Human Anatomy

Sixth Edition

Mc Graw Hill Education

Saladin

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Digital Author

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HUMAN ANATOMY, SIXTH EDITION

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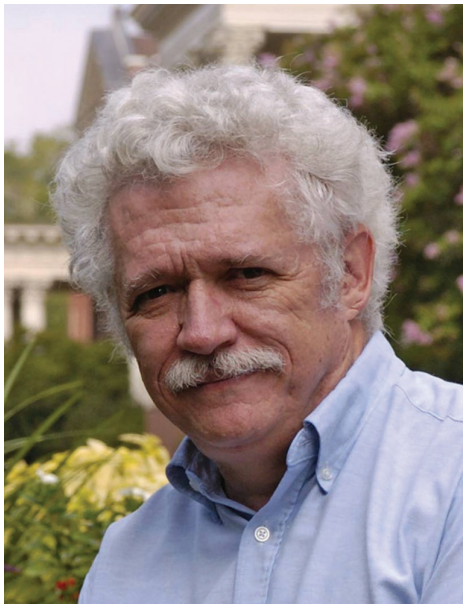
BRIEF CONTENTS

ABOUT THE AUTHORS

KENNETH SALADIN is Distinguished Professor of Biology, Emeritus, at Georgia College & State University. He received his B.S. in zoology at Michigan State University and his Ph.D. in parasitology at Florida State University and joined the Georgia College faculty in 1977. His courses have included human anatomy and physiology, introduction to medical physiology, histology, premedical seminar, and animal behavior, among others. He is a member of the Human Anatomy and Physiology Society, American Association of Anatomists, American Physiological Society, Society for Integrative and Comparative Biology, and American Association for the Advancement of Science. He is the author of the best-selling textbook *Anatomy & Physiology: The Unity of Form and Function* and coauthor, with Robin McFarland, of *Essentials of Anatomy & Physiology.* Ken has used the earnings from his textbooks to fund ecosystem conservation and restoration in the Galápagos Islands, to support the Charles Darwin Research Station in the Galápagos, to remodel and equip a Georgia College anatomy laboratory, to fund the Honors Program and the university's Natural History Museum, and to establish multiple student scholarships and an endowed chair in biomedical science and premedical mentoring. Ken and his wife Diane live in Milledgeville, Georgia, and have two adult children in North Carolina.



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CHRISTINA A. GAN, digital author for the Connect question bank and test bank, has been teaching anatomy and physiology, microbiology, and general biology at Highline College in Des Moines, Washington, since 2004. Before that she taught at Rogue Community College in Medford, Oregon, for six years. Christina earned her M.A. in biology from Humboldt State University, researching the genetic variation of mitochondrial DNA in various salmonid species, and is a member of the Human Anatomy and Physiology Society. When she is not in the classroom or developing digital media, she is climbing, mountaineering, skiing, kayaking, sailing, cycling, and mountain biking throughout the Pacific Northwest.

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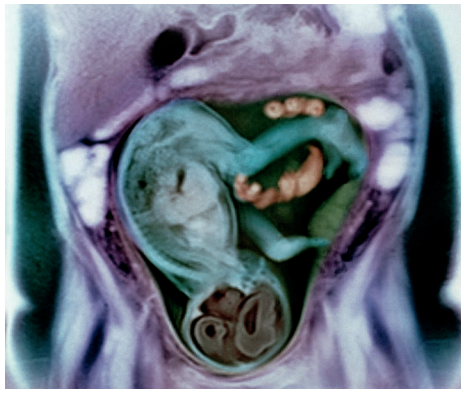


PREFACE

Saladin's *Human Anatomy* goes beyond descriptions of body structure to read as a story that weaves together basic science, clinical applications, the history of medicine, and the evolutionary basis of human structure. Saladin combines this humanistic perspective with vibrant photos and art to convey the beauty and excitement of the subject to beginning students.

Changes to the Sixth Edition

Attending scientific conferences, subscribing to several scientific and medical journals, and engaging in online forums and answering public questions on anatomy, physiology, and health help Ken Saladin stay abreast of advances in the field. In this edition, he introduces newly discovered functions of osteocytes, astrocytes, dendritic cells, the greater omentum, the corneal epithelium, and even eyelashes. He reports new research insights on peroxisome production, tracing white matter tracts of the brain, and endocrine disruptors; new discoveries of cerebral lymphatics, and pulmonary production of blood platelets; and clinical advances in asthma and cancer mortality and survival, cord blood transplants, stem-cell harvesting, and regenerative medicine. These and more examples are listed chapter by chapter later in this section.

In response to users and reviewers, the sixth edition has more concise treatments of gametogenesis, sperm capacitation, fertilization, aneuploidy, and embryology of the sense organs, cardiovascular system, and digestive tract. The muscle chapters are reorganized for better flow, with chapter 10 focusing on the cellular level; chapter 11 on whole-muscle organization, accessory connective tissues, musculoskeletal biomechanics, and the axial musculature; and chapter 12 on the appendicular musculature. Ken has also upgraded some of the book's pedagogical features. There are new, challenging thought questions, and the Study Guide section presents "What's Wrong with These Statements?"—10 statements that all have subtle errors, prompting students to identify what is wrong with them.

New and Enhanced Perspectives

This sixth edition details enhancements to topics already in the previous edition, including new anatomical imaging techniques, ethnic variations in anatomy, osteon structure and microfractures, vascular aging and hypertension, the scope of the immune system, T cell selection, clinical importance of the cricothyroid ligament, colonic histology, photosensory effects on the pineal gland, musculoskeletal biomechanics, and more.

New Art and Photography

This edition includes new drawings of motor units, sectional anatomy of the head, hand innervation, the course of the vagus nerve, the pediatric auditory tube, lumbar puncture, epidermal histology, flat bone structure, gastric and colonic histology, the mechanical advantage of levers, and the spermatic cord. Always watching for opportunities to enhance topics with photos or to replace old photos with better ones, this edition has new photos of diabetic gangrene, rickets, shingles, endemic goiter, muscle histochemistry, rod and cone cell SEMs, an intravenous pyelogram, and ovulation.

Detailed List of Changes

Chapter by chapter, the sixth edition's most significant changes are as follows:

Chapter 1, The Study of Human Anatomy, has added descriptions of dynamic spatial reconstruction, open MRI, and Doppler ultrasound.

Chapter 2, Cytology—The Study of Cells, has new clinical topics including mitochondrial diseases and birth defects arising from primary cilium dysfunctions. It has updates on mitochondrial DNA, the role of gap junctions in the lens and cornea, and peroxisome production. It describes the vascular corrosion cast technique seen in many of the book's SEM photos.

Chapter 3, Histology—The Study of Tissues, has new Clinical Applications on biopsy and regenerative medicine, and functional updates on urothelium (transitional epithelium) and epithelial basement membranes.

Chapter 4, Human Development, has reduced the level of detail, at reviewer and user suggestions, on gametogenesis, sperm capacitation, fertilization, and aneuploidy.

