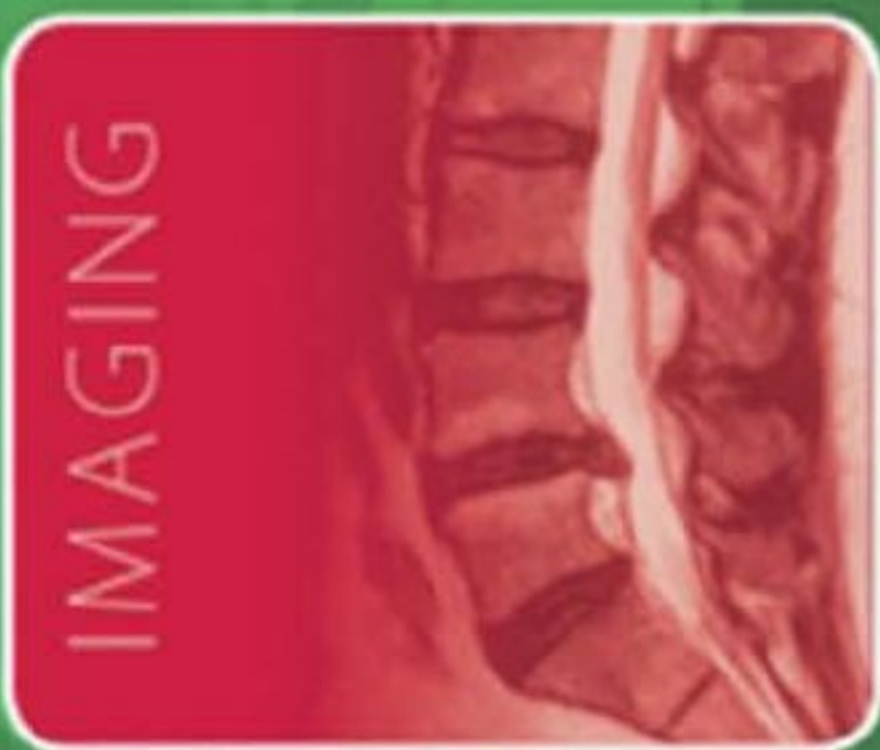
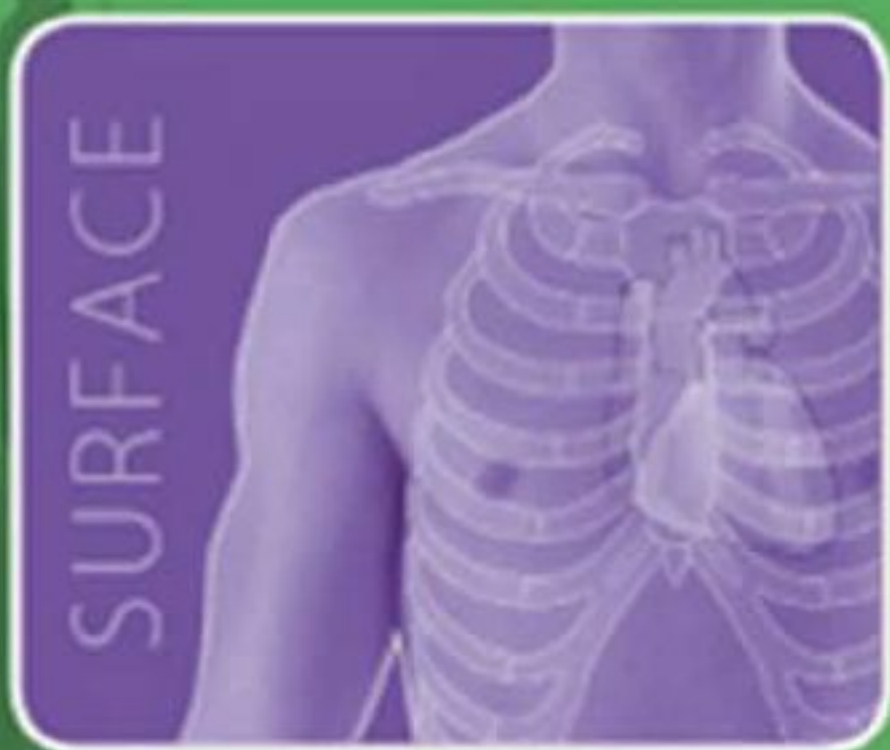
GRAY'S BASIC ANATOMY





SECOND EDITION

Richard L. Drake A. Wayne Vogl Adam W. M. Mitchell

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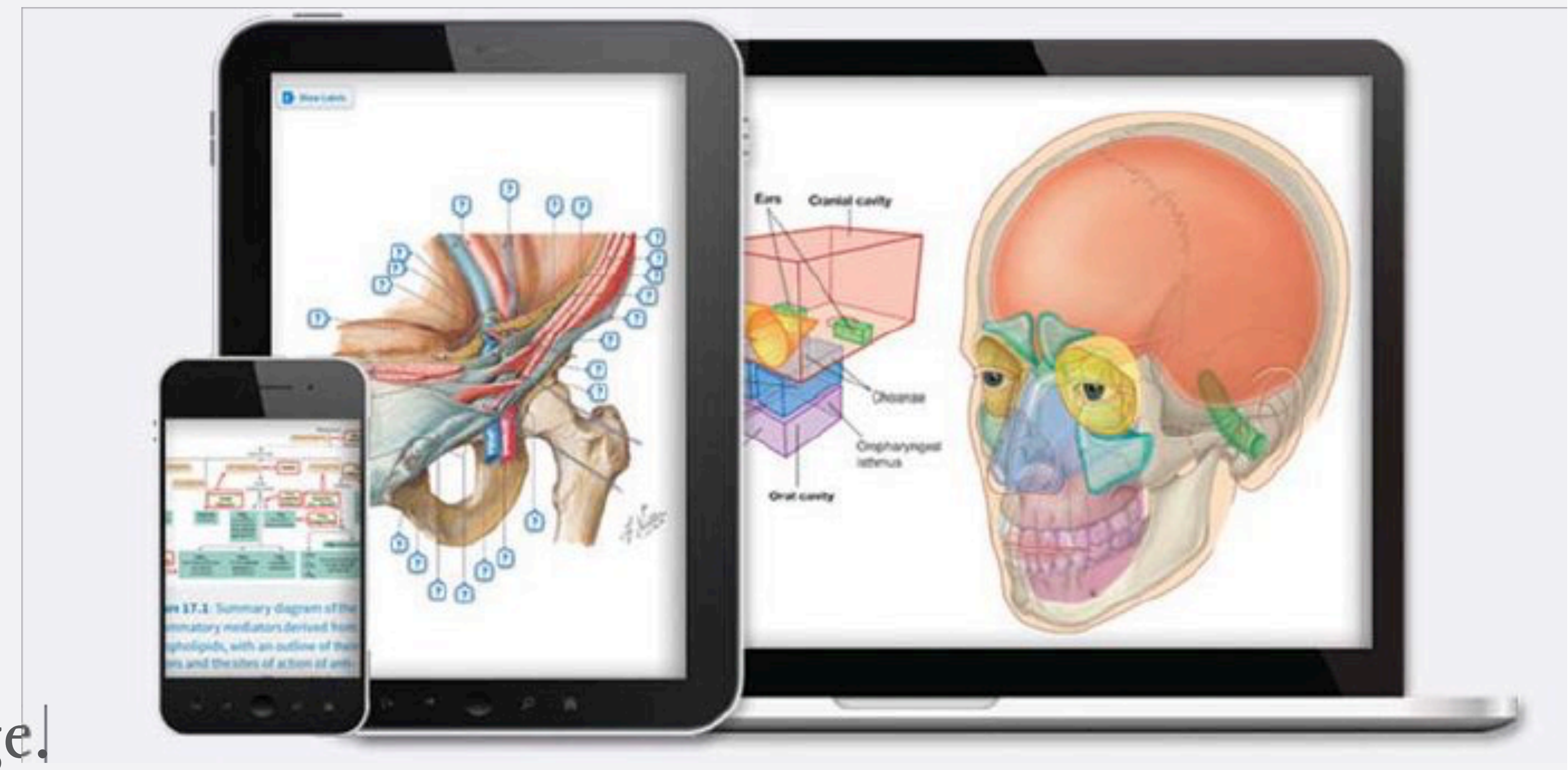

