris and part of adductor magnus) (Fig. 79.4). The femoral nerve divides soon after entering the anterior compartment of the thigh beneath the inguinal ligament. The obturator nerve enters the medial thigh proximally and medially from the pelvis and divides into its main branches, which run anterior and posterior to adductor brevis.
Branches of the femoral artery and the deep artery of the thigh are the main suppliers to the skin of the thigh distal to the inguinal ligament and
gluteal fold. All groups receive a supply from the femoral artery system, particularly from the deep artery of the thigh and its branches. The adductor muscles receive a contribution from the obturator artery and the hamstrings receive a proximal supply from the inferior gluteal artery.

The external iliac artery continues below the inguinal ligament as the femoral artery, which is accessed for percutaneous or open vascular procedures. Surgical control of this vessel is necessary for femoral cutdown for delivery of aortic endografts, femoral endarterectomy and bypass procedures (aortobifemoral, axillobifemoral, femorofemoral, infra-inguinal). It descends along the anteromedial part of the thigh in the femoral triangle (see below), enters and passes through the adductor (subsartorial) canal, and becomes the popliteal artery as it passes through an opening in adductor magnus near the junction of the middle and distal thirds of the thigh. Its first 3–4 cm are enclosed in the femoral sheath, along with the femoral vein. The femoral artery gives off several branches in the proximal thigh, including the superficial epigastric, superficial circumflex iliac, superficial external pudendal, deep external pudendal and deep artery of the thigh. It gives off the descending genicular artery within the adductor canal.

Anterior to the artery in the femoral triangle are the skin, tela subcutanea, superficial inguinal nodes, fascia lata, femoral sheath, superficial circumflex iliac vein (crossing in the tela subcutanea) and the femoral branch of the genitofemoral nerve. Near the apex of the triangle, the medial femoral cutaneous nerve crosses in front of the artery from the lateral to the medial side. Posteriorly, the posterior wall of the femoral sheath separates the artery from the tendons of psoas major, pectineus and adductor longus. The artery is separated from the hip joint by the tendon of psoas major, from pectineus by the femoral vein and deep femoral vessels, and from adductor longus by the femoral vein. Proximally, the nerve to pectineus passes medially behind the artery. The femoral vein is medial to the artery in the proximal part of the triangle and becomes posterior distally at the apex.

Within the adductor canal, the femoral artery is covered by skin, tela subcutanea and fascia musculorum, sartorius, and the fibrous roof (subsartorial fascia) of the canal. The saphenous nerve lies at first lateral, then anterior and finally medial to the artery. Adductor longus and adductor magnus are posterior; vastus medialis and its nerve are anterolateral; the femoral vein is also posterior proximally but becomes lateral distally.
Femoral triangle

The femoral triangle (Scarpa's triangle) is a depressed intermuscular space in the anteromedial aspect of the proximal thigh, lying immediately distal to the inguinal ligament (see Fig. 79.3). The latter constitutes the base of the femoral triangle's outline. Its lateral boundary is the medial margin of sartorius, its medial boundary the medial margin of adductor longus, and its distal extremity, the apex, is where sartorius overlaps adductor longus. Its floor is provided laterally by iliacus and psoas major, and medially by pectineus and adductor longus. Its roof is the overlying fascia lata. The femoral vessels, passing from mid-base to apex, are in the deepest part of the triangle. Lying lateral to the artery and outside the femoral sheath is the femoral nerve, which divides into multiple branches on entering the femoral triangle.

Lymphatic drainage

The triangle also contains fat and lymph nodes. The superficial inguinal nodes form proximal and distal groups. The proximal group usually consists of five or six nodes just distal to the inguinal ligament. Its lateral members receive afferent vessels from the gluteal region and the adjoining infra-umbilical anterior abdominal wall. Medial members receive superficial vessels from the external genitalia (including the inferior vagina), inferior anal canal and peri-anal region, adjoining abdominal wall, umbilicus and vessels accompanying the round ligament. The distal group usually consists of four or five nodes along the termination of the long saphenous vein. They receive all the superficial vessels of the lower limb, except those from the posterolateral calf. All superficial inguinal nodes drain to the external iliac nodes, some via the femoral canal and others anterior or lateral to the femoral vessels. Numerous vessels interconnect the individual nodes.

The proximal inguinal nodes are almost invariably affected in malignant or infective diseases of the prepuce, penis, labia majora, scrotum, perineum, anus and distal vagina, or in diseases affecting the skin and superficial structures in these regions, in the infra-umbilical part of the abdominal wall or in the gluteal region. The distal group is implicated only in disease or injury to the limb.

There are 1–3 deep inguinal nodes, situated medial to the femoral vein. One lies just distal to the saphenofemoral junction, another in the femoral canal, and the most proximal node lies laterally in the femoral ring. The
middle node is the most inconstant and the proximal node is often absent. All receive deep lymphatics that accompany the femoral vessels, lymph vessels from the glans penis or clitoris, and a few efferents from the superficial inguinal nodes. Their own efferents traverse the femoral canal to the external iliac nodes. Numerous lymph vessels that connect the deep inguinal to the external iliac lymph nodes traverse the femoral septum.

**Adductor canal**

The adductor canal (Hunter's canal; subsartorial canal) begins at the apex of the femoral triangle and extends distally as far as the distal attachment of the tendon of adductor magnus. It is bounded anterolaterally by vastus medialis, posteromedially by adductor longus, and distal to adductor longus by adductor magnus. Its anteromedial boundary (often referred to as the roof) is a strong and dense fascia that extends from the medial surface of vastus medialis to the medial edge of adductors longus and magnus, overlapping in its reach the femoral vessels in the adductor canal. The canal contains the femoral artery and vein, the descending genicular and muscular branches of the femoral artery and their corresponding venous tributaries, the saphenous nerve, and the nerve to vastus medialis (until it enters its muscle). The femoral vessels pass from the adductor canal into the popliteal fossa via the adductor hiatus, an opening in the tendon of adductor magnus adjacent to the body of the femur, two-thirds of the way down the adductor canal.

**Tips and Anatomical Hazards**

The lateral femoral cutaneous nerve can become entrapped at three sites along its course: close to the vertebral column; within the abdominal cavity as the nerve travels across the pelvis; and as it leaves the pelvis. This last location is the most common site of nerve injury; entrapment is thought to occur as the nerve passes through or deep to the inguinal ligament just medial to the anterior superior iliac spine. The angulation of the nerve as it crosses the iliac crest makes it vulnerable to compression during movement: for example, hip extension can increase the angulation and tension on the nerve. Surgical bolsters should be placed under the anterior superior iliac spines during prone operations to avoid compression of the lateral femoral cutaneous
Injury produces an area of impaired sensation in the distal cutaneous distribution of the lateral femoral cutaneous nerve, often with pain and paraesthesia on the anterolateral aspect of the thigh (meralgia paraesthetica). This area does not extend across the midline of the thigh anteriorly, or below the knee, or behind the hamstring tendons laterally. The posterior branch of the lateral femoral cutaneous nerve, which supplies a thin strip of skin from the greater trochanter of the femur down to about two-thirds of the way to the knee, can be affected separately. This branch leaves the main trunk of the nerve, usually distal to the inguinal ligament, and then turns laterally to pierce tensor fasciae latae.

Isolated lesions of the obturator nerve are extremely rare but occasionally result from direct trauma (sometimes during parturition) anterior dislocations of the hip. The nerve can also be injured by an obturator hernia, or be involved together with the femoral nerve in retroperitoneal lesions close to their origins from the lumbar plexus. Compression of the nerve by herniated bowel loops at the obturator foramen can result in referred hip, medial thigh or knee pain, the so-called Howship–Romberg sign.

During gluteal approaches to the hip, the sciatic nerve can be moved farther from the surgical field by rotating the hip medially and thus putting the short lateral rotator muscles on stretch.

The attachment of piriformis to the greater trochanter is a surgical landmark for the insertion of certain types of intramedullary rods into the femur as the bone is perforated just medial to it.

Splitting gluteus maximus close to its lateral insertion precludes the risk of denervating significant parts of the muscle because the main nerve supply travels medial to this point.

On fluoroscopy, the proximal femoral artery overlies the medial two-thirds of the head of the femur.

The deep femoral artery usually arises from the femoral artery 3–5 cm inferior to the inguinal ligament in a posterolateral direction.

The femoral vein is catheterised 2–3 cm inferior to the inguinal ligament and medial to the femoral artery. If a femoral artery pulse is difficult to discern, the two vessels can be differentiated by the ease of compression of the vein with an ultrasound probe.

The inguinal ligament lies 2–3 fingers’ breadths cephalad to the inguinal
crease. This should be considered when the underlying femoral artery is located, so that inadvertent puncture of the external iliac artery, with potential bleeding into the retroperitoneum, can be avoided.\textsuperscript{6} The sciatic nerve can be compressed by the posterior blade of a self-retaining retractor used to split gluteus maximus during posterior approaches to the hip. Femoral hernias are more likely to become incarcerated or strangulated because of their anatomical location and more ridged boundaries. Owing to its abundant blood supply, quadratus femoris must be carefully dissected during posterior approaches to the hip in order to maintain haemostasis. The suprapatellar bursa is found about three fingers’ breadths superior to the proximal edge of the patella.\textsuperscript{6}
References

Single Best Answers

1. Three years after a hip replacement, for a 62 year old male CT imaging indicates that two of the patient's larger hip muscles have been replaced by adipose tissue. The opinion is offered that his superior gluteal nerve could have been injured during the replacement procedure, and the muscles supplied by that nerve have atrophied and been replaced by fat. Which one of the following muscles receives its innervation from the superior gluteal nerve?
   A. Tensor fasciae latae
   B. Rectus femoris
   C. Gluteus maximus
   D. Piriformis
   E. Quadratus femoris

   **Answer: A.** The superior gluteal nerve innervates gluteus medius, gluteus minimus and tensor fasciae latae. Injury to this nerve would result in atrophy of these muscles.

2. Which one of the following muscles forms the lateral portion of the floor of the femoral triangle?
   A. Adductor longus
   B. Iliopsoas
   C. Sartorius
   D. Pectineus
   E. Rectus femoris

   **Answer: B.** As iliacus and psoas major pass below the inguinal ligament to form iliopsoas, this muscle forms the lateral aspect of the floor of the femoral triangle. The medial floor of this triangle is formed by pectineus.
3. After being diagnosed with an acetabular fracture, a 45-year-old male is taken to the operating theatre for fracture repair. During the postoperative neurological examination, the surgeon notices loss of sensation to the skin of the inferior half of the buttocks, and of the posterior and upper medial thigh. The patient had a normal neurovascular examination preoperatively. Which one of the following nerves is mostly likely to have been injured during the operation?

A. Posterior femoral cutaneous nerve  
B. Obturator nerve  
C. Sciatic nerve  
D. Femoral nerve  
E. Lateral femoral cutaneous nerve

**Answer:** A. The skin of the posterior thigh is supplied by the posterior femoral cutaneous nerve. This nerve also gives rise to the inferior clunial nerves, which supply the skin over the lower edge of gluteus maximus.

4. Which one of the following options best describes a sinking of the pelvis on the unsupported side when a patient tries to stand on the affected limb, and can be due to paralysis of the gluteal muscles, developmental dysplasia of the hip or coxa vara?

A. Trendelenburg sign  
B. Scarpa's sign  
C. Poupart's sign  
D. Hunter's sign  
E. Howship–Romberg sign

**Answer:** A. Diseases of the hip can result in an inferior tilt of the pelvis when weight is placed on the ipsilateral side. Additionally,
as gluteus medius is important in maintaining a neutrally positioned pelvis contralaterally with ambulation, injury to it or its nerve supply (superior gluteal nerve) can result in the Trendelenburg sign.

5. Which one of the following structures would be most likely to be swollen in a patient presenting with a gluteal abscess?
   A. Lymph nodes travelling with the superior gluteal vein
   B. Anterolateral abdominal wall lymph vessels
   C. Lymph vessels surrounding the inferior gluteal nerve
   D. Superficial inguinal nodes
   E. Popliteal nodes

**Answer: D.** Lymphatic drainage of the gluteal region is via the superficial inguinal lymph nodes. Therefore, pathology of the gluteal region, such as an abscess, can result in enlargement of the superficial inguinal nodes.
Clinical Case

1. A patient presents to their physician with radiating dysaesthesias extending from the left popliteal fossa to the plantar aspect of the foot. Physical examination is found to be within normal limits. An MRI of the left lower extremity is performed. T2-weighted axial images reveal a hyperdense mass arising from the left tibial nerve at the bifurcation of the sciatic nerve in the distal posterior thigh (Fig. 79.5). A posterior surgical approach to the distal thigh is performed. At operation, a spherical soft mass is found that involves the tibial nerve, as preoperative imaging had indicated. The tumour is intrafascicular and significantly distorts the anatomy of the tibial nerve: the common fibular nerve is normal and has no signs of pathology (Fig. 79.6A). The tumour is resected (Fig. 79.6B) without complications and the patient is doing well. Pathological examination of the mass reveals a schwannoma.
FIG. 79.5 Axial T2-weighted MRI of the left distal thigh. Note the mass (arrow).
(Courtesy Dr Robert Spinner, Department of Neurosurgery, Mayo Clinic, Rochester, MN, USA.)
A. **Summarize the course and distribution of the sciatic nerve in the thigh.**

The sciatic nerve is composed of spinal nerve contributions from L4-S3 and is the thickest nerve in the body. It comprises two nerves, the common fibular and tibial nerves, which are encased in a common epineurial sheath. The tibial nerve contains the ventral rami of L4–S3 while the common fibular nerve contains the ventral rami of L4–S2. The two nerves are separated within the nerve sheath by the Compton–Cruveilher septum, composed of connective and adipose tissues. These two components of the sciatic nerve are mixed nerves supplying the posterior thigh muscles, the ischial attachment of adductor magnus and most structures inferior to the knee, except for the sensory distribution of the saphenous nerve on the medial aspect of the leg and foot. The sciatic nerve also sends articular branches to the hip, knee and ankle joints.

The sciatic nerve (that is, the encased tibial and common fibular nerves) exits through the greater sciatic foramen, inferior to piriformis. It continues to descend deep to gluteus maximus and along the posterior aspect of the acetabulum, and courses over obturator internus, quadratus femoris and the superior and inferior gemelli. It continues inferiorly between the greater trochanter and the ischial tuberosity; at this point, the surface marking of the nerve is halfway between these bony features. The sciatic nerve then courses
through the posterior compartment of the thigh, along the posterior aspect of adductor magnus. It usually separates into the tibial and common fibular nerves proximal to the knee as it is crossed by the long head of biceps femoris at the apex of the popliteal fossa; however, the location of the bifurcation is highly variable.
CHAPTER 80
Hip

Florence Unno, James Learned, Keith A Mayo

Core Procedures

- Open reduction internal fixation of acetabular fractures; open reduction internal fixation of femoral head and neck fractures
- Closed reduction screw fixation of femoral neck fractures
- Arthroplasty, hemiarthroplasty
- Osteotomies of the pelvis; osteotomies of the neck of the femur and proximal femur
- Closed and open reduction of hip dislocation
- Hip joint arthroscopy
- Arthrocentesis; diagnostic and therapeutic injections of the hip joint and other extra-articular musculotendinous structures
- Irrigation and debridement of the hip joint
- Paediatric hip joint: pinning for slipped capital femoral epiphysis; osteotomy, epiphysiodesis and arthrodiastasis for Legg–Calvé–Perthes disease
In utero, the hip is formed from a condensation of mesenchyme in the lower limb bud, which differentiates until week 20, before maturation starts. After birth, the acetabulum is formed from the coordinated growth of the Y-shaped triradiate cartilage that will eventually form the depths of the acetabulum, and the saucer-shaped acetabular cartilage that will form the articular rim. The shape of the acetabulum is mostly determined by the age of 8 years, but growth continues through ossification centres that appear at 8 or 9 years and fuse by the age of 17 or 18.\textsuperscript{1,2} The ossification process in the proximal femur reaches the greater trochanter and the neck of the femur by birth. The cartilage that is not ossified contains three growth plates responsible for the longitudinal growth of the proximal femur and for its shape. The lack of appropriate contact pressure between the acetabulum and the proximal femur during growth results in an incongruent joint.\textsuperscript{3}
Surgical surface anatomy

Bony landmarks important for approaches to the hip joint include the iliac crest, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), anterior inferior iliac spine (AIIS), posterior inferior iliac spine (PIIS), body of pubis and pubic symphysis, ischial tuberosity and greater trochanter. A point just inferior and lateral to the midpoint of the inguinal ligament marks the position of the hip joint. Posteriorly, the greater sciatic foramen is approximated on a line made between the ischial tuberosity and PSIS. The femoral artery is just medial to the femoral nerve and both enter the thigh inferiorly at about the midpoint of the inguinal ligament (Video 80.1).
Clinical anatomy

The hip joint is a constrained enarthrodial joint. The cartilage covering the head of the femur is thickest at the centre and thinner at the equator, the opposite being true for the cartilage lining the acetabulum. The acetabular cartilage is horseshoe-shaped, open inferiorly at the acetabular notch; a central cavity, the acetabular fossa, is occupied by synovium-covered fat over which the ligament of the head of the femur (ligamentum teres) can glide. The transverse acetabular ligament bridges the notch, defining a passageway through which the nutrient vessels enter the joint. Three extra-articular ligaments reinforce the capsule and are intimately connected to it. The iliofemoral ligament (Y-shaped ligament of Bigelow), between the intertrochanteric line and the inferior portion of the AIIS, is the strongest ligament in the human body. The pubofemoral ligament, which is attached to the obturator crest and the superior pubic ramus, blends into it. Posteriorly, the ischiofemoral ligament (ligament of Bertin) consists of a triangular band of fibres between the ischium and the intertrochanteric line. The hip joint is stable by virtue of its geometry. Its congruence is augmented by the acetabular labrum, a fibrocartilaginous gasket that is also believed to function as a suction seal, preventing synovial fluid from leaving the joint space. The neurovascular anatomy and the muscles of the hip are described in Chapter 79.

Biomechanics of the hip

The hip is the most proximal joint that connects the axial skeleton to the lower limb. It plays an essential role in posture, balance and movement, including gait. Pelvic tilt maintains the sagittal alignment of the spine. It occurs mainly at the hip joint, which acts as a fulcrum between the force of body weight and the force of contraction of the abductors of the hip; these forces result in an equal and opposite joint reaction force at the hip. Measurements in vivo have shown that this force equals 2.3–2.9 times body weight during monopodal stance; 1.6–3.3 times body weight when walking; and around 5 times body weight during running or ascending and descending stairs. To maintain a stable hip, the torque produced by body weight is countered by the contraction of gluteus medius and gluteus minimus. Weakness of these muscles can lead to gait abnormalities (Trendelenburg, Duchenne and waddling gaits). Weakness of gluteus
maximus can also result in gait imbalance (maximus lurch), as does muscle spasticity (circumductory, scissoring, paralytic and quadriplegic patterns).

The bony geometry of the joint is also essential for determining the arc of motion and the stability of the hip. When surgery around the hip is planned, it is essential to understand the biomechanics at play and to restore function through muscle balance and optimal geometry. Some of the key elements to consider are described in Fig. 80.1.
FIG. 80.1  A, Radiographic features of the hip. Caput collum diaphysial (CCD) angle. Normal is approximately 126°. Caveat: the angle represents the anatomical neck–shaft angle on a true anteroposterior view of the femur only. Any rotation of the femur will result in an apparent increase of the CCD angle. B, Biomechanical features. C, Clinical features. Key: LR, lateral rotation; MR, medial rotation.
Surgical approaches

A thorough understanding of the local anatomy is paramount to ensure extensile yet safe exposure of the hip (see Chs 76, 79 and 81). Structures can be altered by a pre-existing pathological process, making it more difficult to identify the anticipated surgical planes. Clinicians must be aware that the traumatized hip is prone to forming heterotopic bone that can restrict motion and cause pain: careful dissection is therefore required to prevent iatrogenic muscle injury.

Posterolateral approach to the hip and acetabulum: Gibson

The Gibson approach is illustrated in Fig. 80.2.
FIG. 80.2 The Gibson approach and surgical dislocation. A. The skin incision (dashed line) is made distally in line with the femur and is continued proximally over gluteus medius. Note that tensor fasciae latae is an anterior structure proximally. ASIS, Anterior superior iliac spine. B. Proximally, communicating vessels indicate the interval between gluteus maximus and gluteus medius (green arrows). The fascia lata has been incised. The ascending branch of the entrance of the medial circumflex femoral artery into the trochanteric anastomosis (blue arrows) indicates the cranial border of quadratus femoris; the arterial branch supplying the head of the femur lies in this muscle. C. The tendon of piriformis is identified and gluteus medius retracted to help define the depth of the osteotomy. The periosteum is incised along the line of the planned osteotomy (dashed line). D. The digastric osteotomy leaves vastus lateralis and gluteus medius attached to the osteotomy fragment. Note that the sciatic nerve should be identified but not skeletonized, as done here for illustrative purposes. E. Distally, the osteotomy exits just distal to the origin of vastus lateralis (white arrow). After cuts have been made, a Hohmann retractor everts the
fragment, sometimes completing the osteotomy through a controlled fracture (green arrow). F, A Z-shaped capsulotomy is performed, taking care to preserve the acetabular labrum. If there is a posterior wall fracture, the capsulotomy is modified to avoid devascularization of the fragment. G, The hip is dislocated in flexion and lateral (external) rotation. H, Hohmann retractors allow the acetabulum to be visualised clearly. I, The capsule is closed (1); the osteotomy is fixed with screws (2); the fascia lata is closed (3).

The posterolateral approach preserves gluteus maximus by using the internervous plane between gluteus maximus (inferior gluteal nerve) and gluteus medius (superior gluteal nerve). The patient is placed in the lateral decubitus position. The skin incision is centred on the greater trochanter, extending distally over the femur in line with its long axis. Proximally, the incision is continued in the same axis or with a slight posterior curve over the anticipated interval between gluteus maximus and gluteus medius. Proximal to the greater trochanter, vessels crossing the fascia lata between gluteus maximus and gluteus medius are helpful guides to the interval between the two muscles; the vessels are cauterized and the fascia lata is incised. The trochanteric bursa is incised. The communication of the ascending branch of the medial circumflex femoral artery (MCFA) with the cruciate anastomosis (from the ascending branch of the lateral circumflex artery) can be seen over the greater trochanter, perpendicular to the axis of the femur. Posteriorly, the MCFA defines the level of the superior border of quadratus femoris. Dissection of the posterior aspect of the femur distal to this point can potentially injure the deep branch of the MCFA, the main artery supplying the head of the femur. Piriformis, which is most easily found in its tendinous portion on the posterior aspect of the greater trochanter, is identified. The course of the sciatic nerve is confirmed: its anticipated location is posterior to quadratus femoris and the conjoint tendons formed by gemellus inferior, obturator internus and gemellus superior. Any anatomical variant is noted to ensure proper protection of the nerve.

**Surgical hip dislocation**

A surgical hip dislocation is an anterior dislocation of the hip that allows access to the femoral head and neck as well as the acetabulum, without compromising the MCFA, the main vascular supply to the femoral head. It can be performed through a posterolateral (Gibson) approach, a posterior (Kocher–Langenbeck) approach or an anterior approach (distal portion of Hueter or Smith-Peterson approach).
Anterior approach to the pelvis and acetabulum: ilio-inguinal approach

This anterior approach is illustrated in Fig. 80.3.
The anterior approach gives access to the entire iliac fossa from the sacroiliac joint to the pubic symphysis; it requires the development of three wound intervals called windows. The patient is supine. The skin incision begins posterior to the gluteus medius pillar and curves distally following the line of the iliac crest, staying slightly lateral to it in order to avoid skin irritation. At the level of the ASIS, the incision curves medially towards the superior aspect of the pubic symphysis, staying two fingers’ breadths cranial to it. The incision extends past the midline by 2–3 cm. The first (or lateral) window allows access to the entire internal aspect of the iliac fossa from the sacro-iliac joint posteriorly to the iliopectineal eminence anteriorly by releasing the insertion of the abdominal muscles from the iliac crest, leaving a thick fascial and periosteal cuff for repair. Iliacus is elevated subperiosteally to expose the iliac fossa; nutrient vessels from the iliolumbar vessels are
identified and cauterised. The connective tissue over the ASIS is not mobilized initially, in order to maintain tissue tension and facilitate the development of the second (or middle) window.

The second window is created by incising the aponeurosis of external abdominal oblique beginning at the ASIS and extending medially towards the lateral border of the ipsilateral rectus sheath. Medially, the incision is cranial to the spermatic cord (males) or the round ligament (females), which consequently do not need to be mobilized. The common origin of internal abdominal oblique and transversus abdominis is released from the inguinal ligament, taking a 1–2 mm cuff of the ligament with the aponeurosis to facilitate repair. The lateral femoral cutaneous nerve is identified, usually 1–2 cm medial to the ASIS in close approximation to the insertion of internal abdominal oblique; it is mobilized cranially and distally to protect it from stretch. The ilio-inguinal nerve, which perforates transversus abdominis near the anterior part of the iliac crest and runs parallel and cranial to the inguinal ligament, must be protected. The iliopectineal fascia is identified: it separates the muscular space (lacuna musculorum) that contains iliopsoas, the femoral nerve and the lateral femoral cutaneous nerve, from the vascular space (lacuna vasorum) that contains, from medial to lateral, Cloquet’s nodes, the femoral vein and artery, and the femoral branch of the genitofemoral nerve. The iliopectineal fascia (thickening of the psoas sheath) is exposed by retracting iliopsoas and the femoral nerve medially and the vessels laterally. It is divided under direct visualization down to the superior pubic ramus. The lesser pelvis can now be entered and the pelvic brim and quadrilateral surface accessed.

The surgeon stands on the contralateral side to develop the third (or intrapelvic) window. The fascia over the rectus sheath is exposed over 10–12 cm, starting at the pubic symphysis and extending cranially. The linea alba is incised vertically. The retroperitoneal space is accessed between the left and right heads of rectus abdominis. The urinary bladder is protected. Subperiosteal dissection is performed on the coxal bone from medial to lateral, ligating or cauterizing the retropubic vascular anastomosis between the obturator vessels and the inferior epigastric vessels (corona mortis) or external iliac vessels as they are encountered. Failure to do this can result in catastrophic bleeding. The three windows are now open, exposing the entirety of the internal aspect of the pelvis.

Closure is an essential step of the approach. The floor of the inguinal canal is restored by repairing the conjoint tendon (or inguinal falx) to the inguinal
ligament. The aponeuroses of external oblique and the rectus sheath are then closed. The attachment of the abdominal wall to the iliac crest is secured with transosseous sutures; defects in the repair can result in abdominal hernias.

**Posterior approach to the acetabulum: Kocher–Langenbeck**

The Kocher–Langenbeck approach is illustrated in **Fig. 80.4**.
FIG. 80.4 The Kocher–Langenbeck approach. A, With the patient prone, the distal skin incision parallels the femur (with the hip in neutral rotation), stopping at the greater trochanter. The proximal incision aims toward the posterior superior iliac spine (circled). GMax, gluteus maximus. B, The iliotibial tract is split along the femur. The gluteal fascia is then split along the raphe between the sacral and anterior portions of gluteus maximus. The first branch of the inferior gluteal nerve to gluteus maximus may be encountered within 9–10 cm of the trochanter and limits safe dissection. C, The tendon of gluteus maximus is divided when greater exposure is needed. D, The course of the sciatic nerve should be traced. Most commonly, it is found anterior/deep to piriformis (held with forceps) and posterior/superficial to the conjoint tendon and quadratus femoris. E, The conjoint tendon (composed of gemellus superior, gemellus inferior and obturator internus) is visualised by sharply dividing the overlying muscle belly (forceps placed underneath); this allows for suture placement and precise division. F, These muscles are used to protect the nerve from retractors placed in the lesser sciatic foramen. G, Cranially, the approach is limited by the superior gluteal neurovascular bundle. H, Clamps can be carefully placed through the greater sciatic foramen to facilitate fracture reduction. I, The capsulotomy shows the head of the femur reduced within the intact acetabulum.

Originally described by Letournel and Judet, the posterior approach allows access to posterior fractures of the acetabulum. Its distal portion (Moore or Southern approach) is also commonly used for hip arthroplasty. The Kocher–Langenbeck approach consists of two surgical limbs that meet at the greater trochanter. The proximal (or gluteal) limb starts at the greater trochanter and extends toward the PSIS. The first branch of the inferior gluteal nerve may be encountered within 9–10 cm of the trochanter and limits further posterior dissection. The distal (or femoral) limb runs in line with the longitudinal axis of the femur and usually ends at the distal end of the femoral insertion of gluteus maximus. The femoral limb is often carried through the skin, subcutaneous fat and iliotibial tract first, so the interval between the iliac and sacral parts of gluteus maximus can subsequently be palpated. The incision through the fascia overlying gluteus maximus is aligned with this
intramuscular interval to minimize iatrogenic trauma. When fractures necessitate further exposure, the tendon of gluteus maximus can be partially or completely divided. Care should be taken to protect or ligate the muscular branch of the superior gluteal artery, which courses on the deep aspect of the tendon of gluteus maximus.

The trochanteric bursa is divided and the course of the sciatic nerve is confirmed using the landmarks and relationships described in the Gibson approach. Exposure of the retroacetabular surface proceeds with isolation and division of piriformis and the conjoint tendons of gemellus superior and inferior and obturator internus, preserving the circulation to the head of the femur. Blunt retractors can be placed in the lesser sciatic foramen because the tendons of gemellus superior and inferior and obturator internus protect the sciatic nerve. Proximally, the abductor muscles of the hip can be carefully reflected from the capsule from posterior to anterior. However, a Gibson approach may be preferred for fractures extending further anteriorly. Careful proximal dissection of the posterior border of the coxal bone is critical because the superior gluteal neurovascular bundle lies at the angle of the greater sciatic foramen and is at risk of iatrogenic injury during exposure, reduction and fixation. Once the greater sciatic foramen is exposed, it can be used for palpation of fracture lines and placement of reduction clamps, but retractors should not be placed there routinely. Closure starts with the repair of the short lateral rotators. The tendon of gluteus maximus is then repaired, if necessary, and the iliotibial tract, deep dermis and skin are closed.

**Anterior approach to the hip: Hueter**

The Hueter approach is illustrated in Fig. 80.5.
FIG. 80.5  The Hueter approach. A, The skin incision begins approximately 2 cm lateral and distal to the anterior superior iliac spine and extends distal and laterally over the muscle belly of tensor fasciae latae. Cranially, the anterior superior iliac spine and iliac crest are outlined. The dashed line shows the expected course of the lateral femoral cutaneous nerve. B, The fascial incision is over tensor fasciae latae. C, Tensor fasciae latae is retracted laterally, allowing access to the anterior aspect of the hip capsule through the posterior aspect of the tensor sheath. The ascending branch of the lateral circumflex femoral artery limits the inferior extent of the approach and can be sacrificed depending on surgical indications. D, Rectus femoris is retracted medially and a T- or L-shaped capsulotomy allows the hip to be dislocated anteriorly by combined lateral rotation and adduction. If intact, it will be necessary to divide the ligament of the head of the femur to facilitate dislocation.

The Hueter approach exploits the internervous plane between the femoral
and superior gluteal nerves. Also referred to as the modified Smith-Petersen, anterior or ‘direct anterior’ approach to the hip, it is used for hip arthroplasty, surgical dislocation, irrigation of the hip, and fracture fixation of the head and neck of the femur. The intrapelvic extension of this plane allows the ‘lateral window’ of the ilio-inguinal approach to be visualised through an ASIS osteotomy rather than by division of theinguinal ligament.

The skin incision is made over the muscle belly of tensor fasciae latae, avoiding the lateral femoral cutaneous nerve. The incision extends proximally toward the lateral edge of the ASIS and distally toward the lateral border of the patella. The fascia of tensor fasciae latae is incised longitudinally and the muscle belly is dissected from its medial fascia and retracted laterally. Dissection is continued cranially to the level of the crest, exposing it and the anterior inferior iliac spine (AIIS). The straight head of rectus femoris, which originates from the AIIS, forms the medial border of this deep interval, and gluteus medius forms the lateral border. Distally, dissection is limited by the ascending branch of the lateral circumflex femoral artery (LCFA). This leash of vessels should be preserved for fracture fixation, but is routinely ligated and divided for anterior hip arthroplasty when perfusion of the head of the femur is no longer critical.

The hip capsule is covered with a layer of fat and iliocapsularis: both can be sharply elevated from lateral to medial and retracted. A T-shaped capsulotomy is typically performed to allow access to the joint. When a surgical dislocation is planned, division of the ligament of the head of the femur is often required to facilitate an anterior dislocation in traction and lateral rotation. The capsule is loosely closed before the superficial fascia overlying tensor fasciae latae is repaired. The dermis of the anterior thigh should be closed carefully to avoid iatrogenic injury to the lateral femoral cutaneous nerve.

### Tips and Anatomical Hazards

The MCFA is at risk during posterior and cranial capsulotomies, posterior approaches to the hip, or placement of intramedullary nails in the trochanteric fossa. Timing of fracture surgery, the position achieved at reduction and the technique of dissection are also important in preserving the blood...
The main blood supply to the head of the femur arises from the MCFA, which usually originates from the deep femoral artery (profunda femoris artery). The MCFA runs over the tendon of iliopsoas from medial to lateral, close to the cortex of the neck of the femur. It crosses the tendon of obturator externus posteriorly to reach the cranial aspect of quadratus femoris and then crosses the tendons of gemellus superior and inferior and obturator internus (triceps coxae) anteriorly before perforating the joint capsule, giving rise to three or four branches, the retinacular vessels. These vessels course posteriorly and superiorly along the neck of the femur in a synovial fold between gemellus superior and the tendon of piriformis until they penetrate the head of the femur at the level of its cartilaginous border.

The MCFA anastomoses distally with the inferior gluteal artery (constant) and with the superior gluteal and internal pudendal arteries (occasionally). Proximal anastomoses are seen between the obturator, internal pudendal and lateral circumflex femoral arteries.

Although different fracture patterns can be seen in the proximal femur, the direction of the force generated by a muscle is dictated by its site of insertion. Some classical vectors of displacement can consequently be expected.

When the neck of the femur is affected, it tends to fall in varus and retroversion relative to the femoral diaphysis. In a subtrochanteric fracture, the proximal fragment will typically displace in abduction, flexion and lateral rotation due to the unopposed pull of the abductors and the short lateral rotators of the hip, and iliopsoas. Failure to anticipate those deforming forces will lead to suboptimal restoration of hip geometry.

When a modality of treatment is chosen, it is essential to differentiate stable fractures from those that will not withstand the forces generated by gravity and body weight. For instance, a vertically orientated fracture of the neck is more likely to be unstable and require fixation than a more horizontal fracture.

On the acetabular side, the direction and magnitude of the applied forces are the main determinants of injury patterns, which consequently show important variability. Failure to recognize the different fracture patterns could lead to errors in the management of
those injuries.
References

Single Best Answers

1. One year after a femoral neck fracture of the right hip that was treated with a total hip replacement, a 60-year-old male patient presents to the physician for a follow-up visit. When he walks, the left pelvis tilts downward during the right monopodal phase of gait, and the right shoulder drops. Which one of the following is the most probable cause of this gait abnormality?