Chapter 5, The Integumentary System, has a new Clinical Application on sunscreens, sunburn, and skin cancer.

Chapter 6, The Skeletal System I: Bone Tissue, has new clinical coverage of osteomalacia, rickets, and osteosarcoma, and updates on osteoporosis, the endocrine role of osteocytes, and limitation of microfractures by osteon structure. It includes enhanced art on flat bone structure.

Chapter 7, The Skeletal System II: Axial Skeleton, has a new sectional view of the head and its cavities, and new clinical coverage of cleft palate and lip.

Chapter 8, The Skeletal System III: Appendicular Skeleton, had little need for change but has an upgraded illustration of the clavicle for improvement in its surface features.

Chapter 9, The Skeletal System IV: Joints, updates the material science of joint prostheses.

Chapter 10, The Muscular System I: Muscle Cells, has improved illustrations of the neuromuscular junction, motor units, and the histochemistry of muscle fiber types, and new clinical coverage of rigor mortis and fibromyalgia. Chapters 10 to 12 on the

muscular system are reorganized so that chapter 10 focuses on the cellular level; chapter 11 discusses the accessory connective tissues of muscle, whole-muscle structure and organization, musculoskeletal biomechanics, and the axial muscles; and chapter 12 discusses the appendicular muscles.

Chapter 11, The Muscular System II: Axial Musculature, now incorporates material moved from chapters 10 and 12 and has enhanced coverage of accessory connective tissues, muscle compartments, muscle–bone attachments, musculoskeletal biomechanics, a new illustration of lever biomechanics, and a clinical update on types and treatment of inguinal hernias.

Chapter 12, The Muscular System III: Appendicular Musculature, updates the treatment of carpal tunnel syndrome.

Chapter 13, The Nervous System I: Nervous Tissue, updates astrocyte functions and the role of electrical synapses in neuronal synchrony.

Chapter 14, The Nervous System II: Spinal Cord and Spinal Nerves, now covers lumbar puncture and adds new illustrations of shingles and the distribution of hand innervation from the brachial plexus.

Chapter 15, The Nervous System III: Brain and Cranial Nerves, has new drawings of regional functions of the cerebral cortex and distribution of the vagus nerve; new clinical coverage of stroke and trigeminal neuralgia; and scientific updates on brain senescence, functions of the red nucleus and insula, and mapping of the brain with diffusion tensor imaging.

Chapter 16, The Nervous System IV: Autonomic Nervous System and Visceral Reflexes, has a redrawn figure 16.2 to better compare sympathetic, parasympathetic, and somatic efferent pathways, and it expands slightly on pre- and postganglionic fibers and their neurotransmitters.

Chapter 17, The Nervous System V: Sense Organs, has scientific updates on the roles of the eyelashes, corneal epithelium, and vitreous body; new clinical coverage of phantom pain, macular degeneration, and diabetic retinopathy; new SEM photos of rod and cone cells; a new drawing of the pediatric and adult auditory tubes as related to middle-ear infection; and a more concise treatment of ear and eye embryology.

Chapter 18, The Endocrine System, has enhanced discussions of pineal gland innervation and function, melatonin, the endocrine pancreas, and endemic goiter (with a new photo), and a new interpretation of anterior pituitary chromophobes. It has new clinical coverage of congenital absence of the pituitary gland (panhypopituitarism) and hypo- and hyperthyroidism, and has added a basic pathophysiology of diabetes mellitus.

Chapter 19, The Circulatory System I: Blood, updates the status of cord blood transfusions and the harvesting of stem cells from circulating blood; enhances coverage of the role of blood circulation in thermoregulation and of the role of erythroblasts; and reports a startling new finding on where most blood platelets are produced.

Chapter 20, The Circulatory System II: The Heart, updates the treatment options for patent ductus arteriosis and has a more concise treatment of cardiac embryology.

Chapter 21, The Circulatory System III: Blood Vessels, gives an updated multicultural perspective on vascular aging and hypertension; adds new challenge questions on identifying arteries in a magnetic resonance angiogram and identifying blood vessels used for routine clinical purposes; and treats blood vessel embryology more concisely.

Chapter 22, The Lymphoid System and Immunity, now takes an expanded, more contemporary view of the meaning of *immune system.* It reports the recent discovery of cerebral lymphatics and has enhanced discussions of lymphatic vessel peristalsis and lymph flow, the maturation and selection of T cells, and the antigen-presenting role of dendritic cells.

Chapter 23, The Respiratory System, has improved descriptions of the nasal and tracheal mucosae, the bronchial tree, and the cricothyroid ligament in relation to tracheostomy. It updates asthma mortality rates and lung cancer survival, and reports the newly discovered role of the lungs in producing blood platelets.

Chapter 24, The Digestive System, has new clinical coverage of diverticulosis, diverticulitis, hepatitis, cirrhosis, gastroesophageal reflux disease, and gallstones. It has enhanced discussions of mesentery structure and omentum function; dental anatomy and proprioception; salivary gland innervation; anatomy of the ileocecal junction; and ethnic variation in colonic anatomy. It has new illustrations of histology of the stomach and colon, and a more concise treatment of GI embryology.

Chapter 25, The Urinary System, adds new coverage of intravenous pyelography and kidney stone treatment, and corrects a common misconception about female urethral sphincters.

Chapter 26, The Reproductive System, has added substantial new clinical content, with Clinical Applications and other discussions of varicocele, uterine fibroids, uterine cancer, endometriosis, sexually transmitted diseases, contraception, testicular cancer, male breast cancer, and male reproductive tract disorders. It has a new endoscopic photo of ovulation, a revision of penile anatomy to focus more on the uncircumcised state, and an update on environmental endocrine disruptors and their effect on fertility.

A Storytelling Writing Style

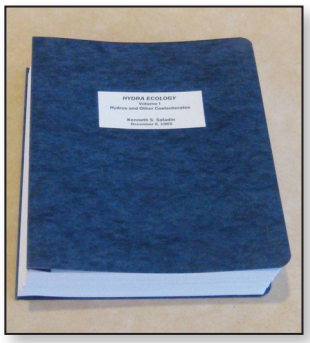
Students and instructors alike cite Saladin's prose style as the number one attraction of this book. Students doing blind comparisons of Ken Saladin's chapters and those of other anatomy books routinely find Saladin clearly written, easy to understand, and a stimulating, interesting read. Saladin's analogy-rich writing enables students to easily visualize abstract concepts in terms of everyday experience. Consider, for example, from chapter 13:

The dimensions of human neurons are more impressive when we scale them up to the size of familiar objects. If the soma of a spinal motor neuron was the size of a tennis ball, its dendrites would form a huge bushy mass that could fill a 30-seat classroom from floor to ceiling. Its axon would be up to a mile long but a little narrower than a garden hose. This is quite a point to ponder. The neuron must assemble molecules and organelles in its "tennis ball" soma and deliver them through its "mile-long garden hose" to the end of the axon.