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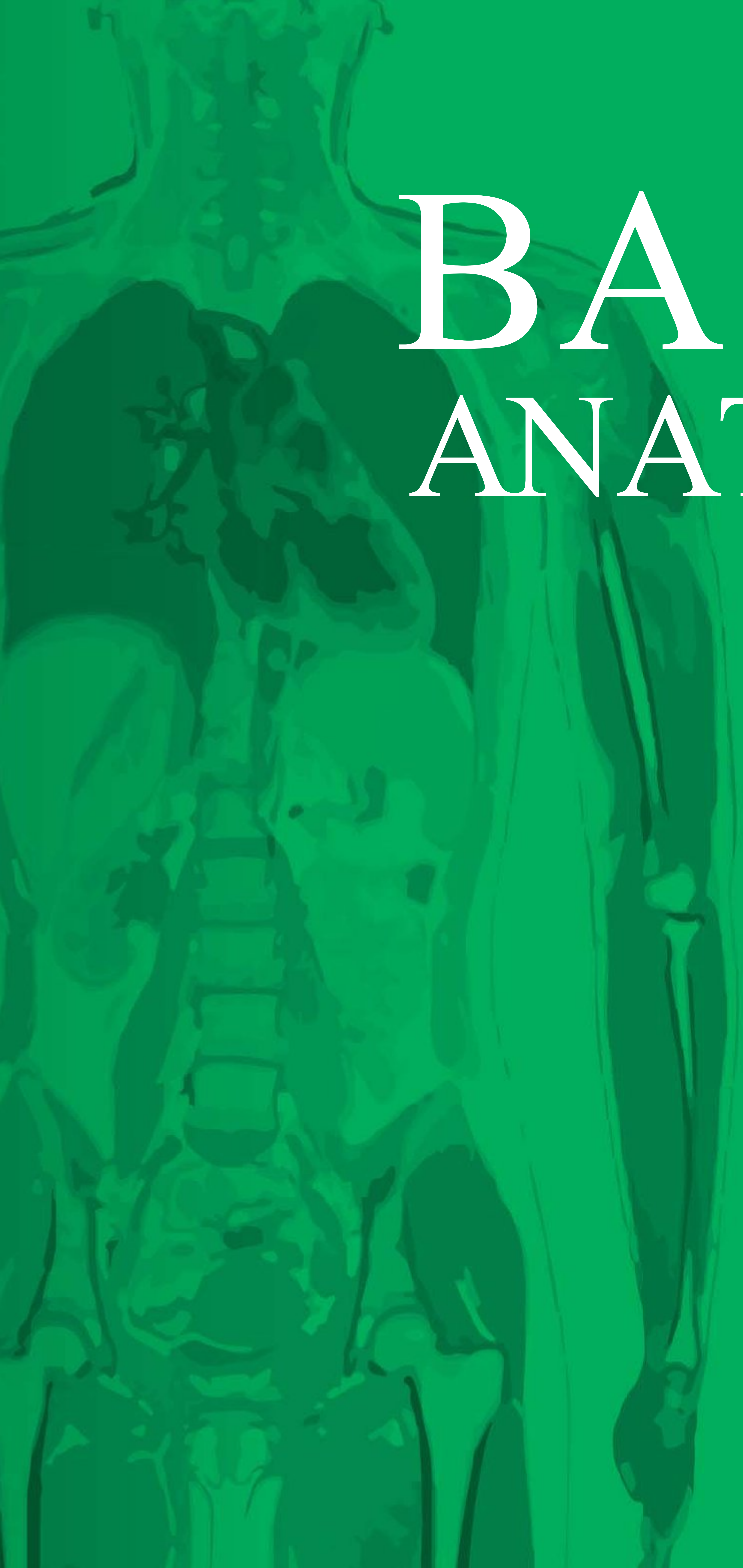

BASIC
ANATOMY

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BASIC ANATOMY

SECOND EDITION

Richard L. Drake, PhD, FAAA

Director of Anatomy
Professor of Surgery
Cleveland Clinic Lerner College of Medicine
Case Western Reserve University
Cleveland, Ohio

A. Wayne Vogl, PhD, FAAA

Professor of Anatomy and Cell Biology
Department of Cellular and Physiological Sciences
Faculty of Medicine
University of British Columbia
Vancouver, British Columbia

Adam W.M. Mitchell, MBBS, FRCS, FRCR

Consultant Radiologist
Chelsea and Westminster Hospital
Honorary Senior Lecturer Imperial College
London, UK

Illustrations by
Richard Tibbitts and Paul Richardson

Photographs by
Ansell Horn

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1600 John F. Kennedy Blvd.
Ste. 1800
Philadelphia, PA 19103-2899

GRAY'S BASIC ANATOMY, SECOND EDITION **ISBN: 978-0-323-47404-7**

Previous edition copyrighted 2012 by Churchill Livingstone, an imprint of Elsevier, Inc.

ISBN: 978-0-323-47404-7

Vice President, Global Content: Madelene Hyde
Director, Content Development: Rebecca Gruliow
Publishing Services Manager: Patricia Tannian
Senior Project Manager: John Casey
Design Direction: Ashley Miner

Printed in China

9 8 7 6 5 4 3 2 1

To my parents who guide me,
To my wife who supports me,
To my students who challenge me
RLD

To my family, my colleagues, my mentors, and my students
AWV

To all my family, Cathy, Max and Elsa, and my colleagues
AWMM

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Acknowledgments

Any book, no matter the size, is a major undertaking, and we want to thank all of the individuals who have helped move this project to completion. These include William Schmitt and Rebecca Gruliow, who both helped in initially evaluating the need for this type of concise textbook and in moving the first edition forward to completion. Madelene Hyde and Rebecca Gruliow guided this second edition through to completion. We also appreciate the contributions of our illustrators, Richard Tibbitts and Paul Richardson, who did all of the artwork.

We'd also like to thank Professor Richard A. Buckingham of the Abraham Lincoln School of Medicine, University of Illinois, for Fig. 8.97B; Dr. Murray Morrison, Dr. Joanne Matsubara, Dr. Brian Westerberg, Laura Hall, and Jing Cui for contributing images for the head and neck chapter; and Dr. Bruce Crawford and Logan Lee for help with images for the surface anatomy of the upper limb.

Finally, we are very appreciative of the numerous individuals, anatomists, and educators who provided feedback on the first edition and whose suggestions were included in this second edition.

Richard L. Drake
A. Wayne Vogl
Adam W.M. Mitchell

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Preface

Gray's Basic Anatomy was developed in response to students and colleagues from around the world who requested a more concise description of anatomy than that presented in *Gray's Anatomy for Students*. To accomplish this goal, we reworked the material to focus mainly on regional anatomy and integrated the clinical material, imaging, and surface anatomy information directly into the text as:

- **Clinical apps**, which give students context for why a strong anatomical background helps facilitate the solving of clinical problems;
- **Imaging apps,** which offer students a great introduction to the different techniques and modalities available for imaging relevant anatomy; and
- **Surface anatomy boxes,** which help students visualize the relationship between anatomical structures and surface landmarks necessary for any kind of patient examination.

In addition, at the beginning of each chapter students are directed to additional learning resources available on Student Consult (Elsevier's online educational website).

Summarizing, *Gray's Basic Anatomy* uses a regional approach, similar to *Gray's Anatomy for Students,* with eight chapters: The Body, Back, Thorax, Abdomen, Pelvis and Perineum, Lower Limb, Upper Limb, and Head and Neck. The artwork presents the same familiar illustrations from *Gray's Anatomy for Students*, but they have been resized to fit within a smaller format while retaining a close physical location to the text with which each figure is associated. Finally, while some verbiage has been sacrificed in keeping with the goal of presenting a concise textbook of anatomy (e.g., muscle descriptions have for the most part been incorporated into tables with no loss of content), additional clinical and imaging material has been added to enhance learning in context.

This second edition includes numerous edits resulting from reader feedback, some new and revised figures, and revisions based on current research in the field of the anatomical sciences.

We hope you will continue to find this new edition a useful and valuable resource whether you are an educator or a student.

Richard L. Drake
A. Wayne Vogl
Adam W.M. Mitchell

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Index of Clinical Apps, Imaging Apps, and Surface Anatomy Boxes

1 The Body

CLINICAL APPS

IMAGING APPS

2 Back

CLINICAL APPS

IMAGING APPS

SURFACE ANATOMY

3 Thorax

CLINICAL APPS

Index of Clinical Apps, Imaging Apps, and Surface Anatomy Boxes

IMAGING APPS

SURFACE ANATOMY

4 Abdomen

CLINICAL APPS

IMAGING APPS

SURFACE ANATOMY

5 Pelvis and Perineum

CLINICAL APPS

SURFACE ANATOMY

6 Lower Limb

CLINICAL APPS

Index of Clinical Apps, Imaging Apps, and Surface Anatomy Boxes

IMAGING APPS

SURFACE ANATOMY

7 Upper Limb

CLINICAL APPS

IMAGING APPS

SURFACE ANATOMY

8 Head and Neck

CLINICAL APPS

IMAGING APPS

SURFACE ANATOMY

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Contents

1 The Body

2 Back

3 Thorax

4 Abdomen

5 Pelvis and Perineum

6 Lower Limb

7 Upper Limb

8 Head and Neck

Contents

1

The Body

ADDITIONAL LEARNING RESOURCES FOR CHAPTER 1, THE BODY, ON STUDENT CONSULT (www.studentconsult.com):

- Short Questions—These are questions requiring short responses, Chapter 1
- Clinical Case
  Appendicitis

What is anatomy?

Anatomy includes those structures that can be seen grossly (without the aid of magnification) and microscopically (with the aid of magnification). Typically, when used by itself, the term *anatomy* tends to mean gross or macroscopic anatomy—that is, the study of structures that can be seen without using a microscopic. Microscopic anatomy, also called histology, is the study of cells and tissues using a microscope.

Observation and visualization are the primary techniques a student should use to learn anatomy. Anatomy is much more than just memorization of lists of names. Although the language of anatomy is important, the network of information needed to visualize the position of physical structures in a patient goes far beyond simple memorization. Knowing the names of the various branches of the external carotid artery is not the same as being able to visualize the course of the lingual artery from its origin in the neck to its termination in the tongue. An understanding of anatomy requires an understanding of the context in which the terminology can be remembered.

HOW CAN GROSS ANATOMY BE STUDIED?

The term *anatomy* is derived from the Greek word *temnein*, meaning "to cut." Clearly, at its root, the study of anatomy is linked to dissection. Dissection of cadavers by students is now augmented, or even in some cases replaced, by viewing prosected (previously dissected) material and plastic models, or using computer teaching modules and other learning aids.

Anatomy can be studied following either a regional or a systemic approach.

- With a **regional approach**, each *region* of the body is studied separately and all aspects of that region are studied at the same time. For example, if the thorax is to be studied, all of its structures are examined. This includes the vasculature, nerves, bones, muscles, and all other structures and organs located in the region of the body defined as the thorax. After studying this region, the other regions of the body (i.e., the abdomen, pelvis, lower limb, upper limb, back, head, and neck) are studied in a similar fashion.
- In contrast, in a **systemic approach**, each *system* of the body is studied and followed throughout the entire body. For example, a study of the cardiovascular system looks at the heart and all of the blood vessels in the body. This approach continues for the whole body until every system, including the nervous, skeletal, muscular, gastrointestinal, respiratory, lymphatic, and reproductive systems, has been studied.

IMPORTANT ANATOMICAL TERMS

The anatomical position

The anatomical position is the standard reference position of the body used to describe the location of structures (Fig. 1.1). The body is in the anatomical position when standing upright with feet together, hands by the side, and face looking forward. The mouth is closed and the facial expression is neutral. The rim of bone under the eyes is in the same horizontal plane as the top of the opening to the ear, and the eyes are open and focused on something in the distance. The palms of the hands face forward with the fingers straight and together and with the pad of the thumb turned 90° to the pads of the fingers. The toes point forward.