A. Persistent pain in the operated hip
B. Injury to the obturator nerve
C. Weakness of gluteus medius
D. Weakness of gluteus maximus

**Answer: C.** In normal monopodal stance, the ipsilateral gluteus medius contracts to counteract the force of gravity that pulls the contralateral pelvis down. Muscle weakness (deconditioning, tendinous disinsertion from the greater trochanter, injury to the superior gluteal nerve) results in an inability to keep the pelvis level. In the single-leg phase of gait on the affected side, the contralateral hip consequently drops (Trendelenburg gait). There can be an ipsilateral drop of the shoulder (Duchenne de Boulogne gait) as a way of maintaining the alignment of the spine when a dynamic scoliosis is induced by the Trendelenburg gait. Pain is associated with an antalgic gait, where the stance phase of gait is abnormally shortened relative to the swing phase. Injury to the obturator nerve affects adductor muscles; as a result, the leg is abducted during the swing phase and the weight is transferred over the contralateral side in an effort to bring the affected limb into adduction at heel strike, resulting in a waddling gait. Gluteus maximus gait is characterized by a posterior thrust of the trunk at heel strike in an attempt to compensate for the weakness of the hip extensor muscles, because the hip must be in extension to prevent forward collapse.
of the trunk during midstance phase.

2. Six months after a displaced fracture of the left neck of the femur that was treated with an anterior approach for reduction and a separate lateral approach for screw placement, a patient presents with new left hip pain. An anteroposterior X-ray of the hip shows advanced subchondral sclerosis on the weight-bearing aspect of the femoral head associated with a loss of its sphericity. A CT confirms the diagnosis of avascular necrosis of the head of the femur. Which one of the following surgical errors is most likely to be responsible for this evolution?

A. An extensive anterior capsulotomy used for the reduction of the fracture
B. Excessive traction applied to the femur during surgery
C. Joint penetration by one of the screws
D. Placement of a very cranial posterosuperior screw in the femoral neck

**Answer: D.** The main vascular supply of the head of the femur arises from the medial circumflex femoral artery (MCFA). After leaving the deep femoral artery, it crosses the tendon of obturator externus posteriorly to reach the cranial aspect of quadratus femoris. After crossing the tendons of gemellus superior and inferior and obturator internus anteriorly, the MFCA perforates the joint capsule and gives off retinacular branches, which course on the posterosuperior aspect of the neck of the femur in a synovial fold before penetrating the head of the femur. Placement of a screw outside the bone at this level can injure these arteries. An anterior capsulotomy can be extensive as long as the acetabular labrum is protected. Excessive traction of the femur can be associated with nerve injuries (usually neurapraxia). Joint penetration with a screw results in direct cartilage damage.

3. A 75-year-old woman is admitted to hospital for an elective hip
arthroplasty to treat degenerative osteoarthritis. The surgeon plans to place the implants through an anterior approach to the hip. Which one of the following describes the internervous plane used in this approach?

A. The plane between tensor fasciae latae and sartorius  
B. The plane between tensor fasciae latae and gluteus maximus  
C. The plane between sartorius and adductor longus  
D. There is no internervous plane because tensor fasciae latae fibres are split for the approach

**Answer:** A. The anterior approach to the hip exploits the internervous plane between tensor fasciae latae (superior gluteal nerve) and sartorius (femoral nerve).

4. A 35-year-old female presents 3 months after a femoral neck fracture that had been treated with open reduction internal fixation. She reports inguinal pain and limited motion in flexion and medial (internal) rotation. Which one of the following is this presentation most likely to be associated with?

A. Avascular necrosis of the head of the femur  
B. A neck of the femur reduced or collapsed in retroversion  
C. Excessive contraction of the short external rotators of the hip  
D. A neck of the femur reduced or collapsed in varus

**Answer:** B. The natural deforming forces due to gravity and unopposed muscle tension will usually displace the fractured neck of the femur in varus and/or posterior tilt. Additionally, posterior comminution, which is frequent with fractures of the neck of the femur, can induce posterior collapse after fixation. Such displacements must be anticipated and corrected when the fracture is reduced. A displacement in retroversion is likely to result in mechanical conflict anteriorly between the neck of the
femur and the rim of the acetabulum, limiting flexion and medial rotation. A displacement in varus will result in limb shortening, with possible lateral pain and/or gluteal weakness associated with an increase in the lever arm of the abductors. Post-traumatic avascular necrosis is not associated with limitation in selected planes of motion and is unlikely to be encountered as early as 3 months after injury. Excessive firing of the short lateral rotators of the hip is not typically associated with hip fractures.
Clinical Case

1. A 79-year-old active female sustained a motor vehicle accident. She was sitting in the front passenger seat of a stationary car that was hit from behind by another vehicle at a high velocity. She had her seatbelt on and the air bags opened on impact. Her right knee hit the front dashboard. She presents with multiple contusions and right knee and hip pain. X-rays (Fig. 80.6A–C) showed a right hip dislocation with a fracture involving the posterior wall of the acetabulum.
A. Which one of these ligaments travels posterior to the hip joint: iliofemoral, ischiofemoral, pubofemoral or transverse acetabular?

The ischiofemoral ligament travels posterior to the hip joint. The iliofemoral and pubofemoral ligaments are located anterior to the hip joint. The transverse acetabular ligament is deeply located at the acetabulum.

The hip was reduced emergently to avoid avascular necrosis. A CT was then obtained to evaluate the fracture further and showed extensive erosion of the anterior aspect of the head of the femur (not shown here), precluding isolated repair of the acetabulum. Operative treatment consisted of open reduction internal fixation of the posterior wall of the acetabulum combined with an arthroplasty (Fig. 80.6D–F). The patient recovered satisfactory function during the initial postoperative phase.

B. Which one of these nerves is most endangered by a stretch injury in the case highlighted above: superior gluteal, inferior gluteal, posterior femoral cutaneous, pudendal or sciatic?

Due to its course posterior to the hip joint, the sciatic nerve is most likely to sustain injury to prolonged stretch in such fractures/dislocations, as seen in the current case. Emergent reduction of the dislocation with repair of the fracture is therefore important in preventing sciatic nerve dysfunction.
Thigh

Karen Kim Evans, Marissa Suchyta, Samir Mardini

**Core Procedures**

- Anterolateral thigh (ALT) flap
- Gracilis flap
Surgical surface anatomy

An imaginary line connecting the anterior superior iliac spine to the pubic tubercle marks the proximal border of the anterior thigh. The inguinal ligament travels between these two bony landmarks. The external iliac vessels become the femoral vessels deep to the ligament. Laterally, the lateral femoral cutaneous nerve enters the thigh, usually just medial to the anterior superior iliac spine. The pulse of the femoral artery can be palpated just distal to the inguinal ligament at roughly its midpoint. Distally, the epicondyles of the femur and the patella are easily palpable.
Clinical anatomy

The thigh provides several of the most commonly used workhorse flaps in the armamentarium of plastic surgeons, including the anterolateral thigh (ALT), gracilis, tensor fasciae latae, rectus femoris, anteromedial thigh (AMT) and sartorius flaps. These flaps offer low donor site morbidity, the versatility of both muscle and perforator flaps, and the ability to pursue a two-team approach to reconstruction. This chapter will cover the surgical anatomy of the thigh and the core procedures in reconstructive surgery used for this part of the body.

A thorough understanding of the musculature and of the blood vessels and nerves supplying each muscle is essential (Chs 76 and 79). The thigh is divided into anterior, medial and posterior compartments (Videos 81.1 and 81.2). The anterior compartment includes sartorius and quadriceps femoris, both innervated by the femoral nerve. Quadriceps femoris consists of four parts: rectus femoris, vastus lateralis, vastus medialis and vastus intermedius. Rectus femoris and sartorius can be used as pedicled flaps for coverage of the inguinal region. Vastus lateralis can be used as a pedicled or free flap with the ALT flap. Rectus femoris crosses the hip and knee, whereas the vasti originate from the femur and cross only the knee. The medial compartment contains gracilis, pectineus, adductor longus, adductor brevis, adductor magnus and obturator externus. These are all innervated by the obturator nerve, except for pectineus (femoral or accessory obturator nerve, when present) and part of adductor magnus (sciatic nerve). The gracilis flap will be discussed later. The posterior compartment contains the hamstrings (semitendinosus, semimembranosus and biceps femoris), all innervated by the sciatic nerve. Common flaps in this compartment include the posterior thigh flap, which incorporates biceps femoris for closure of pressure sores.

Cutaneous innervation of the lateral thigh is derived from the lateral femoral cutaneous nerve, which arises from L2–3 ventral rami and passes deep to the inguinal ligament; it is important to preserve this nerve when harvesting flaps in this area.

In the proximal thigh, the femoral artery lies within the femoral triangle, bounded by sartorius laterally, adductor longus medially and the inguinal ligament superiorly (see Fig. 79.2). Just distal to the inguinal ligament, the superficial circumflex iliac and superficial epigastric arteries branch from the lateral and medial surfaces of the femoral artery, respectively. The superficial circumflex iliac artery runs laterally, approximately two fingers’ breadths...
below and parallel to the inguinal ligament. It supplies the inguinal region and is used in groin flaps. The femoral artery gives rise to the deep femoral artery (profunda femoris artery), which typically arises 5 cm distal to the inguinal ligament. The deep femoral artery is the dominant blood supply of the thigh, and the majority of pedicles for reconstructive flap surgery arise from its branches. It courses deep to sartorius and rectus femoris, and divides into ascending, transverse and descending branches.

The ascending branch can be identified in the interval between tensor fasciae latae and rectus femoris, and supplies tensor fasciae latae and the gluteal muscles. The descending branch runs in the interval between rectus femoris and vastus lateralis, and is the blood supply to the anterolateral thigh flap. The branch to rectus femoris arises from the descending branch of the lateral circumflex femoral artery.

The medial circumflex femoral artery usually originates from the posteromedial aspect of the deep femoral artery at the same level as, or near the origin of, the lateral circumflex femoral artery; it arises directly from the femoral artery in approximately 25% of individuals. This branch passes between pectineus and psoas major to supply the medial compartment of the thigh. It divides into ascending and transverse branches. The ascending branch runs between adductors longus and magnus, and is the primary pedicle for a gracilis flap.
Anterolateral thigh free flap

The ALT flap is one of the most commonly used flaps in reconstructive surgery. Despite some anatomical variability, this flap is highly versatile, has a reliable blood supply, can be used to cover a wide variety of defects, has a long vascular pedicle with large-diameter vessels, and can provide muscle, fascia and skin in different combinations. Fascia can be harvested to form neotendon for calcaneal tendon (Achilles tendon) reconstruction. The location of the flap leads to low donor site morbidity and allows for a two-team approach to a reconstruction. The disadvantages of the flap include a potential skin mismatch when used for facial reconstruction, the thickness of the fascio-cutaneous flap in obese patients, and the occasional need for a skin graft at the donor site if the flap is too large in order to allow for primary closure.

The ALT flap is planned by drawing a line on the skin from the anterior superior iliac spine to the superolateral border of the patella (Figs 81.1, 81.2). The flap is supplied by either septocutaneous vessels or musculocutaneous perforators that arise from the descending branch of the lateral circumflex femoral artery. A hand-held Doppler ultrasound is used to identify the perforators to the skin, usually located within a 3 cm radius of the midpoint of the drawn line. The more proximally located perforators are usually septocutaneous, while the distal perforators are usually musculocutaneous, coursing through vastus lateralis. The skin paddle of the flap can be designed based on the identified perforator: a skin paddle up to 35 cm long and 25 cm wide can be used, but there is greater success if multiple perforators are included in the flap. A skin paddle width of 7–9 cm enables primary closure without a skin graft. Vastus lateralis can also be included to create a musculocutaneous flap. Very rarely, if the patient does not have any identifiable perforators in the anatomical boundaries of the ALT, the dominant perforators are medial: in such cases, use of the AMT flap has been described. However, this latter flap is less commonly chosen because the ALT flap has all the advantages of the AMT flap without the anatomical inconsistencies. This chapter will therefore concentrate on the ALT flap, which is the more commonly used workhorse.
FIG. 81.1 Anterolateral thigh (ALT) flap perforator markings. A line is drawn on the skin from the anterior superior iliac spine to the lateral aspect of the patella. The perforators to the ALT flap are located at the midpoint of this line in a circle with a 3 cm radius. The flap is outlined around these perforators.
The designed skin flap is elevated from its medial border. A suprafascial or subfascial incision is made and dissection carried out laterally until the preoperatively identified perforators are found (Fig. 81.3). The suprafascial plane is used if the patient is obese and the flap requirements are thinner, but typically it is more difficult to identify the perforator in this plane. A subfascial incision is recommended if fascia is to be harvested with the flap or if the patient is thin. The lateral femoral cutaneous nerve should be identified and preserved. The dissection continues toward the interval
between rectus femoris and vastus lateralis, where a septum exists. Under loupe magnification, the next step is to identify the small perforators, which arise either septocutaneously between rectus femoris and vastus lateralis, or a musculocutaneous perforator arising from vastus lateralis (Fig. 81.4). Once the perforator is identified and its course through either the muscle or the septocutaneous plane has been determined, the interval between vastus lateralis and rectus femoris is opened to identify the descending branch of the lateral circumflex femoral artery. At this point, it is important to note the anatomy of this vessel where it enters vastus lateralis, particularly if there is an oblique branch. An oblique branch is an anatomical variant in which there is a separate branch from the descending branch with a short pedicle to the skin: this is an important point because the pedicle is usually much shorter when an oblique branch is present. An incision is then made on the lateral border of the flap, and the flap is dissected medially either suprafascially or subfascially until the same vessel is seen, thus ensuring preservation of the perforator (Fig. 81.5). The perforator is dissected in retrograde fashion to its origin from the main pedicle, the descending branch of the lateral circumflex femoral artery (Fig. 81.6). It is important to preserve the nerves to vastus lateralis that accompany the pedicle and that can usually be easily separated from the artery and veins (Fig. 81.7). When the nerves wrap around the pedicle, they must be cut in order to harvest the flap; repair of the nerve with microsurgical techniques is recommended.
FIG. 81.3 ALT flap harvest, subfascial or suprafascial plane. The two planes for flap harvest below and above the fascia are shown. Either of these can be used, based on the size requirements of the flap and whether the surgeon is comfortable finding the perforators in the suprafascial plane.

FIG. 81.4 Perforator dissection: intramuscular dissection. The perforators to the ALT flap are located either in the septum between vastus lateralis and rectus femoris, or within vastus lateralis. Intramuscular dissection of the skin perforator in vastus lateralis is shown here.
FIG. 81.5  Perforator dissection: septocutaneous dissection. The perforators to the ALT flap are located either in the septum between vastus lateralis and rectus femoris, or within vastus lateralis. A septocutaneous perforator that has been dissected up to the skin paddle is shown here.

FIG. 81.6  A two-perforator ALT flap. The ALT flap has been dissected with two perforators, highlighting the long pedicle that can be obtained.
FIG. 81.7  The branch to vastus lateralis. It is important to preserve the nerve to vastus lateralis. A portion of vastus lateralis has been dissected, but the nerve was spared in order to preserve innervation to the remaining portion of vastus lateralis.

Depending on the defect, portions of vastus lateralis and/or fascia can be harvested with the skin component (Fig. 81.8). Chimeric flaps are helpful for complete mobility of the muscle and/or skin based on separate branches from the main pedicle (Fig. 81.9). Vascularized fascia can be used for tendon repairs, abdominal wall defects and tendon gliding surfaces. Vascularized muscle can be employed for large bony surfaces.
FIG. 81.8  Vastus lateralis harvest. A portion of vastus lateralis can be harvested based on the descending branch of the lateral circumflex femoral artery (LCFA). The flap can be contoured to fit any defect size.

FIG. 81.9  A chimeric ALT and vastus lateralis flap. A chimeric flap based on separate branches from the descending branch of the lateral circumflex femoral artery allows harvesting of a separate piece of muscle and skin for reconstruction of complex deformities.
Gracilis flap

Gracilis can be used as a functional muscle flap for facial reanimation and for upper-extremity reconstruction; it is also used as a pedicled flap for inguinal region coverage and ischial coverage. The flap can be harvested with or without the skin.\(^5\) The muscle is a thigh adductor, but its redundancy in the presence of other functioning thigh adductors means that harvesting the muscle as a free muscle flap leads to limited morbidity. Furthermore, an inconspicuous scar location is an added benefit.\(^5,6\)

With the patient in the frog-leg position, a line is drawn on the skin marking the course of adductor longus, as well as a parallel line 3 cm posterior to the first line. The incision is marked 5 cm distal to the inguinal crease and extended 10–15 cm, depending on the size of the patient and length of gracilis needed (Fig. 81.10). This flap is supplied by the ascending branch of the medial circumflex femoral artery and can be harvested with the obturator nerve for functional muscle transfers (Fig. 81.11). The incision is made through the skin and subcutaneous tissue down to the fascia lata, avoiding injury to the long saphenous vein, which lies anterior to the incision (Fig. 81.12). The fascia lata is cut over adductor longus and the dissection is then continued posteriorly until the fascia between adductor longus and gracilis is reached. Adductor longus is retracted anteriorly and the pedicle of gracilis is exposed. The vascular pedicle, the ascending branch of the medial circumflex femoral artery, enters the muscle deeply at a 90° angle; it arises from the underside of adductor longus and is generally 8–10 cm inferior to the pubic tubercle in adults (Fig. 81.13). Minor branches are found on the undersurface of the muscle distally and proximally. The plane between adductor longus and gracilis and adductor magnus is created and the pedicle, as well as the branch of the obturator nerve, is exposed. Exposure of gracilis is performed toward the pubic tubercle proximally and 15–20 cm distally, depending on the size of the muscle needed for the reconstruction. The muscle is dissected circumferentially throughout this length, taking care not to injure the epimysium of the muscle. The vascular pedicle is then dissected proximally, extending it to the desired length. Usually, the pedicle is dissected proximally until its take-off from the deep femoral artery and vein. For functional transfer, the obturator nerve is dissected proximally to the obturator foramen. Interfascicular dissection is required to separate the branch to gracilis from the other anterior branches of the obturator nerve to adductors longus and brevis. The pedicle, nerve and muscle are then divided
for transfer (Fig. 81.14).

**FIG. 81.10** Gracilis flap markings. With the patient in the frog-leg position, a line is drawn on the skin marking the course of adductor longus, as well as a parallel line 3 cm posterior to it. The skin incision is marked 5 cm distal to the inguinal crease.

**FIG. 81.12** Gracilis flap harvested with preservation of the long saphenous vein. It is important to preserve the long saphenous vein when harvesting the gracilis flap. The vein is located anterior to the muscle.
FIG. 81.13 Gracilis with blood supply. The vascular pedicle, the ascending branch of the medial circumflex femoral artery, enters the muscle body deep at a 90° angle, arising from the underside of adductor longus, and is generally 8–10 cm inferior to the pubic tubercle in adults. Minor branches perfuse the muscle distally and proximally.
FIG. 81.11  Blood and nerve supply to gracilis. The gracilis flap with its blood supply from the medial circumflex femoral artery and innervation from the anterior branch of the obturator nerve.
To harvest a gracilis skin paddle, it is important to include the perforators to the skin proximally along the muscle. The transverse upper gracilis (TUG) musculocutaneous flap was described in 1992 and includes a skin paddle that is oriented transversely over the proximal third of the muscle. This flap has gained in popularity as a secondary flap option for breast reconstruction.

**Tips and Anatomical Hazards**

The selection of perforators is an important step in ensuring the viability of a flap. Usually, the largest-calibre perforator is chosen. With large flaps, two or more perforators can be harvested to ensure adequate blood flow to the entire flap. In this case, a temporary clamp can be placed on one of the perforators and skin perfusion checked either by laser-assisted fluorescent angiography or clinically. Rarely, no usable perforators will be found in the ALT anatomical zone, in which case either another flap or the AMT flap must be used.

Perforator dissection technique with loupe magnification is crucial to prevent vasospasm and thrombosis. It is important to maintain a bloodless field to ensure constant visualization of the perforators. Excessive tension on the perforators and main pedicle must be avoided and the surgical field must be kept moist to avoid desiccation. Care must be taken not to injure the adventitia of the vessels during
dissection. A thorough understanding of the pedicle and its perforator anatomy is essential. To avoid donor site morbidity, stopping the dissection of the pedicle proximally at the origin of the branches to rectus femoris is recommended in order to ensure viability of the muscle. In addition, the location of the lateral femoral cutaneous nerve of the thigh should be noted in order to avoid postoperative neuromas. Primary closure should not be too tight because there are reports of compartment syndrome after large ALT flap harvest; closure of the superficial fascia (Scarpa's fascia), but not the deeper fascia, is therefore recommended.

The thickness of the flap in obese patients can be a deterrent, especially for areas of the body that require thinner tissue. In these cases, adipose-fascial flaps with skin grafts versus the harvesting of a thin ALT flap can be considered, although perfusion may be questionable in the thin ALT flap. The incision for the gracilis flap should be placed as posteriorly as possible to minimize scar formation. In larger patients, it is sometimes difficult to gain adequate pedicle length deep to adductor longus. In this situation, gracilis can be transposed anterior to adductor longus, thereby allowing complete visualization of the medial circumflex femoral artery. For facial reanimation, 6-0 vicryl sutures can be placed in two rows at the anterior surface of gracilis, allowing accurate restoration of in situ tension and length during inset of the muscle in the reconstruction. Gracilis is ideal for restoring a spontaneous smile in cases of congenital facial nerve palsy (Fig. 81.15).
FIG. 81.15 Gracilis used for facial reanimation. It is ideal for facial reanimation surgery to restore a spontaneous smile.
References


Single Best Answers

1. Which one of the following best describes the compartments of the thigh?
   A. Anterior, medial and posterior
   B. Anterior, lateral and posterior
   C. Anterior, superior and medial
   D. Anterior, superficial posterior and deep posterior

   Answer: A. The thigh is divided into anterior medial, and posterior compartments. The anterior compartment incudes sartorius and quadriceps femoris (rectus femoris, vastus lateralis, vastus medialis and vastus intermedius), all innervated by the femoral nerve. Rectus femoris and sartorius can be used as pedicled flaps for coverage of the inguinal region. Vastus lateralis can be used as a pedicled or free flap with the anterolateral thigh flap. Rectus femoris crosses the hip and knee joints, whereas the vasti originate from the femur and cross the knee joint only. The medial compartment contains gracilis, pectineus, adductor longus, adductor brevis, adductor magnus and obturator externus. The obturator nerve innervates all of these muscles, except pectineus (femoral nerve) and part of adductor magnus (sciatic nerve). The posterior compartment contains semitendinosus, semimembranosus and biceps femoris, all innervated by the sciatic nerve. Common flaps in this compartment include the posterior thigh flap, which incorporates biceps femoris for pressure sore closure.

2. Which one of the following best describes the blood supply to the anterolateral thigh flap?
   A. Ascending branch of the lateral circumflex femoral artery
   B. Perforators from the descending branch of the lateral circumflex femoral artery
C. Medial circumflex femoral artery  
D. Femoral artery

**Answer: B.** The flap is supplied by either septocutaneous vessels or musculocutaneous perforators that arise from the descending branch of the lateral circumflex femoral artery.

3. Which one of the following septa houses the blood supply to the anterolateral thigh flap?  
A. Septum between vastus lateralis and vastus medialis  
B. Septum between vastus lateralis and tensor fasciae latae  
C. Septum between vastus lateralis and rectus femoris  
D. Septum between sartorius and vastus medialis

**Answer: C.** The septum between vastus lateralis and rectus femoris is an important landmark for locating the perforators to the skin island of the anterolateral thigh flap. The septum houses these small perforators, which arise from the descending branch of the lateral circumflex femoral artery.

4. Which one of the following describes the location of the dominant blood supply to gracilis?  
A. Posterior to adductor magnus  
B. Anterior to adductor longus  
C. Posterior to adductor longus  
D. Superficial to adductor longus

**Answer: C.** Posterior to adductor longus. Adductor longus is retracted anteriorly and the pedicle of gracilis, which lies deep and posterior to adductor longus, is exposed. The vascular pedicle, the ascending branch of the medial circumflex femoral artery, enters the muscle deep at a 90° angle, arises from the
underside of adductor longus and is generally 8–10 cm inferior to the pubic tubercle in adults.

5. Which one of the following nerves supplies gracilis for functional transfer?
   A. Lateral femoral cutaneous nerve
   B. Femoral nerve
   C. Sciatic nerve
   D. Obturator nerve

Answer: D. Obturator nerve. For functional transfer, the obturator nerve is dissected proximally to the obturator foramen. Interfascicular dissection is required to separate the branch to gracilis from the anterior branches of the obturator nerve to adductors longus and brevis. The pedicle, nerve and muscle are then divided for transfer.
Clinical Cases

1. A male patient presents with a history of a calcaneal tendon (Achilles tendon) rupture and delayed repair with a tendon graft which subsequently became infected and required multiple debridements. The interposition tendon graft must be removed. A free anterolateral thigh (ALT) flap with fascia lata is used for reconstruction of the defect because this flap allows reconstruction of both the skin and the tendon. The fascia lata of the thigh is rolled to form a neotendon underneath the flap and is attached to the proximal and distal ends of the native calcaneal tendon (Fig. 81.16). Postoperatively, the patient might experience numbness over the lateral thigh. What nerve has been injured in such a case?
FIG. 81.16  A, Preoperative markings of the ALT flap and fascia. B, A preoperative image of the leg defect with missing calcaneal tendon. C, The flap incised on the thigh. The fascia is elevated with the skin paddle below the thigh skin. D, For free flap reconstruction, the posterior tibial artery and vein were prepared proximal to the defect. E, On the undersurface of the flap, the fascia was rolled to form a neotendon. F and G, Postoperative views. The patient could dorsiflex and plantar flex the ankle without difficulty.

A. Femoral nerve
B. Lateral femoral cutaneous nerve
C. Obturator nerve
D. Posterior femoral cutaneous nerve
E. Saphenous nerve
**Answer: B.** The lateral femoral cutaneous nerve exits the pelvis deep to the inguinal ligament, just medial to the anterior superior iliac spine. It then descends along the anterolateral thigh toward the knee. As this branch of the lumbar plexus is cutaneous, injury to it or to its branches during flap dissection and harvest might result in decreased sensation along its distribution. The femoral nerve is more medially located and found lateral to the femoral artery within the femoral triangle. The obturator nerve serves the medial compartment muscles, the posterior femoral cutaneous nerve is found in the posterior compartment of the thigh, and the saphenous nerve travels with the long saphenous vein along the medial aspect of the lower limb.

2. A diabetic patient with peripheral vascular disease presents with a large soft tissue defect encompassing the entire dorsum of the foot, with exposed metatarsals, phalanges and tendons ([Fig. 81.17A and B](#)). An ALT flap was harvested for coverage of the dorsal surface of the foot ([Fig. 81.17C and D](#)). The ALT is ideal in this case due to a long pedicle, reliable large vessels and thin, vascularized fascia and skin. During surgery for ALT, a muscle was found to be bleeding superolaterally. The attachment of the muscle is the lateral aspect of the anterior superior iliac spine. Which one of the following muscles does this represent?
FIG. 81.17  A and B, Preoperative views of the foot defect. C and D, An ALT flap was harvested for coverage of the dorsal surface of the foot. The ALT is ideal in this case due to a long pedicle, reliable large vessels and thin, vascularized fascia and skin. E and F, Postoperative views following placement of the ALT free flap.

A. Sartorius  
B. Gracilis  
C. Tensor fasciae latae  
D. Rectus femoris  
E. Vastus intermedius

**Answer:** C. Tensor fasciae latae arises from the anterior superior iliac spine and adjacent iliac crest. Sartorius also arises from this bony point but more medially. Gracilis is found in the medial compartment of the thigh, and rectus femoris arises partially from the anterior inferior iliac spine.

3. A young girl with a congenital facial nerve palsy requires a two-stage reconstruction with an innervated gracilis flap (Fig. 81.18). The first stage
involves a cross-facial nerve graft in which segments of harvested sural nerve are coapted to a functioning terminal branch of the contralateral facial nerve, and tunnelled subcutaneously under the upper lip to her right cheek. The second stage involves preparing an innervated gracilis flap. During the harvesting of this flap, a cutaneous nerve is seen piercing gracilis and travelling to the skin of the upper medial thigh. Which one of the following nerves does this represent?
FIG. 81.18  
A, Preoperative view. B, Skin markings for harvesting sural nerve grafts. C and D, Harvesting gracilis with a branch of the obturator nerve. E, Gracilis inset into the right cheek to restore the smile. The obturator nerve is anastomosed to the sural nerve graft. F, A postoperative image of a spontaneous smile achieved with a gracilis muscle flap.
A. Cutaneous branch of the obturator nerve  
B. Lateral femoral cutaneous nerve  
C. Anterior femoral cutaneous nerve  
D. Saphenous nerve  
E. Accessory obturator nerve

**Answer: A.** The skin of the upper medial thigh is supplied by the cutaneous branch of the obturator nerve. The lateral femoral cutaneous nerve descends along the anterolateral thigh toward the knee. The anterior femoral cutaneous nerves supply skin of the anterior thigh between the distributions of the lateral femoral cutaneous nerve and cutaneous branch of the obturator nerve. The saphenous nerve travels with the long saphenous vein along the medial aspect of the lower limb. The accessory obturator nerve is variably present; it crosses over the pubic bone and does not have a cutaneous branch.
Popliteal fossa

Mazin Fageir

Core Procedures

- Repair of neurovascular structures
- Excision of lesions: for example, Baker cyst, tumours
- Fixation of avulsed posterior cruciate ligament (PCL) attachment
- Fixation of posterior knee structures: for example, fixation of posterior fractures of the femoral condyle, posterior capsular repair
- Gastrocnemius recession for contracture
- Hamstring lengthening
Surgical surface anatomy

The uppermost part of the popliteal fossa is about a hand's breadth proximal to the knee joint line; in most individuals, the sciatic nerve divides into the tibial and common fibular nerves in this region. The insertion tendon of biceps femoris forms a thick cord that can be traced distally to the head of the fibula. The common fibular nerve runs along the medial border of the tendon of biceps femoris. The cord-like tendon of semitendinosus lies medial to the broad tendon of semimembranosus. Inferiorly, the two heads of gastrocnemius are palpable posterior to the femoral condyles. Flexing the knee may facilitate palpation of the tendons of the hamstrings and the popliteal artery. The popliteal artery bifurcates at the level of the head of the fibula.

The superior half of the popliteal fossa forms a soft elevation between the tendons of the hamstrings. In the fully extended knee, fat protrudes between the tendons of the medial and lateral hamstrings. Flexing the knee reveals a depression, the popliteal fossa, and renders the tendons of the hamstrings more prominent. The popliteal artery runs along an imaginary line drawn from the junction of the middle and distal thirds of the thigh, 2.5 cm medial to the posterior midline of the lower extremity, to a midpoint between the femoral condyles; the vessel continues inferolaterally to divide at the inferior border of popliteus (Fig. 82.1).
FIG. 82.1 The posterior aspect of the knee and leg. Key: 1, popliteal artery: passing from a point (black X) 2.5 cm medial to the posterior midline of the thigh at the junction of its middle and lower thirds to a point halfway between the femoral condyles/the midaxial line of the calf (blue X); 2, iliotibial tract; 3, tendon of biceps femoris and common fibular nerve located medially; 4, semimembranosus and semitendinosus; 5, gracilis; 6, popliteal fossa; 7, head of fibula; 8, gastrocnemius, lateral head; 9, gastrocnemius, medial head; 10, soleus; 11, posterior tibial artery
and tibial nerve, which run from the midline of the calf at the neck of the fibula level to a point one-third of the way from the posterior border of the medial malleolus to the calcaneal tendon; 12, medial malleolus; 13, lateral malleolus and short saphenous vein passing posteriorly; 14, calcaneal tendon insertion on to calcaneus. (Adapted from R.L. Drake, A.W. Vogl, A.W.M. Mitchell, R.M. Tibbitts, P.E. Richardson (eds), Gray’s Atlas of Anatomy, Elsevier, Churchill Livingstone, 2008.)
Surgical anatomy

The popliteal fossa is a fat-filled space that facilitates the passage of neurovascular structures between the thigh and the leg. In cadavers, the diamond-shaped space is bound superomedially by the tendons of semitendinosus and semimembranosus, superolaterally by the tendon of biceps femoris, and inferiorly by the two heads of gastrocnemius. In the living, the two heads of gastrocnemius meet in the midline and the popliteal fossa per se extends distally deeper to the muscle.

The skin, superficial and popliteal fasciae form the roof of the popliteal fossa; the two heads of gastrocnemius lie distally. The skin overlying the fossa receives its blood supply from branches of the popliteal artery and perforating vessels, and is innervated by branches of the posterior femoral cutaneous nerve derived from S1–3 ventral rami. The skin tension lines (Langer's lines) over the fossa run parallel to the flexion skin crease, which means that a transverse skin incision is less likely to produce flexion contractures.

The superficial fascia contains the short saphenous vein, which may be accompanied by the medial sural cutaneous nerve and branches of the posterior femoral cutaneous nerve. The vein pierces the fascia to drain into the popliteal vein. The medial sural cutaneous nerve, a branch of the tibial nerve, commonly pierces the fascia at the popliteal fossa but it may also run deep to the popliteal fascia up to the midcalf. Branches from the posterior femoral cutaneous nerve traverse this layer in their ascent from the leg.

The popliteal fascia is continuous with the fascia lata and the crural fascia. The popliteal fascia is strong and therefore capable of limiting expansion of the contents of the fossa: for example, the tibial nerve may be compressed by an aneurysm of the popliteal artery (Fig. 82.2).
The popliteal fossa contains the popliteal artery and vein, the terminal part of the short saphenous vein, the tibial and common fibular nerves, the posterior femoral and sural cutaneous nerves, variable articular twigs from the terminal part of the posterior branch of the obturator nerve, popliteal lymph nodes and multiple bursae (Fig. 82.3; see Fig. 82.2).
The popliteal artery, the deepest of the neurovascular structures, is the continuation of the femoral artery distal to the adductor hiatus. It runs along an imaginary line drawn from the junction of the middle and distal thirds of the thigh, 2.5 cm medial to the posterior midline, to a point halfway between the femoral condyles, and continues inferolaterally to divide into the tibial and common fibular nerves at the inferior border of popliteus. At the joint line, the artery is closely related to the joint capsule with a mean distance of 2.8 mm, and to the posterior horn of the lateral meniscus. The artery supplies intra-articular structures, the hamstrings, gastrocnemius, soleus, plantaris and the skin around the knee. The popliteal and femoral arteries communicate via the genicular anastomosis. The popliteal artery gives rise to five genicular branches that supply the knee joint and regional structures:
the superior medial and lateral genicular, the inferior medial and lateral genicular, and the middle genicular arteries. The superior genicular vessels encircle the distal femur. The middle genicular artery originates near the midpoint of the posterior knee and pierces the posterior joint capsule to supply the cruciate ligaments; in so doing, it tethers the popliteal artery to the joint capsule. The inferior genicular arteries originate under gastrocnemius. The genicular arteries anastomose with the recurrent tibial, circumflex fibular branches of the posterior tibial and descending genicular arteries.

The popliteal vein traverses the popliteal fossa contained in a fibrous sheath together with the popliteal artery; the vein lies superficial to the artery and deep to the tibial nerve. The short saphenous vein pierces the popliteal fascia between the two heads of gastrocnemius to drain into the popliteal vein at, or just superior to, the joint line.

The tibial nerve descends along the middle of the fossa, crossing the popliteal artery from lateral to medial. Proximally, the nerve gives off articular branches, the medial sural cutaneous nerve and motor branches to gastrocnemius, soleus, popliteus and plantaris. The common fibular nerve descends obliquely along the medial border of biceps femoris. It gives off the lateral sural cutaneous nerve and articular branches, exits the popliteal fossa superficial to the lateral head of gastrocnemius, and pierces fibularis longus to wind around the head and neck of the fibula. In most cases, superficial branches of the posterior femoral cutaneous nerve pierce the popliteal fascia to enter the popliteal fossa. Branches join to form the nerve proper, which runs deep to the popliteal fascia and superficial to biceps femoris to reach the posterior thigh (Fig. 82.4).
The popliteal fossa contains 5–7 scattered lymph nodes embedded in fat. The superficial node lies in the subcutaneous tissue near the termination of the short saphenous vein and receives superficial lymphatic drainage from the leg. The deep nodes are closely related to the popliteal vessels and receive drainage from the knee joint and the deep lymphatics of the leg.