EVOLUTION OF A STORYTELLER

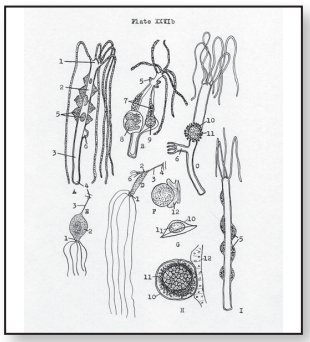
Ken Saladin's penchant for writing began early. For his tenth-grade biology class, he wrote a 318-page monograph on hydras with 53 original India ink drawings and 10 original photomicrographs. We at McGraw-Hill think of this as Ken's "first book." At a young age, Ken already was developing his technical writing style, research habits, and illustration skills.

Courtesy of Ken Saladin



Courtesy of Ken Saladin

Ken Saladin's "first book," *Hydra Ecology* (1965)

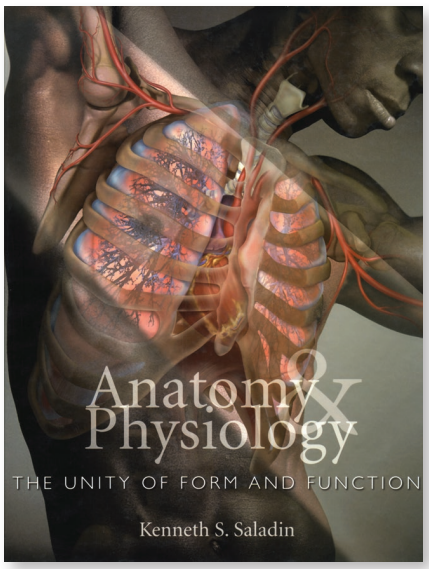


Courtesy of Ken Saladin

Some of Ken's first pen-and-ink artwork (1965)

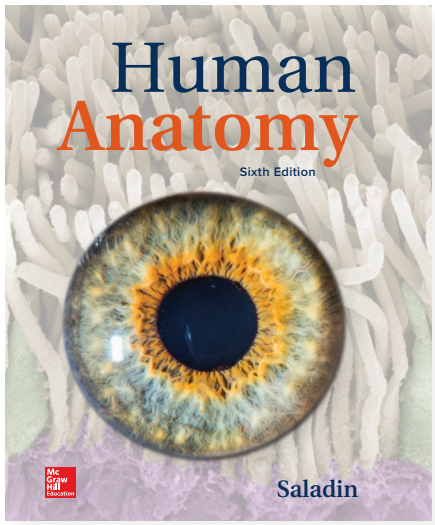
Courtesy of Ken Saladin

Ken in 1964

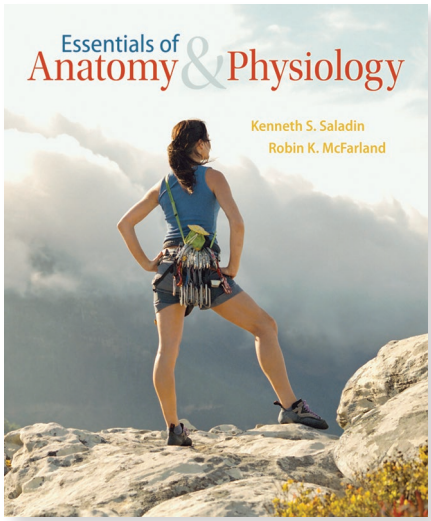


Ken's first textbook published in 1997

Ken served as an A&P textbook reviewer and testbank writer for several years and then embarked on his first book for McGraw-Hill in 1993. He published the first edition of *Anatomy & Physiology: The Unity of Form and Function* in 1997 and his first edition of *Human Anatomy* in 2004. The story continues with *Human Anatomy,* sixth edition.



The story continues in 2019



Essentials book published in 2013

Instructive Artwork for Visual Learners

Saladin's stunning illustrations and photos entice students who regard themselves as "visual learners."

Vivid Illustrations with rich textures and shading and bold, bright colors bring anatomy to life.

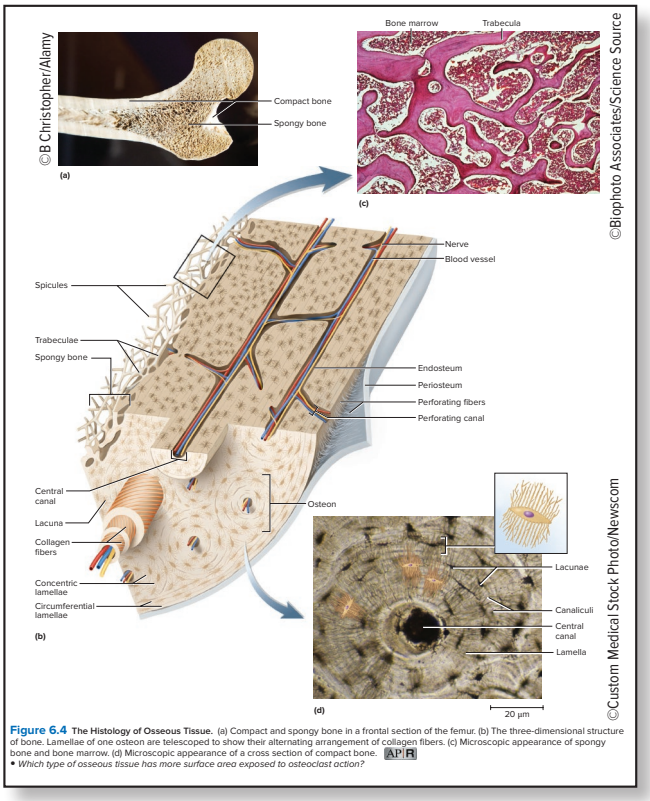


Figure 6.4 **The Histology of Osseous Tissue.** (a) Compact and spongy bone in a frontal section of the femur. (b) The three-dimensional structure of bone. Lamellae of one osteon are telescoped to show their alternating arrangement of collagen fibers. (c) Microscopic appearance of spongy bone and bone marrow. (d) Microscopic appearance of a cross section of compact bone. AP|R
• *Which type of osseous tissue has more surface area exposed to osteoclast action?*

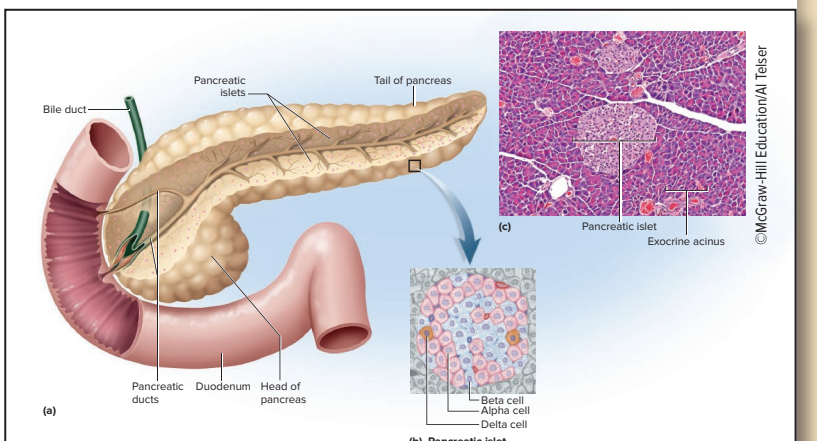


Figure 18.9 **The Pancreas.** (a) Gross anatomy and relationship to the duodenum. (b) Cells of a pancreatic islet. PP cells are not shown; they are few in number and cannot be distinguished with ordinary histological stains. (c) Light micrograph of a pancreatic islet amid the darker exocrine tissue.
• *What is the function of the exocrine cells in this gland?* AP|R

Process Figures relate numbered steps in the art with corresponding numbered text descriptions.