Anatomical planes

Three major groups of planes pass through the body in the anatomical position (Fig. 1.1).

- **Coronal planes** are oriented vertically and divide the body into anterior and posterior parts.
- **Sagittal planes** also are oriented vertically, but are at right angles to the coronal planes and divide the body into right and left parts. The plane that passes through the center of the body dividing it into equal right and left halves is termed the **median sagittal plane**.
- **Transverse, horizontal**, or **axial planes** divide the body into superior and inferior parts.

Terms to describe location

Anterior (ventral) and posterior (dorsal), medial and lateral, superior and inferior

Three major pairs of terms are used to describe the location of structures relative to the body as a whole or to other structures (Fig. 1.1).

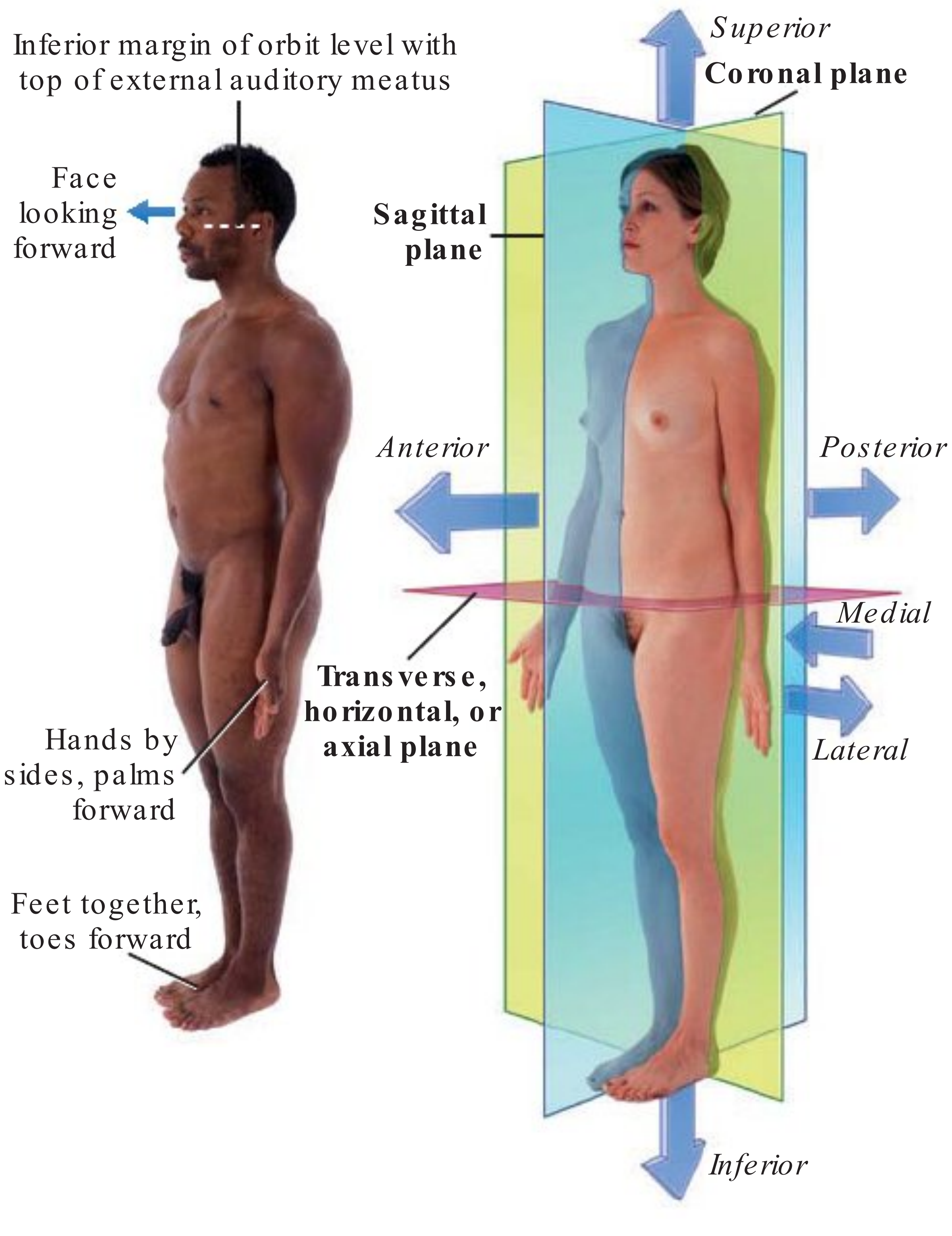

Fig. 1.1 The anatomical position, planes, and terms of location and orientation.

- **Anterior** (or **ventral**) and **posterior** (or **dorsal**) describe the position of structures relative to the "front" and "back" of the body. For example, the nose is an anterior (ventral) structure, whereas the vertebral column is a posterior (dorsal) structure.
- **Medial** and **lateral** describe the position of structures relative to the median sagittal plane and the sides of the body. For example, the thumb is lateral to the little finger.
- **Superior** and **inferior** describe structures in reference to the vertical axis of the body. For example, the head is superior to the shoulders.

Proximal and distal, cranial and caudal, and rostral

Other terms used to describe positions include proximal and distal, cranial and caudal, and rostral.

- **Proximal** and **distal** are used with reference to being closer to or farther from a structure's origin, particularly in the limbs. For example, the hand is distal to the elbow joint. These terms are also used to describe the relative positions of branches along the course of linear structures, such as airways, vessels, and nerves. For example, distal branches occur farther away toward the ends, whereas proximal branches occur closer to and toward the origin.
- **Cranial** (toward the head) and **caudal** (toward the tail) are sometimes used instead of superior and inferior, respectively.
- **Rostral** is used, particularly in the head, to describe the position of a structure with reference to the nose. For example, the forebrain is rostral to the hindbrain.

Superficial and deep

Two other terms used to describe the position of structures in the body are **superficial** and **deep**. These terms are used to describe the relative positions of two structures with respect to the surface of the body. For example, the sternum is superficial to the heart.

Imaging

DIAGNOSTIC IMAGING TECHNIQUES

In 1895 Wilhelm Röntgen used the X-rays from a cathode ray tube to expose a photographic plate and produce the first radiographic exposure of his wife's hand. Over the past 35 years there has been a revolution in medical imaging, which has been paralleled by developments in computer technology.

Plain radiography

The basic physics of X-ray generation has not changed.

X-rays are photons (a type of electromagnetic radiation) and are generated from a complex X-ray tube, which is a type of cathode ray tube (Fig. 1.2). The X-rays are then collimated (i.e., directed through lead-lined shutters to stop them from fanning out) to the appropriate area, as determined by the radiographic technician. As the X-rays pass through the body they are attenuated (reduced in energy) by the tissues. Those X-rays that pass through the tissues interact with the photographic film.

In the body:

- Air attenuates X-rays a little.
- Fat attenuates X-rays more than air but less than water.
- Bone attenuates X-rays the most.

These differences in attenuation result in differences in the level of exposure of the film. When the photographic film is developed, bone appears white on the film because this region of the film has been exposed to the least amount of X-rays. Air appears dark on the film because these regions were exposed to the greatest number of X-rays. Modifications to this X-ray technique allow a continuous stream of X-rays to be produced from the X-ray tube and collected on an input screen to allow real-time visualization of moving anatomical structures, barium studies, angiography, and fluoroscopy (Fig. 1.3).

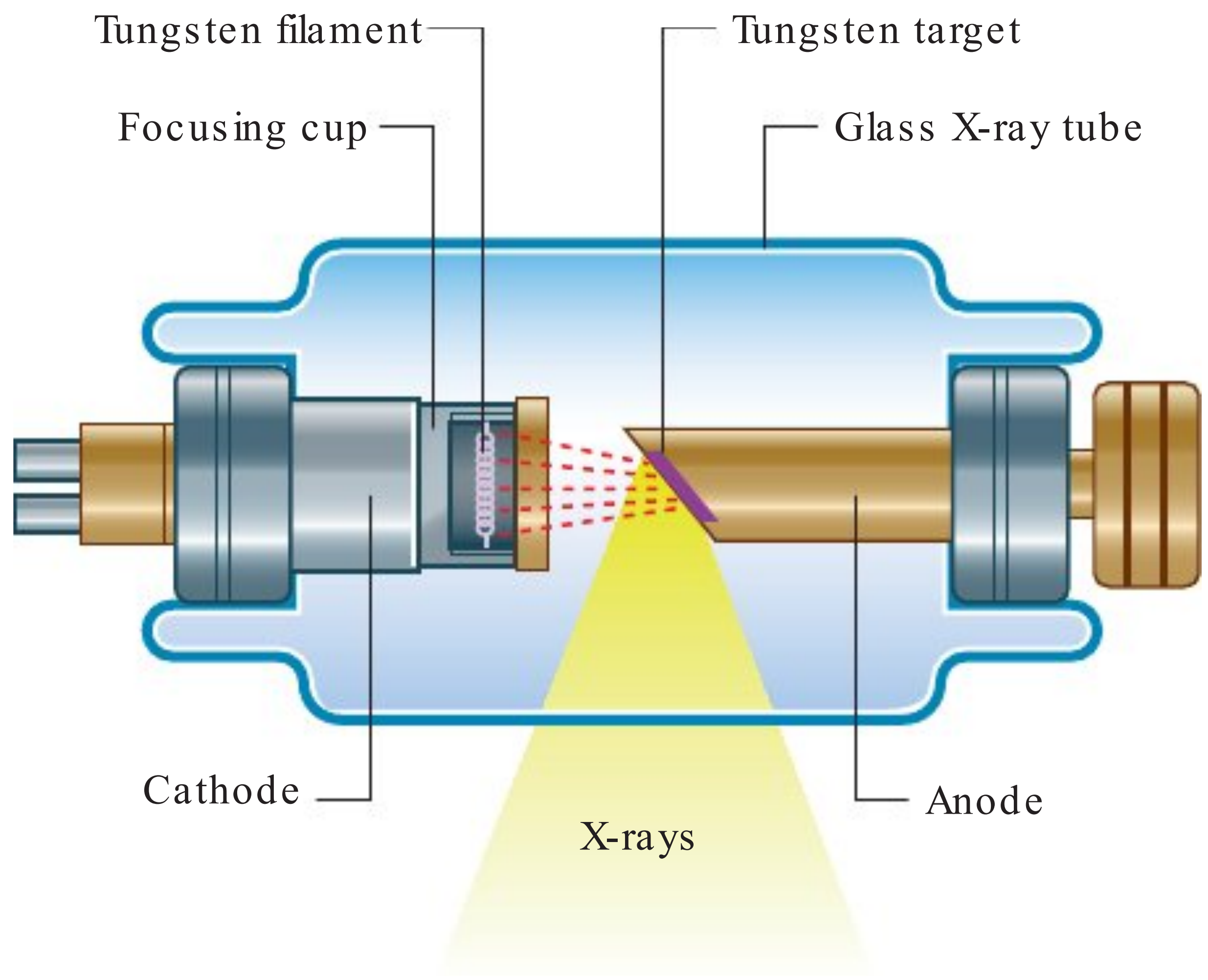

Fig. 1.2 Cathode ray tube for the production of X-rays.