The floor of the popliteal fossa extends from the medial and lateral supracondylar lines of the femur proximally to the soleal line of the tibia distally. In addition to the posterior surfaces of the distal femur and proximal tibia, the floor is formed by popliteus, investing fascia and the joint capsule. Popliteus is attached to the lateral condyle of the femur and meniscus proximally, and to the posteromedial tibia just proximal to the soleal line distally. The reflected part of the tendon of semimembranosus forms the oblique popliteal ligament, reinforcing the posterior joint capsule. A fibrous extension of the tendon of semimembranosus forms the investing fascia of
popliteus.
Surgical approaches and considerations

The direct posterior approach to the knee is used for vascular repair; fixation of posterior femoral condyle and tibial plateau fractures; repair of avulsed PCL tibial insertion; gastrocnemius recession; hamstring lengthening; excision of tumour or cysts; posterior synovectomy; and, recently, posterior inlay PCL repair. A lazy S-shaped incision is begun superolaterally over biceps femoris at the required level; the incision is curved medially towards the midpoint of the skin crease and extended distally over the medial head of gastrocnemius. Avoiding acute angles, a full-thickness fasciocutaneous flap is created. The incision crosses the short saphenous vein, the sural cutaneous nerves and the superficial branches of the posterior femoral cutaneous nerve in the superficial fascia. In its ascent, the short saphenous vein leads the surgeon to the popliteal fossa.

The popliteal fascia is incised from a point just medial to the entry point of the short saphenous vein up to the most superior aspect of the popliteal fossa by tracing the tibial nerve proximally. At this point, the sciatic nerve often divides into the tibial and common fibular nerves. The common fibular nerve is traced down the medial border of biceps femoris. The popliteal artery and vein run deep to the tibial nerve.

To gain access to the posteromedial joint space, deep dissection proceeds just anterior to the medial head of gastrocnemius, which may be detached from its femoral origin and subsequently repaired. To gain access to the posterolateral joint space, deep dissection proceeds between the lateral head of gastrocnemius and biceps femoris. The common fibular nerve is at risk here. The deep dissection is equivalent to the medial and lateral approaches to the knee. Very rarely, the posterior joint space is entered between the two heads of gastrocnemius. The exposure can be extended distally to expose the terminal branches of the popliteal artery.

Posterior knee arthroscopy is used in synovectomy; PCL reconstruction; all-inside repair of the posterior horn of the medial meniscus; and excision of tissue or tumours posterior to the PCL. The posteromedial portal is introduced through a triangle bound by the medial collateral ligament, the medial head of gastrocnemius and the tendon of semimembranosus at the level of the joint line. The posterolateral portal is introduced just anterior to the tendon of biceps femoris.
Anatomical variants

Occasionally, the sciatic nerve divides above or, less often, below the most superior part of the popliteal fossa. Rarely, the nerve may trifurcate. In one-third of individuals, the sural nerve is formed by the medial and lateral sural cutaneous branches of the tibial and the common fibular nerves, respectively. Less commonly, the nerve may originate solely from either the tibial or common fibular nerve.

The popliteal artery divides into its terminal branches at the lower border of popliteus in most people but it may divide more proximally or trifurcate. Occasionally, two popliteal veins will accompany the artery.

A bifurcated or trifurcated tendon of popliteus and an accessory popliteus have been reported. Biceps femoris may have a tibial insertion or more than two heads, or the short head may be absent.

Paediatric considerations

Anaesthetic blockade of the sciatic nerve can be performed through the popliteal fossa. The adult landmark, 10 cm proximal to the skin crease, is corrected in children using the ratio of the length of the shaft of the child's femur to the length of the shaft of the adult femur.

Tips and Anatomical Hazards

- The skin tension lines (Langer's lines) run parallel to the flexor crease.
- From superficial to deep, the tibial nerve, the popliteal vein and the popliteal artery traverse the fossa.
- In most individuals, the sciatic nerve divides into the tibial and the common fibular nerves at the most superior border of the fossa.
- The tibial nerve descends along the midline of the fossa superficial and slightly lateral to the popliteal vessels.
- The common fibular nerve descends obliquely along the medial border of biceps femoris.
- The sural nerve arises from contributions from the tibial and common fibular nerves in one-third of individuals.
- The popliteal artery lies a mean distance of 2.8 mm posterior to the joint.
capsule of the knee. It divides into the anterior and posterior tibial arteries at the lower border of popliteus in most individuals. The posterior approach provides exposure to the posterior aspect of the femoral condyles and tibial plateau; insertion of the PCL; regional neurovascular structures; the posterior joint capsule; and popliteus, hamstrings and the origins of gastrocnemius.

Posterior

The short saphenous vein lies medial to the medial sural cutaneous nerve and can be safely ligated. Damage to the terminal branches of the posterior femoral cutaneous nerve may cause paraesthesia over the popliteal fossa. Damage to the medial or lateral sural cutaneous nerve may cause a well-tolerated paraesthesia over the calf or a painful neuroma. Damage to the common fibular nerve in the popliteal fossa may cause paralysis of dorsiflexors (leading to foot drop) and foot evertors, and paraesthesia over the lateral leg and dorsum of the foot. Damage to the tibial nerve may cause paralysis of plantar flexors of the foot. The posterior division of the obturator nerve may be absent; it gives off articular branches to the knee. Damage to the popliteal vein may cause a haematoma. The popliteal artery runs in close proximity to the posterior joint capsule of the knee; damage may cause ischaemia distal to the knee joint and blood loss. Damage to the genicular arteries may devascularize intra-articular structures and cause significant postoperative bleeding/haematoma.

Intra-Articular

Cartilage and meniscus may be damaged as a scalpel is introduced close to the joint line. This may cause pain, accelerate osteoarthritis and/or result in a mechanical block to joint movements. Damage to the meniscotibial (coronary) ligament may destabilize the meniscus.


Single Best Answers

1. Which one of the following statements about the popliteal fossa is correct?
   A. The tendon of biceps femoris forms the superomedial border of the popliteal fossa
   B. The sciatic nerve commonly divides within the popliteal fossa
   C. The popliteal artery divides into the anterior and posterior tibial arteries at the superior border of popliteus in most cases
   D. An articular branch of the obturator nerve is always present
   E. The sural nerve can be a branch of the tibial nerve, the common fibular nerve or both

   **Answer: E.** The sural nerve can be a branch of the tibial nerve, the common fibular nerve or both. In one third of individuals, the sural nerve is formed by the communicating branches of the medial cutaneous nerve from the tibial nerve and the lateral cutaneous nerve of the leg from the common fibular nerve. Less commonly, the nerve may originate only from the tibial or the common fibular nerves.

2. Which one of the following statements about immediate post-traumatic haemarthrosis associated with cruciate ligament injury is true?
   A. It indicates an associated bony evulsion
   B. It results from injury to the posterior joint capsule
   C. It indicates multi-ligament injury
   D. It results from injury to the middle genicular artery
   E. It indicates an associated meniscal injury

   **Answer: D.** It results from injury to the middle genicular artery. The middle genicular artery originates from the popliteal artery.
near the midpoint of the posterior knee and supplies the cruciate ligaments.

3. Which one of the following statements about anatomical relations in the popliteal fossa is correct?
   A. The popliteal artery lies between the popliteal vein and the posterior capsule of the knee
   B. The tibial nerve lies between the popliteal vein and the posterior capsule of the knee
   C. The popliteal artery is closely related to the posterior horn of the medial meniscus
   D. The common fibular nerve is closely related to the tendon of semitendinosus

**Answer:** A. The popliteal artery lies between the popliteal vein and the posterior capsule of the knee. The major neurovascular structures along the posterior midline of the popliteal fossa are, from superficial to deep, the tibial nerve, the popliteal vein and the popliteal artery. The common fibular nerve descends inferolaterally along the tendon of biceps femoris.

4. Which one of the following statements about the posterior approach to the popliteal fossa is correct?
   A. The common fibular nerve is at risk in its superficial course within the popliteal fossa
   B. The incision traverses the long saphenous vein
   C. Cutaneous branches of the posterior femoral cutaneous nerve are at risk superficial to the popliteal fascia
   D. At the level of the joint line, the anterior tibial artery is closely related to the posterior capsule of the knee
   E. A low posterolateral arthroscopy portal endangers the lateral sural cutaneous nerve
Answer: C. Cutaneous branches of the posterior femoral cutaneous nerve are at risk superficial to the popliteal fascia. Proximally, the posterior femoral cutaneous nerve lies deep to the popliteal fascia. The nerve pierces this fascia, formed by one or more branches, to lie in the superficial fascia. It supplies the skin overlying the popliteal fossa and the skin of the proximal posterior leg.

5. A 32-year-old male undergoes open reduction and internal fixation of a comminuted fracture of the tibial plateau via an extended posterolateral approach. Postoperatively, he is noted to have ipsilateral ‘steppage gait’. Which one of the following structures has been injured?
   A. Common fibular nerve
   B. Sural nerve
   C. Posterior division of the obturator nerve
   D. Infrapatellar branch of the saphenous nerve
   E. Tibial nerve

Answer: A. Common fibular nerve. The sciatic nerve divides into the tibial and common fibular nerves at the most superior aspect of the popliteal fossa. The common fibular nerve descends inferolaterally along the tendon of biceps femoris. It lies between the tendon of biceps femoris and the lateral head of gastrocnemius, and winds posterior to the head of the fibula, then lateral and finally anterior to the neck of the fibula to enter the leg. Damage in the popliteal fossa might result in paralysis of dorsiflexors (causing a foot drop) and foot evertors, and paraesthesia over the lateral leg and dorsum of the foot.
Clinical Cases

1. A 28-year-old female horse rider is thrown off the back of her horse, landing on her flexed left knee. She is unable to bear weight on or to flex the knee joint. Following initial treatment according to Advanced Trauma Life Support (ATLS) guidelines, an isolated injury to the left knee is suspected. Initial X-rays of the left knee are shown in Fig. 82.5. The dislocated patella is reduced in the Accident and Emergency department and the limb is splinted. Regular neurovascular observation reveals weak distal arterial pulses in the affected limb. A vascular surgeon is consulted.

A. What is the investigation of choice and why?

Angiography, computed tomography angiography (CTA) and on-table angiography are examples of first-line investigation modalities used to evaluate possible arterial injuries following limb trauma. Locally agreed protocols in trauma centres and units will dictate the investigation of choice. CTA can be used to visualize arteries and veins in various parts of the body, including the limbs. In addition to evaluating potential vascular injury in this case, CTA facilitates evaluation of the patellofemoral congruity and fracture configuration (Fig. 82.6).
B. To achieve maximum compression across the fracture site, open reduction and internal fixation via a direct posterior approach is performed. The incision line is outlined on Fig. 82.7. What are the useful anatomical landmarks for incision planning and what structures are at risk in each fascial layer?
The direct posterior approach to the knee is performed with the patient in the prone position. The tendons of the hamstrings and the head of the fibula can be palpated and marked. The joint line cannot be palpated posteriorly because of the heads of gastrocnemius and the strong popliteal fascia. The transverse skin crease is 2–3 cm above the joint (see Fig. 82.7). The most superior aspect of the popliteal fossa is a hand’s breadth proximal to the joint line. Additionally, the path of the neurovascular structures can be estimated and marked.

The posterior approach provides adequate exposure of the posterior part of the femoral condyles. A lazy S-shaped incision is made. In the superficial layer, the short saphenous vein and branches of the posterior femoral cutaneous nerve are at risk of injury; deep to the popliteal fascia, the popliteal artery and vein, the tibial and common fibular nerves, the sural cutaneous nerves and genicular arteries are all at risk of injury.

Restoration of the articular surface and fixation of the main bony fragments were achieved using headless screws (Fig. 82.8).

**FIG. 82.8** Restoration of the articular surface and fixation of the main bony fragments with headless screws. **A,** On-table screening pre-fixation. **B,** Final on-table images.
2. A 31-year-old male truck driver presents to his family physician with recurrent right knee pain and effusion with no associated trauma. No other joints are affected. Four years ago, he was found to have pigmented villonodular synovitis (PVNS) following an arthroscopic biopsy. Diffuse joint involvement mainly affecting the suprapatellar bursa of the right knee was found (Fig. 82.9). An open synovectomy through an anterior approach was performed and symptomatic control of the disease was achieved for 3 years. On examination now, the patient is found to have a reduced range of motion and fullness posteriorly and a repeat MRI scan is performed (Fig. 82.10).

FIG. 82.9 Diffuse joint involvement mainly affecting the suprapatellar bursa of the right knee.
FIG. 82.10  Repeat MRI scan of this patient's right knee.

A. What structures are indicated by the arrow on Fig. 82.10?
Popliteal artery and vein.

B. Following adequate counselling, an arthroscopic posterior synovectomy is agreed with the patient. Outline the entry points of the posteromedial and posterolateral arthroscopic portals.
   The posteromedial portal is introduced through a triangle bounded by the medial collateral ligament, the medial head of gastrocnemius and the tendon of semimembranosus at the level of the joint line. The posterolateral portal is introduced just anterior to the tendon of biceps femoris.

C. Name the structures at risk of injury at each portal site.
   The posteromedial portal endangers the long saphenous vein and saphenous nerve. The posterolateral portal endangers the common fibular nerve.
Knee

Mazin Fageir

Core Procedures

• Joint arthroplasty (most common)
• Open/arthroscopic anterior and posterior cruciate ligament repair
• Joint arthroscopy, e.g. meniscectomy, removal of loose bodies
• Joint washout with or without synovectomy for infection
• Fixation of distal femoral fractures
• Microfracture of osteochondral defects
• Patellectomy
• Treatment of osteochondritis dissecans, e.g. mosaicplasty
• Arthroscopically assisted tibial plateau fracture fixation
Embryology

Chondrification in the femur, tibia and fibula begins by stage 18 (42–44 days post fertilization); the condyles and a mesenchymal patella are distinguishable at stages 19–20 (45–50 days post fertilization). Flexures corresponding to joints develop between the cartilaginous precursors of the long bones. The knee joint cavity appears during stage 22 (52–55 days post fertilization), initially as the femoropatellar joint, starting at the edge of the articular interzone. Intra-articular structures develop from the interchondral disc; the menisci develop from the eccentric portions of the articular interzone during this stage but are not easily distinguishable until after stage 23 (53–58 days post fertilization). Patellar chondrification starts during stages 21–22. Condensation occurs successively in the following structures: patellar ligament (stages 18–19), fibular collateral ligament and tendon of popliteus (stage 19), patellar retinacula and cruciate ligaments (stage 19–20), tibial collateral ligament and menisci (stage 20), patellar chondrification (stages 21–22); and oblique popliteal ligament and articular capsule (stage 23). (For further reading about the development of the knee, see the references.1–3)
Surgical surface anatomy

Surface landmarks of the knee can be made more visible by flexing and extending the joint (Fig. 83.1). In subjects with well-defined muscles, three parts of the tendon of quadriceps femoris are observed. Vastus medialis forms a visible soft bulge superomedial to the patella. In contrast, the aponeurosis of vastus lateralis and the iliotibial tract form a firm flat surface superolateral to the patella. The patellar ligament extends from the apex of the patella to the tibial tuberosity. The anterior edge of the iliotibial tract is observed lateral to the patella. The subcutaneous surface of the tibia is continuous with the medial condyle of the tibia.
FIG. 83.1 The anterior aspect of the knee and leg. Key: 1, vastus lateralis; 2, vastus medialis; 3, iliotibial tract; 4, tendon of quadriceps femoris overlying suprapatellar bursa; 5, sartorius; 6, anterior horns of menisci: located above knee joint line (dotted line) and either side of patellar ligament; 7, Gerdy's tubercle (tubercle of iliotibial tract); 8, head of fibula; 9, patellar ligament insertion on to tibial tuberosity; 10, anterior tibial artery (red) and deep fibular nerve (yellow): pass from halfway between head of fibula and tibial tuberosity to a point halfway between...
The bulging vastus medialis is palpated superomedial to the patella. The entirety of the patella can be palpated, except its articular surface. The borders of the patellar ligament are traced from the apex of the patella to its insertion on to the tibial tuberosity. For the medial parapatellar approach, an anterior midline skin incision along the middle of the patella and a capsular incision along the medial border of the patella are used. Flex and extend the joint to palpate the medial joint line. Palpate laterally along the joint line, noting the transition from soft to firm resistance, and mark the edge of the patellar ligament. With the knee flexed, the patellar ligament is traced superiorly to its osteotendinous junction with the patella and the anterior edge of the femoral condyle. The triangular space bound by the patellar ligament, the condyle of the femur and the joint line is the ‘soft spot’, where the joint capsule is superficial: it provides access for arthroscopy portals and open meniscectomy.

Palpate the adductor tubercle on the superior edge of the medial condyle of the femur in the interval between vastus medialis and the insertion of the hamstring muscles. The anteriorly convex skin incision of the medial approach starts just proximal to the adductor tubercle and extends distally 6 cm inferior to the joint line, parallel to the medial border of the patella.

Palpate the lateral border of the patella and the lateral epicondyle of the femur. Palpate Gerdy’s tubercle (the tubercle of the iliotibial tract) on the anterior aspect of the lateral condyle of the tibia midway between the apex of the patella and the head of the fibula. A curved incision in line with the distal femur, lateral edge of the patella, over Gerdy’s tubercle and extending 5 cm inferior to the joint line is used for the lateral approach.

The saphenous nerve becomes distal to the adductor hiatus on the medial side of the knee and then runs with the long saphenous vein. The latter ascends a hand’s breadth posterior to the medial border of the patella. The anterior tibial artery and the deep fibular nerve start at a point midway between the tibial tuberosity and the head of the fibula.

Surgical anatomy

The skin over the anterior knee receives most of its blood supply from a rich
anastomosis between the genicular branches (primarily medial genicular) of the popliteal artery, the recurrent tibial and circumflex fibular branches of the posterior tibial artery, and the descending genicular branch of the femoral artery (Fig. 83.2). Proximally, perforating arteries through the thigh muscles contribute significantly to the cutaneous blood supply. Incisions along the intermuscular planes are therefore less likely to disrupt the blood supply to the skin. The infrapatellar branch of the saphenous nerve, the anterior femoral cutaneous branches of the femoral nerve, and the lateral femoral cutaneous nerves all contribute to the proximal peripatellar plexus. The infrapatellar branch of the saphenous nerve runs laterally just below the joint line and contributes to the distal peripatellar plexus. The skin of the anterior midline is subjected to greater tension during flexion when compared to the sides, which means that a medial parapatellar skin incision is under less tension during knee flexion when compared to an anterior midline incision. However, an anterior midline incision interrupts less blood supply to the lateral skin when compared with a medial parapatellar incision. Cosmetically, curvilinear incisions following the half-circular folding lines surrounding the patella will result in less conspicuous scars.
The subcutaneous tissue around the knee contains the long saphenous vein and the infrapatellar branch of the saphenous nerve medially, and the short saphenous vein, the terminal branches of the posterior femoral cutaneous nerve and the medial and lateral sural cutaneous nerves posteriorly. The deep fascia of the thigh (fascia lata) and the deep fascia of the leg (crural fascia) form a stocking-like structure surrounding the thigh and leg, respectively. The fascia lata and the crural fascia send strong muscular septa deep to the bones. The fascia lata contributes fibres to the medial and lateral patellar retinacula. Inferiorly, the crural fascia attaches to the proximal tibia just inferior to its articular surface and is adherent to the periosteum of the subcutaneous surface of the tibia. Posteriorly, the fascia lata and the crural fascia are continuous with the popliteal fascia. The fascial planes around the knee are arranged into three layers, which are easily distinguishable on the lateral side but fuse together at various points on the medial side. The outer layer (layer 1) is continuous with the fascia lata. It encloses
sartorius medially and biceps femoris posterolaterally. The fascia around sartorius is an extension of the outer layer and overlies the tendons of gracilis and semitendinosus, which therefore run between the outer and the middle layers, deep to sartorius. Posteriorly, layer 1 covers gastrocnemius and is continuous with the popliteal fascia. It sends fibres to the patellar retinacula on each side. Laterally, the thick and strong iliotibial tract constitutes part of this layer and is attached to Gerdy's tubercle on the tibia.

The middle layer (layer 2) consists of the superficial part of the tibial collateral ligament (containing vertical and oblique portions), the fibular collateral ligament, the anterolateral ligament (but see later) and the medial and lateral patellofemoral ligaments. Posteriorly, the layer is reinforced by an expansion of semimembranosus. The superficial part of the tibial collateral ligament attaches to the medial femoral epicondyle proximally and fans out to attach to the subcutaneous border of the tibia 6–7 cm below the joint line posterior to the pes anserinus. The cord-like fibular collateral ligament is attached to the lateral femoral epicondyle and the head of the fibula, piercing the tendon of biceps femoris and separated from the joint capsule by a bursa. The collateral ligaments are tightest in full knee extension, contributing to joint stability (Video 83.1). The anterolateral ligament has been described as attaching to the posterosuperior corner of the lateral femoral epicondyle and running inferomedially to attach to the margin of the lateral tibial plateau, however its existence remains the subject of debate (for example, it has been described as a part of a bifurcated fibular collateral ligament). The expansion of semimembranosus forms the oblique popliteal and arcuate popliteal ligaments. The oblique popliteal ligament is an expansion posterior to the medial tibial condyle that spans superolaterally towards the lateral femoral condyle. The arcuate popliteal ligament attaches to the posterior part of the head of the fibula and spans superomedially over the tendon of popliteus. Both the oblique popliteal and arcuate popliteal ligaments blend with the posterior knee joint capsule. The middle and deep layers contribute fibres to the patellar retinacula.

The deep layer (layer 3) is the joint capsule and is distinct from the other layers, except anteriorly. The capsule is composed of a superficial fibrous layer and a deep synovial membrane. It is incomplete anteriorly, where it is continuous with the tendon of quadriceps femoris, the patella and the patellar ligament, and also posterior to the lateral condyle of the tibia, where it contains an opening for the tendon of popliteus. It is thickened medially, where its vertically orientated fibres make up the deep medial part of the
tibial collateral ligament, which is attached to the medial femoral epicondyle and the tibia at the level of the meniscus. The anterior capsule is innervated by articular branches from the nerves to quadriceps femoris; the superior and inferior medial and lateral genicular nerves; and the common and recurrent fibular nerves. The complex relationships of the soft tissue structures around the anterolateral aspect of the knee is reflected in the lack of consensus regarding their names (e.g. lateral capsular ligament, mid third lateral capsular ligament, short lateral ligament). A lateral thickening in the capsule, the ‘short lateral ligament’, runs from the lateral femoral condyle to the head of the fibula, deep to the fibular collateral ligament. The capsule also contributes fibres to the patellar retinacula and receives reinforcement from the iliotibial tract. The tendon of popliteus pierces the capsule under the arcuate popliteal ligament to run between the capsule and the lateral meniscus. The popliteofibular ligament (short external lateral ligament), a stabilizer of the posterolateral corner of the knee, extends from the tendon of popliteus to the head of the fibula. Anteriorly, the joint space continues proximally as the suprapatellar bursa, for approximately 5 cm proximal to the base of the patella. Rarely, the joint space extends more proximally. The synovial membrane lines all parts of the joint cavity not covered by articular cartilage and is attached to the margins of the articular surfaces of the femur, tibia and patella and the edges of the menisci. The synovial membrane lines the fibrous layer medially and laterally. The two layers separate around the extensor mechanism and infrapatellar fat pad anteriorly and the intercondylar fossa posteriorly. The infrapatellar fat pad and the cruciate ligaments are lined by synovial membrane and so are extrasynovial. The infrapatellar fat pad is richly innervated and conveys a significant proportion of the blood supply to the patella.

Quadriceps femoris forms the main bulk of the anterior thigh. The four parts of quadriceps femoris converge distally to insert on the proximal patella via a strong tendon. The patella, the largest sesamoid bone, is contained within this tendon. The articular surface of the patella is formed of two asymmetrical facets separated by a longitudinal ridge; the lateral facet is typically larger. The medial and lateral patellar retinacula, primarily aponeurotic extensions of the medial and lateral vasti, reinforce the joint capsule. The small articularis genus muscle, derived from vastus intermedius, attaches superiorly to the anterior femur and inferiorly to the synovial membrane of the anterior joint capsule. It elevates the synovial
membrane superiorly when the knee is fully extended. The patellar ligament extends from the apex of the patella to the tibial tuberosity.

The femoral condyles vary in shape: the lateral has a single radius of curvature compared to the multiple radii of curvature of the medial condyle. The condyles protrude distally, separated anteriorly by the trochlea, a shallow depression which articulates with the patella, and posteroinferiorly by the intercondylar fossa, a space mostly occupied by the cruciate ligaments. The epicondyles, which are projections from the outer surfaces of the condyles, provide attachments for the tibial and fibular collateral ligaments. The tibial plateau articulates with the femoral condyles via the interpositioned menisci. The lateral side of the tibial plateau is flatter than the medial side for articulation with the broader lateral femoral condyle. The medial and lateral aspects of the tibial plateau slope posteriorly and are separated by the intercondylar eminence, which is formed by the medial and lateral intercondylar tubercles. The anterior and posterior intercondylar tubercles provide attachment for the menisci and the cruciate ligaments. Just below the joint line, the lateral condyle of the tibia bears Gerdy's tubercle anterolaterally and a facet for articulation with the fibula inferolaterally. Gerdy's tubercle provides attachment to the iliotibial tract. Inferomedial to Gerdy's tubercle, the broad tibial tuberosity protrudes anteriorly.

Tibiofemoral congruence is maintained by the menisci, which are stabilized by multiple connections. The menisci are primarily attached to the tibial facets and the joint capsule by the meniscotibial (coronary) ligaments. The secondary connections – the transverse ligament of the knee, the meniscofemoral ligaments and capsular attachment – all stabilize the menisci throughout the range of motion of the knee joint. The C-shaped medial meniscus is attached medially to the joint capsule and the undersurface of the tibial collateral ligament. The more mobile lateral meniscus is rounded in shape and is not attached to the fibular collateral ligament or the side of the capsule. Only 10–30% of the peripheral parts of the menisci are vascularized in adulthood.\(^2\) The meniscal horns are richly innervated; the centre third is not innervated.

The cruciate ligaments are extrasynovial and innervated. They are named with reference to their tibial attachment. The anterior cruciate ligament (ACL) runs from the anterior intercondylar area of the tibia close to the anterior horn of the lateral meniscus to its attachment on the posteromedial surface of the lateral femoral condyle. The posterior cruciate ligament (PCL) is thicker and stronger than the ACL and runs from the posterior surface of
the proximal tibia to an extensive attachment on the lateral surface of the medial femoral condyle and the intercondylar fossa. The cruciate ligaments are formed from multiple bundles (Fig. 83.3). The meniscofemoral ligaments (MFLs) were first described in 1858 by Humphry. They are more frequently seen in young knees and appear to degenerate with age. The number and description of MFLs varies greatly: up to four have been reported. Most frequently, an anterior meniscofemoral ligament (aMFL) of Humphry and a posterior meniscofemoral ligament (pMFL) of Wrisberg are described, extending from the posterior horn of the lateral meniscus to the lateral surface of the medial femoral condyle. The aMFL is attached to the anterior surface of the PCL, and the pMFL is attached to the posterior surface of the PCL. They are believed to act as secondary restraints to posterior tibial translation. Other MFLs attach to the medial meniscus and anterior horns of both menisci. The transverse ligament of the knee connects the menisci and may connect with the ligamentum mucosum.

![Fig. 83.3](image-url) The left knee joint. A. The anterior aspect in full flexion. B. The posterior aspect in extension. (With permission from R.L. Drake, A.W. Vogl, A. Mitchell et al (eds), Gray's Atlas of Anatomy, Elsevier, Churchill Livingstone, 2008.)

In the anatomical position, the anatomical axis of the femur is directed inferomedially about 9° from the vertical axis. Similarly, the anatomical axis of the tibia is directed inferomedially about 3° from the vertical axis.
Anatomical variants

In females, the anterior aspects of both femoral condyles are less prominent in relation to the trochlea: the anteroposterior and mediolateral aspect ratios are reduced and the Q angle is increased.\textsuperscript{14} The patellar insertion of quadriceps femoris may form a bilaminar, trilaminar or tetralaminar arrangement and may be continuous with the patellar ligament over the anterior surface of the patella.\textsuperscript{15} Variations of the patellar ligament include aplasia and a single report of a doubled tendon.\textsuperscript{16} The medial patellofemoral ligament is broader and more frequently present, highlighting its role as the principal passive medial stabilizer of the patella.\textsuperscript{15} An enlarged discoid meniscus is a common abnormality, predominantly affecting females in a 2:1 ratio. The enlarged meniscus, almost always lateral, is thought to be due to abnormally shaped condyles and may be associated with meniscal cysts.\textsuperscript{17} A limited number of cruciate ligament variants exist, usually in association with meniscal abnormalities, e.g. discoid meniscus.\textsuperscript{18} Congenital absence of the ACL occurs in 17 per 1,000,000 live births.\textsuperscript{19}

Paediatric considerations

The open physis in children represents a weak point in long bones. The most common type of physial fracture is the Salter–Harris type II.\textsuperscript{20} Similarly, the intercondylar tubercle (tibial spine) is prone to avulsion if the ACL is overstressed.\textsuperscript{21} The patella ossifies 3–6 years after birth; it is cartilaginous and therefore invisible on plain knee X-rays of children under the age of 3 years. The multiple ossification centres of the patella join to form a single bone. Failure of fusion results in a bipartite or tripartite patella, which could be mistaken for a fracture. Ossification failure is commonly bilateral. A bipartite patella rarely occurs. The patella may be absent or hypoplastic.\textsuperscript{18}
Surgical approaches and considerations

Open approaches to the knee are utilized in surgical management of knee trauma, joint arthroplasty and situations where arthroscopic instruments fall short of providing adequate exposure and reach. Most open knee surgery can be performed through an anterior longitudinal incision. The fully extended medial parapatellar approach provides access to most intra-articular structures. The approach uses an anterior midline skin incision and a medial parapatellar capsular incision. The capsular incision can be extended proximally in the interval between vastus medialis and rectus femoris, and distally through the crural fascia and periosteal layer of the tibia to the level of the insertion of the patellar ligament. Safe proximal extension covering the distal third of the thigh is possible because the motor branches of the femoral nerve are given off proximal to that level. Meticulous repair of the capsule, retinacula and muscular aponeuroses is pertinent to the function of the extensor mechanism and stability of the patellofemoral joint. The approach is commonly used in total joint arthroplasty; the skin incision divides the infrapatellar branch of the saphenous nerve, resulting in numbness lateral to the scar.

The large cavity of the knee joint is accessible from multiple sides. Anteromedially and anterolaterally, the joint cavity is covered by the capsule, the retinacula, subcutaneous tissue and skin. The superficial parts of the joint cavity are palpable as fluid-filled soft spots on either side of the extensor mechanism and provide exposure to intra-articular structures, the articular sides of the femur, tibia and patella. The major neurovascular structures descend to the leg posterior to the knee and are surgically accessible through the posterior approach to the knee. For meniscectomy, an anterolateral or anteromedial longitudinal, horizontal or oblique incision is used. The preferred oblique incision starts at the outer edge of the proximal osteotendinous junction of the patella tendon, descending obliquely away from the patella tendon at about 45° to the level of the joint line. The classic open medial and lateral meniscectomy approaches have been largely superseded by anterior arthroscopy. Anterolateral and anteromedial portals are commonly utilized to introduce an arthroscope and instruments through the ‘soft spots’ into the joint cavity (Fig. 83.4). Arthroscopy is employed in cruciate ligament repair, meniscectomy or repair, synovectomy and arthroscopic assisted fracture repair.
FIG. 83.4  Anterolateral and anteromedial portals are commonly utilized to introduce an arthroscope and instruments through the ‘soft spots’ into the joint cavity.

The medial approach provides exposure to the medial structures and posteromedial corner of the knee joint. The approach is used for tibial collateral ligament, meniscal and ACL repair. The saphenous nerve and long saphenous vein are encountered in the superficial layer between sartorius and gracilis. Deeper dissection progresses just anterior to sartorius. Sartorius, gracilis and semitendinosus are retracted posteriorly to reveal the tibial collateral ligament. A longitudinal capsulotomy is performed anterior or posterior to the tibial collateral ligament to access the joint.

The lateral approach is used in surgical repair of the lateral supporting and bony structures. In ACL repair, the lateral approach can be used to access the intercondylar fossa. The common fibular nerve runs posterior to the tendon of biceps femoris; therefore, the dissection progresses anterior to this tendon. Incising the fascia lata in the interval between the iliotibial tract and biceps femoris exposes the fibular collateral ligament. The joint capsule is opened anterior or posterior to the ligament.