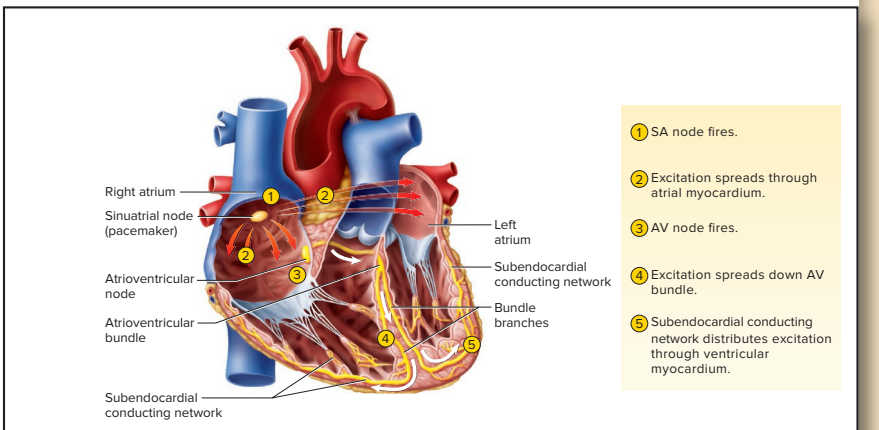


Figure 20.13 **The Cardiac Conduction System.** Electrical signals travel along the pathways indicated by the arrows.
• *Which atrium is the first to receive the signal that induces atrial contraction?*

Orientation Tools, such as dissection planes and a compass on the anatomical art, clarify the perspective from which a structure is viewed.

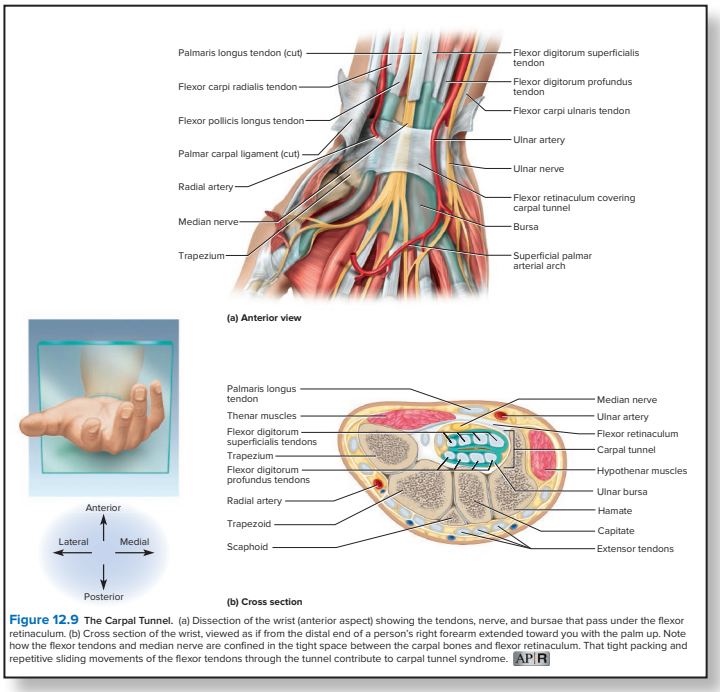


Figure 12.9 **The Carpal Tunnel.** (a) Dissection of the wrist (anterior aspect) showing the tendons, nerve, and bursae that pass under the flexor retinaculum. (b) Cross section of the wrist, viewed as if from the distal end of a person's right forearm extended toward you with the palm up. Note how the flexor tendons and median nerve are confined in the tight space between the carpal bones and flexor retinaculum. That tight packing and repetitive sliding movements of the flexor tendons through the tunnel contribute to carpal tunnel syndrome. AP R

The Psychology of Learning

Having taught human anatomy and histology for 40 years, Saladin knows what works in the classroom and incorporates those approaches into the pedagogy of *Human Anatomy.*

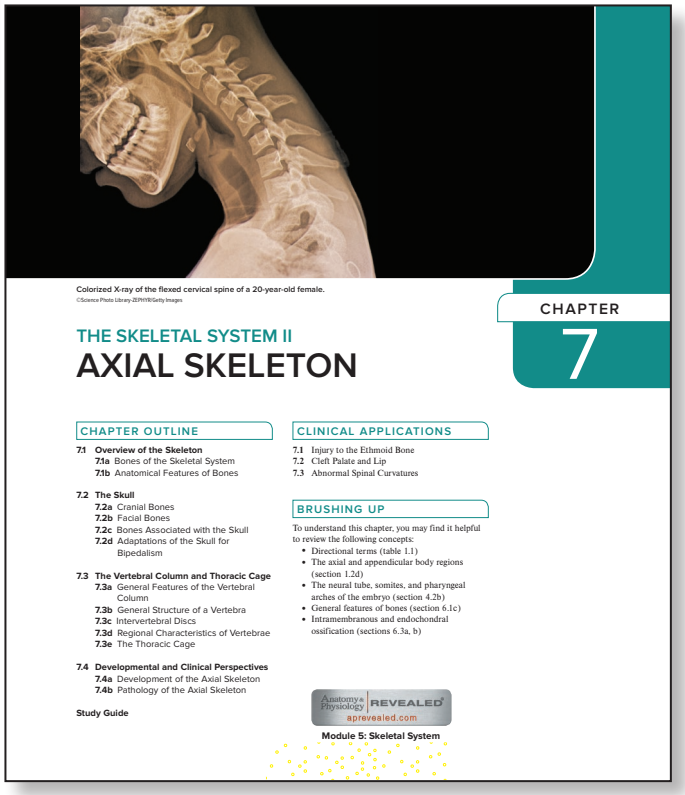
Chapters Organized for Preview and Review

Chapter Outline provides a content preview and facilitates review and study.

Clinical Applications pique the interest of health-science students by showing the clinical relevance of the core science.

Brushing Up reminds students of the relevance of earlier chapters to the one on which they are currently embarking.

Anatomy & Physiology REVEALED® icons indicate which area of this interactive cadaver dissection program corresponds to the chapter topic.