Fig. 1.3 Fluoroscopy unit.

Contrast agents

To demonstrate specific structures, such as bowel loops or arteries, it may be necessary to fill these structures with a substance that attenuates X-rays more than bowel loops or

Fig. 1.4 Barium sulfate follow-through.

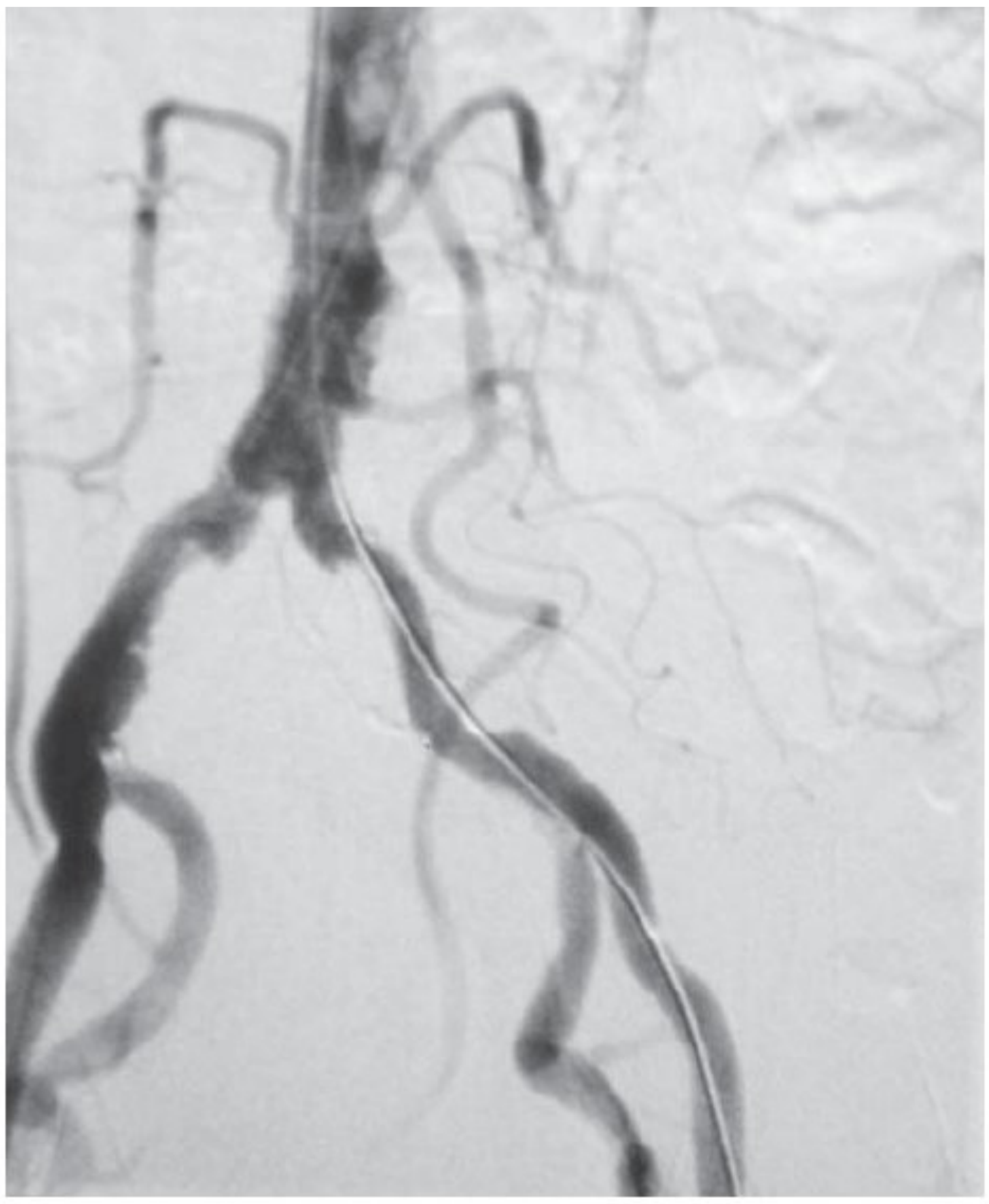

Fig. 1.5 Digital subtraction angiogram.

Fig. 1.6 Ultrasound examination of the abdomen.

Fig. 1.7 Computed tomography scanner.

arteries do normally. It is, however, extremely important that these substances are nontoxic. Barium sulfate, an insoluble salt, is a nontoxic, relatively high-density agent that is extremely useful in the examination of the gastrointestinal tract. When a **barium sulfate suspension** is ingested it attenuates X-rays and can therefore be used to demonstrate the bowel lumen (Fig. 1.4).

For some patients it is necessary to inject contrast agents directly into arteries or veins. In this case, iodine-based molecules are suitable contrast agents. **Iodine** is chosen because it has a relatively high atomic mass and so markedly attenuates X-rays, but also, importantly, it is naturally excreted via the urinary system. Intra-arterial and intravenous contrast agents are extremely safe and are well tolerated by most patients. These agents not only help in visualizing the arteries and veins, but because they are excreted by the urinary system, can also be used to visualize the kidneys, ureter, and bladder in a process known as **intravenous urography.**

Subtraction angiography

During angiography it is often difficult to appreciate the contrast agent in the vessels through the overlying bony structures. To circumvent this, the technique of subtraction angiography has been developed. Simply, one or two images are obtained before the injection of contrast media. These images are inverted (such that a negative is created from the positive image). After injection of the contrast media into the vessels, a further series of images are obtained, demonstrating the passage of the contrast through the arteries and into the veins. By adding the "negative precontrast image" to the positive postcontrast images, the bones and soft tissues are subtracted to produce a solitary image of contrast only (Fig. 1.5).

Ultrasound

Ultrasonography of the body is widely used for all aspects of medicine (Fig. 1.6).

Ultrasound is a very high frequency sound wave (not electromagnetic radiation) generated by piezoelectric materials, such that a series of sound waves is produced. Importantly, the piezoelectric material can also receive the sound waves that bounce back from the internal organs. The sound waves are then interpreted by a powerful computer, and a real-time image is produced on the display panel.

Doppler ultrasound

Developments in ultrasound technology, including the size of the probes and the frequency range, mean that a broad range of areas can now be scanned.

Traditionally ultrasound is used for assessing the abdomen (Fig. 1.6) and the fetus in pregnant women. Ultrasound is also widely used to assess the eyes, neck, soft tissues, and peripheral musculoskeletal system. Probes have been placed on endoscopes, and endoluminal ultrasound of the esophagus, stomach, and duodenum is now routine. Endocavity ultrasound is carried out most commonly to assess the genital tract in women using a transvaginal or transrectal route. In men, transrectal ultrasound is the imaging method of choice to assess the prostate in those with suspected prostate hypertrophy or malignancy.

Fig. 1.8 Computed tomography scan of the abdomen at vertebral level L2.

Doppler ultrasound enables determination of flow, its direction, and its velocity within a vessel using simple ultrasound techniques. Sound waves bounce off moving structures and are returned. The degree of frequency shift determines whether the object is moving away from or toward the probe and the speed at which it is traveling.

Computed tomography

Computed tomography (CT) was invented in the 1970s by Sir Godfrey Hounsfield, who was awarded the Nobel Prize in Medicine in 1979. Since this inspired invention, there have been many generations of CT scanners.

A CT scanner obtains a series of images of the body (slices) in the axial plane. The patient lies on a bed, an X-ray tube passes around the body (Fig. 1.7), and a series of images are obtained. A computer carries out a complex mathematical transformation on the multitude of images to produce the final image (Fig. 1.8).

Magnetic resonance imaging

The process of magnetic resonance imaging (MRI) is dependent on the free protons in the hydrogen nuclei in molecules of water (H_2O). Because water is present in almost all biological tissues, the hydrogen proton is ideal. The protons within a patient's hydrogen nuclei should be regarded as small bar magnets, which are randomly oriented in space. The patient is placed in a strong magnetic field, which aligns the bar magnets. When a pulse of radio waves is passed through the patient the magnets are deflected, and as they return to their aligned position they emit small radio pulses. The strength and frequency of the emitted pulses and the time it takes for the protons to return to their pre-excited state produces a signal. These signals are analyzed by a powerful computer, and an image is created (Fig. 1.9).

By altering the sequence of pulses to which the protons are subjected, different properties of the protons can

Fig. 1.9 A T2-weighted image in the sagittal plane of the pelvic viscera in a woman.

be assessed. These properties are referred to as the "weighting" of the scan. By altering the pulse sequence and the scanning parameters, T1-weighted images (Fig. 1.10A) and T2-weighted images (Fig. 1.10B) can be obtained. These two types of imaging sequences provide differences in image contrast, which accentuate and optimize different tissue characteristics.