**Tips and Anatomical Hazards**

The capsule thickens medially to form the deep part of the tibial collateral ligament.
The deep part of the tibial collateral ligament attaches to the tibia at the level of the medial meniscus. The superficial part of the tibial collateral ligament attaches to the tibia 6–7 cm inferior to the joint line. The joint space extends proximally about 5 cm proximal to the base of the patella. The infrapatellar fat pad is richly innervated and conveys most of the blood supply to the patella. The menisci are attached to the periphery of the tibial plateau by the lateral and medial meniscotibial (coronary) ligaments. The medial meniscus is less mobile than the lateral meniscus. Only 10–30% of the peripheral parts of the menisci are vascularized in adulthood. The cruciate ligaments are formed from multiple bundles. The medial patellofemoral ligament is broader and more frequently present than the lateral patellofemoral ligament. Failure of fusion of patellar ossification centres results in a bipartite or tripartite patella. The lateral aspect of the tibial plateau is more inferior than its medial aspect. The inferior genicular vessels spiral on either side of the tibia under gastrocnemius. The subcutaneous layer contains the long saphenous vein and the infrapatellar branch of the saphenous nerve medially, and the short saphenous vein, terminal branches of the posterior femoral cutaneous nerve and the medial and lateral sural cutaneous nerves posteriorly (Fig. 83.5).
FIG. 83.5  Articular cartilage (1) and meniscus (4) can be damaged by scalpels or instruments. A more anteriorly placed incision or instrument risks damage to the patellar ligament (2), the anterior horns of the menisci or the transverse ligament of the knee (3). The infrapatellar branch of the saphenous nerve (5) is often sacrificed in the medial parapatellar approach. When the approach is not used for joint arthroplasty, care must be taken not to damage the anterior horn of the medial meniscus or its anterior insertion into the tibia, the medial meniscotibial (coronary) ligament (8). Overzealous release of the patellar ligament (2) near its tibial insertion or excessive lateral retraction of the patella (10) risks iatrogenic damage to the extensor mechanism, which can be difficult to repair. The inferior medial genicular artery (9) spirals around the tibia under the cover of the medial head of gastrocnemius. The saphenous nerve (11) and long saphenous vein (12) are encountered in the superficial fascia along the posterior border of sartorius (13) and must be protected. The fibular collateral ligament (15) is at risk of damage if an oblique or transverse incision is extended posteriorly. Longitudinal lateral incision may damage the lateral meniscus (16) or lateral meniscotibial ligament (17). The inferior lateral genicular artery (18) runs deep to the lateral head of gastrocnemius and superficial to the posterolateral joint capsule. The common fibular nerve (14) runs posterior to the tendon of biceps femoris (19). The nerve is protected if the deep dissection is carried out anterior to the muscle. The tendon of popliteus (20) is at risk as it passes deep to the fibular collateral ligament (15) and superficial to the lateral meniscus (16). *Note the relationship between the tibial collateral ligament (6) and medial meniscus (7). The common fibular nerve runs posterior to the tendon of biceps femoris. Blind insertion of instruments into the joint risks damage to the articular cartilage, menisci, patellar ligament, transverse ligament of the knee and meniscofemoral ligaments. The tibial collateral ligament is at risk of damage if a medial incision is
extended posteriorly. The fibular collateral ligament is at risk of damage if a lateral incision is extended posteriorly. Capsular incision at the level of the joint line may damage the menisci, transverse ligament of the knee or meniscofermoral ligaments. Excessive retraction of the patella risks iatrogenic damage to the extensor mechanism, which can be difficult to repair.
References

12. Gupte CM, Bull AM, Thomas RD, Amis AA. The meniscofemoral ligaments: secondary restraints to the


Single Best Answers

1. Which one of the following statements about the surgical anatomy of the knee joint is correct?

A. The patellar ligament and the infrapatellar branch of the saphenous nerve are at risk of damage during lateral approaches to the tibial condyle
B. The cruciate ligaments are named with reference to their femoral attachment
C. The tendon of popliteus is superficial to the lateral meniscus and deep to the joint capsule and the fibular collateral ligament
D. The cruciate ligaments are intrasynovial
E. In a coronal section, the tibial condyles are at the same level

Answer: C. The tendon of popliteus is superficial to the lateral meniscus and deep to the joint capsule and the fibular collateral ligament. Popliteus is attached to the lateral femoral condyle anteroinferior to the origin of the fibular collateral ligament. The intra-articular portion of the tendon passes between the lateral meniscus and the lateral joint capsule to exit the joint through a hiatus in the lateral meniscotibial (coronary) ligament of the lateral meniscus under the arcuate popliteal ligament. The cord-like tendon flattens to attach to a broad area on the posterior tibia above the soleal line to form the floor of the popliteal fossa. The tendon of popliteus sends fibres to the head of the fibula to form the important popliteofibular ligament. The tendon is also connected to the lateral meniscus and the arcuate popliteal ligament by strong fibres. Popliteus is innervated by the tibial nerve. The muscle laterally rotates the femur on the fixed tibia or medially rotates the tibia on the femur; it is thought to ‘unlock’ the fully extended knee at the beginning of flexion.
2. Which one of the following is NOT an important surgical landmark in a lateral approach to the tibial plateau?
   A. The adductor tubercle
   B. Gerdy’s tubercle (tubercle of the iliotibial tract)
   C. The knee joint line
   D. The tendon of biceps femoris
   E. The lateral femoral condyle

   **Answer: A.** The lateral approach to the knee provides access to bony and supporting structures. In anterior cruciate ligament repair, the lateral approach can be used to access the intercondylar fossa. Identify the lateral border of the patella, the lateral femoral condyle, the iliotibial tract, tendon of biceps femoris, the joint line and Gerdy's tubercle (tubercle of the iliotibial tract). An anteriorly convex lateral skin incision is used. Begin the incision over the posterior third of the lateral femoral epicondyle at the level of the middle of the patella. The incision is extended distally over the tubercle of the iliotibial tract. The common fibular nerve travels posterior to the tendon of biceps femoris and therefore the dissection progresses anterior to this tendon. Incising the fascia lata in the interval between the iliotibial tract and biceps femoris exposes the fibular collateral ligament. The joint capsule can be opened anterior or posterior to the ligament if required.

3. Which one of the following statements about the vascular anatomy of the knee is correct?
   A. The descending genicular artery, a branch of the popliteal artery, contributes to the anastomosis around the knee joint
   B. The inferior genicular vessels spiral around the tibia superficial to their respective collateral ligaments
   C. The majority of the blood supply to the patella is delivered via
the tendon of quadriceps femoris
D. The superior genicular vessels provide most of the blood supply to the cruciate ligaments
E. The central parts of the menisci are avascular in adults

Answer: E. The central parts of the menisci are avascular in adults. In the fetus, the menisci are highly vascular; the genicular branches of the popliteal artery provide most of their blood supply, forming a premeniscal capillary network around the periphery of the menisci. During development, there is a gradual decrease in vascularity and a concomitant increase in the collagen content of the menisci. The peripheral 10–30% of the medial meniscus and 10–25% of the lateral meniscus are relatively vascularized, which means that peripheral tears have the potential to heal. The central parts of the menisci receive nourishment from synovial fluid via diffusion or mechanical pumping.

4. Which one of the following statements about the biomechanics of the knee joint is INCORRECT?
A. The proximal articular surface of the tibia has a posterior slope of 7–10°
B. The anterior cruciate ligament is the primary restraint to anterior tibial translation
C. The posterior cruciate ligament makes a secondary contribution to varus-valgus stability
D. The medial meniscus does not contain mechanoreceptors.
E. The patella has the thickest articular cartilage in the human body

Answer: D. The menisci contain mechanoreceptors that transform mechanical deformation into electric signals. Subtypes
of mechanoreceptors, such as Pacinian and Golgi tendon organs, convey afferent feedback about joint motion and position, which means that the menisci play an important afferent role in the sensory feedback from the knee.

5. Which one of the following statements about the anatomy of the cruciate ligaments is INCORRECT?

A. The majority of the blood supply to the cruciate ligaments is provided by the superior genicular vessels
B. The anterior cruciate ligament consists of anteromedial and posterolateral bundles
C. The blood supply to the cruciate ligaments is provided mostly by the middle genicular artery
D. The cruciate ligaments are named in relation to their insertion
E. The cruciate ligaments are innervated by an articular branch from the tibial nerve

**Answer: A.** The anterior cruciate ligament has a better blood supply than the posterior cruciate ligament. The cruciate ligaments receive the majority of their blood supply from the middle genicular artery; the tibial attachments of the cruciate ligaments are supplied by the inferior genicular vessels. The middle genicular artery reaches the ligaments at the posterolateral corner of the intercondylar fossa and descends along the posterior border of the anterior cruciate ligament. The middle and inferior genicular arteries form a network in the synovial membrane surrounding and supplying the ligaments. The fibrocartilaginous zones of the anterior cruciate ligament and the posterior middle third of the posterior cruciate ligament are avascular.
Clinical Cases

1. A 25-year-old female fell off her pushbike while coming down a hill at high speed. She sustained an injury to her left knee and skin abrasions over her left knee and elbow. She tried to stand up after the fall but was unable to weight-bear on her left lower limb. There were no other injuries and she was otherwise fit and well. The initial anteroposterior X-ray of the knee is shown in Fig. 83.6 and demonstrates a proximal tibial fracture.

![Fig. 83.6](image)

**FIG. 83.6** The initial anteroposterior X-ray of the left knee. Vertical fracture through lateral tibial plateau.

A. Name the structures numbered 1–7 on the X-ray.

The structures are: 1, lateral epicondyle of femur; 2, lateral tibial plateau; 3, neck of fibula; 4, medial condyle of femur; 5, medial epicondyle of femur; 6, intercondylar eminence; 7, medial condyle of tibia.

B. What branch of the sciatic nerve is closely related to structure number 3? If it is injured, how might the patient present?

The common fibular nerve; it divides into the superficial and deep fibular nerves.

Injury to the common fibular nerve may cause paralysis of dorsiflexion of
the foot, causing foot drop, paralysis of the foot evertors, and paraesthesia over the lateral leg and dorsum of the foot.

C. For surgical correction of the fracture, a lateral incision line is planned, as seen in Fig. 83.7. Which branch of the popliteal artery is at risk of injury if the proximal tibia is exposed to just inferior to the attachment of the lateral meniscotibial (coronary) ligament?

D. Which nerve is at risk of injury? What muscle is its anatomical landmark at this point?
The common fibular nerve is at risk of injury.
The common fibular nerve descends along the posterior border of biceps femoris. It spirals around the posterior aspect of the head of the fibula to lie lateral and then anterior to the neck of the fibula.

E. Which ligament attaches the lateral meniscus to the periphery of the tibial plateau?
The lateral meniscotibial (coronary) ligament.

2. A 64-year-old female patient has long-standing knee pain that has developed gradually; there has been no associated trauma. The pain
wakes her up at night and is limiting her ability to exercise. She has rheumatoid arthritis and is taking methotrexate and infliximab. She had a left elbow replacement with a satisfactory outcome. She works as a property manager and has an active lifestyle. Her family physician organizes plain X-rays of the patient's knee.

A. What are the structures labelled 1 and 2 on Fig. 83.8A?
Answer: 1, anterior cruciate ligament; 2, posterior cruciate ligament.

B. What are the radiological changes of arthritis labelled 3 and 4 on Fig. 83.8B?
Answer: 3, osteophyte formation; 4, cyst formation.

C. What are the radiological changes of arthritis labelled 1 and 2 on Fig. 83.9?

Answer: 1, subchondral sclerosis; 2, osteophyte formation.

D. The surgical skin incision (blue) and the capsular incision (red) are planned as shown on Fig. 83.10. What important structure traverses the subcutaneous layer and is at risk of injury as a result of the skin incision?
The infrapatellar branch of the saphenous nerve.

E. What internervous plane does the proximal extension of the capsular incision traverse?

There is no internervous plane. The femoral nerve supplies quadriceps femoris. Over the distal third of the anterior thigh, the dissection can be extended proximally without risk of denervating quadriceps femoris because the motor branches are given off more proximally.

The immediate postoperative X-rays are shown in Fig. 83.11.
FIG. 83.11 Immediate postoperative X-rays. A, An anteroposterior view. B, A lateral view.
Compartments of the leg

Thomas A Schildhauer, Christian Fisahn

Core Procedures

• Open reduction internal fixation of tibial/fibular fractures
• Closed reduction intramedullary fixation of tibial/fibular fractures
• Application of less invasive stabilization system (LISS) plate to the tibia
• Tibial/fibular osteotomies
• Body of the fibula harvest for vascularized bone graft
• Bone grafting and operative fixation of tibial/fibular non-unions
• Four-compartment fasciotomies for compartment syndrome
Surgical surface anatomy

Prior to surgical incisions/approaches to the leg, various anatomical surface landmarks should be appreciated. Anteriorly, the patellar ligament is attached to the tibial tuberosity 3–5 cm inferior to the knee joint line. Inferior to the tuberosity, the anterior border of the tibia can be palpated distally to the ankle, where the medial malleolus of the tibia can be seen and felt. The distal part of the long saphenous vein usually courses just anterior to the medial malleolus; the tibial nerve and posterior tibial vessels travel posterior to the medial malleolus. Gerdy's tubercle is felt approximately 1 cm inferior to the knee joint line and 2–3 cm lateral to the tibial tuberosity. The head of the fibula can be palpated approximately 2 cm distal to the knee joint line and is in line with the lateral malleolus of the distal fibula. Importantly, the common fibular nerve courses around the head of the fibula to curve around its neck.

Anterior surface

Tibialis anterior originates from the proximal half to two-thirds of the lateral tibia. Descending inferomedially across the anterior aspect of the leg, the muscle becomes tendinous before inserting on to the first metatarsal and medial cuneiform. Lying lateral to tibialis anterior, extensor digitorum longus arises from the lateral condyle of the tibia and proximal three-quarters of the medial fibula. The muscle passes inferiorly, becoming tendinous at approximately the same level as tibialis anterior, prior to dividing into four slips and inserting on to phalanges two to five. Extensor hallucis longus lies between, and is partially overlapped by, tibialis anterior and extensor digitorum longus. Its origin is from the middle half of the medial fibula, medial to that of extensor digitorum longus; its fibres end in a tendon that runs along the anterior aspect of the muscle and passes deep to the inferior extensor retinaculum to insert on to the dorsal aspect of the base of the distal phalanx of the great toe. Fibularis tertius arises from the distal third of the medial fibula and inserts on to the dorsal surface of the fifth metatarsal.

The anterior tibial artery emerges into the anterior compartment above the interosseous membrane. It then runs along the anterior aspect of the interosseous membrane, lying proximally between tibialis anterior and extensor digitorum longus, and distally between tibialis anterior and extensor hallucis longus. The common fibular nerve can often be palpated as
a firm cord curving laterally around the neck of the fibula. It proceeds deep to fibularis (peroneus) longus, bifurcating into the superficial and deep fibular nerves. Proximally, the superficial fibular nerve runs deep to fibularis longus. It emerges anterolaterally in the distal third of the fibula, passing between fibularis longus and brevis and extensor digitorum longus before branching into the medial and intermediate dorsal cutaneous nerves. The deep fibular nerve runs anterior to the interosseous membrane, travelling with the anterior tibial artery in the distal two-thirds of the leg (Fig. 84.1A). 1-3
FIG. 84.1  The muscle attachments of the left tibia and fibula. A, Anterior aspect. Key: 1, semimembranosus; 2, medial patellar retinaculum; 3, epiphyseal line (growth plate); 4, tibial collateral ligament; 5, gracilis; 6, sartorius; 7, semitendinosus; 8, tibialis anterior; 9, capsular attachment; 10, iliobibial tract; 11, capsular attachment; 12, fibular collateral ligament; 13, biceps femoris; 14, patellar ligament; 15, epiphyseal line (growth plate); 16, fibularis longus; 17, extensor digitorum longus; 18, tibialis posterior; 19, fibularis brevis; 20, extensor hallucis longus; 21, extensor digitorum longus; 22, fibularis tertius; 23, epiphyseal line (growth plate); 24, epiphyseal line (growth plate). B, Posterior aspect. Key: 1, gap in capsule for popliteus tendon; 2, soleus; 3, flexor hallucis longus; 4, fibularis brevis; 5, epiphyseal line (growth plate); 6, capsular attachment; 7, semimembranosus; 8, epiphyseal lines (growth plates); 9, popliteus; 10, soleus; 11, tibialis posterior; 12, flexor digitorum longus; 13, epiphyseal line (growth plate); 14, capsular attachment. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Figs 83.3B, 83.4B.)

Posterior surface

Gastrocnemius is the most superficial muscle of the posterior leg. Its two heads have tendinous attachments to the lateral and medial condyles of the femur. Its muscle fibres extend to approximately mid-calf, where they begin to insert into a broad aponeurosis on its anterior surface. The aponeurosis gradually narrows and receives the tendon of soleus on its deep surface to form the calcaneal (Achilles) tendon. Soleus lies deep to gastrocnemius, originating from the posterior aspect of the head of the fibula, the proximal quarter of the body of the fibula, and the soleal line. Tibialis posterior, flexor digitorum longus and flexor hallucis longus comprise the deep flexor group of the leg. Flexor digitorum longus lies deep to soleus, originating from the posteromedial tibia. Flexor hallucis longus arises from the distal two-thirds of the posterior fibula and travels inferolaterally to pass posterolateral to flexor digitorum longus at the ankle. It lies deep to the calcaneal tendon and soleus, and lateral to flexor digitorum longus. Tibialis posterior arises between flexor hallucis longus and flexor digitorum longus from the upper two-thirds of the posteromedial fibula, lateral posterior tibia and intraosseous membrane.\textsuperscript{1,2}

The posterior tibial artery runs through the flexor compartment and bifurcates into the medial and lateral plantar arteries midway between the medial malleolus and calcaneal tubercle, deep to abductor hallucis. The artery travels posterior to tibialis posterior, flexor digitorum longus, the tibia and the ankle joint, sitting lateral to extensor hallucis longus. The fibular artery branches off the posterior tibial artery, travelling obliquely to the fibula, and descending either between tibialis posterior and flexor hallucis
longus or within flexor hallucis longus. The long saphenous vein arises anterior to the medial malleolus and follows an anteroposterior course over the distal third of the medial tibia before travelling superiorly along the medial aspect of the leg. The tibial nerve descends alongside the posterior tibial artery and veins. It begins deep to soleus and gastrocnemius, passing superficially in the distal third of the leg. Distally, the sural nerve descends lateral to the calcaneal tendon, near the short saphenous vein, and supplies the posterior and lateral skin of the distal third of the leg. It then passes distal to the lateral malleolus along the lateral side of the foot and fifth toe, supplying the overlying skin (Fig. 84.1B).1,2

Lateral surface

Fibularis longus, the most superficial of the two lateral compartment muscles, originates on the head and proximal two-thirds of the lateral fibula, the deep surface of the deep fascia and the anterior and posterior intermuscular septa; the common fibular nerve passes between its attachments to the head and shaft of the fibula. Proximally, fibularis longus lies posterior to extensor digitorum longus and anterior to soleus and flexor hallucis longus. Distally, it runs posterior to fibularis brevis and ends in a tendon that passes posterior to the lateral malleolus, crosses the sole of the foot obliquely and is attached to the lateral side of the base of the first metatarsal and the lateral aspect of the medial cuneiform (Ch. 86). Fibularis brevis originates from the distal two-thirds of the lateral fibula and posterior crural intermuscular septum. It passes downwards, ending in a tendon that passes behind the lateral malleolus together with, and anterior to, that of fibularis longus. It is inserted into a tuberosity on the lateral side of the base of the fifth metatarsal.1,2
Clinical anatomy

The tibia and fibula are approximately equal in length but are very different in terms of structure and function. The tibia is robust and transmits most of the stress during walking, whereas the fibula is slender and contributes primarily to ankle stability. The fibula is almost entirely enclosed in muscle.²

The leg consists of four compartments: anterior, lateral, superficial posterior and deep posterior.⁴ The anterior compartment contains tibialis anterior, extensor hallucis longus, extensor digitorum longus, fibularis tertius, the deep fibular nerve and the anterior tibial artery and veins. The lateral compartment contains fibularis longus and fibularis brevis, both supplied by the superficial fibular nerve. The superficial posterior compartment contains gastrocnemius, soleus and plantaris. The deep posterior compartment contains tibialis posterior, flexor digitorum longus, flexor hallucis longus, popliteus, the tibial nerve and the posterior tibial artery and veins (Fig. 84.2).

The anterior and lateral compartments are separated by the anterior
intermuscular septum; the lateral and posterior compartments are separated by the posterior intermuscular septum. The anterior and deep posterior compartments are separated by the interosseous membrane between the tibia and fibula. The superficial and deep posterior compartments are separated by the transverse intermuscular septum. Surgical dissection of this region is based on the neuromuscular planes defined by these septa.\textsuperscript{5}

Veins are notoriously variable, although there are themes. The superficial venous system of the leg, the saphenous system, is composed of a series of longitudinal channels. Alterations in the saphenous system, such as dilation and tortuosity, result in varicose veins and potential venous ulcers. The long saphenous vein is enclosed in a loose compartment of fat and areolar tissue lying on the deep fascia. The short saphenous vein lies within the deep fascia and extends from the lateral malleolus to the popliteal fossa. These veins communicate with the medial perforating veins of the ankle, receiving substantial tributaries from the medial aspect of the ankle. Anterior crural veins ascend diagonally across the anterior surface of the tibia toward the long saphenous vein. Perforating veins connect the superficial veins of the leg to the deep veins by piercing the crural fascia; the perforating veins have valves.\textsuperscript{6}
Surgical approaches to the tibia and fibula

The anterior approach to the tibia is commonly used. Anterolateral, posterolateral and posteromedial approaches may also be chosen, depending on the site of pathology (for example, fracture location) or the need for operative visualization. In the setting of open fractures or significant trauma, the skin and soft tissues normally dictate the operative approach, and skin necrosis and wound complications are not uncommon.

Anterior approach to the tibia

The anterior approach provides access to the medial and lateral surfaces of the tibia and is primarily used for open reduction and internal fixation of tibial fractures. The incision is centred over the fracture, 1 cm lateral to the anterior border of the tibia. It is important to remember that the border is subcutaneous; wound complications and issues with primary closure can therefore occur if the incision is made within 1 cm of this bony ridge. Skin and subcutaneous tissues are elevated to expose the fracture site. Periosteal stripping must be minimal because the periosteum provides a small amount of the blood supply to fractured pieces of bone. Typically, plates are applied to the subcutaneous surface of the bone, on its tensile side. When the medial skin flap is reflected, the surgeon must exercise caution because the long saphenous vein is on the medial side of the calf. The risk of injury to both the long saphenous vein and the saphenous nerve increases at the distal extent of the incision. The tendon sheaths of the extensor muscles must not be violated if the incision is extended distally because this may lead to unwanted adhesions. In open tibial fractures or those with traumatized medial tissues, care must be taken when elevating a medial flap or placing a plate medially because this thin, traumatized skin may necrose. In open fractures where the medial skin is compromised, an anterolateral approach should be considered for debridement and possible fixation. If oedema precludes primary closure, a direct medial approach will require rotational or free flap coverage, whereas the anterolateral musculature allows for a more conservative approach to coverage (Fig. 84.3A).\textsuperscript{1,2,4}
FIG. 84.3  A, The anterior approach to the tibia. Tibialis anterior has been lifted from the lateral surface of the tibia; periosteal incision and elevation are kept to a minimum. Red line indicates location of incision. B, The anterolateral approach to the tibia. The knee joint is entered by dividing the synovium; the lateral meniscus is detached from its soft tissue attachments inferiorly in order to develop a plane between the undersurface of the lateral meniscus and the tibial plateau. The fascia overlying tibialis anterior is incised and the muscle belly is mobilized from the lateral aspect of the tibial shaft. Red line indicates location of incision.

Anterolateral approach to the tibia

The anterolateral approach is preferred when the subcutaneous surface of the bone is unsuitable for an anterior approach and is used to expose the middle two-thirds of the tibia. This approach is usually less ideal for the primary fixation of closed fractures but can be used for bone grafting of the
tibia. The incision is 1–2 cm lateral to the anterior border of the tibia. Tibialis anterior is elevated off the lateral tibia; dissection should not be extended past the posterolateral corner of the tibia to avoid injuring the deep fibular nerve and anterior tibial vessels. This neurovascular bundle must be identified if the incision is extended to the distal third of the tibia because it lies directly on the periosteum. The periosteum should be kept intact and elevated on the periphery of the fracture only as needed for reduction. Just the skin should be closed, and not the fascia, to minimize the risk of compartment syndrome (Fig. 84.3B).\textsuperscript{1,2,4}

**Posterolateral approach to the tibia**

The posterolateral approach exposes the middle two-thirds of the tibia and is used for internal fixation of fractures and bone grafting. This approach can be used for non-unions where bone grafting is required and where access to both the fibula and the tibia is required. During patient positioning, remember that the fibula is more posterior to the tibia; surgical approach and visualization can be complicated if this relationship is not taken into account. The incision is made over the lateral head of gastrocnemius, remembering that the short saphenous vein runs up the posterolateral aspect of the leg and can be damaged when the skin flaps are moved. If necessary, the vein may be ligated without impairing venous return from the leg. In order to reduce postoperative bleeding, branches of the fibular artery should be ligated or coagulated. Superficial tissues are elevated to locate the posterior intermuscular septum. Dissection is carried out between the lateral and superficial posterior compartments to the lateral surface of the fibula. Flexor hallucis longus is elevated off the posterior aspect of the fibula to the level of the interosseous membrane. Proceeding with caution, the contents of the deep posterior compartment are elevated from the interosseous membrane. The exposure may be retracted and extended if needed because the tibial nerve and posterior tibial vessels lie just posterior to the contents of the deep posterior compartment. The exposure is extended medially until the posterior surface of the tibia is identified and tibialis posterior and flexor digitorum longus are elevated from the posterior surface of the tibia to visualize the fracture or other pathology. If there are any concerns regarding swelling or possible compartment syndrome, only the skin, and not the fascia, should be closed (Fig. 84.4A).\textsuperscript{1,2,4}
FIG. 84.4  A, The posterolateral approach to the tibia. Flexor hallucis longus is detached from its origin on the fibula and retracted posteriorly and medially. Dissection is continued posteriorly, staying on the posterior surface of the fibula. Red line indicates location of incision. B, The posteromedial approach to the tibia. An epi-periosteal plane is developed between the pes anserinus and the medial head of gastrocnemius at the posteromedial border of the tibia. The muscle is gently freed from the bone by blunt dissection. Red line indicates location of incision.

Posteromedial approach to the tibia

The posteromedial approach is useful when the soft tissue precludes other surgical approaches and can also be extended to incorporate fractures of the tibial plateau. One benefit of a posterior approach is that the relatively straight, flat nature of the posterior tibia minimizes the amount of plate bending and contouring required. The incision is centred over the fracture 1–2 cm posterior to the posteromedial surface of the tibia. The short saphenous vein and sural nerve are identified and protected, and are often moved anteriorly with the adjacent skin flap. The fascia of the deep posterior
compartment is incised and flexor digitorum longus is identified and elevated from the posterior surface of the tibia. More proximally, fibres from soleus must be elevated as well. There is no need to dissect beyond the posterolateral aspect of the tibia; deep dissection may injure the deep fibular nerve and anterior tibial vessels. The posterior soft tissue attachments provide the most robust vascular supply to the tibia and therefore muscular and subperiosteal elevation should be minimized (Fig. 84.4B).1,2,4

Approach to the fibula

Approaches to the fibula can be used for decompression of the compartments of the leg, resection of tumours and treatment of non-union of tibial fractures. The incision is placed just posterior to the long axis of the fibula and can be extended from the knee to the lateral malleolus. If extending the incision proximally, it is useful to curve it posteriorly along the axis of the tendon of biceps femoris and bluntly dissect along the posterior surface of the tendon. The common fibular nerve may be found where it wraps around the neck of the fibula by following the tendon distally to its point of insertion; the nerve is subcutaneous at this point and can sometimes be palpated prior to incision. It should be removed from the surgical field by gently retracting it over the head of the fibula using a Penrose drain. All branches of the common fibular nerve should be identified and preserved; the superficial fibular nerve sometimes arises more proximally than normal and should be avoided. The interval between the lateral and superficial posterior compartments is identified and the body of the fibula exposed by blunt dissection down to bone. The superficial fibular nerve and the small saphenous vein are at risk of damage with the posterior skin flap and must be protected.

Proceeding more distally, flexor hallucis longus is elevated from the posterolateral fibula. The cutaneous branches of the superficial fibular nerve should be identified and isolated at the junction of the middle and distal thirds of the tibia. The nerve usually crosses 10.5–12.5 cm proximal to the lateral malleolus, but this is variable and therefore care should always be taken when operating in this region (Fig. 84.5).1,2,4
**FIG. 84.5** Approach to the fibula. The fibular muscles are retracted anteriorly and the interosseous membrane is stripped from the anterior border of the fibula in a proximal to distal direction. The muscles are stripped from the anterior surface of the fibula and the interosseous membrane is stripped from its fibular attachment in a proximal to distal direction. Red line indicates location of incision. (Modified from Surgical Exposures in Orthopaedics. Hoppenfeld S, de Boer P, Buckley R (Eds) 5th edition. Philadelphia: Wolters Kluwer.)

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**Dual-incision fasciotomy for compartment syndrome**

A medial incision is made 2 cm posterior to the posteromedial surface of the tibia, taking care not to injure the short saphenous vein or sural nerve. The transverse intermuscular septum is identified and the deep posterior compartment is released, followed by the superficial posterior compartment. To limit injury to the underlying neurovascular bundle, only the fascia should
be incised. The anterior and lateral compartments are accessed through a single lateral longitudinal incision based 2 cm anterior to the body of the fibula. After the skin has been incised, the anterior intermuscular septum that divides the anterior and lateral compartments should be identified. The anterior compartment is released by a longitudinal incision that is centred between the intermuscular septum and the anterior border of the tibia. The lateral compartment is then released in line with the fibula and posterior to the intermuscular septum. Care must be taken to identify the superficial fibular nerve.\(^7\)

**Single-incision fasciotomy for compartment syndrome**

Single-incision fasciotomy avoids a medial incision while still providing adequate exposure and compartment release. A single skin incision is made on the posterior surface of the fibula 5 cm proximal to the lateral malleolus and 4–7 cm distal to the head of the fibula, and full-thickness anterior and posterior skin flaps are developed. The anterior and posterior intermuscular septa, the cutaneous branches of the superficial fibular nerve at the distal third of the fibula, and the fascia overlying the anterior, lateral and superficial posterior compartments should all be identified. The posterior intermuscular septum is grasped in order to keep it taut and fibularis longus and brevis are elevated from its surface. The deep posterior compartment is released by incising the posterolateral fibular insertion of the lateral intermuscular septum sharply or with electrocautery. The fascia should be incised directly off the posterolateral fibula to minimize inadvertent injury to adjacent structures. When the four-compartment fasciotomy is complete, all compartments should be checked to ensure adequate release has been achieved (Fig. 84.6).\(^8,9\)
FIG. 84.6 Single-incision fasciotomy for compartment syndrome. A–C, Decompression of the anterior and lateral compartments. A, A longitudinal incision is made over the anterolateral aspect of the lower leg, starting at the level of the tibial tubercle and extending to end 6 cm above the level of the ankle. Red line indicates location of incision. B, A transverse section showing the fascial compartments. Decompressing the deep flexor compartment may involve lifting soleus off the intermuscular septum, which is then divided under direct vision, taking care to avoid the posterior neurovascular bundle. C, The fascia over the anterolateral compartments is incised in the line of the skin incision. D–F, Decompression of the superficial and deep flexor compartments. D, A longitudinal incision is made over the posteromedial aspect of the lower leg, starting at the level of the tibial tubercle and extending the incision distally, to end 6 cm above the ankle. Red line indicates location of incision. E, A transverse section showing the fascial compartments. F, The fascia over the anterolateral compartments is incised in the line of the skin incision.
Paediatric considerations: acute extremity compartment syndrome occurs mainly in fractures of the lower extremities. Previous studies indicate that children tolerate increased pressures in the leg compartments for longer periods of time than adults before the effects become irreversible. The diagnostic tools utilized for adults cannot directly translate to paediatric cases, often delaying the diagnosis. With anterolateral approaches to the distal tibia, be careful of the superficial fibular nerve as it crosses the fibula and proceeds distally and medially.

The anterior compartment is the most common site of acute compartment syndrome. If untreated, ankle and foot contractures, dyseaesthesia in the distribution of the deep and superficial fibular nerves or foot drop might develop. Elevated pressures in the remaining compartments can cause similar pathology based on the neurovascular/muscular contents of the respective compartment.

Acute extremity compartment syndrome is defined by an increase in compartmental pressure causing a decrease of perfusion pressure, leading to hypoxia of the tissues. The leg is frequently the location of acute extremity compartment syndrome, usually from tibial fractures. In order to treat acute extremity compartment syndrome in the leg, emergency surgical release and four-compartment fasciotomy must be performed, emphasizing a wide release of the compartment. In order to decrease the recurrence of acute extremity disorder, surgeons must not close wounds too early. If adequate perfusion and function cannot be restored, amputation might be required.

Surgery of the leg should attempt to stay within the neurovascular and fascial planes travelling between its compartments. Direct muscle dissection will result in possible injury to the muscle and excessive bleeding. Extreme care must be used in surgical manoeuvres around the neck of the fibula in order to avoid the common fibular nerve. Very proximal surgical approaches to the anterior leg can damage the infrapatellar branch of the saphenous nerve. Posterior surgical approaches must avoid injury to the tibial nerve and its branches.
Compression of the popliteal vein should be avoided in positioning the surgical patient in order to avoid deep vein thrombosis. For the leg, the major neurovascular structures to avoid include the common fibular nerve and its branches, the main trunks of the sural and saphenous nerves, and the tibial and fibular arteries. The knee joint (proximally) and the ankle joint (distally) should be avoided in surgery of the leg.
References


1. A 29-year-old male presents to the physician for removal of a cast from his left leg. He sustained a fracture of the left lower extremity 6 weeks prior, which was immobilized in a cast that extended from just below the knee to the foot. At the time of injury, there was severe pain but normal strength in the extremity. When the cast is removed, physical examination shows a pronounced left ‘foot drop’ with paraesthesia and sensory loss over the dorsum of the left foot and lateral leg. Injury to which one of the following nerves is the most likely cause of this finding?
A. Common fibular
B. Superficial fibular
C. Deep fibular
D. Sciatic
E. Tibial

**Answer:** A. The common fibular nerve is a branch of the sciatic nerve. It descends on the lateral side of the popliteal fossa before winding around the neck of the fibula. It then divides into superficial and deep branches that supply the lateral and anterior compartments of the leg, respectively. Due to its superficial course, it is easily injured in patients with long leg casts (running from just below the knee). The nerve supplies the dorsiflexors of the foot and the skin of the first web space (via the deep fibular nerve), and the evertors of the foot and the skin of the lateral side of the leg and the dorsum of the foot (via the superficial fibular nerve).

2. After being struck from behind by a motor vehicle, a 55-year-old male presents to the hospital with a swelling of his upper posterior leg. Imaging reveals a large haematoma of the popliteal
artery that is compressing his tibial nerve. During neurological examination, which one of the following movements would be likely to be diminished in strength?

A. Dorsiflexion of the foot
B. Flexion of the thigh
C. Extension of the digits
D. Extension of the leg
E. Plantar flexion of the foot

**Answer: E.** Plantar flexion is mostly produced by gastrocnemius and soleus, which are supplied by the tibial nerve. The tibial nerve leaves the popliteal fossa by passing deep to gastrocnemius and soleus, and lies posterior to the popliteal artery. Therefore, a haematoma of the popliteal artery will also compress this nerve. Dorsiflexion of the foot is due to contraction of the muscles in the anterior compartment of the leg.

3. A 45-year-old male is admitted to hospital after a fall and subsequent leg injury. On physical examination, the patient has a foot drop but eversion is unaffected. Which one of the following nerves is most likely to be injured?

A. Tibial
B. Common fibular
C. Superficial fibular
D. Saphenous
E. Deep fibular

**Answer: E.** The deep fibular and superficial fibular nerves are branches of the common fibular nerve. The deep fibular nerve innervates muscles of the anterior compartment of the leg and the skin between the great and second toes, while the superficial
fibular nerve innervates the lateral compartment muscles of the leg, which are evertors of the foot and the skin on most of the dorsum of the foot. If the common fibular nerve were damaged, all the structures that receive innervation via this nerve would be compromised. Damage to the superficial fibular nerve would affect the ability to evert the foot but would not result in foot drop, making the deep fibular nerve, which innervates the dorsiflexors of the foot, the best choice as the injury described includes foot drop with conservation of the ability to evert the foot. The saphenous nerve is a cutaneous nerve while the tibial nerve innervates posterior compartment muscles.

4. The anterior tibial artery travels over which one of the following structures *en route* to the anterior compartment of the leg?
   A. Soleus
   B. Crural fascia
   C. Interosseous membrane
   D. Common fibular nerve
   E. Fibularis longus

**Answer:** C. Once the anterior tibial artery branches from the popliteal artery, it travels anteriorly over the interosseous membrane to enter the deep aspect of the anterior compartment of the leg. The crural fascia envelops the leg; soleus lies posterior to the anterior tibial artery; fibularis longus is lateral to the artery; the common fibular nerve is superior to this location.
Clinical Case

1. A 50-year-old male is brought to the trauma room following a motor vehicle collision (approximately 50 miles per hour). Radiographic imaging reveals the following injuries: firstly, a left body of the femur fracture; secondly, a floating knee (left side) with distal femoral fracture and proximal leg fracture (Figs 84.7, 84.8). Testing of the compartment pressures of the leg (normal 10–12 mmHg) reveals a pressure of 120 mmHg in the anterior compartment and 40 mmHg in the lateral compartment. The patient is urgently sent to the operating theatre for cross-joint fixation of the lower limb via an external fixator plus open reduction and internal fixation of the leg (Figs 84.9, 84.10). In addition, an emergent dual-incision fasciotomy (Fig. 84.11A) for compartment syndrome is performed. Afterwards, dermatotraction (Fig. 84.11B) is applied in order to close the lateral and medial wounds over the next couple of days. The final open reduction and internal fixation of the proximal and distal femoral fractures are performed 1 week after the injury.