Colorized X-ray of the flexed cervical spine of a 20-year-old female.
©Science Photo Library-ZEPHYR/Getty Images

CHAPTER 7

THE SKELETAL SYSTEM II

AXIAL SKELETON

CHAPTER OUTLINE

CLINICAL APPLICATIONS

BRUSHING UP

To understand this chapter, you may find it helpful to review the following concepts:
- Directional terms (table 1.1)
- The axial and appendicular body regions (section 1.2d)
- The neural tube, somites, and pharyngeal arches of the embryo (section 4.2b)
- General features of bones (section 6.1c)
- Intramembranous and endochondral ossification (sections 6.3a, b)

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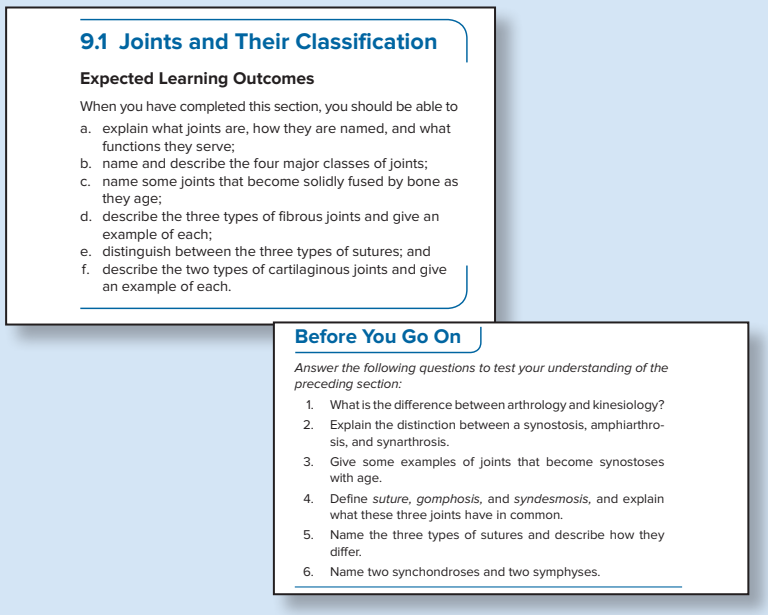
Module 5: Skeletal System



9.1 Joints and Their Classification

Expected Learning Outcomes

When you have completed this section, you should be able to

a. explain what joints are, how they are named, and what functions they serve;
b. name and describe the four major classes of joints;
c. name some joints that become solidly fused by bone as they age;
d. describe the three types of fibrous joints and give an example of each;
e. distinguish between the three types of sutures; and
f. describe the two types of cartilaginous joints and give an example of each.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

1. What is the difference between arthrology and kinesiology?
2. Explain the distinction between a synostosis, amphiarthrosis, and synarthrosis.
3. Give some examples of joints that become synostoses with age.
4. Define *suture*, *gomphosis*, and *syndesmosis*, and explain what these three joints have in common.
5. Name the three types of sutures and describe how they differ.
6. Name two synchondroses and two symphyses.

Reinforced Learning

Each section is a conceptually unified topic, framed between a pair of learning "bookends"—a set of learning objectives at the beginning and a set of review and self-testing questions at the end. Each section is numbered for easy reference in lecture, assignments, and ancillary materials. These "bookends" provide the student an optimistic impression of short, easily digestible sections manageable in short bits of reading time.

Expected Learning Outcomes give the student a preview of key points to be learned within the next few pages.

Before You Go On prompts the student to pause and spot-check his or her mastery of the previous few pages before progressing to new material.

Vocabulary Building

Several features help build a student's level of comfort with medical vocabulary.

Pronunciation Guides Knowing proper pronunciation is key to remembering and spelling terms. Saladin gives simple, intuitive "pro-NUN-see-AY-shun" guides to help students over this hurdle and widen the student's comfort zone for medical vocabulary.

Word Origins Accurate spelling and insight into medical terms are greatly enhanced by a familiarity with commonly used word roots, prefixes, and suffixes.

Footnotes throughout the chapters help build the student's working lexicon of word elements. An end-of-book Glossary provides clear definitions of the most important or frequently used terms.

Building Your Medical Vocabulary An exercise at the end of each chapter helps students creatively use their knowledge of new medical word elements.

Any point where two bones meet is called a **joint (articulation),** whether or not the bones are movable at that interface. The science of joint structure, function, and dysfunction is called **arthrology.**[1] The study of musculoskeletal movement is **kinesiology**[2] (kih-NEE-see-OL-oh-jee). This is a branch of **biomechanics,** which deals with a broad variety of movements and mechanical processes in the body, including the physics of blood circulation, respiration, and hearing.

[1]*arthro* = joint; *logy* = study of
[2]*kinesio* = movement; *logy* = study of

Building Your Medical Vocabulary

State a meaning of each word element and give a medical term from this chapter that uses it or a slight variation of it.

1. haplo-
2. gameto-
3. zygo-
4. tropho-
5. cephalo-
6. gyneco-
7. -genesis
8. syn-
9. meso-
10. terato-

Answers in appendix A

Self-Assessment Tools

Saladin provides students with abundant opportunities to evaluate their comprehension of concepts. A wide variety of questions from simple recall to analytical evaluation cover all six cognitive levels of Bloom's Taxonomy of Educational Objectives.

Before You Go On questions test simple recall and lower-level interpretation of information read in the previous few pages.

Apply What You Know tests a student's ability to think of the deeper implications or clinical applications of a point he or she just read.

Figure Legend Questions posed in many of the figure legends prompt the student to interpret the art and apply it to the reading.

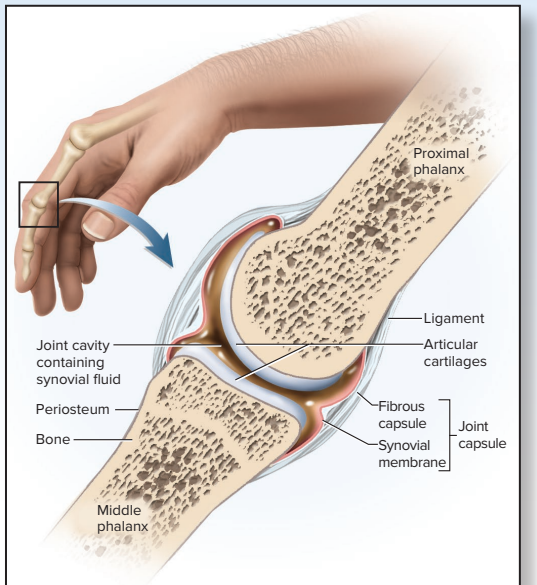


Figure 9.4 **Structure of a Simple Synovial Joint.** Most synovial joints are more complex than the interphalangeal joint shown here.
• *Why is a meniscus unnecessary in an interphalangeal joint?*

Apply What You Know

Martha is showing a sonogram of her unborn baby to her coworkers. Her friend Betty tells her she shouldn't have sonograms made because X-rays can cause birth defects. Is Betty's concern well founded? Explain.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

12. In what sense can spontaneous abortion be considered a protective mechanism?
13. Mutation and nondisjunction both produce chromosomal abnormalities. What is the difference between them?
14. Why is a baby more likely to be born with anatomical defects stemming from teratogen exposure at 30 days than from exposure at 10 days?