From the clinical point of view:

- Most T1-weighted images show dark fluid and bright fat—for example, within the brain the cerebrospinal fluid (CSF) is dark.
- T2-weighted images demonstrate a bright signal from fluid and an intermediate signal from fat—for example, in the brain the CSF appears white.

MRI can also be used to assess flow within vessels and to produce complex angiograms of the peripheral and cerebral circulation.

Nuclear medicine imaging

Nuclear medicine involves imaging using gamma rays, which are another type of electromagnetic radiation. The important difference between gamma rays and X-rays is that gamma rays are produced from within the nucleus of an atom when an unstable nucleus decays, whereas X-rays are produced by bombarding an atom with electrons.

For an area to be visualized, the patient must receive a gamma-ray emitter, which must have a number of properties to be useful, including a reasonable half-life (e.g., 6 to 24 hours); an easily measurable gamma ray; and an energy deposition in as low a dose as possible in the patient's tissues.

The most commonly used radionuclide (radioisotope) is technetium-99m. This may be injected as a technetium salt or combined with other complex molecules. For example, by combining technetium-99m with methylene diphosphonate (MDP), a radiopharmaceutical is produced. When injected into the body this radiopharmaceutical specifically binds to bone, allowing assessment of the skeleton. Similarly, combining technetium-99m with other compounds permits assessment of other parts of the body; for example, the urinary tract and cerebral blood flow.

Images obtained using a gamma camera are dependent on how the radiopharmaceutical is absorbed, distributed, metabolized, and excreted by the body after injection.

Positron emission tomography

Positron emission tomography (PET) is an imaging modality for detecting positron-emitting radionuclides. A positron is an antielectron, which is a positively charged particle of antimatter. Positrons are emitted from the decay of proton-rich radionuclides. Most of these radionuclides are made in a cyclotron and have extremely short half-lives.

The most commonly used PET radionuclide is fluorodeoxyglucose (FDG) labeled with fluorine-18 (a positron emitter). Tissues that are actively metabolizing glucose take up this compound, and the resulting localized high concentration of this molecule compared to background emission is detected as a "hot spot."

PET has become an important imaging modality in the detection of cancer and the assessment of its treatment and recurrence.

IMAGE INTERPRETATION

Plain radiography

Plain radiographs are undoubtedly the most common form of image obtained in a hospital or local practice. Before interpretation, it is important to know about the imaging technique and the standard views obtained.

In most instances (apart from chest radiography), the X-ray tube is 1 m away from the X-ray film. The object in question, for example a hand or a foot, is placed upon the film. When describing subject placement for radiography, the part closest to the X-ray tube is referred to first and that closest to the film is referred to second. For example, when positioning a patient for an anteroposterior (AP) radiograph, the more anterior part of the body is closest to the tube and the posterior part is closest to the film.

When X-rays are viewed on a viewing box, the right side of the patient is placed to the observer's left; therefore, the observer views the radiograph as though looking at a patient in the anatomical position.

Chest radiograph

The chest radiograph is one of the most commonly requested plain radiographs. An image is taken with the patient erect and placed posteroanteriorly (PA chest radiograph); that is, with the patient's back closest to the X-ray tube.

Occasionally, when patients are too unwell to stand erect, films are obtained on the bed in an anteroposterior (AP) position. These films are less standardized than PA films, and caution should always be taken when interpreting AP radiographs.

A good quality chest radiograph will demonstrate the lungs, cardiomediastinal contour, diaphragm, ribs, and peripheral soft tissues.

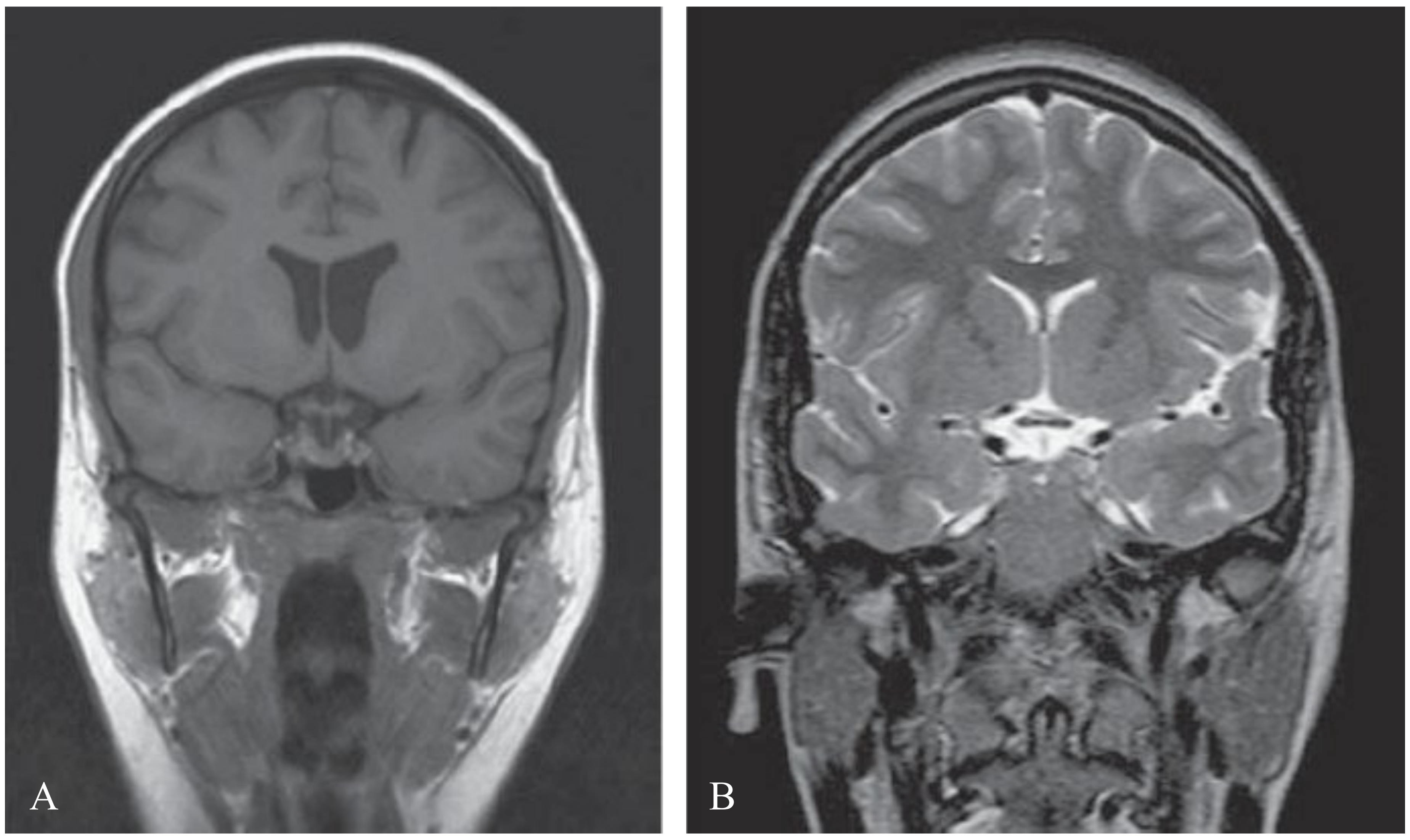

Fig. 1.10 T1-weighted **(A)** and T2-weighted **(B)** magnetic resonance images of the brain in the coronal plane.

Abdominal radiograph

Plain abdominal radiographs are obtained in the AP supine position. From time to time an erect plain abdominal radiograph is obtained when small bowel obstruction is suspected.

Gastrointestinal contrast examinations

High-density contrast medium is ingested to opacify the esophagus, stomach, small bowel, and large bowel. The bowel is insufflated with air (or carbon dioxide) to provide a double-contrast study. In many countries, endoscopy has superseded upper gastrointestinal imaging, but the mainstay for imaging the large bowel is the double-contrast barium enema. Typically the patient needs to undergo bowel preparation, in which powerful cathartics are used to empty the bowel. At the time of the examination a small tube is placed into the rectum and a barium suspension is run into the large bowel. The patient undergoes a series of twists and turns so that the contrast passes through the entire large bowel. The contrast is emptied and air is passed through the same tube to insufflate the large bowel. A thin layer of barium coats the normal mucosa, allowing mucosal detail to be visualized (see Fig. 1.4).

Urological contrast studies

Intravenous urography is the standard investigation for assessing the urinary tract. Intravenous contrast medium is injected, and images are obtained as the medium is excreted through the kidneys. A series of films are obtained during this period from immediately after the injection up to approximately 20 minutes later, when the bladder is full of contrast medium.

This series of radiographs demonstrates the kidneys, ureters, and bladder and enables assessment of the retroperitoneum and other structures that may press on the urinary tract.

Computed tomography

Computed tomography is the preferred terminology rather than computerized tomography, though physicians use both terms interchangeably.

Most images are acquired in the axial plane and viewed such that the observer looks from below and upward toward the head (from the foot of the bed). By implication:

- the right side of the patient is on the left side of the image; and
- the uppermost border of the image is anterior.

Many patients are given oral and intravenous contrast media to differentiate bowel loops from other abdominal organs and to assess the vascularity of normal anatomical structures. When intravenous contrast is given, the earlier the images are obtained, the greater the likelihood of arterial enhancement. As the time is delayed between injection and image acquisition, a venous phase and an equilibrium phase are also obtained.

The great advantage of CT scanning is the ability to extend and compress the gray scale to visualize the bones, soft tissues, and visceral organs. Altering the window settings and window centering provides the physician with specific information about these structures.

Magnetic resonance imaging

There is no doubt that MRI has revolutionized the understanding and interpretation of the brain and its coverings (Fig. 1.10). Furthermore, it has significantly altered the practice of musculoskeletal medicine and surgery. Images can be obtained in any plane and in most sequences. Typically the images are viewed using the same principles as computed tomography. Intravenous contrast agents are also used to further enhance tissue contrast. Typically, MRI contrast agents contain paramagnetic substances (e.g., gadolinium and manganese).