**FIG. 84.7** An anteroposterior X-ray of the pelvis and proximal thigh. Note the proximal femoral fracture (arrow).
FIG. 84.8  X-rays of the lower limb. A, A distal femoral fracture (arrow). B, A fracture of the proximal tibia (arrow).
FIG. 84.9  Postoperative X-rays of the femur: note the placement of external fixation devices.

FIG. 84.10  Postprocedural images: note the placement of internal fixation hardware.
A. During anterior surgical repair of the tibial fracture shown in Fig. 84.8B, a large blood vessel is found to be bleeding between the fracture site and the laterally placed fibula. The upper free margin of the interosseous membrane is seen just inferior to the vessel. What is this vessel?

1. Sural artery
2. Fibular artery
3. Posterior tibial artery
4. Anterior tibial artery
5. Popliteal artery
Answer: 4. The anterior tibial artery arises from the popliteal artery and enters the anterior compartment of the leg superior to the upper free margin of the interosseous membrane.

B. During application of the fixation plates for the tibial fracture (see Fig. 84.10), a nerve is seen coursing deep to tibialis anterior along its upper third. What is this nerve and what motor deficit would the patient have postoperatively if the nerve were injured?

1. Tibial nerve with loss of plantar flexion of the ankle
2. Deep fibular nerve with loss of dorsiflexion of the ankle
3. Superficial fibular nerve with inability to evert the ankle
4. Common fibular nerve with decreased strength of dorsiflexion and eversion of the ankle
5. Femoral nerve with inability to extend the knee

Answer: 2. After arising from the common fibular nerve as it courses around the neck of the fibula, the deep fibular nerve travels deep to the muscles of the anterior compartment of the leg and innervates them; the primary function of these muscles is to dorsiflex the ankle.

C. While making the skin incision for the fasciotomy shown in Fig. 84.11A, a cutaneous nerve is severed in the distal third of the lateral leg. Which one of the following is the most likely nerve to have been injured?

1. Saphenous nerve
2. Deep fibular nerve
3. Superficial fibular nerve
4. Sural nerve
5. Posterior femoral cutaneous nerve

Answer: 3. After piercing the muscles of the lateral compartment of the leg near its distal third, the superficial fibular nerve travels along the lateral leg and supplies the overlying skin of the lateral leg and the lateral foot.
CHAPTER 85
Ankle

Alastair Younger, Husam Alrumaih

Core Procedures

• Ankle joint fusion/replacement
• Arthroscopic procedures
• Joint releases
• Ligament repair
• Tendon debridement, repairs and transfers
• Osteotomies
• Fracture care
• Contracture releases
Embryology

Böhm has described the developmental phases of the foot.¹ At stage one (second month) of development the foot is in 90° equinus and is adducted; at stage two (beginning of the third month) the foot is in 90° equinus, adducted and markedly supinated; at stage three (middle of the third month) the foot is dorsiflexed at the ankle but a mild degree of equinus is still present, marked supination persists and the first metatarsal remains adducted; at stage four (beginning of the fourth month) the foot pronates and reaches a position of mid-supination, a slight metatarsal varus remains but there is no equinus.
Surgical surface anatomy

Tibialis anterior presents a fusiform enlargement at the lateral side of the tibia and projects beyond the anterior border of this bone; its tendon can be traced on the front of the tibia and ankle joint, and thence along the medial side of the foot to the base of the first metatarsal. The fleshy fibres of fibularis (peroneus) longus are strongly marked at the upper part of the lateral side of the leg; the muscle is separated by furrows from extensor digitorum longus (anterior) and soleus (posterior). Inferiorly, the fleshy fibres end abruptly in a tendon that overlaps the more flattened elevation of fibularis brevis; below the lateral malleolus, the tendon of fibularis brevis is the more marked. The anterior tibial artery becomes superficial and can be traced over the ankle as it becomes the dorsalis pedis artery, which can then be followed to the proximal end of the first intermetatarsal space. The pulsation of the posterior tibial artery becomes evident near the lower end of the posterior aspect of the tibia, and is easily detected behind the medial malleolus (Fig. 85.1).

![Diagram of branches of the posterior tibial artery](image-url)

**FIG. 85.1** Branches of the posterior tibial artery, posteromedial view of the ankle. (From S. Standring (ed.), Gray’s Anatomy, forty-first ed. © Elsevier, 2016, Fig. 84.10.)

The so-called soft spots of the ankle are areas that can be palpated easily;
they can be used during clinical examination to identify the margins of the joint and during arthroscopy to identify arthroscopic portal sites. The anterior medial soft spot lies between the medial malleolus and tibialis anterior. The anterior lateral soft spot is lateral to extensor hallucis longus and medial to the fibula. The posterior medial soft spot is located posterior to tibialis posterior at the junction of the talus, medial malleolus and tibia. The posterior lateral soft spot is found behind the lateral malleolus and tendons of fibularis longus and brevis, and anterior to the calcaneal (Achilles) tendon.
Clinical anatomy

Bones and joints

The ankle (talocrural joint) is a hinge joint and is approximately uniaxial. The distal end of the tibia, including the medial malleolus, together with the lateral malleolus of the fibula and the transverse tibiofibular ligament, form a deep recess ('mortise') for the body of the talus (Fig. 85.2). The capsule of the joint fits closely around its articular surfaces; as in every hinge joint, it is weak anteriorly and posteriorly but reinforced laterally and medially by collateral ligaments. Although the ankle appears to be a simple hinge joint, its axis of rotation is dynamic, shifting during dorsiflexion and plantar flexion. Dorsiflexion results in the joint adopting the ‘close-packed’ position, with maximal congruence and ligamentous tension; all major thrusting movements, in walking, running and jumping, are exerted from this position. The body of the talus is slightly wider anteriorly (Fig. 85.3); it becomes firmly wedged between the malleoli in full extension, whereas there is slight laxity at the joint and some degree of side-to-side tilting is possible in flexion, although no appreciable lateral movement can occur without stretch of the inferior tibiofibular syndesmosis.³
FIG. 85.2  A coronal section through the left ankle and talocalcaneal joint (seen from behind). (With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed. Elsevier, Urban & Fischer. Copyright 2013.)

FIG. 85.3  The talus and its articular sites. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 84.8C.)
Ligaments

The ligaments of the ankle joint are the medial and lateral collateral ligaments (Video 85.1). The deltoid (medial collateral) ligament is divided into superficial and deep portions (Fig. 85.4). The superficial portion arises from the whole extent of the medial malleolus, while the deep has two distinct bands – superficial and deep. The superficial band is composed of a tibionavicular part that arises from the anterior aspect of the medial malleolus and inserts into the navicular; a tibiospring part that rises from the medial malleolus and inserts into the plantar calcaneonavicular ligament (spring ligament); a tibiocalcaneal part that arises from the medial malleolus and inserts into the sustentaculum tali; and a posterior superficial tibiotalar part. The deep band is composed of anterior and posterior parts. The deep anterior tibiotalar part inserts into the non-articular part of the medial talus and is continuous with the medial portion of the interosseous talocalcaneal ligament. The deep posterior tibiotalar part runs between the posterior side of the medial malleolus and the medial side of the talus.
The plantar calcaneonavicular ligament is composed of three parts: the superomedial and inferior calcaneonavicular ligaments and the inferior plantar oblique ligament.\(^4\)\(^5\) The anterior fibular ligament travels from the anterolateral surface of the distal tibia (Chopart's tubercle) to the fibula, passing inferiorly as it goes laterally, and the posterior tibiofibular ligament connects the posterior aspect of the medial malleolus to the back of the fibula; both ligaments can be seen during ankle arthroscopy.

The lateral collateral ligament is composed of the anterior talofibular ligament, which arises from the anterior aspect of the fibula and inserts into...
the junction of the neck and body of the talus; the calcaneofibular ligament, which courses anterosuperiorly to posteroinferiorly as it arises from the tip of the lateral malleolus and inserts into the lateral aspect of the calcaneus; and the posterior talofibular ligament, which is a thick horizontal band passing from the posterior aspect of the fibula to the lateral side of the posterior process of the talus.

**Retinacula at the ankle**

Near the ankle joint, the tendons of the muscles of the leg are bound down by localized, band-shaped thickenings of the deep fascia termed retinacula, which collectively serve to prevent bowstringing of the underlying tendons during muscle contraction. There are superior and inferior extensor retinacula, superior and inferior fibular retinacula, and a flexor retinaculum.6

**Extensor retinacula**

The superior extensor retinaculum is attached laterally to the distal end of the anterior border of the fibula and medially to the anterior border of the tibia. It is wider (approximately 3 cm) medially and narrower (1.5 cm) laterally, and binds down the tendons of tibialis anterior, extensor hallucis longus, extensor digitorum longus and fibularis tertius immediately proximal to the anterior aspect of the ankle joint (Fig. 85.5). The anterior tibial vessels and deep fibular nerve pass deep to the superior extensor retinaculum, and the superficial fibular nerve passes superficially. Its proximal border is continuous with the crural fascia, and dense connective tissue connects its distal border to the inferior extensor retinaculum. It blends laterally with the superior fibular retinaculum and medially with the upper border of the inferior extensor retinaculum. The tendon of tibialis anterior is the only extensor tendon that possesses a synovial sheath at the level of the superior extensor retinaculum. A band runs from the retinaculum to the anterior surface of the tibia, separating tibialis anterior from extensor hallucis longus. The inferior extensor retinaculum is a Y-shaped band lying anterior to the ankle joint (see Fig. 85.5). The stem of the Y is located laterally, where it is attached to the anterosuperior surface of the calcaneus, anterior to the calcaneal sulcus. The band passes medially, forming a strong loop around the tendons of fibularis (peroneus) tertius and extensor digitorum longus (Fig. 85.6). From the deep surface of the loop, a band passes laterally behind the talocalcaneal interosseous ligament and is attached to the calcaneal sulcus.
At the medial end of the loop, two diverging limbs extend medially to complete the Y-shape of the retinaculum. The proximal limb consists of superficial and deep layers. The superficial layer crosses the tendon of extensor hallucis longus and then adheres firmly to the deep one; in some cases, it continues superficial to the tendon of tibialis anterior, before blending with the deep layer. The deep layer passes deep to the tendons of extensor hallucis longus and tibialis anterior, but superficial to the anterior tibial vessels and deep fibular nerve, to reach the medial malleolus. The distal limb extends downwards and medially, and blends with the plantar aponeurosis; it is superficial to the tendons of extensor hallucis longus and tibialis anterior, the dorsalis pedis artery and the terminal branches of the deep fibular nerve.
FIG. 85.5  The extensor retinacula and synovial sheaths of the tendons of the ankle, anterior aspect. (With permission from R.L. Drake, A.W. Vogl, A. Mitchell (eds), Gray’s Anatomy for Students, second ed. Elsevier, Churchill Livingstone. Copyright 2010.)
**Flexor retinaculum**

The flexor retinaculum is attached anteriorly to the medial malleolus, and extends posteroinferiorly to the medial process of the calcaneus and the plantar aponeurosis. Three septa pass posteriorly from the retinaculum to deeper structures (deltoid ligament, calcaneus), creating four canals. The anterior septum passes between tibialis posterior and flexor digitorum longus to create a tunnel for tibialis posterior. The middle septum passes between flexor digitorum longus and the neurovascular bundle to form canals for each component. The posterior septum passes between the neurovascular bundle and flexor hallucis longus. The upper border of the flexor retinaculum is continuous with the crural fascia, which divides around the calcaneal tendon to create the tendon sheath. The lower border of the flexor retinaculum continues into the fascia on the medial border of the foot.
Fibular (peroneal) retinacula

The superior fibular retinaculum arises from the lateral malleolus just above and superficial to the lateral collateral ligament. It passes superficial to the tendons of fibularis longus and brevis, and is attached to the calcaneus and the crural fascia around the calcaneal tendon. The inferior fibular retinaculum is continuous anteriorly with the inferior extensor retinaculum and is attached posteriorly to the lateral surface of the calcaneus. Some of its fibres are fused with the periosteum on the fibular trochlea (peroneal tubercle) of the calcaneus, forming a septum (bony or fibrous) between the tendons of fibularis longus and brevis.

Vascular supply

Arteries

The anterior tibial artery becomes superficial at the ankle midway between the malleoli and gives off the anterior medial and lateral malleolar arteries. The dorsalis pedis artery (Fig. 85.7) is usually the continuation of the anterior tibial artery distal to the ankle; it passes to the proximal end of the first intermetatarsal space, where it pierces the first dorsal interosseus to join the plantar arch (Ch. 86). The posterior tibial artery gives rise to a medial malleolar branch, a communicating branch to the fibular artery, and a calcaneal branch, and terminates as the medial and lateral plantar arteries (see Fig. 85.7). The fibular artery arises from the posterior tibial artery; approximately 2.5 cm from its origin and 5.0 cm above the lateral malleolus, it communicates with the anterior lateral malleolar artery as a perforating branch, and then passes down anterior to the tibiofibular syndesmosis to anastomose with the lateral tarsal artery.
Veins

The long saphenous vein (great saphenous vein) is a continuation of the medial marginal vein of the foot. The short saphenous vein (small saphenous vein) begins posterior to the lateral malleolus as a continuation of the lateral marginal vein.

Innervation

The ankle joint is innervated by articular branches from the deep fibular, saphenous, sural and tibial nerves (or medial and lateral plantar nerves, depending on the level of division of the tibial nerve); occasionally, the superficial fibular nerve also supplies the ankle joint. The posterior tibial vessels and tibial nerve are related to the capsule of the ankle joint anteriorly, the flexor retinaculum medially, and flexor hallucis longus laterally. Branches of the tibial nerve near the ankle include articular branches to the tibiotalar
and subtalar joints, a medial calcaneal branch, and a branch to adductor digiti minimi. The tibial nerve ends under the flexor retinaculum by dividing into the medial and lateral plantar nerves (Ch. 86). The medial plantar nerve gives branches to flexor digitorum brevis from its lateral side and abductor hallucis from its medial side. The saphenous nerve (a mostly cutaneous branch of the femoral nerve) divides distally into a branch that continues along the tibia to the ankle, and a branch that passes anterior to the ankle to supply the skin on the medial side of the foot, often as far as the first metatarsophalangeal joint. The superficial fibular nerve pierces the deep fascia in the distal third of the leg and divides into a large, medial, dorsal cutaneous nerve and a smaller, more laterally placed, intermediate dorsal cutaneous nerve, usually after piercing the deep fascia, but sometimes while it is still deep to the fascia. As mentioned earlier, the deep fibular nerve innervates the ankle and then divides into a lateral terminal branch to extensor digitorum brevis and extensor hallucis brevis, and branches to the tarsal and metatarsophalangeal joints of the middle three toes. The medial terminal branch of the deep fibular nerve travels lateral to the dorsalis pedis artery and supplies two dorsal digital nerves that in turn supply adjacent sides of the great and second toes. Before dividing, it gives rise to a branch to the metatarsophalangeal joint (Ch. 86).
Surgical approaches and considerations

Open surgical approaches

Anterior approach

Anterior surgical approaches provide exposure to the distal tibia, ankle joint and superior surface of the talus. Indications include open reduction and fixation of Pilon fractures, ankle arthrodesis, total ankle arthroplasty, debridement of infected ankles and removal of loose bodies. Beginning 10 cm proximal to the joint, a 15 cm incision is made over the anterior ankle, crossing the joint midway between the malleoli. For a medial variation to this approach, a 15 cm incision anterior to the medial malleolus is made with incision into the deep fascia on the medial side of the tendon of tibialis anterior with retraction of tibialis anterior laterally. The superior extensor retinaculum is incised and the plane between extensor digitorum longus and extensor hallucis longus identified a few centimetres above the joint. Next, the anterior tibial artery and deep fibular nerve are identified and retracted medially together with extensor hallucis longus. Extensor digitorum longus is retracted laterally and the anterior ankle joint exposed and incised: the full width of the ankle joint is then exposed with subperiosteal and subcapsular dissection of the tibia and talus.

Posterolateral approach

Posterolateral approaches to the ankle joint provide exposure to the posterior aspect of the lateral malleolus, posterior ankle joint, lateral or posterior aspect of the fibula and fibularis tendons and their retinacula. An incision is made along the posterior border of the fibula almost to the inferior aspect of the lateral malleolus and is typically centred about a fibular fracture, when present. The fibula is accessed with superficial dissection, taking care to avoid the superficial fibular nerve: with deeper dissection, fibularis longus and brevis are retracted posteriorly. For access to the posterior aspect of the lateral malleolus, fibularis longus and brevis are retracted anteriorly. The interval between flexor hallucis longus and the fibularis tendons is next identified, and the intervening connective tissue is bluntly split. Flexor hallucis longus is elevated off the distal posterior tibia and retracted medially to allow access to the posterior aspect of the lateral malleolus.
Posteromedial approach

Posteromedial approaches to the ankle allow for exposure of the medial malleolus and posterior aspect of the tibia and are indicated for open reduction internal fixation of medial malleolar and Pilon fractures. Dissection is performed most frequently between tibialis posterior and flexor digitorum. A 10 cm longitudinal curved incision is made with its concavity pointing anteriorly, beginning 5 cm proximal to the medial malleolus on the posterior border of the tibia. The incision is curved distally following the posterior border of the medial malleolus and ends 5 cm distal to the medial malleolus. Avoiding the long saphenous vein and saphenous nerve, the flexor
retinaculum is incised behind the medial malleolus in such a way that it can be repaired. Tibialis posterior is next retracted anteriorly and the neurovascular bundle, flexor hallucis longus, and flexor digitorum longus are retracted posteriorly. Finally, subperiosteal dissection is performed to expose the posterior border of the tibia.

**Lateral approach**

Lateral approaches to the ankle provide exposure of the lateral malleolus and posterolateral fibula for procedures such as open reduction internal fixation of the fibula or syndesmosis and percutaneous placement of syndesmosis screws. For fractures, incisions are centred over the fracture site. Begin by placing a longitudinal skin incision along the posterior margin of the fibula and, if needed, extend the incision 2 cm distal to the distal aspect of the lateral malleolus. Superficial dissection begins, taking care to avoid injury to the short saphenous vein and sural nerve which run posterior to the fibula. Next, the periosteum of the subcutaneous surface of the fibula is incised: just enough periosteum should be stripped off to expose the fracture site and achieve a reduction. As the incision is extended proximally, care must be taken not to injure the superficial fibular nerve as it crosses from posterior to anterior over the body of the fibula at the proximal end of ankle incisions.

The approach can be developed proximally to become continuous with the lateral approach to the fibula or extended distally to become continuous with Ollier's lateral approach to the tarsus, the Kocher lateral approach to the ankle and tarsus, or the lateral approach to the calcaneus. Terminal branches of the fibular artery which lie deep to the medial surface of the distal fibula can be injured if dissection does not stay subperiosteal; if the vessels are injured, haematomas can form after removal of the tourniquet.

⚠️ **Tips and anatomical hazards**

A thorough understanding of the intra-articular anatomy of the normal ankle joint that can be visualised through an arthroscope is essential. Anterior ankle arthroscopy has been associated with iatrogenic injury to every cutaneous nerve around the ankle. The subcutaneous tissue around the ankle contains three cutaneous nerves, saphenous,
superficial fibular and sural, which may be injured during ankle and subtalar arthroscopy. All three are variable in their position, point of division and penetration of the deep fascia. The saphenous nerve runs next to the medial malleolus and is at risk with placement of anteromedial portals. The superficial fibular nerve is at risk in foot and ankle surgery. After penetrating the crural fascia it travels on to the dorsum of the foot where it divides into medial and intermediate dorsal cutaneous nerves, which divide into four common digital nerves that divide again into seven dorsal digital nerves. The superficial fibular nerve can be injured proximally during open reduction and internal fixation of the ankle; lateral approaches to the ankle; and with placement of lateral ankle arthroscopic portals. Its lower branches can be injured during the anterior approach to the ankle and with the anterior approach to the foot for navicular, cuneiform, tarsometatarsal joint and talonavicular joint exposures. The sural nerve penetrates the crural fascia and runs behind the lateral malleolus, traverses the lateral border of the foot and branches over the base of the fifth metatarsal.

With posterolateral approaches to lateral ankle fractures, care must be taken not to release the posterior inferior tibiofibular ligament off the fragment or to devitalise the posterior malleolar fragment, which can lead to post-fixation syndesmotic instability. Proximally, the superficial fibular nerve is at risk with superficial dissection.\(^\text{12}\) It is found entering the subcutaneous tissues approximately 10 cm proximal to the distal tip of the lateral malleolus. In order to protect the tibial nerve and posterior tibial vessels, maintain them deep to flexor hallucis longus. Distal dissection places the sural nerve at risk: transecting the nerve can lead to formation of a painful neuroma and numbness along the lateral side of the foot.
References


Single Best Answers

1. A patient presents with ankle pain and swelling after a sports match. Physical examination finds moderate inversion laxity with the ankle held in dorsiflexion but no inversion is found with the ankle in plantar flexion. Which one of the following ligaments has been damaged?
   A. Anterior tibiofibular ligament
   B. Posterior tibiofibular ligament
   C. Calcaneofibular ligament
   D. Deltoid ligament

   **Answer: C.** The posterior tibiofibular ligament, anterior tibiofibular ligament and the calcaneofibular ligament are stabilizers of the lateral ankle, but the calcaneofibular ligament is tightest in dorsiflexion and inversion. The anterior tibiofibular ligament is tautest in dorsiflexion and inversion of the ankle.

2. A competitive skier makes a turn to the right around a slope. The left ski turns in the snow, causing eversion of the left foot. Which one of the following ligaments is the most likely to be injured?
   A. Calcaneofibular ligament
   B. Anterior tibiofibular ligament
   C. Deltoid ligament
   D. Calcaneofibular ligament

   **Answer: B.** Eversion of the foot causes the talus to press against the lateral malleolus, pushing the distal fibula laterally. This movement first affects the anterior tibiofibular ligament.

3. Which of the following movements has the greatest range of motion at the ankle joint?
A. Dorsiflexion
B. Plantar flexion
C. Eversion
D. Inversion

**Answer: B.** Plantar flexion moves the ankle joint through 50°, dorsiflexion through 20°.

4. Which one of the following muscles dorsiflexes and inverts the foot?
   A. Fibularis longus
   B. Extensor digitorum longus
   C. Tibialis anterior
   D. Tibialis posterior

   **Answer: C.** Tibialis anterior is a dorsiflexor of the ankle joint and inverts the foot; it is most active when these two movements are combined.

5. In which one of the following positions of the ankle does a sprain most commonly occur?
   A. Plantar flexion
   B. Inversion
   C. Dorsiflexion and eversion
   D. Plantar flexion and inversion

   **Answer: D.** Plantar flexion and inversion of the ankle: the anterior talofibular ligament is the most common ligament injured in such sprains.
Clinical case

1. A basketball player sprained his left ankle after landing on an opponent's foot following a jump shot. His ankle went over and it was very painful. The ankle swelled very quickly and he could not bear full weight on it. Later that day, the patient went to an accident and emergency department, where an X-ray confirmed that there were no fractures. The patient was not immobilized following the sprain or given elbow crutches. He presents to a specialist 4 weeks post injury and at this stage the ankle is still very swollen and painful. The patient has an important international tournament in 6 weeks’ time. This is his first ankle injury. The ankle is stiff first thing in the morning for 30 minutes and then sore after walking for more than 15 minutes. The patient does not feel he can run yet. He has no significant past medical history and uses an inhaler for mild asthma.

A. Which of the following nerves would NOT be involved in conveying pain from the ankle in such an injury?

A. Sural
B. Deep fibular
C. Saphenous
D. Tibial
E. Posterior femoral cutaneous

Answer: E. The posterior femoral cutaneous nerve supplies the skin of the posterior thigh and knee but does not extend to the ankle.

Examination reveals that the ankle is still significantly swollen both in the capsule and over the lateral collateral ligament. The patient has moderately flat feet bilaterally. He has regained the majority of active movement at the ankle. Knee over foot (dorsiflexion) is painful and restricted to about half in standing and weight-bearing. Weakness of the invertors and evertors of the ankle is noted and the ability to stand and balance on one leg is diminished. The ankle joint is not stiff on testing but becomes sore on trying to stress the anterior/lateral ankle ligaments, the most commonly injured ligament in the ankle being the anterior talofibular ligament.

The diagnosis is a grade two (partial ligament tearing) ankle sprain with
injury involving the anterior talofibular ligament. Unfortunately, this patient did not receive the best advice from the start: to optimize recovery and allow the ligament to heal in the correct position a ski-boot brace could have been worn for 4 weeks, being taken off regularly to do range-of-movement exercises. This would have allowed the pain and swelling to settle much earlier. However, healing time has been prolonged for this man.

B. Anteriorly, the anterior talofibular ligament is most closely related to which of the following distal tendons?

A. Fibularis longus
B. Fibularis brevis
C. Tibialis posterior
D. Extensor digitorum longus

Answer: D. The anterior talofibular ligament is related anteriorly to extensor digitorum longus.

A supportive ankle brace in which the patient will be able to return to basketball is advised. He starts wearing this at all times during the day to help reduce pain and swelling, which works very well, and after 10 days he notices his pain and swelling have improved by 80%. During this period, he has already started to strengthen his ankle muscles, along with some stability training and balance practice. After 2 weeks in the brace, some tip-toe drills and further strengthening work are gradually added in. After 4 weeks of treatment, he starts running drills and is taking part in light training. He progresses to end-stage hopping drills and final high-level strengthening of the ankle. By week 6, he can participate fully in training and his running is back up to full speed without pain. He is advised after 4 weeks to use the brace only for sport and any active training, and to continue physiotherapy sessions.

With the use of an ankle brace this patient is able to compete for his country with no pain and no risk of re-injury. He is advised to use the brace/tape for 3 months until his ankle is strong enough to compensate for the weakened lateral ligament.

C. Which of the following is not a part of the lateral ligament of the ankle?

A. Calcaneofibular ligament
B. Plantar calcaneonavicular ligament
C. Posterior talofibular ligament
D. Anterior talofibular ligament

Answer: B. Plantar calcaneonavicular ligament. The anterior and posterior talofibular ligaments and the calcaneofibular ligament make up the lateral ligament of the ankle.

The patient is reviewed regularly to ensure he reaches the final stages of rehabilitation over this 3-month period, and advised to keep up with his ankle rehabilitation for the remainder of his sporting career, owing to the increased laxity of the injured ligament, which is likely to persist.

This case demonstrates that being given the most appropriate and early treatment for an injury is vital to ensure that the injured structure heals in the best possible position. If this is not in place, then recovery and return to sport can be delayed and there may be residual long-term weakness or instability in an area.
CHAPTER 86
Foot

Alastair Younger, Husam Alrumaih

**Core Procedures**

- Joint fusion
- Joint replacement
- Arthroscopic procedures
- Joint release
- Ligament repair
- Tendon debridement, repair and transfer
- Osteotomy
- Fracture
- Contracture release
Surgical surface anatomy

The dorsal surface of the foot has a smooth, convex outline, which inclines gradually laterally and rapidly medially from a summit formed successively by the head of the talus, the navicular, the intermediate cuneiform and the second metatarsal. The head of the talus forms a rounded projection in front of the ankle joint when the foot is forcibly dorsiflexed. On the medial side of the foot, the medial process of the calcaneal tuberosity and sustentaculum tali are palpable. The tuberosity of the navicular is palpable about 2.5–3.0 cm anterior to the medial malleolus.

Further forwards, the ridge formed by the base of the first metatarsal can be felt and the body of the bone can be traced to its expanded head. The medial sesamoid of the hallux is beneath the base of the proximal phalanx. On the lateral side of the foot, the most posterior bony point is the lateral process of the calcaneal tuberosity. The greater part of the lateral surface of the calcaneus is subcutaneous; if present, the trochlear process can be felt here, below and anterior to the lateral malleolus. Further forwards, the base of the fifth metatarsal is prominent, and the body and head of the bone can be traced distally. As is the case with the metacarpals, the dorsal surfaces of the metatarsals are easily palpated; their heads do not form prominences because their plantar surfaces are obscured by muscles and other overlying soft tissues (Video 86.1). The phalanges are readily palpable throughout their whole extent.

The tendons that spread out on the dorsum of the foot, from medial to lateral, are those of tibialis anterior (most medial and largest), extensor hallucis longus, extensor digitorum longus (to the second, third, fourth and fifth toes), and fibularis (peroneus) tertius. Extensor digitorum brevis produces a rounded mound on the dorsum of the foot with fullness anterior to the lateral malleolus. Dorsal interossei bulge between the metatarsals.
Clinical anatomy

Bones and joints

The hindfoot consist of the talus and calcaneus (Figs 86.1 and 86.2; see Fig. 85.3). The subtalar joint has three points of contact (facets) with the calcaneus and is involved with inversion and eversion of the foot. The posterior facet is the largest, the middle facet is located medially and the anterior facet is continuous with the talonavicular joint. In conjunction with the subtalar joint, the transverse tarsal joint (Chopart's joint) contributes to foot flexibility during the gait cycle. The calcaneonavicular joint is supported by the plantar calcaneonavicular (spring) ligament, a complex connecting the sustentaculum tali of the calcaneus to the plantar aspect of the navicular and supporting the head of the talus as part of the talocalcaneonavicular joint (Fig. 86.3). The calcaneocuboid joint is saddle-shaped and is supported by the dorsal and plantar calcaneocuboid ligaments; the lateral limb of the bifurcate ligament (Chopart's ligament; composed of the calcaneonavicular and calcaneocuboid ligaments) provides superior restraint. Inversion of the subtalar joint locks the transverse tarsal joint and allows for a stable hindfoot/midfoot for toe-off. Eversion of the subtalar joint unlocks the transverse tarsal joint to allow the supple foot to accommodate to the ground just after heel strike. The plantar aponeurosis allows for load/force transfer between the hindfoot and forefoot during ambulation.
FIG. 86.1 The bones of the left foot, with muscle attachments. **A**, Dorsal aspect. **B**, Plantar aspect. The attachments of tibialis posterior to the metatarsals vary and those to the third and fifth metatarsals are sometimes absent. (From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 84.5.)
The midfoot begins at the articulation between the navicular and cuneiforms, and consists of articulations between the cuboid and fourth and fifth metatarsals. Midfoot joints include the naviculocuneiform, intercuneiform and tarsometatarsal (Lisfranc's) joints. The latter consists of the first, second and third metatarsocuneiform joints and the fourth and fifth metatarsocuboid joints. The ligamentous support of the tarsometatarsal joint consists of an interosseous layer (the strongest layer), which contains Lisfranc's ligament, originating from the plantar aspect of the medial cuneiform and inserting on to the base of the second metatarsal; a plantar
layer, which is less strong; and a dorsal layer, which is the weakest layer.

The midfoot is divided into three columns: a medial column comprising the first metatarsal, medial cuneiform and navicular; a middle column comprising the second and third metatarsals and middle (intermediate) and lateral cuneiforms; and a lateral column composed of the fourth and fifth metatarsals and cuboid. The medial column carries most of the load during standing. The middle column is the least mobile and allows for rigidity during push-off. The lateral column is the most mobile of the three columns and allows for flexibility when walking on uneven ground.

The forefoot extends from the tarsometatarsal joints to the tips of the toes. The first metatarsal is the shortest and widest, and carries 50% of the weight during the gait cycle. The second metatarsal is the longest. The joints of the forefoot include the metatarsophalangeal and the proximal and distal interphalangeal joints. The deep transverse metatarsal ligament holds the sesamoids of the hallux in place as the head of the first metatarsal moves medially. The tendon of adductor hallucis has a broad insertion over the lateral aspect of the lateral sesamoid and lateral aspect of the base of the proximal phalanx. The plantar plate is made up of a dense phalangeosesamoidal complex: it must be lax before abnormal dorsal translation of the proximal phalanx can occur.

**Vascular supply**

The blood supply to the foot and ankle arises from three primary sources: the anterior and posterior tibial arteries and the fibular (peroneal) artery (Ch. 85).³,⁴

As it crosses into the foot, the anterior tibial artery becomes the dorsalis pedis artery, which is usually palpable over the dorsum of the foot just lateral to the tendon of extensor hallucis (Fig. 86.4A and Video 86.2). Its branches include the arcuate and the lateral and medial tarsal arteries. The dorsalis pedis artery terminates at the first intermetatarsal space, where it divides into the first dorsal metatarsal artery and deep plantar artery, the latter contributing to the plantar arch. The arcuate artery travels deep to the extensor tendons and gives off dorsal metatarsal arteries that run in the second, third and fourth intermetatarsal spaces. The plantar arch gives rise to the perforating and plantar metatarsal arteries.
The posterior tibial artery is palpable posterior to the medial malleolus, where the posterior tibial vessels and tibial nerve are related to the capsule of the ankle joint anteriorly, the flexor retinaculum medially, and flexor hallucis longus laterally. The artery gives off the posterior medial malleolar artery, a communicating branch and the artery of the tarsal canal (the dominant arterial supply to the body of the talus). As it passes beneath the sustentaculum tali, the posterior tibial artery divides into the lateral and medial plantar arteries (Fig. 86.4B; see Fig. 85.7). The lateral plantar artery gives rise to a calcaneal branch (first branch – this is the major vascular supply to the heel), branches to adductor digiti minimi (second branch), and
a plantar digital artery to the fifth toe (third branch); its continuation is the plantar arch. The medial plantar artery anastomoses with the first dorsal metatarsal artery, which is a branch of the dorsalis pedis artery. The dorsal metatarsal arteries from the dorsalis pedis artery and the arcuate artery anastomose with the plantar metatarsal arteries of the first three intermetatarsal spaces.

The fibular artery gives off a lateral malleolar branch and a communicating branch at the ankle, and a calcaneal branch in the foot (see Fig. 85.7): it supplies the lateral flap associated with a standard extensile approach to the calcaneus.

The dorsal venous arch drains into the long and short saphenous veins (Ch. 85).

**Innervation**

The superficial fibular nerve becomes subcutaneous approximately 15 cm proximal to the lateral malleolus; on the foot, it splits into a medial dorsal cutaneous nerve to the skin of the dorsomedial aspect of the hallux and an intermediate dorsal cutaneous nerve. The saphenous nerve supplies sensation to the medial foot, entering anterior to the medial malleolus. Branches of the tibial nerve include the medial calcaneal nerve, which innervates the medial surface of the heel, and the medial and lateral plantar nerves (Fig. 86.5). The medial plantar nerve innervates abductor hallucis, flexor hallucis brevis, flexor digitorum brevis and the two medial lumbricals. The lateral plantar nerve innervates adductor hallucis, quadratus plantae, dorsal and plantar interossei, the two lateral lumbricals and abductor digiti minimi (via Baxter's nerve, which is the first branch of the lateral plantar nerve). Baxter's nerve courses between quadratus plantae and flexor digitorum brevis, and provides sensation to the lateral part of the plantar surface of the foot and the lateral surface of the fourth and fifth toes. Injury to either of the plantar nerves can lead to weak flexion of the metatarsophalangeal joints. The sural nerve typically supplies the skin of the fourth web space.
Traditionally, the plantar surface of the foot is described as consisting of four layers, covered superficially by the plantar fascia, which is attached to the medial process of the calcaneal tuberosity and the base of the fifth metatarsal (lateral band), the plantar plate and the bases of the five proximal phalanges. The plantar fascia functions to increase the height of the arch of the foot as the toes dorsiflex during the toe-off (preswing) phase of the gait cycle and is
also important for affording support to the medial arch of the foot. The first layer of muscles contains abductor hallucis, flexor digitorum brevis and abductor digiti minimi. The second layer contains quadratus plantae (flexor accessorius), the lumbricals, the tendons of flexor digitorum longus and flexor hallucis longus, and the medial and lateral plantar arteries. The third layer contains flexor hallucis brevis, flexor digiti minimi brevis, and the oblique and transverse heads of adductor hallucis. The fourth layer contains the dorsal and plantar interossei and the tendons of fibularis longus and tibialis posterior.
Surgical approaches and considerations

The talus is a commonly fractured bone in the hindfoot. It often requires surgery to fix and is best approached with anteromedial and anterolateral dual incisions (Figs 86.6 and 86.7, respectively). The anteromedial approach can be extended to an extensile anteromedial approach (Fig. 86.8). The incision for the anteromedial approach runs from the medial malleolus proximally to the base of the first metatarsal distally. The deltoid branches of tibialis posterior are at risk here because they supply the medial two thirds of the body of the talus. The fibres of the extensor retinaculum are longitudinally incised followed by a subperiosteal dissection of the talonavicular joint. It is of paramount importance to limit the soft tissue stripping and preserve as much as possible of the periosteal blood supply (Fig. 86.9).