Testing Your Recall sections at the end of each chapter offer 20 simple recall questions to test retention of terminology and basic ideas.

What's Wrong with These Statements? requires students to concisely explain why the false statements are untrue.

Testing Your Comprehension questions are clinical application and other interpretive essay questions that require the student to apply the chapter's basic science to clinical or other scenarios.

Testing Your Recall

1. Below L2, the vertebral canal is occupied by a bundle of spinal nerve roots called
   a. the terminal filum.
   b. the descending tracts.
   c. the gracile fasciculus.
   d. the medullary cone.
   e. the cauda equina.
2. The brachial plexus gives rise to all of the following nerves *except*
   a. the axillary nerve.
   b. the radial nerve.
   c. the obturator nerve.
   d. the median nerve.
   e. the ulnar nerve.
3. Between the dura mater and vertebral bone, one is most likely to find
   a. arachnoid mater.
   b. denticulate ligaments.
   c. cartilage.
   d. adipose tissue.
   e. spongy bone.
4. Which of these tracts carries motor signals destined for the postural muscles?
   a. the gracile fasciculus
   b. the cuneate fasciculus
   c. the spinothalamic tract
   d. the vestibulospinal tract
5. A patient has a gunshot wound that caused a bone fragment to nick the spinal cord. The patient now feels no pain or temperature sensations from that level of the body down. Most likely, the _____ was damaged.
   a. gracile fasciculus
   b. medial lemniscus
   c. tectospinal tract
   d. lateral corticospinal tract
   e. spinothalamic tract
6. Which of these is *not* a region of the spinal cord?
   a. cervical
   b. thoracic
   c. pelvic
   d. lumbar
   e. sacral
7. In the spinal cord, the neurosomas of the lower motor neurons are found in
   a. the cauda equina.
   b. the posterior horns.
   c. the anterior horns.
   d. the posterior root ganglia.
   e. the funiculi.
8. The outermost connective tissue wrapping of a nerve is called
   a. the epineurium.
   d. the arachnoid mater.
   e. the dura mater.
9. The intercostal nerves between the ribs arise from which spinal nerve plexus?
   a. cervical
   b. brachial
   c. lumbar
   d. sacral
   e. none of them
10. All somatic reflexes share all of the following properties *except*
    a. they are quick.
    b. they are monosynaptic.
    c. they require stimulation.
    d. they are involuntary.
    e. they are stereotyped.
11. Outside the CNS, the neurosomas of neurons are clustered in swellings called _____.
12. Distal to the intervertebral foramen, a spinal nerve branches into a posterior and anterior _____.
13. The cerebellum receives feedback from the muscles and joints by way of the _____ tracts of the spinal cord.
14. Motor innervation of the leg proper comes predominantly from the _____ plexus.
15. Neural circuits called _____ in the spinal

What's Wrong with These Statements?

Briefly explain why each of the following statements is false, or reword it to make it true.

1. More people get rheumatoid arthritis than osteoarthritis.
2. A doctor who treats arthritis is called a kinesiologist.
3. Synovial joints are also known as synarthroses.
4. The lateral and medial menisci are shock-absorbing cartilages in the elbow joint.
5. Reaching behind you to take something out of your hip pocket involves hyperextension of the elbow.
6. The lateral and medial malleoli are protrusions of the two sides of the tibia in the tarsal region.
7. To stand on tiptoes to reach something on a high shelf, you would use dorsiflexion of the calcaneus.
8. At a cartilaginous joint, the facing surfaces of the two bones are covered with layers of cartilage and there is a narrow space with lubricating fluid between them.
9. Synovial fluid is secreted by the bursae.
10. Several sutures can be found in the long bones of the upper and lower limbs.

Answers in appendix A

Testing Your Comprehension

1. Why are there menisci in the knee joint but not in the elbow, the corresponding joint of the upper limb? Why is there an articular disc in the temporomandibular joint?
2. What ligaments would most likely be torn if you slipped and your foot was suddenly forced into an excessively inverted position: (a) the posterior talofibular and calcaneofibular ligaments, or (b) the medial ligament? Explain. What would the resulting condition of the ankle be called?
3. In order of occurrence, list the joint actions (flexion, pronation, etc.) and the joints where they would occur as you (a) sit down at a table, (b) reach out and pick up an apple, (c) take a bite, and (d) chew it. Assume that you start in anatomical position.
4. What structure in the elbow joint serves the same purpose as the anterior cruciate ligament (ACL) of the knee?
5. List the six types of synovial joints and for each one, if possible, identify a joint in the upper limb and a joint in the lower limb that fall into each category. Which of these six joints have no examples in the lower limb?

CLINICAL APPLICATION 14.2

Poliomyelitis and Amyotrophic Lateral Sclerosis

Poliomyelitis[15] and *amyotrophic lateral sclerosis*[16] (ALS) are two diseases that result from the destruction of motor neurons. In both diseases, the skeletal muscles atrophy from lack of innervation.

Poliomyelitis (polio) is caused by the poliovirus, which destroys motor neurons in the brainstem and anterior horn of the spinal cord. Signs of polio include muscle pain, weakness, and loss of some reflexes, followed by paralysis, muscular atrophy, and sometimes respiratory arrest. The virus spreads through water contaminated by feces. Historically, polio afflicted many children who contracted the virus from contaminated public swimming pools. For a time, the polio vaccine nearly eliminated new cases, but the disease has lately begun to reemerge among children in some countries because of antivaccination politics.

ALS is also known as Lou Gehrig[17] disease after the baseball player who succumbed to it. It is marked not only by the degeneration of motor neurons and atrophy of the muscles, but also sclerosis (scarring) of the lateral regions of the spinal cord—hence its name. Most cases occur when astrocytes fail to reabsorb the neurotransmitter glutamate from the tissue fluid, allowing it to accumulate to a neurotoxic level. The early signs of ALS include muscular weakness and difficulty in speaking, swallowing, and using the hands. Sensory and intellectual functions remain unaffected, as evidenced by the accomplishments of astrophysicist and best-selling author Stephen Hawking (fig. 14.7), who was stricken with ALS while he was in college. Despite near-total paralysis, he had a slowly progressive form of the disease, remained intellectually undiminished, and communicated with the aid of a speech synthesizer and computer. Tragically, many people are quick to assume that those who have lost most of their ability to communicate their ideas and feelings have no ideas and feelings to communicate. To a victim, this may be more unbearable than the loss of motor function itself.

Figure 14.7 Stephen Hawking (1942–2018). "When I was first diagnosed with ALS, I was given two years to live. Now 45 years later, I am doing pretty well" (CNN interview, 2010).