Nuclear medicine imaging

Most nuclear medicine images are functional studies. Images are usually interpreted directly from a computer, and a series of representative films are obtained for clinical use.

SAFETY IN IMAGING

Whenever a patient undergoes an X-ray or nuclear medicine investigation, a dose of radiation is given (Table 1.1). As a general principle, it is expected that the dose given is as low as reasonably possible for a diagnostic image to be obtained. Numerous laws govern the amount of radiation exposure that a patient can undergo for a variety of procedures, and these are monitored to prevent any excess or additional dosage.

Imaging modalities such as ultrasound and MRI are ideal because they do not impart significant risk to the patient. Moreover, ultrasound imaging is the modality of choice for assessing the fetus.

Table 1.1 The approximate dosage of radiation exposure as an order of magnitude

Examination	Typical effective dose (mSv)	Equivalent duration of background exposure
Chest radiograph	0.02	3 days
Abdomen	1.00	6 months
Intravenous urography	2.50	14 months
CT scan of head	2.30	1 year
CT scan of abdomen and pelvis	10.00	4.5 years

Body systems

SKELETAL SYSTEM

The skeleton can be divided into two subgroups, the axial skeleton and the appendicular skeleton. The axial skeleton consists of the bones of the skull (cranium), vertebral column, ribs, and sternum, whereas the appendicular skeleton consists of the bones of the upper and lower limbs (Fig. 1.11).

The skeletal system consists of cartilage and bone.

Cartilage

Cartilage is an avascular form of connective tissue consisting of extracellular fibers embedded in a matrix that contains cells localized in small cavities. The amount and kind of extracellular fibers in the matrix vary depending on the type of cartilage. In heavy weightbearing areas or areas prone to pulling forces, the amount of collagen is greatly increased and the cartilage is almost inextensible. In contrast, in areas where weightbearing demands and stress are less, cartilage containing elastic fibers and fewer collagen fibers are common. The functions of cartilage are to:

- support soft tissues,
- provide a smooth, gliding surface for bone articulations at joints, and
- enable the development and growth of long bones.

There are three types of cartilage:

- hyaline—most common; matrix contains a moderate amount of collagen fibers (e.g., articular surfaces of bones);
- elastic—matrix contains collagen fibers along with a large number of elastic fibers (e.g., external ear);
- fibrocartilage—matrix contains a limited number of cells and ground substance amidst a substantial amount of collagen fibers (e.g., intervertebral discs).

Cartilage is nourished by diffusion and has no blood vessels, lymphatics, or nerves.

Bone

Bone is a calcified, living, connective tissue that forms the majority of the skeleton. It consists of an intercellular calcified matrix, which also contains collagen fibers, and several types of cells within the matrix. Bones function as:

Fig. 1.11 The axial skeleton and the appendicular skeleton.

- supportive structures for the body,
- protectors of vital organs,
- reservoirs of calcium and phosphorus,
- levers on which muscles act to produce movement, and
- containers for blood-producing cells.

There are two types of bone, compact and spongy (trabecular or cancellous). Compact bone is dense bone that forms the outer shell of all bones and surrounds spongy bone. Spongy bone consists of spicules of bone enclosing cavities containing blood-forming cells (marrow). Classification of bones is by shape.

- Long bones are tubular (e.g., humerus in the upper limb; femur in the lower limb).
- Short bones are cuboidal (e.g., bones of the wrist and ankle).
- Flat bones consist of two compact bone plates separated by spongy bone (e.g., skull).
- Irregular bones are bones with various shapes (e.g., bones of the face).
- Sesamoid bones are round or oval bones that develop in tendons.

Bones are vascular and are innervated. Generally, an adjacent artery gives off a nutrient artery, usually one per bone, which directly enters the internal cavity of the bone and supplies the marrow, spongy bone, and inner layers of compact bone. In addition, all bones are covered externally, except in the area of a joint where articular cartilage is present, by a fibrous connective tissue membrane called the periosteum, which has the unique capability of forming new bone. This membrane receives blood vessels whose branches supply the outer layers of compact bone. A bone stripped of its periosteum will not survive. Nerves accompany the vessels that supply the bone and the periosteum. Most of the nerves passing into the internal cavity with the nutrient artery are vasomotor fibers that regulate blood flow. Bone itself has few sensory nerve fibers. On the other hand, the periosteum is supplied with numerous sensory nerve fibers and is very sensitive to any type of injury.

Developmentally, all bones come from mesenchyme by either intramembranous ossification, in which mesenchymal models of bones undergo ossification, or endochondral ossification, in which cartilaginous models of bones form from mesenchyme and undergo ossification.

Imaging app

Determination of skeletal age

Throughout life the bones develop in a predictable way to form the skeletally mature adult at the end of puberty. In western countries, skeletal maturity tends to occur between the ages of 20 and 25 years.

Up until the age of skeletal maturity, bony growth and development follow a typically predictable ordered state, which can be measured through either ultrasound, plain radiographs, or MRI scanning. Typically, the nondominant (left hand) is radiographed and is compared with a series of standard radiographs. From these images the bone age can be determined (Fig. 1.12).

Fig. 1.12 A developmental series of radiographs showing the progressive ossification of carpal (wrist) bones from 3(**A**) to 10(**D**) years of age.

Clinical app

Bone marrow transplants

There are two types of bone marrow, red marrow (otherwise known as myeloid tissue) and yellow marrow. Red blood cells, platelets, and most white blood cells arise from within red marrow. In yellow marrow a few white cells are made; however, this marrow is dominated by large fat globules (producing its yellow appearance).

From birth most of the body's marrow is red; however, as the subject ages, more red marrow is converted into yellow marrow within the medulla of the long and flat bones.

There are a number of diseases that may involve the bone marrow, including infection and malignancy. In patients who develop a bone marrow malignancy (e.g., leukemia), it may be possible to harvest nonmalignant cells from the patient's bone marrow or cells from another person's bone marrow. The patient's own marrow can be destroyed with chemotherapy or radiation and the new cells infused. This treatment is referred to as a bone marrow transplant.

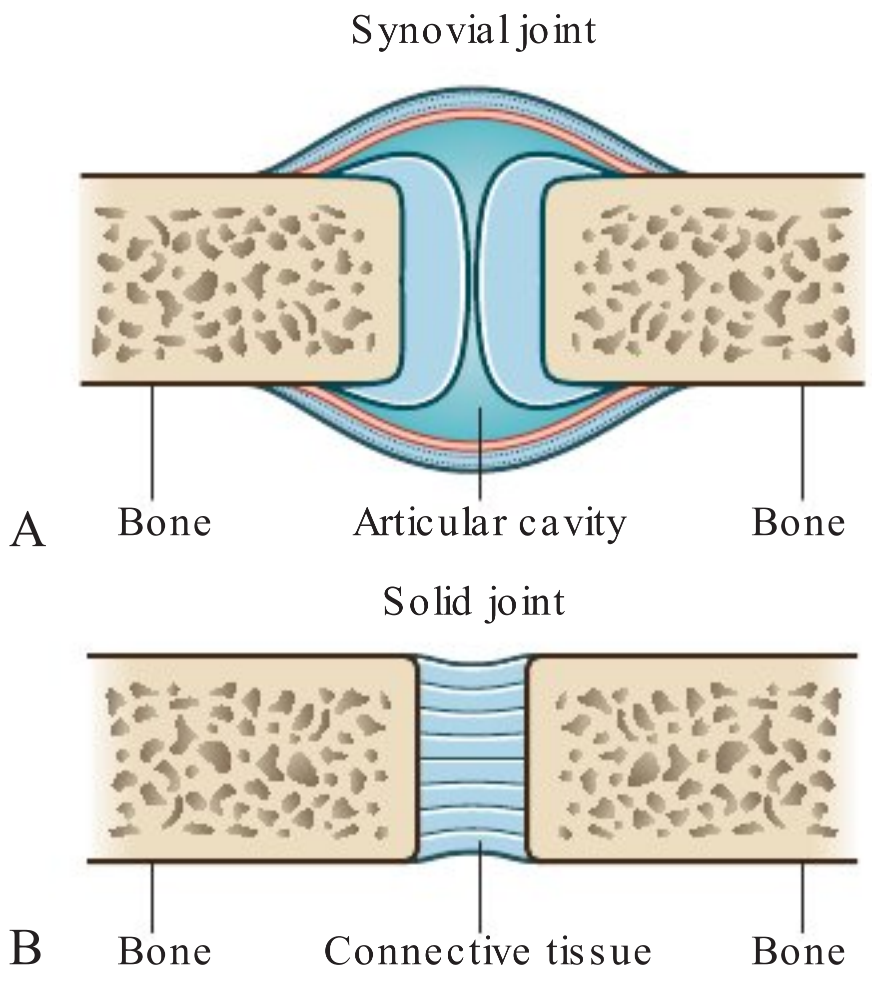

Fig. 1.13 Joints. **A.** Synovial joint. **B.** Solid joint.

Clinical app

Bone fractures

Fractures occur in normal bone because of abnormal load or stress, in which the bone gives way. Fractures may also occur in bone that is of poor quality (osteoporosis). In these cases, a normal stress is placed upon a bone that is not of sufficient quality to withstand this force and subsequently fractures.

In children whose bones are still developing, fractures may occur across the growth plate or across the shaft. These shaft fractures typically involve partial cortical disruption, similar to breaking a branch of a young tree; hence they are termed "greenstick" fractures.

Clinical app

Avascular necrosis

Avascular necrosis is cellular death of bone resulting from a temporary or permanent loss of blood supply to that bone. A typical site for avascular necrosis is a fracture across the femoral neck in an elderly patient. In these patients blood flow to the femoral head is compromised. It subsequently undergoes necrosis and collapses. In these patients it is necessary to replace the femoral head with a prosthesis.

Clinical app

Osteoporosis

Osteoporosis is a disease in which the bone mineral density is significantly reduced. This renders the bone significantly more at risk of fracture. Typically, osteoporotic fractures occur in the femoral necks, the vertebrae, and the wrists. Although osteoporosis may occur in men, especially elderly men, the typical patients are postmenopausal women.