FIG. 86.6 Anteromedial incision for dual approach to the neck of the talus. (From Clare M.P., Maloney P.J. Prevention of Avascular Necrosis with Fractures of the Talar Neck. Foot and Ankle Clinics, 2019-03-01, Volume 24, Issue 1, Pages 47-56, Copyright © 2018 Elsevier Inc.)
FIG. 86.7 Anterolateral incision for dual approach to the neck of the talus. (From Clare M.P., Maloney P.J. Prevention of Avascular Necrosis with Fractures of the Talar Neck. Foot and Ankle Clinics, 2019-03-01, Volume 24, Issue 1, Pages 47-56, Copyright © 2018 Elsevier Inc.)
FIG. 86.8 Extensile anteromedial approach to the talus with medial malleolar osteotomy. Note full visualisation of the body of the talus (arrow). (From Clare M.P., Maloney P.J. Prevention of Avascular Necrosis with Fractures of the Talar Neck. Foot and Ankle Clinics, 2019-03-01, Volume 24, Issue 1, Pages 47-56, Copyright © 2018 Elsevier Inc.)
The anteromedial approach can be extended distally between tibialis posterior and tibialis anterior. There are no major neurovascular structures in this region and superficial small veins can be cauterized during the approach, which will give access to the talonavicular joint, or distally for access to the cuneiforms, first metatarsal base and naviculocuneiform and intertarsal joints. The tendon of tibialis anterior can be found at its insertion on the medial cuneiform or the base of the first metatarsal. The knot of Henry is located on the plantar aspect of the cuneiform, where flexor digitorum longus (FDL) and flexor hallucis longus (FHL) cross.

The anterolateral approach starts with an incision based on the fourth metatarsal and lines this bone up with the talus. The superficial fibular nerve is at risk with this approach and care should be taken not to cut it. Extensor digitorum brevis is split to gain access to the lateral talus. Sinus tarsi dissection should be kept to the minimum: only dissect what is necessary to achieve fracture exposure and reduction (Fig. 86.10).
One important approach to the midfoot and the metatarsals is the dorsomedial approach, which gives access to the first tarsometatarsal (TMT) joint, required during first TMT fusions, and to the medial base of the second TMT. The incision is centred over the TMT area, between the tendons of extensor hallucis longus (EHL) and extensor hallucis brevis (EHB).

**Tips and anatomical hazards**

The sural nerve is most vulnerable during the extensile lateral approach to the calcaneus, screw placement for stress fractures of the proximal fifth metatarsal and calcaneal (Achilles) tendon repair, especially when using percutaneous techniques. The second metatarsal experiences more stress during gait and is the most common metatarsal to incur a stress fracture. The deep fibular nerve innervates extensor digitorum brevis and extensor hallucis brevis, and provides sensation to the skin of the first
interdigital space. It can be compressed by the inferior extensor retinaculum in anterior tarsal tunnel syndrome and is vulnerable during repair of calcaneonavicular coalitions and during approaches for reduction of a Lisfranc injury. Injury to the deep fibular nerve leads to weak or absent function in extensor digitorum brevis and extensor hallucis brevis.

The proper plantar digital nerve arising from the medial plantar nerve is at risk with a medial plantar approach to the medial sesamoid.

The intermediate dorsal cutaneous nerve from the superficial fibular nerve can be transected with arthroscopic portal placement, or encased in scar after wound closure. This nerve is vulnerable with anterolateral portal placement for arthroscopy and during open reduction internal fixation of distal fractures of the fibula.

The medial dorsal cutaneous nerve is vulnerable to injury during hallux valgus surgery.

The midfoot and forefoot are frequently injured during a lateral ankle sprain, and although they are often overlooked during clinical examination, these injuries may contribute to the development of chronic ankle instability.\(^6\)
References


Single Best Answers

1. Which one of the following ligaments connects the medial cuneiform to the base of the second metatarsal?
   A. Spring ligament
   B. Chopart's ligament
   C. Lisfranc's ligament
   D. Intermetatarsal ligament

   **Answer: C.** Lisfranc's ligament arises from the lateral surface of the medial cuneiform and inserts on to the medial aspect of the base of the second metatarsal near the plantar surface. It is the largest and strongest ligament of the tarsometatarsal joint complex. The spring ligament (plantar calcaneonavicular ligament) is a broad, thick band of fibres that connects the anterior margin of the calcaneus to the navicular. It supports the head of the talus and helps maintain the medial longitudinal arch of the foot.

2. Which one of the following nerves innervates the skin of the first web space of the foot?
   A. Tibial nerve
   B. Superficial fibular nerve
   C. Common fibular nerve
   D. Deep fibular nerve

   **Answer: D.** The deep fibular nerve innervates the skin of the first web space and is a branch of the common fibular nerve.

3. Which one of the following muscles is attached to the tuberosity of the navicular?
   A. Tibialis posterior
B. Tibialis anterior
C. Flexor hallucis brevis
D. Fibularis tertius

**Answer:** A. Tibialis posterior inserts into the tuberosity of the navicular, the bases of the second, third and fourth metatarsals, the medial, intermediate and lateral cuneiforms, and the cuboid.

4. On which surface of the calcaneus is the sustentaculum tali located?
   A. Medial
   B. Lateral
   C. Anterior
   D. Superior

**Answer:** A. The sustentaculum tali is a horizontal shelf that arises from the medial surface of the calcaneus. The superior surface is concave and articulates with the middle articular surface of the talus. The inferior surface bears a groove for the tendon of flexor hallucis longus.
Clinical case

1. A first-year female medical student enjoys running for exercise and relief of tension. Near the end of a particularly long and strenuous run, she suddenly develops a severe pain on the bottom of her foot. She immediately stops running and sits down to rest; the pain subsides somewhat but persists. Although she rests from running for several days, the pain does not go away and is particularly apparent if she stands for long periods in the gross anatomy laboratory. In frustration, she finally goes to a sports medicine clinic to seek relief. Clinical evaluation reveals her foot to be normal in size, colour and temperature. There is tenderness on the bottom of her foot from the heel to the heads of the metatarsals, especially just anterior to the calcaneal tuberosity. Radiological tests reveal no fracture or other bone or joint deformities. Neurological tests demonstrate no nerve involvement other than the pain, which appears to be related entirely to the soft tissues on the plantar surface of her foot.

A. What are the possible diagnoses?
One initial diagnosis might be a stress fracture of a metatarsal. Plain X-rays show the bones to be normal, but this does not always rule out stress fractures because they can be very fine and may be revealed only by a bone scan (scintigraphy). Normal colour and temperature of the foot would seem to rule out a vascular problem. The pain therefore appears to be related to the soft tissues (muscles, ligaments and so on). A common foot injury in runners (up to 9% of running injuries) is plantar fasciitis.

B. What soft tissue structures are located on the plantar surface of the foot between the calcaneal tuberosity and the heads of the metatarsals?

All of the plantar intrinsic muscles, the plantar aponeurosis, long and short plantar and spring ligaments, and the plantar arteries, veins and nerves are located between the heads of the metatarsals and the calcaneal tuberosity.

C. What single fibrous structure spans these bones?
The plantar aponeurosis.

D. What is the function of the plantar aponeurosis and the long plantar, spring and short plantar ligaments?
The plantar aponeurosis and the long plantar, spring and short plantar ligaments primarily maintain the longitudinal arch of the foot.
E. Considering the function of these structures and the action of the foot involved in running, what might be the mode of injury?

Each time the heel of the foot strikes the ground in running there is a tremendous strain on the longitudinal arch and on the muscles of the anterior leg, which together act as shock absorbers. These stresses often produce painful micro-tears in the muscle attachments to the tibia (‘shin splints’) and tears in the plantar aponeurosis.

F. How might the condition be treated?

Conservative treatment comprising rest, ice and non-steroidal anti-inflammatory drugs is preferred. Exercises to lengthen the calcaneal (Achilles) tendon and the plantar aponeurosis help to prevent future injuries. Heel cushions that elevate the tender areas can help.
Anatomy in surgical training and education in the UK

Peter A Brennan, Susan M Standring, Duncan SG Scrimgeour

In the UK, surgical training follows a defined pathway. After completion of undergraduate medical school training (usually a 5-year programme, which is often increased to 6 years if an intercalated BSc degree is added, and is sometimes reduced to 4 years for graduate entry students), newly qualified doctors undertake 2 years in a Foundation Programme (FY1 and FY2), enabling the acquisition of the generic skills required by all practising doctors. After successful completion, doctors wishing to pursue a surgical career subsequently enter a 2-year Core Surgical Training (CST) programme, followed by 5–6 years of higher surgical training (HST) or a 7–8 year run-through programme (trainees appointed to ST1 posts in a specialty will continue through to ST8 and certification of completion of training without having to go through any further competitive interviews, provided they meet the requirements of the specialty curriculum). CST usually comprises four 6 month rotations in surgical specialties and can also include emergency medicine and critical care. In order to progress to year three of surgical training, doctors must gain appropriate competencies, including passing the summative Membership of the Royal College of Surgeons (MRCS) examination.

This examination can be taken at any time following qualification and is in two parts: Part A MRCS consists of a 5 hour multiple choice question (MCQ) examination, taken as two papers with a suitable break between them. Both papers are sat on the same day. Paper 1, Applied Basic Science (3 hours), has 180 questions, of which 75 are anatomical. Paper 2, Principles of Surgery in General (2 hours), has 120 questions. The papers cover generic surgical sciences and the core knowledge required for the safe practice of all surgical specialties. To achieve a pass in Part A, a candidate has to reach a level of competence in each of the two papers, and also exceed the overall pass mark set for Part A, as determined by the standard-setting process. The required anatomical knowledge is shown in Box 1, with a breakdown of the marks and weighting provided in Box 2.
Box 1

Anatomical knowledge required for MRCS

- Regional anatomy of thorax, abdomen, pelvis, perineum, limbs, spine, head and neck
- Microscopic anatomy of tissues and organs of surgical relevance
- Surgically related embryology and development
- Surface anatomy
- Imaging anatomy

Box 2

Breakdown of the 75 anatomy questions in Part A MRCS Paper 1: Applied Basic Sciences (total 180 questions)

- Regional anatomy (63 questions)
  - Thorax 6
  - Abdomen 15
  - Pelvis 4
  - Perineum 2
  - Limbs 15
  - Spine 3
  - Head and neck 10
  - Brain 6
  - Autonomic nervous system 2
- Surgically related embryology (8 questions)
- Surface and imaging anatomy (4 questions)

Candidates who pass Part A are then eligible to sit Part B. This is an Objective Structured Clinical Examination (OSCE), consisting of 22 stations, of which 18 are manned and each is of 9 minutes' duration; 2 are preparation
stations to analyse results before presenting to examiners; and 2 are rest stations. A break is provided after 11 stations. Of the 18 manned stations (each carrying equal marks, with a maximum of 20 marks per station), 10 assess clinical skills, including examination, communication and procedural skills, and 8 test knowledge. The highest mark possible is 360 (18 × 20 marks) (Figs 1 and 2). A breakdown of the manned stations is shown in Table 1. The three anatomy stations might include radiological anatomy, topographical anatomy or surface anatomy, as well as the application of anatomy in clinical practice, including patient safety. To succeed in Part B, candidates must pass both the clinical skills and knowledge content areas.

FIG. 1 A typical anatomy station for the MRCS Part B OSCE.
FIG. 2 A procedural station for the MRCS Part B OSCE. In this case, venous cannulation.

TABLE 1
Breakdown of the 18 manned stations in Part B MRCS

<table>
<thead>
<tr>
<th>Content</th>
<th>Number of stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical skills (n=10)</td>
<td></td>
</tr>
<tr>
<td>Clinical examination</td>
<td>4</td>
</tr>
<tr>
<td>Communication skills (e.g. history taking, breaking bad news)</td>
<td>4</td>
</tr>
<tr>
<td>Procedural skills</td>
<td>2</td>
</tr>
<tr>
<td>Knowledge (n=8)</td>
<td></td>
</tr>
<tr>
<td>Anatomy</td>
<td>3</td>
</tr>
<tr>
<td>Applied surgical physiology and critical care</td>
<td>3</td>
</tr>
<tr>
<td>Applied surgical pathology</td>
<td>2</td>
</tr>
</tbody>
</table>
Our own recently published research of over 7000 MRCS candidates has found that candidates who sit Part A in FY1 obtain higher marks above the set pass marks and are more likely to pass than candidates in all other training years. Conversely, CST1 candidates (in the first year of core training) are more likely to pass Part B MRCS than more junior trainees. Following our published findings, candidates seem to be taking Part A MRCS earlier than was previously the case. It is worthwhile noting that candidates are currently allowed a maximum of six attempts at Part A and four attempts at Part B.

On successful completion of CST and both parts of MRCS, candidates can apply for higher specialty training (HST) in one of the 10 surgical disciplines recognized in the UK and become a specialty registrar (StR). Throughout FY, CST and HST, trainees will complete work-based assessments (WBAs) in their place of training. These will include operative assessments, case-based discussion and assessment of anatomical knowledge relevant to the surgery being assessed. The Joint Committee for Surgical Training (JCST) requires at least 40 WBAs to be completed in each year of surgical training from CST onwards. At the end of each year, trainees have an Annual Review of Competence Progression (ARCP), where all evidence of work undertaken during the year is assessed by a panel to ensure that progress is being made according to the criteria for each surgical curriculum.

Towards the end of HST, trainees will sit the examination for Fellowship of the Royal College of Surgeons (FRCS), known in the UK as the exit examination. As with MRCS, the FRCS comprises two sections, one written and one clinical. Section 1 consists of two papers, taken on the same day. Paper 1 (2 hours) consists of MCQs; paper 2 (2.5 hours) consists of extended matching items (EMI) questions. In both papers, surgical anatomy is tested across the specialty being examined. Section 2, the clinical examination, is taken on successful completion of Section 1. It is generally attempted over 2 days and has both clinical examination and oral components, where knowledge of surgical anatomy is again tested. There is one long case (20 minutes) and two short cases (10 minutes each) in the clinical stations. The oral examination comprises scenario-/patient-based structured interviews consisting of four 30-minute sessions. Candidates are allowed a maximum of four attempts for both Section 1 and Section 2.

In summary, surgical anatomy forms a significant component of both formative (WBA) and summative (MRCS and FRCS) assessments in UK surgical training (Fig. 3). We have recently published on the predictive
validity of MRCS for both entry into HST and ARCP outcomes during specialty training (Fig. 4). MRCS performance has also been found to predict success at both Section 1 and Section 2 FRCS. We believe that, for safe surgical practice, a detailed working knowledge of anatomy is essential. It is reassuring to find that the summative MRCS examination predicts subsequent career progress, with those doctors who struggle to pass the examination being more likely to have difficulty obtaining an StR position (recruitment is done competitively in a national process), as well as unfavourable ARCP outcomes during higher surgical training, and are more likely to fail the UK exit exam at first attempt (Sections 1 and 2 of the FRCS).
FIG. 3  Susan teaching anatomy using prepared cadaveric material.
FIG. 4  Peter and Duncan, authors on the above references on surgical education.
References

Anatomy in surgical training and education: a North American perspective

Nicole Mak, Sam M Wiseman

It is well recognized that anatomy represents a critically important keystone in the teaching of medicine, especially in the teaching of surgery.\(^1\) During training, the surgical resident must not only develop a comprehensive understanding of operative anatomy, but also concurrently develop the skill set that is required for the safe and successful conduct of a variety of discipline-specific procedures. Knowledge of anatomy is essential for the safe handling and dissection of living tissues, and also allows for the acquisition of a deep understanding of the steps and manoeuvres that are required for the conduct of operations. Although the specifics of anatomical knowledge and expertise vary considerably between surgical specialties and subspecialties, and even between individual surgeons, all successful procedures are facilitated by this skill set, regardless of the specific pathology that is being treated or the regional anatomical variation encountered.

Prior to beginning a surgical residency, most trainees have experience and knowledge that are limited to the anatomy that they learned during medical school. In recent years, many changes in healthcare have made it increasingly difficult for surgical residents to acquire their operative anatomical knowledge solely in the operating room. These changes include: duty hour restrictions, expansion of subspecialty fellowship training, increased procedural complexity, limitations in operating room resources and increased concerns regarding litigation.\(^2\) In order to compensate for these changes, surgical training programmes have adopted novel teaching tools to help their residents learn anatomy. Currently, most surgical residency programmes have surgical skills laboratories that provide trainees with the resources to help them acquire relevant anatomical knowledge (Fig. 1). In particular, simulation has now become a very important part of surgical education. Simulation is offered in many forms, which range from low to high fidelity,
and may be carried out utilizing models, animals, cadavers, virtual reality and even robotics. Simulation also has the advantage of being less costly and time-consuming than traditional cadaveric dissection. Not surprisingly, the specifics of how each surgical training programme teaches anatomy is currently quite variable. Though the approach and resources employed may differ, the ultimate goal, that of producing skilled and competent surgeons, has remained the same.

In North America, anatomical knowledge may or may not be thoroughly tested during residency training or certification examinations. In general, contemporary surgical examinations primarily evaluate residents’ working knowledge of anatomy within the context of clinically relevant scenarios and case studies. This approach to evaluation of trainees’ anatomical knowledge is true in North America for both of the main certifying bodies: the Royal College of Physicians and Surgeons of Canada (http://www.royalcollege.ca) and the American Board of Surgery (http://www.absurgery.org).

Significant changes in practice have occurred during recent years, driven by the adoption of technology and techniques that have allowed for improved patient outcomes. Despite these changes, the teaching of anatomy will unquestionably continue to remain a fundamental part of the training of
all future surgeons.
**Eponyms**

Achilles tendon: the calcaneal tendon.  
*Achilles, in Greek mythology, died from a wound in his vulnerable heel, inflicted by Paris in the Trojan War.*

Adamkiewicz, artery of: the largest anterior medullary feeder artery to the anterior spinal artery. It varies in level, arising from the lower (T9–11) posterior intercostal, the subcostal or, less frequently, the upper lumbar (L1–2) arteries. Most often occurs on the left side.  
*Albert Adamkiewicz (1850–1921), Professor of Pathology, University of Cracow, Poland.*

Albarran's gland: a portion of the median lobe of the prostate immediately underlying the uvula of the urinary bladder.  
*Joaquín María Albarrán y Domínguez (1860–1912), Cuban urologist.*

*Benjamin Alcock (1801–?), British anatomist who published an article in 1836 on iliac arteries.*

Allen's test: a test of sufficiency of the blood supply to the hand by compression and release of the ulnar and radial arteries, and observation of the colour change of the hand.  
*E. V. Allen (1901–1961), Professor of Medicine, Mayo Clinic, Rochester, Minnesota, USA.*

Allis soft tissue forceps:  
*Oscar Huntington Allis (1836–1931), American surgeon.*

Anderson–Hynes pyeloplasty: disjoined or dismembered pyeloplasty.  

Appleby procedure: distal pancreatectomy with *en bloc* dissection of the coeliac axis (L. Appleby, The coeliac axis in the expansion of the operation for gastric carcinoma, Cancer. 6 (1953) 704–707.)

Arantius, nodule of (lunule of Arantius): a small nodule in the free border of the aortic valves;
–, plate of: one of the four plates of the liver; a fibrous plate underlying the ligamentum venosum.

Julio Caesar Aranzio (Arantius) (1530–1589), pupil of Vesalius; Professor of Medicine and Surgery, Bologna, Italy.

Auerbach’s plexus: the autonomic nervous plexus between the circular and longitudinal layers of the muscle of the gut wall.

Leopold Auerbach (1828–1897), Professor of Neuropathology, Breslau, Poland.

Babinski reflex (Babinski response, Babinski sign): an upgoing plantar response in pyramidal tract disturbances.


Badenoch’s arteries: urethral branches of the prostatic artery (a branch of the inferior vesical artery) that approach the bladder neck at 5 and 7 o’clock.

Alex William Badenoch (1903–1991), Welsh urologist.

Baker’s cyst: popliteal cyst.


Ballance’s sign: fixed dullness in the left flank and shifting dullness in the right flank while the patient is lying on the left side; the sign is associated with splenic rupture in abdominal trauma.

Sir Charles Alfred Ballance (1856–1936), English surgeon who specialized in the fields of otology and neurotology.

Barrett’s oesophagus: abnormal columnar mucosa (Barrett’s mucosa) that covers a variable length of the distal oesophagus.

Norman Rupert Barrett (1903–1979), consultant thoracic surgeon, Royal Brompton Hospital, London, UK.

Bartholin’s ducts and gland: the sublingual salivary gland and its ducts; – glands: the greater vestibular glands on either side of the vaginal orifice.

Casper Bartholin (1655–1738), Professor of Medicine, Anatomy and Physics, Copenhagen, Denmark.

Barton’s fracture: a fracture of the distal radius extending through the dorsal aspect of the articular surface with associated dislocation of the radiocarpal joint. The radiocarpal ligaments are not disrupted, which means that the articular surface of the fractured distal radius remains in contact with the proximal carpal row.
John Rhea Barton (1794–1871), American orthopaedic surgeon, Philadelphia, USA.

**Bassini repair, modified:** primary tissue repair of an inguinal hernia in which the conjoint tendon and aponeurosis of transversus abdominis are fixed to the inguinal ligament.

**Bassini repair, modified:** primary tissue repair of an inguinal hernia in which the conjoint tendon and aponeurosis of transversus abdominis are fixed to the inguinal ligament.

Edardo Bassini (1844–1924), Italian surgeon, University of Padua, Italy.

**Batson's vertebral venous plexus:** the valveless vertebral venous veins that communicate with the prostatic venous plexus and explain the readiness of carcinoma of the prostate to spread to the pelvic bones and vertebrae.

Oscar Batson (1894–1979), Professor of Anatomy, University of Philadelphia, USA.

**Baum's loop:** superior fibres in the optic radiation that course dorso-medially through the parietal lobe toward the occipital cortex.


Donald E. Baxter, American orthopaedic surgeon.

**Bell's muscle:** a band of muscular fibres running from the uvula of the bladder to the opening of the ureter on each side, bounding the trigone.

John Bell (1763–1820), Scottish surgeon and anatomist.

**Bell's nerve:** the long thoracic nerve;
– **palsy:** paresis or paralysis, usually unilateral, of the facial muscles, caused by dysfunction of the facial nerve.

Sir Charles Bell (1774–1842), surgeon, Middlesex Hospital, London, UK.

**Benedikt's syndrome:** a midbrain stroke syndrome involving the red nucleus and the fascicles of the oculomotor nerve (paramedian midbrain syndrome).

Moritz Benedikt (1835–1920), Hungarian–Austrian neurologist.

**Bernasconi and Cassinari, tentorial artery of:** a branch of the meningohypophysial artery (V. Bernasconi, V. Casserini, Caratteristiche angiografiche dei meningeomi del tentorio, Radiol. Med. 43 (1957) 1015–1026).

**Berry, ligament of:** the posterior suspensory ligament of the thyroid. The ligament of Berry suspends each thyroid lobe from the cricoid cartilage and the first two tracheal rings, and extends along the
posteromedial aspect of each lobe.

James Berry (1860–1946), Canadian-born British thyroid surgeon.

Bertin, ligament of: the ischiofemoral ligament.

Exupère Joseph Bertin (1712–1781), French anatomist.

Betz, pyramidal cells of: large pyramidal cells of the cerebral cortex.

Vladimir Aleksandrovich Betz (1834–1894), Professor of Anatomy, Kiev, Ukraine.

Bigelow, ligament of: the iliofemoral ligament.

Henry J. Bigelow (1818–1890), American surgeon.

Billroth I: gastroduodenostomy;
– II: gastrojejunostomy.

Christian Albert Theodor Billroth (1829–1894), German–Austrian surgeon, considered to be the founder of modern abdominal surgery.

Bill's bar: a bony landmark that divides the superior compartment of the internal auditory canal into an anterior and a posterior compartment.

William Fouts House (1923–2012), American otologist, known informally as ‘Dr Bill’.

Blalock–Taussig shunt: the first surgical systemic artery to pulmonary artery shunt.


Bland–White–Garland syndrome: an anomalous origin of the left coronary artery arising from the pulmonary artery (ALCAPA) – a rare, but serious, congenital anomaly. The first clinical description in conjunction with autopsy findings was given by Bland and colleagues in 1933 (E.F. Bland, Congenital anomalies of the coronary arteries: report of an unusual case associated with cardiac hypertrophy, Am. Heart J. 8 (1933) 787–801).

Breschet, sinus of: the sphenoparietal sinus.

Gilbert Breschet (1784–1845), French anatomist.

Broca's area: the speech area of the cerebral cortex.

Pierre Paul Broca (1824–1880), Professor of Clinical Surgery, Paris, France.

Brödel, bloodless line of: the line of division between the areas of kidney supplied by the anterior and posterior branches of the renal artery.

Max Brödel (1870–1941), medical artist, Leipzig, Germany, then Director of Institute of Art as Applied to Medicine, Baltimore, USA.
Brooke ostomy technique: creation of a raised edge for the small intestine as it exits the abdomen for an ostomy so that the mucocutaneous junction is not flat to the skin surface (B.N. Brooke, The management of an ileostomy, including its complications, Lancet. 2 (1952) 102–104).


Buck's fascia: the penile fascial sheath.

Gordon Buck (1807–1877), American surgeon.

Budd–Chiari syndrome: spontaneous thrombosis (complete or partial) of the hepatic veins, with or without additional inferior vena caval thrombosis.

George Budd (1808–1882), Professor of Medicine, King's College Hospital, London, UK. Hans Chiari (1851–1916), Austrian pathologist.

Buerger's test: assessment of the adequacy of the arterial supply to the leg.

Leo Buerger (1879–1943), Austrian-born American physician and urologist.

Burch colposuspension: urethrovaginal fixation to Cooper's ligament.

John Christopher Burch (1900–1977), American obstetrician and gynaecologist.

Burow's triangle advancement flap: a triangle of skin and subcutaneous fat excised so that a pedicle flap can be advanced without buckling the adjacent tissue.

Karl Heinrich August Burow (1809–1874), German surgeon with an interest in the treatment of open wounds.

Cajal, interstitial cells of: cells in the muscularis externa of the gut wall, active as pacemakers in gut motility.

Santiago Ramón y Cajal (1852–1934), Professor of Anatomy, Valencia and then Barcelona, then Professor of Histology and Morbid Anatomy, Madrid, Spain. Cajal shared the Nobel Prize in Physiology or Medicine (1906) with Camillo Golgi for their work on the structure of the nervous system.

Calot, triangle of: the triangle bordered by the common hepatic duct, the cystic artery and the cystic duct.

Jean-François Calot (1861–1944), French surgeon, Rothschild Hospital, Berck-sur-Mer, France. Specialized in the treatment of surgical tuberculosis in children.
**Cameron's ulcer**: a gastric ulcer within a hiatal hernia (A.J. Cameron, J.A. Higgins, Linear gastric erosions: a lesion associated with large diaphragmatic hernia and chronic blood loss anemia, Gastroenterol. 91 (1986) 338–342).

*Alan J. Cameron, American gastroenterologist.*

**Camper's fascia**: the layer of fascia extending between the ischiopubic rami inferior to sphincter urethrae and the deep transverse perineal muscle.

*Pieter (Petrus) Camper (1722–1789), Dutch Professor of Philosophy, Anatomy and Surgery, University of Franeker, Netherlands.*

**Cantlie's line**: a line that separates the right and left lobes of the liver, drawn from the inferior vena cava to just left of the gallbladder fossa.

*Sir James Cantlie (1851–1926), Scottish physician, a pioneer of first aid and co-founder of the Hong Kong College of Medicine for Chinese (subsequently, the University of Hong Kong).*


**Carrel patch**: a technique used in reimplantation of major vascular structures during organ transplantation.

*Alexis Carrel (1873–1944), French surgeon, awarded the Nobel Prize for Physiology or Medicine in 1912 ‘in recognition of his work on vascular suture and the transplantation of blood vessels and organs’.*

**Castell's sign**: a sign elicited by placing the patient supine and percussing the area of the lowest intercostal space (eighth or ninth) in the left anterior axillary line in full inspiration and then in full expiration. If the note changes from resonant on full expiration to dull on full inspiration, the sign is regarded as positive (D.O. Castell, The spleen percussion sign: a useful diagnostic technique, Ann. Intern. Med. 67 (1967) 1264–1267).

*Donald O. Castell (1935–), American gastroenterologist.*


**Cernea classification system**: a system used to describe anatomical variation of the external branch of the superior laryngeal nerve
(EBSLN). This system classifies the EBSLN into three groups based on its relationship to the plane of the superior edge of the superior pole of the thyroid lobe. A type 1 EBSLN crosses the superior pole vessels more than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2A EBSLN crosses the superior pole vessels less than 1 cm superior to the superior edge of the superior pole of the thyroid lobe. A type 2B EBSLN crosses the anterior surface of the thyroid pole below its superior edge. Type 2A and type 2B EBSLNs are at the greatest risk of being injured during thyroidectomy.

Claudio R. Cernea, head and neck surgeon, São Paulo, Brazil.

**Champy lines:** the ideal lines of osteosynthesis used in miniplate fixation in the treatment of mandibular fractures.

Maxime O. Champy (1926–), French maxillofacial surgeon.

Chassaignac's carotid tubercle: the prominent anterior tubercle of the transverse process of the sixth cervical vertebra, against which the carotid artery may be compressed.


**Chiari malformation (Arnold–Chiari malformation):** a congenital brainstem and cerebellar herniation through the foramen magnum.

Julius Arnold (1835–1915), Professor of Pathology, Heidelberg, Germany. Hans Chiari (1851–1916), Austrian pathologist.

**Chiari network:** a network of strands extending from the margin of the inferior vena cava or valves of the coronary sinus to the region of the crista terminalis as a result of incomplete resorption of the right valve of the sinus venosus.

Hans Chiari (1851–1916), Austrian pathologist.

**Chopart's joint:** the transverse tarsal joint between the mid foot and the hind foot;

– **ligament:** the bifurcate ligament (calcaneonavicular ligament and calcaneocuboid ligament);
– **tubercle:** the anterior tibiofibular ligament travels from the anterolateral surface of the distal tibia (Chopart's tubercle) to the fibula.

François Chopart (1743–1795), French surgeon; Professor of Practical Surgery at the École Pratique, Paris, France, from 1771; in 1782, he succeeded Toussaint Bordenave (1728–1782) as Chair of Physiology.

**Clarke's nucleus (Clarke's column):** the basal nucleus in the posterior
horn of spinal grey matter.

*Jacob Augustus Lockhart Clarke (1817–1880), neurologist, Hospital for Epilepsy and Paralysis, London, UK.*

**Cloquet's node:** the most superior deep inguinal lymph node.

*Jules-Germain Cloquet (1790–1883), Professor of Anatomy and Surgery, Paris, France.*

**Clutton sounds:** graduated dilators that are narrower at the tip than at the handle, which displays the size change along the length of the dilator.

*Henry Hugh Clutton (1850–1909), English surgeon.*

**Cobb elevator:**

*John Robert Cobb (1903–1967), American orthopaedic surgeon.*


**Colles' fascia:** the superficial penile fascia, a continuation of Scarpa's abdominal layer.

*Abraham Colles (1773–1843), Irish Professor of Anatomy, Physiology and Surgery, Royal College of Surgeons in Ireland, Dublin, Ireland.*

**Collis's gastroplasty:** a linear stapled gastroplasty of the gastric cardia.

*John Leigh Collis (1911–2003), English surgeon.*

**Compton–Cruveilhier septum:** connective tissue separating the common fibular and tibial components of the sciatic nerve.

*Jean Cruveilhier (1791–1874), French pathologist.*

**Conley, tragal pointer of:** a small cap of cartilaginous tissue that extends below the helix of the auricle in a parotid dissection. Anteromedially, the tissue forms a blunt ‘pointer’, from which it derives its name. The facial nerve is classically described as 1 cm medial and inferior to this pointer. The tragal pointer is not consistently reliable (it is cartilaginous, mobile and asymmetrical, and has a blunt, irregular tip); at best, it should be considered as a guide.

*John J. Conley (1912–1999), American head and neck surgeon.*

**Conn's syndrome:** a disorder of excessive aldosterone production.


**Cooper's pectineal ligament:** thickened periosteum on the pecten pubis; – **suspensory ligaments:** suspensory ligaments of the breast.

*Sir Astley Paston Cooper (1768–1841), British surgeon and
anatomist, Guy’s Hospital, London, UK; Sergeant Surgeon to King George IV, King William IV and Queen Victoria.

**Cottle's test (Cottle's manœuvre):** a test that is used to determine whether the most significant site of nasal obstruction is at the so-called nasal valve or further inside the nasal cavity.

Maurice H. Cottle (1898–1981), American rhinologist; often called the father of modern rhinology. He pioneered several techniques associated with the nasal valve.

**Couinaud segmental anatomy:** division of liver segments based on hepatic scissurae.

Claude Couinaud (1922–2008), French surgeon and anatomist.

**Cowper's glands:** the bulbourethral glands.

William Cowper (1666–1709), British surgeon and anatomist.

**Crohn's disease:** a disorder of unknown aetiology characterized by transmural inflammation of the gastrointestinal tract; may involve any or all parts of the entire gastrointestinal tract from mouth to perianal area, although it is usually seen in the terminal ileal and perianal locations. Crohn's disease was first described by Crohn, Ginzburg and Oppenheimer in 1932 as a transmural inflammatory condition of the terminal ileum.

Burrill Bernard Crohn (1884–1983), American gastroenterologist.

**Crouzon's syndrome:** craniofacial dysostosis – premature closure of cranial vault sutures, maxillary hypoplasia and ocular and aural anomalies.


**Cullen sign:** ecchymosis in the periumbilical region.

Thomas Stephen Cullen (1868–1953), Canadian gynaecologist.

**Cusco's speculum:** a bivalved, self-retaining speculum used to inspect the cervix.

Edward Gabriel Cusco (1819–1894), French surgeon.

**Cushing's syndrome:** a disorder of excessive cortisol production.

Harvey Williams Cushing (1869–1939), American neurosurgeon.

**Dandy cannula;** –, petrosal veins of: the superior petrosal veins.

Walter Edward Dandy (1886–1946), American neurosurgeon.

**DeBakey forceps:** atraumatic tissue forceps used in vascular procedures to avoid tissue damage during manipulation.
Michael Ellis DeBakey (1908–2008), American cardiovascular surgeon and pioneer in surgical procedures for treatment of defects and diseases of the cardiovascular system.