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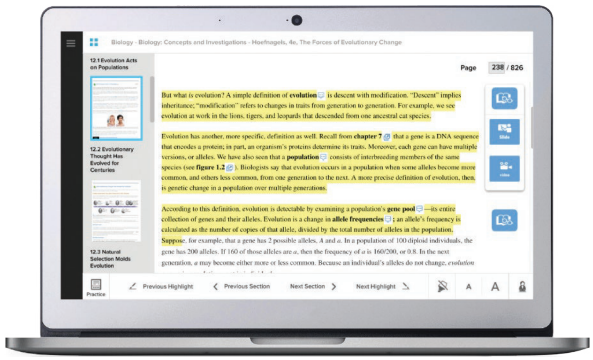

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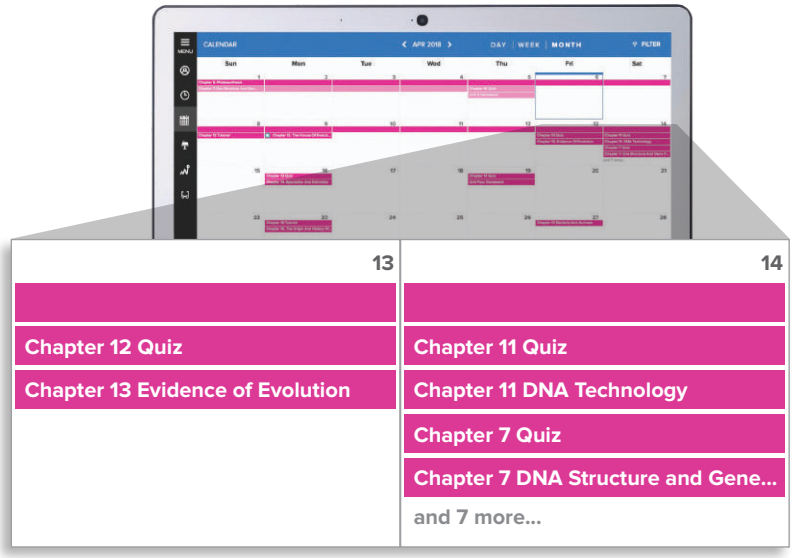

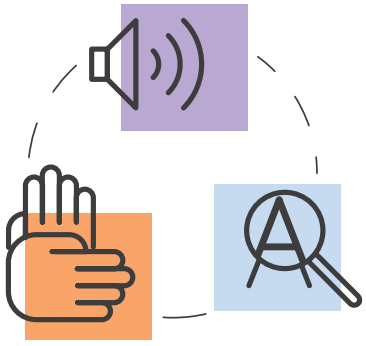

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I wish to thank the hundreds of colleagues who have reviewed my writing over the years and tremendously contributed to the factual accuracy, scientific currency, and presentation style of the book before you. Much of this has come about through revising my flagship book, *Anatomy & Physiology: The Unity of Form and Function,* through eight editions. *Human Anatomy* and my book coauthored with Robin McFarland, *Essentials of Anatomy & Physiology,* have derived their own content improvements as they follow in the wake of the heavily reviewed two-semester textbook.

I wish to thank specifically all of the reviewers of the fifth edition text (listed below). Their feedback has been instrumental to the revision process for this sixth edition. In addition to these commissioned reviews of my chapters, spontaneous feedback from other instructors and from students all over the world has been enormously stimulating and helpful in the incessant effort to approach that elusive asymptote called textbook perfection. I'm deeply appreciative of all the encouragement, information, corrections, and suggestions these readers have sent, and I look forward to many more years of such productive correspondence.

Christina Gan updated the question bank and test bank to closely correlate with the intricate changes made in this sixth edition, and greatly increased the educational value of these books through her work to create self-assessment tools and align McGraw-Hill's Connect resources with the textbook. This has contributed greatly to student and instructor satisfaction with our overall package of learning media, and to the students' success as they master A&P en route to their career aspirations. I am delighted to have Christina on my team.

I would also like to extend appreciation to members of the Life Sciences Book Team at McGraw-Hill Education who have worked with me on this project, including Matthew Garcia, Portfolio Manager; Donna Nemmers, Senior Product Developer; Vicki Krug, Senior Content Project Manager; Lori Hancock, Lead Content Licensing Specialist; Brent dela Cruz, Senior Content Project Manager; David Hash, Lead Designer; and Jeanne Patterson, freelance copy editor. Their efforts have yielded another great edition of the text and its companion media suite of Connect products.

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LETTER TO STUDENTS

Dear Students,

When I was a young boy, I became interested in what I then called "nature study" for two reasons. One was the sheer beauty of nature. I reveled in children's books with abundant, colorful drawings and photographs of animals, plants, minerals, and gems. It was this esthetic appreciation of nature that made me want to learn more about it and made me happily surprised to discover I could make a career of it. At a slightly later age, another thing that drew me still deeper into biology was to discover writers who had a way with words—who could captivate my imagination and curiosity with their elegant prose. Once I was old enough to hold part-time jobs, I began buying zoology and anatomy books that mesmerized me with their gracefulness of writing and fascinating art and photography. I wanted to write and draw like that myself, and I began learning from "the masters." I spent many late nights in my room peering into my microscope and jars of pond water, typing page after page of manuscript, and trying pen and India ink as an art medium. My "first book" was a 318-page paper on some little pond animals called hydras, with 53 illustrations, that I wrote for my tenth-grade biology class when I was 16.

Fast forward about 30 years to when I became a textbook writer, and I found myself bringing that same enjoyment of writing and illustrating to my own anatomy and physiology textbooks. Why? Not only for its intrinsic creative satisfaction, but because I'm guessing that you're like I was—you can appreciate a book that does more than simply give you the information you need. You appreciate, I trust, a writer who makes it *enjoyable* for you through scientific, storytelling prose and a conceptualized way of illustrating things to spark interest and facilitate understanding. Some of you probably think of yourselves as "visual learners" and others as "verbal learners." Either way, I hope this book will serve your learning style.

I know from my own students, however, that you need more than captivating illustrations and enjoyable reading. Let's face it—A&P is a complex subject and it may seem a formidable task to acquire even a basic knowledge of the human body. It was difficult even for me to learn (and the learning never ends). So in addition to simply writing this book, I've given a lot of thought to pedagogy—the art of teaching. I've designed my chapters to make them easier for you to study and to give you abundant opportunity to check whether you've understood what you read—to test yourself (as I advise my own students) before the instructor tests you. Christina Gan, digital author, also produces rich Connect interactive questions that test your understanding as you progress through each chapter. Students have commended these online questions as extremely helpful in learning human anatomy.

Each chapter is broken down into short, digestible bits with a set of learning goals (Expected Learning Outcomes) at the beginning of each section, and self-testing questions (Before You Go On) just a few pages later. Even if you have just 30 minutes to read during a lunch break or a bus ride, you can easily read or review one of these brief sections. There are also numerous self-testing questions at the end of each chapter, in some of the figure legends, and the occasional Apply What You Know questions dispersed through each chapter. The questions cover a broad range of cognitive skills, from simple recall of a term to your ability to evaluate, analyze, and apply what you've learned to new clinical situations or other problems.

The Guided Tour takes you through the learning aids we've created for you within the book itself and additional study aids available within Connect. I hope you will take a little time to look at the Guided Tour to see what we have to offer you.