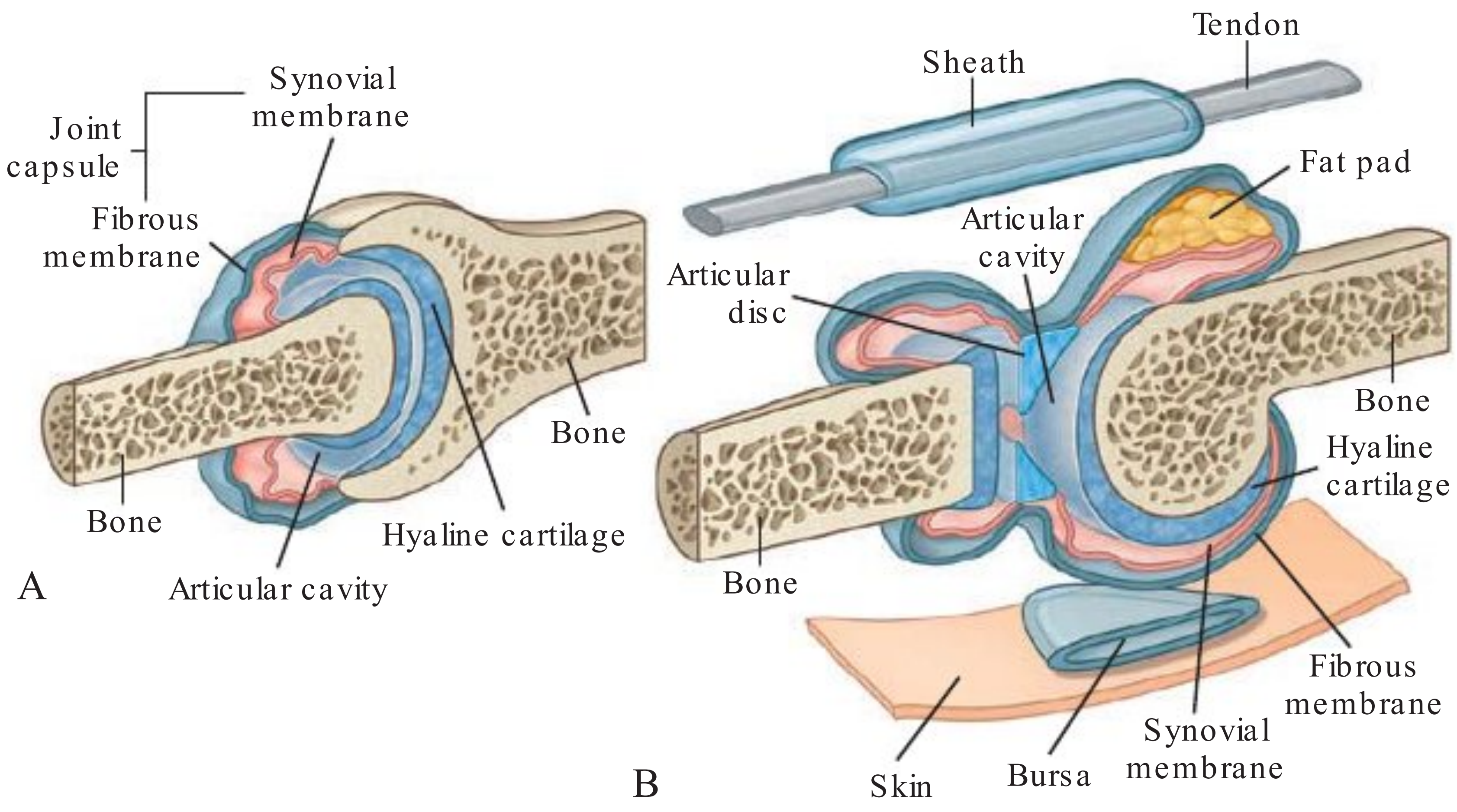

Fig. 1.14 Synovial joints. **A.** Major features of a synovial joint. **B.** Accessory structures associated with synovial joints.

Clinical app

Epiphyseal fractures

As the skeleton develops, there are stages of intense growth typically around the ages of 7 to 10 years and later in puberty. These growth spurts are associated with increased cellular activity around the growth plate and the metaphyseal region. This increase in activity renders the growth plates and metaphyseal regions more vulnerable to injuries such as dislocation across a growth plate or fracture through a growth plate. Occasionally an injury may result in growth plate compression, destroying that region of the growth plate, which may result in asymmetric growth.

Joints

The sites where two skeletal elements come together are termed joints. The two general categories of joints (Fig. 1.13) are those in which:

- the skeletal elements are separated by a cavity (i.e., **synovial joints**); and
- there is no cavity and the components are held together by connective tissue (i.e., **solid joints**).

Blood vessels that cross a joint and nerves that innervate muscles acting on a joint usually contribute articular branches to that joint.

Synovial joints

Synovial joints are connections between skeletal components where the elements involved are separated by a narrow articular cavity. In addition to containing an articular cavity, these joints have a number of characteristic features (Fig. 1.14).

First, a layer of cartilage, usually **hyaline cartilage**, covers the articulating surfaces of the skeletal elements. In other words, bony surfaces do not normally contact one another directly. As a consequence, when these joints are viewed in normal radiographs, a wide gap seems to separate the adjacent bones because the cartilage that covers the articulating surfaces is more transparent to X-rays than bone.

A second characteristic feature of synovial joints is the presence of a **joint capsule** consisting of an inner **synovial membrane** and an outer **fibrous membrane**.

- The synovial membrane attaches to the margins of the joint surfaces at the interface between the cartilage and bone and encloses the articular cavity. The synovial membrane is highly vascular and produces synovial fluid, which percolates into the articular cavity and lubricates the articulating surfaces. Closed sacs of synovial membrane also occur outside joints where they form synovial bursae or tendon sheaths. Bursae often intervene between structures, such as tendons and bone, tendons and joints, or skin and bone, and reduce the friction of one structure moving over the other. Tendon sheaths surround tendons and also reduce friction.
- The **fibrous membrane** is formed by dense connective tissue and surrounds and stabilizes the joint. Parts of the fibrous membrane may thicken to form ligaments, which further stabilize the joint. Ligaments outside the capsule usually provide additional reinforcement.

Another common but not universal feature of synovial joints is the presence of additional structures within the area enclosed by the capsule or synovial membrane:

- **Articular discs** (usually composed of fibrocartilage) absorb compression forces, adjust to changes in the contours of joint surfaces during movements, and increase the range of movements that can occur at joints.
- **Fat pads** occur between the synovial membrane and the capsule and move into and out of regions as joint contours change during movement;
- **tendons**.

Descriptions of synovial joints based on shape and movement

Synovial joints are described based on shape and movement:

- Based on the shape of their articular surfaces, synovial joints are described as plane (flat), hinge, pivot, bicondylar (two sets of contact points), condylar (ellipsoid), saddle, and ball and socket (Fig. 1.15).
- Based on movement, synovial joints are described as uniaxial (movement in one plane), biaxial (movement in two planes), and multiaxial (movement in three planes).

Hinge joints are uniaxial, whereas ball and socket joints are multiaxial.

Specific types of synovial joints (Fig. 1.15)

- Plane joints—allow sliding or gliding movements when one bone moves across the surface of another (e.g., acromioclavicular joint)
- Hinge joints—allow movement around one axis that passes transversely through the joint; permit flexion and extension (e.g., elbow [humeroulnar] joint)

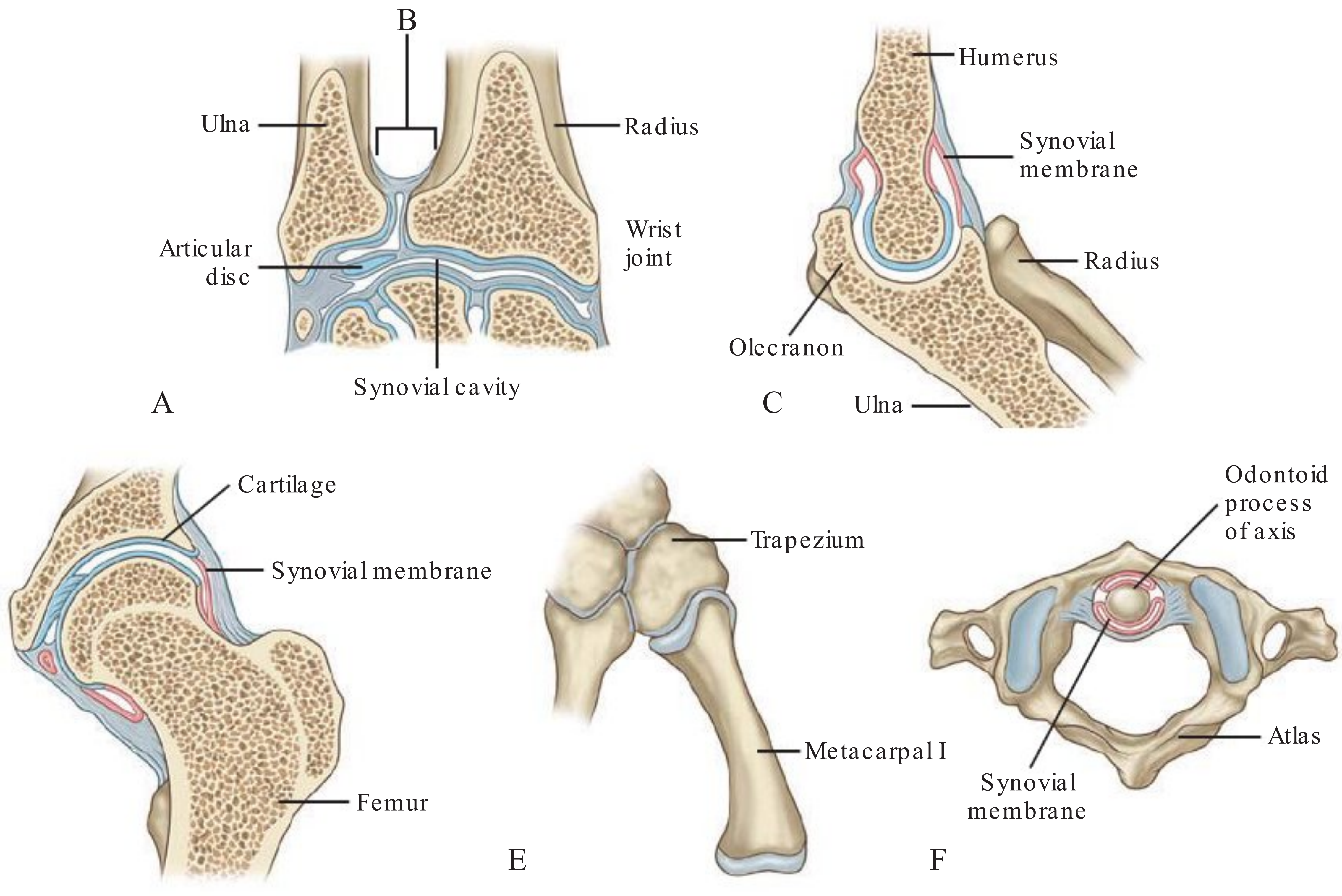

Fig. 1.15 Various types of synovial joints. **A.** Condylar (wrist). **B.** Gliding (radioulnar). **C.** Hinge or ginglymus (elbow). **D.** Ball and socket (hip). **E.** Saddle (carpometacarpal of thumb). **F.** Pivot (atlantoaxial).