**Dejerine–Roussy syndrome:** central post-stroke thalamic pain syndrome.

*Joseph Jules Dejerine (1849–1917) and Gustave Roussy (1874–1948), French physicians.*

**Delphian lymph node:** prelaryngeal (anterior to larynx) lymph node(s), located just above the thyroid isthmus. They may harbour metastatic disease and should be routinely removed as part of a central neck dissection.

*Greek Oracle of Delphi, who could predict the future, so named because the presence of metastatic disease in these lymph nodes predicted that further nodal disease was present in the neck and that the patient had a worse cancer prognosis.*

**Denonvilliers’ fascia:** the rectoprostatic fascia in males and rectovaginal fascia in females.

*Charles-Pierre Denonvilliers (1808–1872), Professor of Anatomy, Paris, France.*

**De Quervain’s approach:** the dorsoradial (snuffbox) approach.

*Fritz de Quervain (1868–1940), Swiss surgeon; Professor of Surgery at the Universities of Basel and Bern, Switzerland. Described both the eponymous disease of the wrist and thyroiditis.*

**Desmarres retractor:** curved lid retractor

*Louis-Auguste Desmarres (1810–1882), French ophthalmologist.*

**Dieulafoy’s lesion:** ectatic submucosal vessels in the cardia of the stomach.

*Georges Dieulafoy (1839–1911), French surgeon.*

**Dingman approach:** a method for repairing zygomatic complex fractures.

*Reed O. Dingman (1906–1985), American plastic and reconstructive surgeon.*

**Disse, space of:** the space between the hepatocyte and sinusoidal endothelium in the microarchitecture of the liver.

*Josef Disse (1852–1912), German anatomist.*

Vinko V. Dolenc (1940–), neurosurgeon, University of Ljubljana, Slovenia.

Doppler effect/shift: the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. In medicine, the Doppler effect is used, for example, to assess the velocity of blood flow in the veins and arteries.

Christian Andreas Doppler (1803–1853), Austrian mathematician and physicist.

Dor fundoplication: a 180° fundoplication.

Jacques Dor (1904–1997), French thoracic surgeon.

Dorello's canal: the invagination of the dura in the petroclival region from the petroclival entrance point to the posterior end of the cavernous sinus; it conveys the mid portion of the abducens nerve. Dorello is credited with the discovery of the canal that bears his name in 1905, although it had been described in 1859 by Wenzel Leopold Gruber.

Primo Dorello (1926–1946), Italian anatomist, Professor of Human Anatomy, Perugia, Italy.

Douglas, line of: the arcuate line, which demarcates the lower limit of the posterior rectus sheath, located halfway between the umbilicus and pubic crest;

–, pouch of: the rectouterine peritoneal pouch.

James Douglas (1675–1742), Scottish physician and anatomist, and Physician Extraordinary to Queen Caroline.

Drummond, marginal artery of (arch of Drummond): the anastomoses between the ileocolic, right colic, middle colic, left colic and sigmoid arteries (the arch of Roilan is the part of this arch between the middle and left colic artery).

Hamilton Drummond (1882–1925), surgeon, Newcastle upon Tyne, UK.

Duane syndrome (Duane retraction syndrome): a rare congenital syndrome characterized by limitation of horizontal eye movement, classified as a congenital cranial dysinnervation disorder (CCDD). Apparently described initially by Jakob Stilling (1887) and Siegmund Türk (1896), but named after Duane (A. Duane, Congenital deficiency of abduction associated with impairment of adduction, retraction movements, contraction of the palpebral fissure and oblique movements of the eye, Arch. Ophthalmol. 34 (1905) 133–150).
Alexander Duane (1858–1926), American ophthalmologist.

**Duchenne gait:** gait changes in Duchenne muscular dystrophy.  
Guillaume Benjamin Amand Duchenne de Boulogne (1806–1875), French neurologist.

**Dupuytren’s disease (Dupuytren’s contracture):** contraction and fibrosis of the palmar (and, occasionally, the plantar) fascia.  
Baron Guillaume Dupuytren (1777–1835), French anatomist and military surgeon; Professor of Surgery, Hôtel Dieu, Paris.  
*Described the surgery of palmar contracture in The Lancet in 1834 and treated Napoleon’s haemorrhoids.*

**Ebstein’s anomaly:** a rare congenital malformation of the heart with downward and rotational displacement of the tricuspid valve to the apex of the right ventricle.  
Wilhelm Ebstein (1836–1912), German physician.

**Eckhard nerves:** the nervi erigentes. Eckhard demonstrated that stimulation of the pelvic nerves that he named nervi erigentes produced penile erection and increased penile blood flow (C. Eckhard, Untersuchungen über die Erektion des Hundes, in: Beiträge zur Anatomie und Physiologie, vol. III, Giessen, Ferber, 1863, pp. 123–166).  
Conrad Eckhard (1822–1905), German physiologist who studied the physiology of erection in dogs.

**Edinger–Westphal nucleus:** the midbrain nucleus containing pre-ganglionic neurones destined to synapse in the ciliary ganglion; it lies close to the nucleus of the oculomotor nerve.  
Ludwig Edinger (1855–1918), Professor of Anatomy, Frankfurt-am-Main, Germany. Karl Westphal (1833–1890), Professor of Psychiatry, Berlin, Germany.

**Ellik evacuator:** an instrument used to evacuate tissue fragments, blood clots or calculi from the urinary bladder.  
Milo Ellik (1905–1976), American urologist.

**Erb's palsy:** the result of injury to the C5 and C6 roots of the brachial plexus.  
Wilhelm Heinrich Erb (1840–1921), German neurologist.

**Eustachian tube (pharyngotympanic tube, auditory tube):** Eustachi is credited with the first accurate description of the tuba auditiva as a connection between the middle ear and the nasopharynx. It has been suggested that his essay, ‘De Auditus Organis’, was the inspiration for the manner of Hamlet’s father’s death in Shakespeare’s *Hamlet* (A.R.)

– **valve**: the inferior vena caval valve in the right atrium.
  
  *Bartolomeo Eustachi (1513–1574), Professor of Anatomy, Rome, Italy, and physician to the Pope.*

**Fallopian canal**: the canal for the facial nerve in the temporal bone;

– **tube**: the uterine tube.

  *Gabriele Fallopio (1523–1562), Professor of Anatomy, Padua, Italy, and a pupil of Vesalius.*

**Fallot, tetralogy of**: a congenital heart disease comprising pulmonary stenosis, right ventricular hypertrophy, ventricular septal defect and overriding of the aorta.

  *Étienne-Louis Fallot (1850–1911), Professor of Medicine, Marseilles, France.*

**Ferguson technique**: a modification of the Milligan–Morgan procedure, in which the mucosal defect edges and skin are closed with a continuous suture (J.A. Ferguson, J.R. Heaton, Closed hemorrhoidectomy, Dis. Colon Rectum. 2 (1959) 176–179).

**Finney pyloroplasty**: side-to-side gastroduodenostomy between the anterior surfaces of the stomach and duodenum.

  *John Miller Turpin Finney (1863–1942), American surgeon, elected the first president of the American College of Surgeons in 1913.*


**Flocks’ arteries**: small urethral branches of the prostatic artery (a branch of the inferior vesical artery) that approach the bladder neck at 1 and 11 o'clock (R.H. Flocks, The arterial distribution within the prostate gland: its role in transurethral prostatic resection, J. Urol. 37 (1937) 524–548).


**Foley catheter**: an indwelling urinary catheter designed to provide continuous drainage of the bladder.

  *Frederic Foley (1891–1966), American urologist, Anker Hospital, St*
Paul, Minnesota, USA.

**Forel, H field of**: ventral tegmental decussation between the red nuclei.
*August Forel (1848–1931), anatomist and neurologist, Zurich, Switzerland.*

**Frazier burr-hole (Frazier's point)**: a burr-hole that lies 3–4 cm from the midline and 6 cm above the external occipital protuberance; it can be used to tap the occipital horn.
*Charles Harrison Frazier (1870–1936), led the development of neurological surgery in the USA.*

**Freyer's prostatectomy**: an approach to open transvesical prostatectomy that probably stimulated the development of prostatic surgery (P.J. Freyer, A new method of performing prostatectomy, Lancet. 1 (1900) 774–777).
*Sir Peter Freyer, Irish urological surgeon.*

**Frey's syndrome**: sweating in the distribution of the auriculotemporal nerve, triggered by eating (‘auriculo-gustatory sweating’) after injury to the facial nerve.
*Lucja Frey (1889–1944), neurologist, Warsaw, Poland.*

**Galen, vein of (deep Galenic venous system)**: the great cerebral vein.
*Claudius Galen (AD 130–200), born Pergamum, Asia Minor; studied there and in Smyrna, Corinth and Alexandria. Physician to Marcus Aurelius and teacher of Anatomy and Medicine in Rome. Author of numerous texts on anatomy, surgery and medicine that were still used in European medical schools into the 17th century.*

**Gallaudet's fascia**: the external deep investing fascia covering external oblique, continuous with the superficial fascia of the perineum (Colles’ fascia).
*Bern Gallaudet (1860–1934), American anatomist, Columbia University, New York, USA.*

**Gans, fissure of**: a structure that lies on the undersurface of the right lobe of the liver behind the gallbladder fossa; it often marks the variable site of division of the portal pedicle to the right posterior sector.
*Henry Gans (1925–2017), Dutch surgeon.*

**Gartner's duct**: a mesonephric duct remnant in the lateral vaginal wall.
*Hermann Treschow Gartner (1785–1827), surgeon in the Norwegian and then Danish armies.*

**Gasserian ganglion**: the sensory ganglion of the trigeminal nerve.
Johann Lorentz Gasser (1723–1765), Austrian anatomist.

**Gerdy's tubercle**: the attachment of the iliotibial tract to the proximal tibia.


**Gerota's fascia**: the layer of connective tissue encapsulating the kidneys and adrenal (suprarenal) glands.

Dimitrie Gerota (1867–1939), Romanian anatomist, radiologist and urologist.

**Geschwind's area**: the inferior parietal lobule.


**Giacomini, band of**: the band on the surface of the uncus;
– **vein**: the short saphenous vein can extend into the posterior thigh as a distinct tributary, the Giacomini vein, which enters the long saphenous vein in the upper thigh.

Carlo Giacomini (1840–1898), Professor of Anatomy, Turin, Italy.


**Gibson approach** (Gibson flap, Gibson operation): a procedure in which the instrument is inserted deep to the deep lamina of temporalis fascia through a scalp incision and used to elevate depressed zygomatic complex fractures.

Sir Harold Delf Gibson (1882–1960), British plastic surgeon.

**Gimbernat's ligament (lacunar ligament)**: termination of the inguinal ligament as it fans out on to the pectineal ligament.

Antoni de Gimbernat (1734–1816), Spanish surgeon and anatomist, Madrid, Spain.

**Glisson, fibrous capsule of (Glisson's sheath)**: a fibrous capsule immediately underlying the visceral peritoneum enveloping the liver.

Francis Glisson (1597–1677), Regius Professor of Medicine, Cambridge, UK. Described rickets in 1671.
**Goldenhar's syndrome**: hemifacial microsomia; a syndrome of dermoid cysts, auricular appendices, asymmetrical malformations of the face and vertebral abnormalities.

*Maurice Goldenhar (1924–2001), American physician.*

**Golgi tendon organ**: a proprioceptive sensory nerve ending embedded among the fibres of a tendon.

*Camillo Golgi (1843–1926), Professor of Histology and Anatomy successively in Padua and then Siena, Italy; shared the Nobel Prize in Physiology or Medicine (1906) with Santiago Ramón y Cajal for their work on the structure of the nervous system.*

**Golgi–Mazzoni corpuscles**: encapsulated corpuscles that detect movement and vibration.

*Camillo Golgi (1843–1926), Italian anatomist and histologist.
Vittorio Mazzoni (1880–1940), Italian physiologist.*

**Goodsall's rule**: cryptoglandular fistular tracts with external openings in the posterior half of the perianal skin will have an internal opening in the posterior midline (curvilinear tract), whereas external openings in the anterior half of the perianal skin will have internal openings at the perpendicular linear point from the anal canal.

*David Henry Goodsall (1843–1906), English colo-proctologist.*


*Roscoe Reid Graham (1890–1948), Canadian surgeon.*

**Grey Turner sign**: ecchymosis in the flanks.

*George Grey Turner (1877–1951), English surgeon.*


**Guerin's sinus**: the largest recess in the roof of the navicular fossa, also known as the lacuna magna;

– **valve**: a fold of mucous membrane occasionally seen in the fossa navicularis,

*Alphonse François Marie Guérin (1816–1895), French surgeon.*

**Guthrie's muscle**: the external urethral sphincter muscle (On the Anatomy and Diseases of the Urinary and Sexual Organs: Containing the Anatomy of the Bladder and of the Urethra, and the Treatment of
George James Guthrie (1785–1856), English general surgeon, military surgeon and ophthalmic surgeon.

**Guyon's canal**: the canal for the ulnar nerve and vessels, defined medially by the pisiform and posteriorly by the flexor retinaculum.

Jean Casimir Félix Guyon (1831–1920), French urologist and anatomist; Professor of Pathology and latterly of Genitourinary Surgery at the University of Paris. Described the canal in 1861.


**Halsted's ligament**: subclavius.

William Stewart Halsted (1852–1922), first Professor of Surgery at Johns Hopkins Medical School, Baltimore, USA in 1892. Fundamental in the formalization of a training system for surgeons in the USA. Halsted performed early biliary tract operations, introduced the plate and buried screw technique for long bone fractures, and started the practice of operating with rubber gloves.

**Hammer's key area**: the confluence of the inferior orbital fissure, the infraorbital nerve, the orbital plate of the palatine bone and the greater wing of the sphenoid (B. Hammer, Orbital Fractures: Diagnosis, Operative Treatment, Secondary Corrections, Hogrefe and Huber, Boston, 1995).

**Beat Hammer**, Swiss orbital and skull-base surgeon.


**Hartmann's pouch**: dilation above the neck of the gallbladder – a pathological entity produced by a contained gallstone;

'Hartmann's procedure': proctosigmoidectomy traditionally defined as a resection of the sigmoid colon, leaving the ends of the colon in discontinuity and maturing the proximal end as a colostomy.

Henri Albert Hartmann (1860–1952), Professor of Surgery, Faculty of Medicine, Paris, France.
Hasson technique: an open technique for entering the abdomen under
direct vision (H.M. Hasson, A modified instrument and method for
Harrith M. Hasson (1931–2012), Egyptian surgeon.

Heald’s ‘holy plane’: the mesorectal fascial plane of dissection that is
followed during a total mesorectal excision (R.J. Heald, The ‘holy
Richard John Heald, English surgeon.

Heineke–Mikulicz stricturoplasty: a procedure to eliminate strictures
that is completed by creating a longitudinal incision on the anti-
mesenteric aspect of the intestine and then reapproximating the
opening transversely.
Walter Herman von Heineke (1834–1901), German surgeon.
Johannes von Mikulicz-Radecki (1850–1905), Polish surgeon.

Heller’s myotomy: laparoscopic oesophagomyotomy to treat achalasia.
Ernst Heller (1877–1964), German surgeon.

Henle, gastrocolic trunk of: the confluence of the right superior colic and
right superior gastroepiploic veins, draining into the superior
mesenteric vein at the inferior border of the neck of the pancreas;
→, loop of: the looped portion of the renal tubule;
→'s spine: a small bony prominence anterior to the supramastoid pit at
the posterosuperior margin of the bony external auditory canal.
Friedrich Gustav Jacob Henle (1808–1885), Professor of Anatomy in
Zurich, Switzerland, then Heidelberg and Göttingen, Germany.

Henry approach: an extensile anterior approach to the radius through
which all or part of the bone may be exposed. The full incision begins
just lateral to the biceps tendon at the level of the flexion crease of the
elbow and can be extended to the styloid process of the radius.
Exposure is achieved by developing the interval between the ‘mobile
wad’ (brachioradialis, extensors carpi radialis longus and brevis) and
the medial superficial flexors, thereby allowing safe access to the key
deeper neurovascular structures
Arnold Kirkpatrick Henry (1886–1962), Professor of Anatomy, Royal
College of Surgeons in Ireland, Dublin, Ireland, and Professor of
Clinical Surgery at the University of Egypt. Author of Extensile
Exposure (1945).

Hepp–Couinaud procedure: hepaticojejunostomy (J. Hepp, C. Couinaud,
L’Abord et l’utilisation du canal hépatique gauche dans les réparations
Hering, canals of: fine terminal ductules lined by cuboidal epithelium, linking the intralobular bile canaliculi with bile ducts in the portal canals.

Hesschel's transverse temporal gyri: gyri on the temporal lobe of the brain.

Hesselbach's fascia: the cribriform fascia;

Hirschsprung's disease: megacolon resulting from congenital absence of autonomic ganglion cells in the distal contracted segment.

His, angle of: the normally acute angle between the abdominal oesophagus and the fundus of the stomach at the gastro-oesophageal junction;


Herophilus: torcular Herophili: the confluence of the sinuses.

Heschl's transverse temporal gyri: gyri on the temporal lobe of the brain.

Hesschel's transverse temporal gyri: gyri on the temporal lobe of the brain.

Hesselbach's fascia: the cribriform fascia;

Heubner, recurrent artery of: the artery that supplies the anteromedial part of the head of the caudate nucleus and the anteroinferior internal capsule.

Hirschsprung's disease: megacolon resulting from congenital absence of autonomic ganglion cells in the distal contracted segment.
Wilhelm His (Junior) (1863–1934), Professor of Anatomy successively at Leipzig, Germany; Basle, Switzerland; and Göttingen and Berlin, Germany. Son of Wilhelm His (Senior).

**Hitselberger's sign**: hypaesthesia of the conchal bowl caused by facial nerve compression, seen in acoustic neuroma.


Carl-Herman Hjortsjö (1914–1978), Swedish physician.

**Hofmann ligaments**: fibrous connective tissue bands that run ventrolaterally from the dura mater to the posterior longitudinal ligament, described by Max Hofmann in 1898 (G.G. Tardieu, C. Fisahn, M. Loukas, et al., The epidural ligaments (of Hofmann): a comprehensive review of the literature, Cureus. 8 (2016) e779).

**Hoffman's test**: elicited by flipping either the volar or dorsal surface of the middle finger and observing the reflex contraction of the thumb and index finger. Hoffmann discussed this reflex in his teaching and used it in his clinical practice, but apparently never published this finding, which was subsequently documented by his pupil, Heinrich Curschmann, in 1911. (N.B. The Hoffmann test may not be a reliable screening tool for predicting the presence of cervical spinal cord compression.)

Johann Hoffmann (1857–1919), German neurologist.

**Hohmann retractors**: handheld retractors used in orthopaedic surgery to pull soft tissues away from the operative field to expose the bone being operated on.

Georg Hohmann, 19th-century German surgeon.

**Horner's syndrome (Bernard–Horner syndrome)**: syndrome of ptosis, anhydrosis, miosis and pseudoenophthalmos following interruption of the sympathetic supply to the eyelid and pupil, respectively (hemifacial anhidrosis may also occur). Horner described this in 1869.

Johann Horner (1831–1886), Professor of Ophthalmology, Zurich, Switzerland. Claude Bernard (1813–1878), French physiologist, considered one of the founders of experimental medicine.

**Houston's valves (Houston's folds)**: three intraluminal folds in the wall of the rectum, described by Houston in 1830.
John Houston (1802–1845), Irish surgeon and anatomist.

Howship–Romberg sign: compression of the obturator nerve by herniated bowel loops at the obturator foramen, producing referred hip, medial thigh or knee pain.

John Howship (1781–1841), English surgeon. Moritz Heinrich Romberg (1795–1873), German neurologist.

Hueter approach:

Carl Hueter (1838–1882), German surgeon.

Humphrey, ligament of: the meniscofemoral ligament, which Humphrey described as running from the lateral meniscus to the posterior cruciate ligament.

George Murray Humphrey (1820–1896), Professor of Anatomy and then of Surgery, Cambridge, UK. Founder of Journal of Anatomy.

Hunter's canal: the subsartorial canal.

John Hunter (1728–1793), surgeon, St George’s Hospital, London, UK. Described ligation of the femoral artery in the subsartorial canal for popliteal aneurysm. Often described as the founder of scientific surgery.

Huntington's disease (Huntington's chorea): an autosomal dominant disease characterized by chronic progressive chorea and mental deterioration.

George Sumner Huntington (1850–1916), American physician.

Isshiki procedure: one of four different surgical procedures developed by Isshiki in the 1970s, collectively referenced as ‘laryngeal framework’ surgery.

Nobuhiko Isshiki (1930–), pioneer of laryngeal framework surgery.


Ivor Lewis oesophagogastrectomy: a gastric pull-up.

Ivor Lewis (1895–1982), Welsh general surgeon.

Jackson's membrane: the right lateral region of the peritoneal reflection.

Jabez North Jackson (1868–1935), Professor of Anatomy and Surgery, Kansas City, USA.

Jacobson's nerve: the tympanic branch of the glossopharyngeal nerve.

Ludwig Levin Jacobson (1783–1843), Danish anatomist.

**Kammerer–Battle incision:** a vertical abdominal wall incision made along the lateral border of rectus abdominis (pararectus), which is retracted medially.


**Kawase approach:** anterior petrosectomy to access the posterior fossa.

Takeshi Kawase, Japanese skull base surgeon.

**Keen approach:** Keen categorized zygomatic fractures as those of the arch, the body or the sutural disjunction. He was the first to introduce an intraoral approach to the zygomatic arch, in which an incision is made in the gingivobuccal sulcus;

'-'s point: a point that lies 2.5–3 cm behind and 2.5–3 cm above the auricle; it may be used to access the trigone of the lateral ventricle.

William Williams Keen (1837–1932), pioneer neurosurgeon in Philadelphia, USA.

**Kehr's sign:** the occurrence of acute pain in the tip of the shoulder due to the presence of blood or other irritants in the peritoneal cavity when a person is lying down and the legs are elevated. Kehr's sign in the left shoulder is considered a classic symptom of a ruptured spleen. It may result from diaphragmatic or peridiaphragmatic lesions, renal calculi, splenic injury or ruptured ectopic pregnancy.

Johannes Otto Kehr (1862–1916), German surgeon and Professor of Surgery.

**Kelly clamp:**

Howard Atwood Kelly (1853–1943), American gynaecologist.

**Kerrison rongeur:** first designed by Kerrison.

Robert Masters Kerrison (1776–1847), English physician.

**Kiesselbach's plexus:** a site of haemorrhage on the nasal septum.

Wilhelm Kiesselbach (1839–1902), German ear, nose and throat surgeon.

**Klumpke's palsy:** a neuropathy involving the lower nerve roots of the brachial plexus.

Augusta Déjerine-Klumpke (1859–1927), American neurologist and neuroanatomist. She was the first woman to intern in a Parisian
hospital, and in 1914 she was elected the first female president of the French Society of Neurology.

**Koch, triangle of**: a triangular area in the wall of the right atrium that marks the site of the atrioventricular node.

*Walter Karl Koch (1880–?), physician and pathologist, Berlin and Freiburg, Germany.*

**Kocher, fourth thyroid vein of**: a vein that is occasionally found exiting the thyroid gland between the middle and inferior thyroid veins, and drains directly into the internal jugular vein;

– **incision**: an oblique left or right subcostal incision;

– **manoeuvre (Kocherization of the duodenum)**: mobilization of the duodenum during most operations involving the duodenum and the head of the pancreas. The steps involved are mobilization of the greater omentum; division of the hepatocolic region of peritoneal reflection towards the duodenum; division of the reflection lateral to the second part of the duodenum; medialization of the duodenum by separation from the underlying fascia; medialization of the head of the pancreas by separation from the underlying fascia;

– **'s lateral approach to the tarsus and ankle**;

– **'s point**: a burr-hole, usually on the right side, in the mid-pupillary line, 1 cm anterior to the coronal suture.

*Emil Theodor Kocher (1841–1917), Swiss Professor of Surgery, University of Bern, Switzerland, researcher and the first neurosurgeon in Switzerland; received the 1909 Nobel Prize in Physiology or Medicine for his work on the physiology, pathology and surgery of the thyroid gland.*


**Kohn, pores of**: microscopic communications between adjacent pulmonary alveoli (H.N. Kohn, Zur Histologie der indurierenden fibrinösen Pneumonie, Münchener Medizinische Wochenschrift. 40 (1893) 42–45).

*Hans Kohn (1866–1935), German physician.*

**Körner's septum**: Körner described a modification of the standard radical mastoidectomy that kept the bone lateral to the mastoid antrum intact. In this way, he prevented damage to the incus and maintained ossicular continuity; in so doing, he identified a dense
bony plate in the mastoid process that represents the persistence of the petrosquamous suture line, just lateral to the antrum that now bears his name (O. Korner, Das Septum petrosquamosum (mastoideum) und seine klinische Bedeutung, Arch. Ohren Nasen Kehlkopfheilk. 17 (1926) 137).

Otto Körner (1858–1935), German otorhinolaryngologist.

Kraissl's lines: the lines of greatest tension in the skin.

Cornelius Kraissl (1902–1999), plastic surgeon, New Jersey, USA.

Krause's end-bulbs (Krause's corpuscles): thermoreceptors sensing cold.

Wilhelm Krause (1833–1910), German anatomist.

Kuntz, nerve of: an inconstant intrathoracic ramus that joins the second intercostal nerve to the ventral ramus of the first thoracic nerve, proximal to the point where the latter gives a branch to the brachial plexus.

Albert Kuntz (1879–1957), American anatomist.

Kupffer cells: specialized macrophages located in the liver sinusoids.

Karl Wilhelm von Kupffer (1829–1902), Professor of Anatomy successively at Kiel, Königsberg and Munich, Germany.

Kussmaul's sign: distension of the jugular veins and paradoxical raised jugular venous pressure on inspiration.

Adolf Kussmaul (1822–1902), German physician.

Labat, classic approach of: draw a line from the greater trochanter to the posterior superior iliac spine (line A) and to the sacral hiatus (line B). Next draw a line (C) perpendicularly from the midpoint of line A to meet line B. The intersection of lines C and B is the needle insertion point for a sciatic nerve block.


Labbé, inferior anastomotic vein of: a vein that connects the superficial middle cerebral (Sylvian) vein and the transverse sinus.

Charles Labbé (1851–1889) French surgeon.

Ladd's bands: peritoneal attachments of the right colon crossing the duodenum.


Margaret Waugh Lambert, British pathologist.
Langer's lines: cleavage or crease lines in the skin produced by the arrangement of the subcutaneous fibrous tissues.  
*Karl Ritter von Edenberg Langer (1819–1887), Professor of Anatomy, Hungary, and then Vienna, Austria.*

Latarjet, nerves of: the anterior and posterior gastric divisions of the vagal trunks.  
*André Latarjet (1877–1947), French anatomist.*

Lazorthes, arcade of: radiculomedullary artery supplying the cervical enlargement of the spinal cord. It most commonly arises from the vertebral artery but may arise from deep cervical or supreme intercostal vessels, to form what is sometimes described as an ‘arterial basket’ around the conus medullaris (G. Lazorthes, A. Gouaze, J.O. Zadeh, et al., Arterial vascularization of the spinal cord: recent studies of the anastomotic substitution pathways, J. Neurosurg. 35 (1971) 253–262).

Le Fort I, II and III fractures: a system of classification of facial fractures.  
*René Le Fort (1869–1951), surgeon, Lille, France.*

Lembert suture: an inverting suture that ensures that serous surface is applied to serous surface when closing gut (A. Lembert, Nouveau procédé d'enterorraphie, Arch. Gen. Med. 13 (1827) 234).  
*Antoine Lembert (1802–1851), French physician.*

*Leonardo da Vinci (1452–1519), Renaissance polymath.*

Leydig cells: the interstitial testosterone-secreting cells of the testis.  
*Franz von Leydig (1821–1908), Professor of Histology successively at Würzburg, Tübingen and Bonn, Germany.*

*Irving Lichtenstein (1920–2000), American surgeon, UCLA, Los Angeles, USA.*

Lieutaud's trigone: the trigone of the bladder.  
*Joseph Lieutaud (1703–1780), French anatomist and pathologist.*

**Lindholm laryngoscope**: the original design, for use in adults, embodied the principle of the curved anaesthetic laryngoscope, positioned in front of the epiglottis. Three further instruments for paediatric use were developed (C.E. Lindholm, *A new endoscope for microlaryngoscopy*, Endoscopy. 11 (1979) 219).

*Carl-Eric Lindholm, Swedish laryngologist.*

**Lisfranc injuries** (*Lisfranc fracture-dislocations*): dislocations of the articulation of the tarsus with the metatarsal bases;

– *ligament*: an interosseous ligament between the second metatarsal and first cuneiform; its integrity is crucial to the stability of the Lisfranc joint, which is the articulation of the tarsus with the metatarsal bases.

*Jacques Lisfranc de Saint-Martin (1790–1847), Professor of Surgery, Paris, France.*

**Lissauer, fasciculus of** (*tract of Lissauer*): the ascending tract in the spinal cord.

*Heinrich Lissauer (1861–1891), neurologist, Breslau, Poland.*

**Lister's tubercle**: a prominence on the posterior surface of the distal radius, ulnar to the groove for the tendon of extensor pollicis longus.

*Lord Joseph Lister (1827–1912), English surgeon, successively Professor of Surgery at Glasgow, Edinburgh and King’s College London, UK. Pioneer of antiseptic surgery.*

**Little's area**: a site of haemorrhage on the nasal septum.

*James Laurence Little (1836–1885), Professor of Surgery, University of Vermont, USA.*

**Littre, glands of**: small periurethral mucous glands of the male urethra.

*Alexis Littre (1658–1726), French anatomist and surgeon.*

**Lockwood approach**: an infra-inguinal (low) approach to managing a femoral hernia without disrupting the inguinal canal.

– *suspenory ligament of*: the thickened area of contact between Tenon's capsule and the sheaths of inferior rectus and inferior oblique in the orbit.

*Charles Barrett Lockwood (1856–1914), British surgeon and anatomist, St Bartholomew’s Hospital, London, UK; one of the founders of the Anatomical Society.*

**Loré, triangle of**: an anatomical area low in the neck, at the thoracic inlet, where the recurrent laryngeal nerve (RLN) may be identified as a single trunk. The apex of the RLN triangle is located inferiorly at the thoracic inlet, its medial wall is the trachea, its lateral wall is the
retracted strap muscles, and its base is located superiorly at the lower edge of the inferior pole of the thyroid.


Lotheissen repair approach: a transinguinal approach for inguinal and femoral hernia repair, in which the transversalis fascia is opened and the components of the conjoint tendon are fixed to the pectineal ligament.

Georg Lotheissen (1868–1941), Austrian surgeon, Vienna, Austria.

Louis, angle of: the sternal angle, the angle formed on the anterior surface of the sternum at the junction of its body and manubrium.

Antoine Louis (1723–1792), Maître de Chirurgie and later Professor of Physiology, Royal College of Surgeons, Paris, France. Designed the prototype of the guillotine, which was originally nicknamed the ‘Louison’ or ‘Louisette’.

Ludwig's angina: a potentially life-threatening, rapidly expanding, diffuse inflammation of the submandibular and sublingual spaces, occurring most often in young adults with dental infections.

Wilhelm Friedrich von Ludwig (1790–1865), German surgeon and obstetrician.

Luschka, ducts of: small, gland-like, tubular structures in the wall of the gallbladder adjacent to the liver, especially in the part covered with peritoneum;

–, foramen of: the lateral aperture in the roof of the fourth cerebral ventricle;

–, joints of (uncovertebral joints of Luschka): small synovial joints on either side of the intervertebral cartilaginous joint in cervical vertebrae C3–7 (between the uncinate process of the inferior vertebral body and the bevelled lateral border of the superior body at each level).

Hubert von Luschka (1820–1875), Professor of Anatomy, Tübingen, Germany.

McBurney incision: an incision placed perpendicular to McBurney's point (one-third of the distance from the right anterior superior iliac spine to the umbilicus);

–'s point: the reputed site of maximal tenderness in appendicitis.

Charles McBurney (1845–1913), American Professor of Surgery, Roosevelt Hospital, New York, USA.

McCall culdoplasty: typically performed at the end of a vaginal hysterectomy to prevent vaginal vault prolapse (M.L. McCall, Posterior


**MacEwan's triangle**: the acknowledged anatomical landmark of the mastoid antrum. MacEwan studied under Lister. His contribution to otology was to place the treatment of intracranial complications of middle ear suppuration on a proper surgical basis. He wrote *Pyogenic Diseases of the Brain and Spinal Cord* in 1893. After his death, the Sir William MacEwan Lecture was established and a MacEwan medal and prize are awarded annually.

Sir William MacEwan (1848–1924), house physician and surgeon at the Royal Infirmary, Glasgow, UK, and later appointed to the staff.

**Mackenrodt's ligament**: the transverse cervical (or cardinal) ligament of the uterus.

Alwin Mackenrodt (1859–1925), Professor of Gynaecology, Berlin, Germany.

**McKeown oesophagogastrectomy**: a tri-incisional oesophagectomy.

**Magendie, foramen of**: the median aperture in the roof of the fourth ventricle.

François Magendie (1783–1855), physician to the Hôtel Dieu, Paris, France.

**Makuuchi incision**: a J-shaped incision that exposes the liver and right-sided retroperitoneal organs (M. Makuuchi, S. Kawasaki, Surgical management of malignant liver disease. In: N. Lygidakis, M. Makuuchi (eds), Pitfalls and Complications in the Diagnosis and Management of Hepatobiliary and Pancreatic Diseases, Stuttgart, Georg Thieme, 1993, pp. 86–88);

-s ligament: the retrocaval ligament.

Masatoshi Makuuchi (1946–), Japanese surgeon.

**Marfan's syndrome**: an autosomal genetic disorder of the connective tissue characterized by a long body and extended limbs and fingers,
often associated with cardiovascular abnormalities such as dissecting aortic aneurysms and valve defects, as well as subluxated ocular lenses.

Antoine Bernard-Jean Marfan (1858–1942), Professor of Infantile Hygiene, Paediatric Clinic, University of Paris, France.

Marshall, ligament of (posterolateral ridge, coumadin ridge): the ridge between the left atrial appendage and left upper pulmonary vein, which is an infolding of the serous pericardium.


Mattox manœuvre: mobilization of the descending colon to the midline to expose the abdominal aorta.

Kenneth Mattox (1938–), American surgeon.


Mayfield head clamp:


Mayo approach: a ligament-sparing approach from the proximal radius to the triquetrum or just beyond, and then distal radial towards the trapezoid, creating a V-shaped flap with the base to the radial side;

– scissors: scissors developed by Mayo clinic surgeons.

– vein: the prepyloric vein.

Charles (1865–1939) and William (1861–1939) Mayo, American surgeons who, with their father, William Worrall Mayo, founded the Mayo Clinic in Rochester, Minnesota, USA.

Meckel's cartilage: the cartilage of the first branchial arch;

– cave: a cerebrospinal fluid-containing arachnoidal pouch protruding from the posterior cranial fossa. Located near the apex of the petrous part of the temporal bone, it houses the trigeminal ganglion and extends forwards, rather like an open-ended, three-fingered glove, enveloping the rootlets of the trigeminal nerve, the trigeminal ganglion and the ophthalmic, maxillary and mandibular divisions of the trigeminal nerve;

– diverticulum: the remains of the vitellointestinal duct.

Johann Meckel (1781–1833), Professor of Anatomy, Halle, Germany.

His grandfather was Professor of Anatomy in Berlin and described the pterygopalatine ganglion and the dural sac, which contains the ganglion of the trigeminal nerve. His father was also Professor of
Anatomy in Halle.

**Meissner's corpuscles**: tactile nerve endings in skin;
- **plexus**: the submucosal autonomic plexus of the intestine.

*George Meissner (1829–1905), Professor of Anatomy and Physiology, Basle, Switzerland; Zoology and Physiology, Freiburg, Germany; and Physiology, Göttingen, Germany.*

**Merkel cells (Merkel corpuscles)**: sensory nerve endings in the skin;
- **disc**: a slowly adapting type I receptor, which lies close to the surface of glabrous skin and is sensitive to sustained pressure.

*Friedrich Sigmund Merkel (1845–1919), Professor of Anatomy successively at Rostock, then Göttingen, Germany.*

**Metzenbaum scissors**: Myron Firth Metzenbaum (1876–1944), American surgeon.

**Meyer's loop**: the fibres of the geniculocalcarine tract that loop forwards in the temporal lobe.

*Adolf Meyer (1866–1950), Swiss-born Professor of Psychiatry, Johns Hopkins School of Medicine, Baltimore, USA.*

**Milligan–Morgan technique**: dissection of a haemorrhoid off the underlying anal sphincter complex and ligation of the vascular pedicle (E. Milligan, C. Morgan, Surgical anatomy of the anal canal and operative treatment of hemorrhoids, Lancet. 2 (1937) 1119–1124).


*Sir Terence Millin (1903–1980), Irish urologist.*

**Minor's syndrome**: in 1995, while at Johns Hopkins University, Minor discovered the superior semicircular canal dehiscence syndrome, a debilitating disorder characterized by sound- or pressure-induced dizziness. With colleagues, he published a description of the clinical manifestations of the syndrome, relating its cause to a dehiscence in the bone covering the superior semicircular canal, and surgical methods to resurface the canal and alleviate the patient's symptoms.

*Lloyd Brookes Minor, American surgeon and currently Carl and Elizabeth Naumann Dean of Stanford University School of Medicine, Stanford, USA. Formerly Provost and Senior Vice-President for Academic Affairs, Johns Hopkins University, Baltimore, USA.*
Mitchell’s trimmer: an osteotrimmer used in a variety of dental fields, such as oral surgery, to aid in raising a mucoperiosteal flap and debriding tissue.

*William Mitchell (1854–1914), dental surgeon who was born in America but worked in England.*

Moebius’ syndrome: a rare congenital neurological disorder characterized by weakness or paralysis of multiple cranial nerves (most often the abducens and facial nerves).

*Paul Julius Möbius (1853–1907), German neurologist.*

Monro, foramen of: the foramen between the lateral and third ventricles of the brain.

*Alexander Monro (1733–1817), Professor of Anatomy, Edinburgh, UK; one of a succession of three Alexander Monros who were appointed to the Chair of Anatomy, University of Edinburgh, over a period spanning 126 years.*

Montgomery, glands of (tubercles of Montgomery): sebaceous glands situated in the areola of the breast (previously described by Morgagni).

*William Montgomery (1797–1859), Professor of Midwifery, Dublin, Ireland.*

Morgagni, columns of: the columns of the anal canal;

– hernia: a congenital diaphragmatic hernia between the sternal and costal attachments of the diaphragm;

–, hydatid of (appendix testis, appendices vesiculosae epoophori): a cyst-like remnant of the Müllerian duct attached to a testis;

–, lacunae of: small depressions or recesses on the mucous membrane of the male urethra;

–, sinus of: a defect in the pharyngobasilar fascia through which the pharyngotympanic (Eustachian) tube and levator veli palatini muscle gain access to the nasopharynx;

–, tubercles of (glands of Montgomery, tubercles of Montgomery): sebaceous glands situated in the areola of the breast.

*Giovanni Battista Morgagni (1682–1771), Professor of Anatomy, Padua, Italy, for 59 years. Described as the founder of modern morbid anatomy.*

Müllerian ducts: paramesonephric ducts. Müller described these in his text *Bildungsgeschichte der Genitalien* in 1830.

*Johannes Peter Müller (1801–1858), German physiologist.*
Müller's muscle: Müller discovered rhodopsin in 1851, and in 1858 published descriptions of the superior and inferior muscles of the tarsal plate, the muscle that bridges the inferior orbital fissure, and the innermost fibres of the circular portion of the ciliary muscle.

Heinrich Müller (1820–1864), German anatomist.

Nashold technique: Nashold et al first described the procedure of intraspinal coagulation of the dorsal root entry zones of avulsed roots in 1972.

Nélaton's line (Roser–Nélaton line): a line connecting the anterior superior iliac spine to the ischial tuberosity passing across the summit of the greater trochanter.

Auguste Nélaton (1807–1873), French physician and surgeon.

Nissen fundoplication: a 360° fundoplication.

Rudolf Nissen (1896–1981), German surgeon.

Nuck, canal of: a diverticulum of the peritoneal membrane extending into the inguinal canal, accompanying the round ligament in the female, or the testis in its descent into the scrotum in the male; usually completely obliterated in the female.

Anton Nuck (1650–1692), Dutch anatomist.

Nuss procedure: minimally invasive procedure, invented in 1987 by Nuss, for treating pectus excavatum.

Donald Nuss, American surgeon.

Oddi, sphincter of: the sphincter at the termination of the common bile duct. The sphincter had already been described by Glisson in the seventeenth century.

Ruggero Oddi (1845–1906), surgeon, Rome, Italy.

Ollier's lateral approach to the tarsus:

Louis Xavier Édouard Léopold Ollier (1830–1900), French surgeon.

Onodi cell: a sphenoethmoidal cell formed by lateral and posterior pneumatization of the most posterior ethmoidal cells over the sphenoidal sinus.

Adolf Onodi (1857–1920), Hungarian laryngologist.

Onuf’s nucleus: a discrete group of motoneurones in the sacral spinal cord that innervate the vesicorectal sphincters and are involved in micturition, defaecation and muscular contraction during orgasm.

Bronislaw Onuf-Onufrowicz (1863–1928), Russian neurologist.

Pacinian corpuscle: a pressure-sensitive mechanoreceptor;

Filippo Pacini (1812–1883), Professor of Anatomy and Physiology,
successively at Pisa and then Florence, Italy.

**Pancoast tumour**: an apical carcinoma of the lung involving C8 and T1 nerves, the cervical sympathetic chain and upper ribs.

*Henry Pancoast (1875–1939), Professor of Radiology, University of Pennsylvania, USA.*

**Paneth cells**: bacteriocidal lysozyme-secreting cells.

*Joseph Paneth (1857–1890), Professor of Physiology, first at Breslau, Poland, then Vienna, Austria.*

**Parinaud's syndrome (dorsal midbrain syndrome)**: a supranuclear vertical gaze disturbance caused by compression of the tectal plate (e.g. by a pinealoma), which results in vertical gaze palsy, convergence–retraction nystagmus and light–near dissociation.

*Henri Parinaud (1844–1905), French ophthalmologist and neurologist.*

**Parkinson's disease (Parkinson's syndrome)**: a syndrome characterized by resting tremor, rigidity, expressionless face and so on, generally caused by degeneration of dopaminergic neurones in the substantia nigra and usually occurring in late life.

*James Parkinson (1755–1824), English physician.*

**Parkinson's triangle**: Parkinson described a triangle in the lateral wall of the cavernous sinus limited medially by the lateral aspect of the trochlear nerve, laterally by the medial aspect of the ophthalmic division of the trigeminal nerve, and posteriorly by the dural edge between the entry points of these two nerves (D. Parkinson, A surgical approach to the cavernous portion of the carotid artery. Anatomical studies and case report, J. Neurosurg. 23 (1965) 474–483).

*Dwight Parkinson (1916–2005), American neurosurgeon.*

**Penrose drain**: a soft, flat, flexible rubber tube used to drain fluid from a surgical site.

*Charles Bingham Penrose (1862–1925), American gynaecologist.*

**Percheron, artery of**: an anatomical variant in which the paramedian thalamus bilaterally is supplied by a single P1 posterior cerebral artery perforator.

*Gérard Percheron (1930–2011), French physician and researcher.*

**Petit's triangle (lumbar triangle of Petit)**: the inferior lumbar triangle bounded inferiorly by the iliac crest, anteriorly by external oblique and posteriorly by latissimus dorsi.

*Jean Louis Petit (1674–1750), French surgeon and anatomist.*
Petren, paracholedochal veins of: marginal veins travelling parallel to the bile duct, which form a plexus with the gastric and pancreaticoduodenal veins.

   T. Petren, German anatomist.

Peyronie's disease: a connective tissue disorder involving the growth of fibrous plaques in the tunica albuginea of the penis, resulting in penile curvature.

   François Gigot de la Peyronie (1678–1747), French surgeon.

Pfannenstiel incision: a transverse curved abdominal incision with downward convexity, above the symphysis pubis.

   Hermann Johann Pfannenstiel/Herman Johannes Pfannenstiel (1862–1909), German gynaecologist, University of Giessen and University of Kiel, Germany.

Pirogoff's triangle: a triangle formed by the intermediate tendon of digastric, the posterior border of mylohyoid and the hypoglossal nerve. Pirogoff is credited with introducing the teaching of applied topographical anatomy in Russia, and was one of the first to use ether in Europe.

   Nikolai Ivanovich Pirogoff (Pirogov) (1810–1881), Russian anatomist and surgeon.

Pitanguy line: a line starting from a point 0.5 cm below the tragus in the direction of the eyebrow and passing 1.5 cm above the lateral extremity of the eyebrow, used to estimate the path of the temporo-frontal branch of the facial nerve in the soft tissue of the face (I. Pitanguy, A.S. Ramos, The frontal branch of the facial nerve: the importance of its variations in face lifting, Plast. Reconstr. Surg. 38 (1966) 352–356).

Poland's syndrome: ipsilateral breast and nipple hypoplasia and/or aplasia, deficiency of subcutaneous fat and axillary hair, absence of the sternal head of pectoralis major, hypoplasia of the rib cage, and hypoplasia of the upper extremity, including cutaneous syndactyly.

   Sir Alfred Poland (1822–1872), English surgeon.

Poupart's ligament: at the anterior superior iliac spine (ASIS), the medial half of the external oblique aponeurosis rolls on itself, between the ASIS and the pubic tubercle, to form the inguinal ligament.

   François Poupart (1616–1709), French physician, anatomist and entomologist.

Pringle manœuvre: temporary compression or clamping of the porta
hepatis to reduce arterial and portal venous blood loss.

James Hogarth Pringle (1863–1941), born in Australia but practised as a surgeon in Scotland, UK.

**Prussak's space**: a subcomponent of the lateral epitympanic space.

Alexander Prussak (1839–1897), Russian otologist.

**Puestow procedure**: pancreaticojejunostomy.


**Rampley forceps**:

Josiah Rampley (1845–1891), Surgical Beadle, known as the Grand Old Man of the London Hospital.

**Ramsay Hunt syndrome**: herpes zoster involvement of the geniculate ganglion associated with facial paresis, hyperacusis, unilateral loss of taste, decrease in lacrimation and salivation, and otalgia.

James Ramsay Hunt (1874–1937), Professor of Neurology, Columbia University, New York, USA.


Mark Michael Ravitch (1910–89), American paediatric surgeon.

**Raynaud's disease**: idiopathic paroxysmal bilateral cyanosis of the digits due to arterial and arteriolar contraction, caused by cold or emotion.

Maurice Raynaud (1834–1881), French physician.

**Reinke's oedema**: chronic laryngitis with swelling of the membranous part of the vocal cords;

– **space**: a potential space between the vocal ligament and the overlying mucosa.

Friedrich Berthold Reinke (1862–1919), French anatomist.

**Retzius, space of (cave of Retzius)**: the retropubic space, the avascular anterior space between the bladder and pubic symphysis;

– **veins of (retroperitoneal venous plexus of Retzius)**: porto-caval anastomoses formed from veins in the walls of the retroperitoneal viscera, creating communications between the mesenteric veins and the inferior vena cava.

Andreas Adolf Retzius (1796–1860), Professor of Anatomy, Karolinska Institute, Stockholm, Sweden.

**Rex, space of**: the space or recess between the round ligament and the liver parenchyma between segments 3 and 4.

Hugo Rex (1861–1936), Czech anatomist.

**Rexed's laminae**: subdivisions of cells of spinal cord grey matter.
Bror Rexed (1914–?), Swedish neuroanatomist.

Rinne's test: a ‘tuning fork test’ designed to assess conductive hearing loss by comparing the sound transmission of bone conduction and air conduction.

Heinrich Adolf Rinne (1819–1868), German otologist.

Riolan, arc of: the anastomosis between the middle and left colic arteries.

Jean Riolan (Secondus) (1577–1657), Professor of Anatomy and Botany, Paris, France.

Rives–Stoppa technique: a technique that involves placement of a retropubic sublay mesh to repair large incisional midline abdominal wall hernias.


Rivinus, duct of: a series of small ducts that drain the sublingual gland and fuse to form Bartholin's duct.

Augustus Quirinus Rivinus (1652–1723), a German physician and botanist.

Rockey–Davis incision: a transverse incision through McBurney's point.

Alpha Eugene Rockey (1857–1927), American military surgeon, Oregon, USA. Gwilym George Davis (1857–1918), American Professor of Surgery, University of Pennsylvania, Philadelphia, USA.

Rolando, sulcus of: the central fissure of the cerebral hemisphere.

Luigi Rolando (1773–1831), Italian anatomist; worked in Turin and Florence, Italy.


David B. Roos, American surgeon.

Rosenmüller, fossa of: the pharyngeal recess.

Johann Christian Rosenmüller (1779–1820), Professor of Anatomy and Surgery, Leipzig, Germany.

Rosenthal, basal veins of: formed by the convergence of the deep Sylvian and anterior cerebral veins; they end by converging with the internal cerebral or great vein in the quadrigeminal cistern. The vein courses from the premesencephalic cistern, through the ambient cistern, and terminates in the quadrigeminal cistern.
Friedrich Christian Rosenthal (1780–1829) anatomist, Greifswald, Germany.

**Ross procedures:**
Donald Ross (1922–2014), South African-born British thoracic surgeon. He developed the Guy’s–Ross heart lung bypass machine, undertook the first homograft of an aortic valve (in 1962) and led the team that carried out the first heart transplantation in the UK in 1968.

**Rotter’s node:** the lymph node between pectoralis major and minor.
Josef Rotter (1857–1924), German surgeon.

**Rouvière, nodes of:** the lateral retropharyngeal lymph nodes;
--, *sulcus of:* a cleft in the liver parenchyma to the right of the liver hilum, containing the right posterior portal pedicle.
Henri Rouvière (1876–1952), French anatomist and embryologist. Professor of Anatomy and Embryology, University of Paris, France.

**Roux-en-Y gastrojejunostomy:** gastrojejunostomy with jejunojunostomy.
-- *procedure:* hepaticojejunostomy/choledochoduodenostomy.
César Roux (1857–1934), Swiss surgeon.

**Ruffini endings (Ruffini bodies, Ruffini corpuscles):** sensory nerve endings, originally described in the skin of the fingers.
Angelo Ruffini (1887–1929), Professor of Histology, Bologna, Italy.

**Rutherford Morrison incision:** a craniolateral extension of McBurney’s incision.
James Rutherford Morrison (1853–1939), British Professor of Surgery, University of Durham, UK.

**Rutkow and Robbins repair:** a mesh plug and patch method for repair of inguinal hernias.
Ira Rutkow (1948–), American surgeon, Johns Hopkins University, Baltimore, USA.

**Saint, epicholedochal veins of:** a fine network of venous drainage on the surface of the bile duct.
James H. Saint, American surgeon.

**Santorini, duct of:** the accessory pancreatic duct;
--, *fissures of:* two fissures in the anterior cartilaginous wall of the external acoustic meatus;
--, *plexus of:* the retropubic venous plexus giving rise to the pudendal
vein.

**Giovanni Domenico Santorini (1681–1737), Professor of Medicine and Anatomy, Venice, Italy.**

**Sappey's line:** a line running around the trunk at approximately the level of the umbilicus, indicating the plane in which truncal lymph drains cephalad to the axilla and caudally into the groin and pelvis; described by Sappey in 1874. (M.P.C. Sappey, Anatomie, physiologie, pathologie des vaisseaux lymphatiques considérés chez l'homme et les vertèbres, Paris, A. Delahaye et E. Lacrosnier, 1874);

**veins of:** small tributaries of the peripheral left portal vein that drain the diaphragm and falciform ligament.

**Marie Philibert Constant Sappey (1810–1896), French anatomist, considered one of the most prominent French anatomists of the 19th century.**

**Scarpa's fascia:** the fibrous layer of the superficial fascia of the lower abdomen;

**'s triangle:** the femoral triangle.

**Antonio Scarpa (1752–1832), Professor of Anatomy, Padua, Italy.**

**Seldinger technique:** the most common method used to place a central intravenous line percutaneously.

**Sven Ivar Seldinger (1921–1998), Swedish radiologist.**

**Senn catspaw retractor:** a retractor with a single right-angled blade at one end and a curled three-pronged claw at the other.

**Nicholas Senn (1844–1908), American surgeon.**

**Sertoli cells:** the supporting cells of the testicular tubules.

**Enrico Sertoli (1842–1910), Professor of Experimental Physiology, Milan, Italy.**

**Shouldice repair:** four-layer tissue repair of an inguinal hernia.

**Earle Shouldice (1890–1965), Canadian surgeon, Thornhill, Canada.**

**Shrapnell's membrane:** the flaccid portion of the tympanic membrane of the ear (H.J. Shrapnell, On the form and structure of the membrana tympani, Lond. Med. Gaz. 10 (1832) 120–124).

**Henry Jones Shrapnell (1792–1834), British anatomist.**

**Sibson's fascia:** the suprapleural membrane.

**Francis Sibson (1814–1876), English physician and anatomist.**

**Siewert classification:** a system that separates tumours of the gastro-oesophageal junction into three types based on the relationship between the tumour origin and the gastro-oesophageal junction,

Jörg Rüdiger Siewert (1940–), German surgeon.

**Simpson’s modified rule**: the rule that states that the volume of a geometrical figure can be calculated from the sum of the volumes of smaller figures of similar shape. The most commonly used two-dimensional measurement for volume measurements is the biplane method of discs (modified Simpson's rule).

Thomas Simpson (1710–1761), British mathematician and inventor.

**Sims’ position**: a position in which the patient lies on their left side with their left thigh slightly flexed and their right thigh acutely flexed on the abdomen;

– **speculum**: a U-shaped instrument used to examine the vaginal walls, particularly for evidence of pelvic organ prolapse.

James Marion Sims (1813–1883), American physician, often referred to as the father of modern gynaecology.

**Sindou technique**: DREZ lesioning for pain.

M. Sindou, French neurosurgeon.

**Sistrunk procedure**: the procedure for removal of a thyroglossal duct cyst. It involves resection of the entire cyst, the central portion of the hyoid bone, and the thyroglossal duct tract that terminates at the foramen caecum. Several modifications of the procedure have been described.

Walter Ellis Sistrunk (1880–1933), American surgeon; originally described this operation in 1920.

**Skene’s glands**: the paraurethral glands.

Alexander Johnston Chalmers Skene (1838–1900), gynaecologist, New York, USA.


**Spence, tail of**: the projection of mammary glandular tissue extending into the axillary region, sometimes forming a visible mass that may enlarge premenstrually or during lactation.

James Spence (1812–1882), Scottish surgeon.

**Spigelian hernia**: a protrusion of preperitoneal fat, peritoneal sac or organ(s) through a congenital or acquired slit-like defect in the Spigelian aponeurosis of the anterior abdominal wall adjacent to the
semilunar line. Named after Adriaan van der Spieghel, who described the linea semilunaris in 1645, the hernia was first described by Josef Klinkosch in 1764 (P.N. Skandalakis, O. Zoras, J.E. Skandalakis, P. Mirilas, Spigelian hernia: surgical anatomy, embryology, and technique of repair, Am. Surg. 72 (2006) 42–48).

– **lobe**: the caudate lobe of the liver.

  *Adriaan van den Spiegel (1578–1625), Flemish anatomist and botanist, University of Padua, Italy; born in Brussels. His name is also written as Spieghel, Spigel, Adrianus Spigelius, Spiegelius and Adriano Spigeli.*


  *John David Spillane (1909–1985), Maurice John Parsonage (1915–2008) and John W. Aldren Turner (1911–1980), neurologists working in the UK.*

**Spurling's test** *(Spurling's manœuvre, neck compression test)*: a provocative test with high sensitivity but relatively low specificity, used to assess cervical nerve root impingement.

  *Roy Glenwood Spurling (1894–1968), American neurosurgeon.*

**Stamm's gastrostomy**: a simple gastrostomy with concentric purse-string sutures.

  *Marin Stamm (1847–1918), American surgeon.*

**Starzle's node**: the lymph node that overlies the common hepatic artery.

  *Thomas Starzle (1926–2017), American surgeon.*

**Stensen's duct**: the excretory duct of the parotid gland (N. Stensen, Observationes anatomicae, quibus varia oris, oculorum & narium vas describuntur novique salivae, lacrymarum & muci fontes deteguntur, Lugduni Batavorum (Leiden), J. Chouët, 1662).

  *Neils Stensen (1638–1686), Danish anatomist, natural scientist and theologian.*

**Struthers, arcade of**: a thickening of the anteromedial aspect of the medial intermuscular septum, forming a myofibrous sheath around the ulnar nerve after it passes from the anterior to the posterior compartment of the arm;

  – **ligament of** a ligamentous or muscular structure (often an extension of
the humeral head of pronator teres), passing between the medial epicondyle and supracondylar processes of the humerus in approximately 1% of individuals.

Sir John Struthers (1823–1899), Scottish anatomist, professor and surgeon.

Sudek's critical point: the point where the lowest sigmoid arteries anastomose with the superior rectal artery is a site where ischaemia may occur as a result of interruption of the marginal artery (P. Sudeck, Ober die Gefässversorgung des Mastdarmes in Hinsicht auf die operative Gangrän, München Med. Wschr. 54 (1907) 1314–1317).

Sylvian fissure: the lateral cerebral sulcus;
Sylvius, aqueduct of: the midbrain channel connecting the third and fourth cerebral ventricles
Sylvian vein: superficial middle cerebral vein;
Sylvian cistern: insular cistern the subarachnoid space associated with the lateral cerebral sulcus (Sylvian fissure). It contains the M1 segment of the middle cerebral artery, the origin of the lenticulostriate arteries, and proximal parts of the middle cerebral artery

François de la Boe Sylvius (1614–1672), physician and scientist (chemist, physiologist and anatomist) and Professor of Medicine, Leiden, Netherlands. He founded the Iatrochemical School of Medicine.

Tenon's capsule (fascia bulbi, bulbar sheath): a thin fascial sheath that envelopes the eyeball from the optic nerve to the corneoscleral junction, separating it from the orbital fat and forming a socket for the eyeball. Sub-Tenon's anaesthesia is delivered by injection of local anaesthetics via a cannula into the space between the fascia bulbi and the sclera. Tenon described the eponymous capsule in 1805–6.

Jacques-René Tenon (1724–1816), French surgeon and pathologist.

Thebesian valve: the valve guarding the orifice of the coronary sinus;
– veins: the small cardiac veins (venae cordis minimae).

Adam Christian Thebesius (1686–1732), anatomist and pathologist, Leiden, Netherlands.

Tinel's sign: the fact that lightly tapping (percussing) over a nerve trunk that has been damaged or is regenerating following trauma causes a sensation of tingling and pain in its distribution up to the site of regeneration. In closed injuries, percussion of the skin over a nerve in which axons have been ruptured evokes sensations that are usually
described as a wave or surge of pins and needles into the cutaneous
distribution of the nerve.

*Jules Tinel (1879–1952), French neurologist.*

**Todaro, tendon of:** a variable tendinous strand attached to the valvular
fold at the termination of the inferior vena cava. It forms the superior
border of the triangle of Koch.

*Francesco Todaro (1839–1918), Professor of Anatomy, Messina, and
then Rome, Italy.*

**Toldt's fascia (fusion fascia of Toldt, white line of Toldt):** an avascular
fascial plane posterior to the ascending or descending colon and
mesocolon, kidney and tail of the pancreas;

**Toldt's fascia:** the fascia located between organs and the posterior
abdominal wall, wherever both are contiguous.

–, **white line of:** the faint white line sometimes created when Toldt's
fascia meets the peritoneal mesothelium. It can arise in several
settings and is most commonly seen at the right and left lateral
peritoneal reflections where the fascia coalesces with the reflection. It
has been used to guide division of the reflection and commencement
of intestinal–mesenteric mobilization. It should not be relied on to do
so because it is not a constant finding.

*Carl Toldt (1840–1920), Austrian anatomist.*

**Toupet fundoplication:** a 270° fundoplication.

*André Toupet (1915–), French surgeon.*

**Tourette's syndrome:** a disorder characterized by compulsive vocal and
motor tics.

*Georges Albert Édouard Brutus Gilles de la Tourette (1857–1904),
French physician.*

**Traube's space:** a crescent-shaped space bounded by the lower edge of
the left lung, the anterior border of the spleen, the left costal margin,
and the inferior margin of the left lobe of the liver. The surface
anatomy of this space is superiorly the left sixth rib, laterally the mid-
axillary line, and inferiorly the left costal margin. Dullness to
percussion over Traube's space may indicate splenomegaly, although
this can also be a normal finding after a meal or may indicate left
pleural effusion. Assessing dullness to percussion may be more
difficult in obese patients. Despite its name, the space was first
described by one of Traube's pupils in 1868.

*Ludwig Traube (1818–1876), German physician and co-founder of*
experimental pathology in Germany.

**Travers retractor**: a self-retaining retractor.

*Benjamin Travers (1783–1858), British surgeon.*

**Treacher Collins syndrome**: mandibulofacial dysostosis.

*Edward Treacher Collins (1862–1932), English surgeon.*

**Treitz, fusion fascia of**: the fascia behind the head of the pancreas;

– **ligament of**: a fold of peritoneum over the suspensory muscle of the duodenum;

– **muscle of**: the suspensory muscle of the duodenum (musculus suspensorius duodenii).

*Václav (Wenzel) Treitz (1819–1872), Professor of Pathological Anatomy, Jagellonian University, Prague, Czech Republic.*

**Trendelenburg gait**: a dipping gait due to hip abductor dysfunction;

– **position**: placement of the patient supine on the operating table, with the head tilted down, allowing the patient's feet and legs to remain above the level of the heart;

– **'s sign**: if, in assessing hip stability, the pelvis on the unsupported side drops down when a person is standing on the leg on the affected side (stance side).

*Friedrich Trendelenburg (1844–1924), Professor of Surgery successively at Rostock, Bonn and Leipzig, Germany.*

**Treves, bloodless fold of**: a peritoneal fold adjacent to the mesoappendix.

*Sir Frederick Treves (1853–1923), surgeon, London Hospital, UK.
Drained the appendicular abscess of King Edward VII in 1902.*

**Troisier's sign**: the clinical finding of a hard, enlarged left supraclavicular node (Virchow's node).

*Charles-Émile Troisier (1844–1919), French pathologist.*

**Trolard, superior anastomotic vein of**: the vein that connects the superior sagittal sinus and the superficial middle cerebral vein (of Sylvius).

*Jean Baptiste Paulin Trolard (1842–1910), French anatomist.*

**Tuffier's line**: a line that may be drawn between the highest points of the iliac crests on which the spine of L4 usually lies in adults.

*Théodore Tuffier (1857–1929), French surgeon.*

**Tullio phenomenon**: sound-induced vertigo, dizziness, nausea and/or nystagmus, first described in 1929 by Professor Tullio. He drilled minute holes in the semicircular canals of experimental animals and
noted that it caused them balance problems when exposed to sound. 
The Tullio phenomenon is a feature of Minor’s syndrome.

Pietro Tullio (1881–1941), Italian biologist.

Valsalva, aortic sinuses of: the aortic sinuses;
– manoeuvre: any forced expiratory effort (‘strain’) against a closed
airway, whether at the nose and mouth or at the glottis.

Antonio Maria Valsalva (1666–1723), Professor of Anatomy,
Bologna, Italy.

Vater, ampulla of (papilla of Vater): the ampulla at the junction of the
common hepatic and pancreatic ducts.

Abraham Vater (1684–1751), Professor of Anatomy, Botany,
Pathology and Therapeutics, Wittenburg, Germany.

Velpeau, tunnel of: quadrilateral tunnel.

Alfred Armand Louis Marie Velpeau (1795–1867), French surgeon
and anatomist.

Venus, dimples of: when present, skin dimples overlying the impalpable
posterior superior iliac spines.

Venus was the goddess of love and beauty in Roman mythology.

Veress needle: a spring-loaded needle used to create a
pneumoperitoneum in laparoscopic surgery (J. Veress, Neues
Instument zur Ausführung von Brust- oder Bauch-punktionen und
Pneumothoraxbehandlung, Deutsche Med. Wochenshr. 41 (1938) 1480–
1481).

Jénos Veres/Veress (1903–1979), Hungarian chest physician.

Vesalius, foramen of: the sphenoidal emissary foramen;
–, vein of: the communicating vein between the cavernous sinus and
pterygoid plexus.

Andreas Vesalius (1514–1564), Professor of Anatomy, Padua, Italy.
His great work De Humani Corporis Fabrica (On the Fabric of
the Human Body), published in 1543, remains one of the most
influential works of human anatomy.

Vidian artery: the artery of the Vidian canal is a branch of either the
distal maxillary artery or the petrous portion of the internal carotid
artery;
– canal: the pterygoid canal;
– nerve: the nerve of the pterygoid canal.

Guido Guidi Vidius (1500–1561), Professor of Medicine, Pisa, Italy.
His findings were published posthumously as De Anatome
Corporis Humani.

**Virchow's node**: Virchow described the eponymous node associated with carcinoma of the stomach in 1848.

*Rudolf Virchow (1821–1902), German physician, pathologist and polymath.*

**von Brunn's cell nests**: epithelial cell masses in the male urethra.

*Albert von Brunn (1849–1895), German anatomist.*

**von Meyenburg complexes**: multiple biliary hamartomas.

*Hans von Meyenburg (1887–1971), Swiss pathologist.*

**von Sölder phenomenon**: corneomandibular reflex or jaw-winking phenomenon (F. von Sölder, Der Corneomandibularreflex, Neurol. Zbl. 21 (1902) 111).

*Friedrich von Sölder (1867–1943), Austrian physician*


– **ring**: an incomplete ring of lymphoid tissue, situated in the naso-oropharynx.

*Heinrich Wilhelm Gottfried von Waldeyer-Hartz (1836–1921), Professor of Pathology at Breslau, Poland, and then Berlin, Germany.*

**Weber's syndrome**: a midbrain stroke syndrome involving the cerebral peduncle and the ipsilateral fascicles of the oculomotor nerve.

*Hermann Weber (1823–1918), German-born English physician.*

**Weber test**: a ‘tuning fork test’ that differentiates between sensorineural and conductive deafness.

*Ernst Heinrich Weber (1795–1878), German physiologist and psychologist, best known for his work on sensory responses to weight, temperature and pressure.*

**Weigert–Meyer rule**: the rule that, when complete, duplicated ureters insert separately into the bladder. The upper-pole ureter is the ectopic ureter and its orifice inserts inferomedially in the bladder; the lower-pole ureter is the normal ureter (C. Weigert, Über einige Bildungsfehler der Ureteren, Virchows Archiv für pathologische Anatomie und Physiologie und für klinische Medizin. 70 (1877) 490; R. Meyer, Zur Anatomie und Entwicklungsgeschichte der Ureter verdoppelung, Virchows Archiv für pathologische Anatomie
und Physiologie und für klinische Medizin. 87 (1907) 408).

**Wernicke's area**: the motor speech area in the superior temporal lobe of the cerebral cortex.

*Karl Wernicke (1848–1904), psychiatrist, Breslau, Poland, and then Halle, Germany.*

**Wharton's duct**: main duct of the submandibular salivary gland;
– **jelly**: a homogenous intercellular substance of the umbilical cord; gives a reaction for mucin and contains thin collagenous fibres that increase in number with fetal age.

*Thomas Wharton (1614–1673), physician and anatomist, St Thomas’s Hospital, London, UK. Remained on duty there during the Great Plague of 1665.*

**Whipple procedure**: pancreaticoduodenectomy.

*Allen Oldfather Whipple (1881–1963), American surgeon.*

**Whitnall, transverse ligament of**: a ligament that originates from the trochlea and inserts into the lateral orbital wall, approximately 10 mm above Whitnall's tubercle;
– **'s tubercle**: a tubercle on the orbital surface of the zygomatic bone.

*Samuel Ernest Whitnall (1876–1950), Professor of Anatomy, successively at McGill University, Montreal, Canada, and Bristol, UK.*

**Willis, circle of**: the arterial anastomosis at the base of the brain.

*Thomas Willis (1621–1675), physician to King James II; practised first in Oxford, then London, UK.*

**Wiltse's interval**: the space between longissimus and multifidus, located a few centimetres lateral of the midline, used to access the posterolateral lumbar spine with minimal muscle damage.

*Leon L. Wiltse (1913–2005), American orthopaedic surgeon.*

**Winslow, foramen of**: the anatomical window posterolateral to the porta hepatis.

*Jacob B. Winslow (1669–1760), Professor of Anatomy and Surgery, Paris, France.*

**Wirsung, duct of**: the main pancreatic duct.

*Johann Georg Wirsung (1589–1643), German physician, Prosector in Anatomy, Padua, Italy.*

**Witzel technique**: the creation of a serosal tunnel over a jejunostomy tube by suturing the small intestinal wall over the tube longitudinally (O. Witzel, Zur Technik der Magenfistelanlegung, Zbl Chir. 32 (1891)
Wolffian ducts: mesonephric ducts.

Caspar Wolff (1733–1794), born in Berlin, Professor of Anatomy, St Petersburg, Russia; one of the pioneers of embryology.

Wrisberg, ligament of: a band attached to the posterior cruciate ligament of the knee;

–, nerve of: the nervus intermedius.

Heinrich August Wrisberg (1736–1808), Professor of Anatomy, Göttingen, Germany. He named the nervus intermedius as the ‘portio media inter communicantem faciei et nervum auditorium’ in 1777.

Zinn, circle of (zonula of Zinn, circle of Haller): an (often incomplete) vascular circle within the sclera, formed by branches of the short posterior ciliary arteries, whose centripetal branches supply the laminar region of the optic nerve head.

Johann Gottfried Zinn (1727–1759), Professor of Medicine and Director of Botanical Gardens, Göttingen, Germany.

Zuckerkandl, glands of (organ of Zuckerkandl): chromaffin tissue derived from neural crest cells located near the origin of the inferior mesenteric artery;

– tubercle: a remnant of the ultimobranchial body; the posterolateral projection of the thyroid gland, located adjacent to the junction of the thyroid and cricoid cartilages. When present, it constitutes a useful anatomical landmark for identification of the recurrent laryngeal and the superior parathyroid gland during thyroidectomy. Zuckerkandl described the tubercle in 1902 as the ‘processus glandulae thyroideae’.

Emil Zuckerkandl (1849–1910), Hungarian–Austrian anatomist.
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ECRB, Extensor carpi radialis brevis

ECRL, Extensor carpi radialis longus

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ECU, Extensor carpi ulnaris

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ETV, Endoscopic third ventriculostomy
EUS, Endoscopic ultrasound
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FCU, Flexor carpi ulnaris

FDP, Flexor digitorum profundus

FDS, Flexor digitorum superficialis

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SMAS, **Superficial muscular aponeurotic system**

SMV, **Superior mesenteric vein**

SNc, **Substantia nigra pars compacta**

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SNLB, **Sentinel lymph node biopsy**

SNr, **Substantia nigra pars reticulata**

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