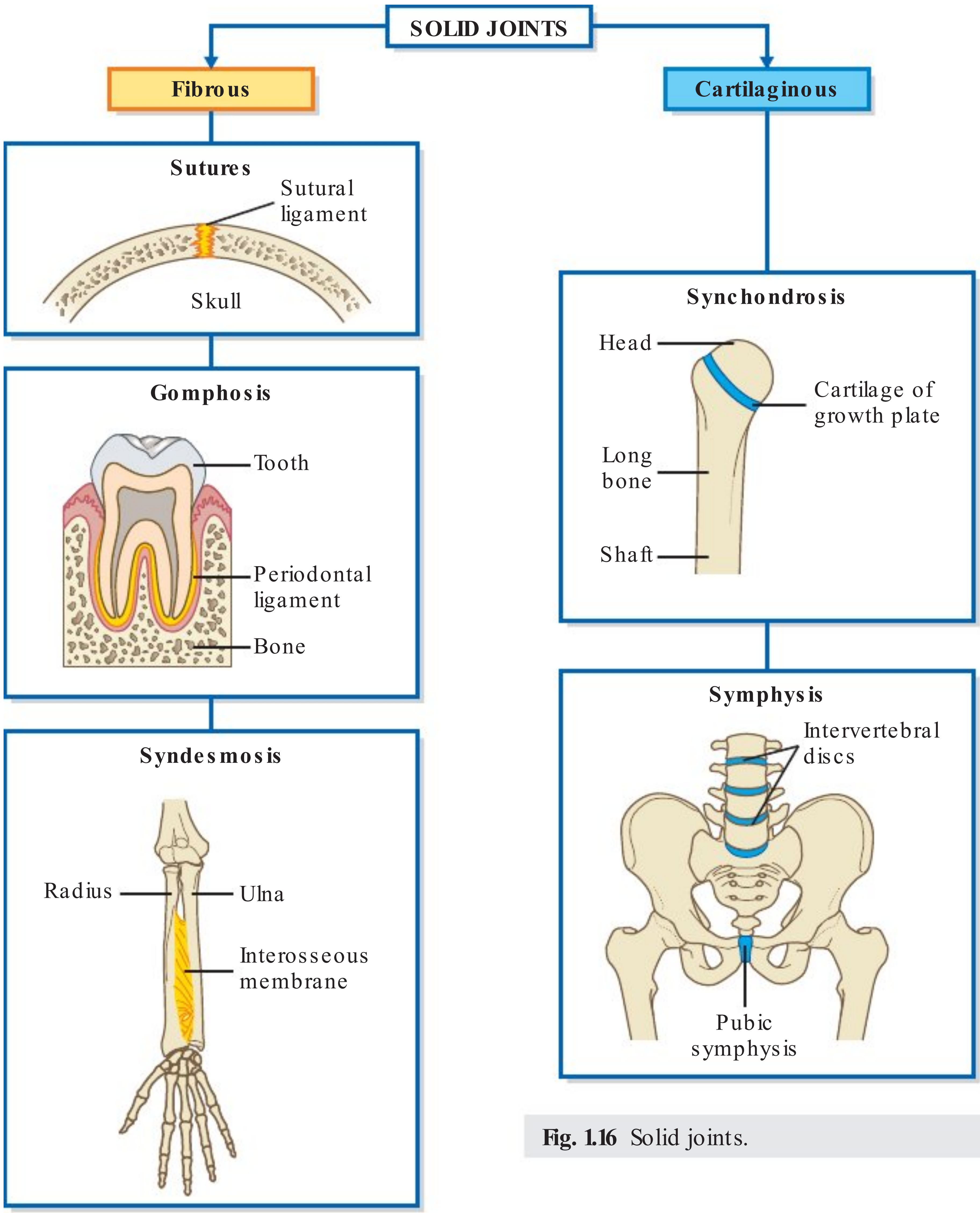

Fig. 1.16 Solid joints.

- Pivot joints—allow movement around one axis that passes longitudinally along the shaft of the bone; permit rotation (e.g., atlantoaxial joint)
- Bicondylar joints—allow movement mostly in one axis with limited rotation around a second axis; formed by two convex condyles that articulate with concave or flat surfaces (e.g., knee joint)
- Condylar (ellipsoid) joints—allow movement around two axes that are at right angles to each other; permit flexion, extension, abduction, adduction, and circumduction (limited) (e.g., wrist joint)
- Saddle joints—allow movement around two axes that are at right angles to each other; the articular surfaces are saddle shaped; permit flexion, extension, abduction, adduction, and circumduction (e.g., carpometacarpal joint of the thumb)
- Ball and socket joints—allow movement around multiple axes; permit flexion, extension, abduction, adduction, circumduction, and rotation (e.g., hip joint)

Solid joints

Solid joints are connections between skeletal elements where the adjacent surfaces are linked together either by fibrous connective tissue or by cartilage, usually fibrocartilage (Fig. 1.16). Movements at these joints are more restricted than at synovial joints.

Fibrous joints include sutures, gomphoses, and syndesmoses.

- **Sutures** occur only in the skull where adjacent bones are linked by a thin layer of connective tissue termed a *sutural ligament*.
- **Gomphoses** occur only between the teeth and adjacent bone. In these joints, short collagen tissue fibers in the periodontal ligament run between the root of the tooth and the bony socket.
- **Syndesmoses** are joints in which two adjacent bones are linked by a ligament. Examples are the ligamentum flavum, which connects adjacent vertebral laminae, and an interosseus membrane, which links, for example, the radius and ulna in the forearm.

Cartilaginous joints include synchondroses and symphyses.

- **Synchondroses** occur where two ossification centers in a developing bone remain separated by a layer of cartilage, for example the growth plate that occurs between the head and shaft of developing long bones.

These joints allow bone growth and eventually become completely ossified.

- **Symphyses** occur where two separate bones are interconnected by cartilage. Most of these types of joints occur in the midline and include the pubic symphysis between the two pelvic bones, and intervertebral discs between adjacent vertebrae.

Clinical app

Joint replacement

Joint replacement is undertaken for a variety of reasons. These predominantly include degenerative joint disease and joint destruction. Joints that have severely degenerated or lack their normal function are painful, which can be life limiting, and in otherwise fit and healthy individuals can restrict activities of daily living. In some patients the pain may be so severe that it prevents them from leaving the house and undertaking even the smallest of activities without discomfort.

Large joints are commonly affected, including the hip, knee, and shoulder. However, with ongoing developments in joint replacement materials and surgical techniques, even small joints of the fingers can be replaced.

Typically, both sides of the joint are replaced. In the hip joint the acetabulum will be reamed, and a plastic or metal cup will be introduced. The femoral component will be fitted precisely to the femur and cemented in place (Fig. 1.17).

Fig. 1.17 This is a radiograph, anterior-posterior view, of the pelvis after a right total hip replacement. There are additional significant degenerative changes in the left hip joint, which will also need to be replaced.

Clinical app

Degenerative joint disease

Degenerative joint disease is commonly known as osteoarthritis or osteoarthrosis. The disorder is related to aging but not caused by aging. Typically, there are decreases in water and proteoglycan content within the cartilage. The cartilage becomes more fragile and more susceptible to mechanical disruption. As the cartilage wears, the underlying bone becomes fissured and also thickens. Synovial fluid may be forced into small cracks that appear in the bone's surface, which produces large cysts. Furthermore, reactive juxta-articular bony nodules are formed (osteophytes). As these processes occur, there is slight deformation, which alters the biomechanical forces through the joint. This in turn creates abnormal stresses, which further disrupt the joint (Fig. 1.18).

Fig. 1.18 This radiograph demonstrates the loss of joint space in the medial compartment and presence of small spiky osteophytic regions in the joint.

Clinical app

Arthroscopy

Arthroscopy is a technique of visualizing the inside of a joint using a small camera placed through a tiny incision in the skin. Arthroscopy can be performed in most joints, including the elbow and wrist joints. However, it is most commonly performed in the knee, shoulder, ankle, and hip joints.

Arthroscopy allows the surgeon to view the inside of the joint and its contents. Notably, in the knee, the menisci and the ligaments are easily seen, and it is possible using separate puncture sites and specific instruments to remove the menisci and repair the cruciate ligaments. The advantages of arthroscopy are that it is performed through small incisions, it enables patients to quickly recover and return to normal activity, and it only requires either a light anesthetic or regional anesthesia during the procedure.

SKIN AND FASCIAS

Skin

The skin is the largest organ of the body. It consists of the epidermis and the dermis. The epidermis is the outer cellular layer of stratified squamous epithelium, which is avascular and varies in thickness. The dermis is a dense bed of vascular connective tissue.