I hope you enjoy your study of this book, but I know there are always ways to make it even better. Indeed, what quality you may find in this edition owes a great deal to feedback I've received from students all over the world. If you find any typos or other errors, if you have any suggestions for improvement, if I can clarify a concept for you, or even if you just want to comment on something you really like about the book, I hope you'll feel free to write to me. I correspond quite often with students and would enjoy hearing from you.

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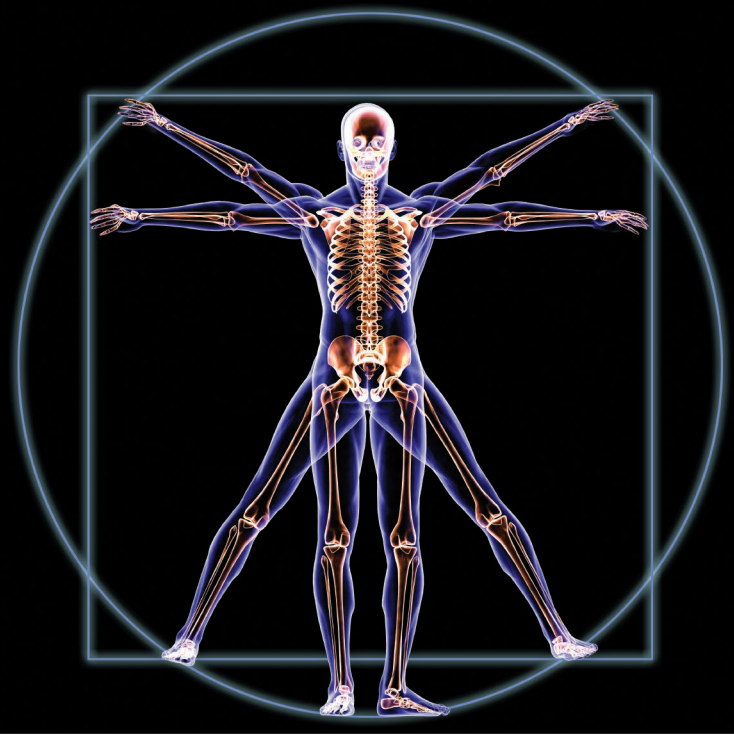

Colorized X-ray of the human skeleton in the style of Leonardo da Vinci's *Vitruvian Man*

PART ONE

CHAPTER 1

THE STUDY OF HUMAN ANATOMY

CHAPTER OUTLINE

CLINICAL APPLICATIONS

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Module 1: Body Orientation

This book is an introduction to the structure of the human body. It is meant primarily to provide a foundation for advanced study in fields related to health and fitness. Beyond that purpose, however, the study of anatomy can also provide a satisfying sense of self-understanding. Even as children, we're curious about what's inside the body. Dried skeletons, museum exhibits, and beautifully illustrated atlases of the body have long elicited widespread public fascination.

This chapter lays a foundation for our study of anatomy by considering some broad, unifying themes. We will consider what this science encompasses and what methods are used for the study of anatomy. We will lay out a general "road map" of the human body to provide a context for the chapters that follow. We will also get some insights into how a beginning anatomy student can become comfortable with medical terminology.

1.1 The Scope of Human Anatomy

Expected Learning Outcomes

When you have completed this section, you should be able to

a. define *anatomy* and some of its subdisciplines;
b. name and describe some approaches to studying anatomy;
c. describe some methods of medical imaging; and
d. discuss the variability of human anatomy.

Human anatomy is the study of the structural basis of body function. It provides an essential foundation for understanding **physiology,** the functional relevance of that structure; anatomy and physiology together are the bedrock of the health sciences. You can study human anatomy from an atlas; yet as beautiful, fascinating, and valuable as atlases are, they teach almost nothing but the locations, shapes, and names of things. This book is different; it deals with what biologists call **functional morphology**[1]—not just the structure of organs, but the functional reasons behind it.

Anatomy and physiology complement each other; each makes sense of the other, and each molds the other in the course of human development and evolution. Thus, we can say that the human body exhibits a *unity of form and function.* We can't delve into the details of physiology in this book, but enough will be said of function to help you make sense of human structure and to more deeply appreciate the beauty of human form.

1.1a The Anatomical Sciences

Anatomy is an ancient human interest, undoubtedly older than any written language we know. We can only guess when people began deliberately cutting into human bodies out of curiosity, simply to know what was inside. Some of the earliest and most influential books of anatomy were written by the Greek philosopher Aristotle (384–322 BCE), the Greek physician Galen (129–c. 200 CE), and the Persian physician Avicenna (Ibn Sina, 980–1037 CE). For nearly 1,500 years, medical professors in Europe idolized these "ancient masters" and considered their works above reproach. Modern human anatomy, however, dates to the sixteenth century, when Flemish physician and professor Andreas Vesalius (1514–64) questioned the accuracy of the earlier authorities and commissioned the first accurate anatomical illustrations for his book, *De Humani Corporis Fabrica* (*On the Structure of the Human Body,* 1543) (fig. 1.1). The tradition begun by Vesalius has been handed down to us through such famous contemporary works as *Gray's Anatomy,* Frank Netter's *Atlas of Human Anatomy,* and many others, to the richly illustrated textbooks used by college students today.

For all its attention to the deceased body, or **cadaver,**[2] human anatomy is hardly a "dead science." New techniques of study continually produce exciting new insights into human structure and its functional relevance; anatomists have discovered far more about the human body in the last century than in the 2,500 years before. Anatomy now embraces several subdisciplines that study human structure from different perspectives. **Gross anatomy** is the study of structure visible to the naked eye, using methods such as surface observation, dissection, X-rays, and MRI scans. **Surface anatomy** is the external structure of the body, and is especially important in conducting a physical examination of a patient. **Radiologic anatomy** is the study of internal structure, using X-rays and other medical imaging techniques described in the next section.

Systemic anatomy is the study of one organ system at a time and is the approach taken by most introductory textbooks such as this one. **Regional anatomy** is the study of multiple organ systems at once in a given region of the body, such as the head or chest. (See the Atlas of Regional and Surface Anatomy following chapter 12.) Medical schools and anatomy atlases typically teach anatomy from a regional perspective, because it is more practical to dissect all structures of the head and neck, the chest, or a limb, than it would be to try to dissect the entire digestive system, then the cardiovascular system, and so forth. Dissecting one system almost invariably destroys organs of other systems that stand in the way. Furthermore, as surgeons operate on a particular area of the body, they must think from a regional perspective and attend to the interrelationships of all structures in that area.

Ultimately, the structure and function of the body result from its individual cells. To see those, we usually take tissue specimens, thinly slice and stain them, and observe them under the microscope. This approach is called **histology (microscopic anatomy). Histopathology**[3] is the microscopic examination of tissues for signs of disease. **Cytology**[4] is the study of the structure and function of individual cells. Many important aspects of human structure are so small we can see them only with the electron microscope (see chapter 2, section 2.1). Structure at the subcellular to molecular level is called **ultrastructure.**

1.1b Methods of Study

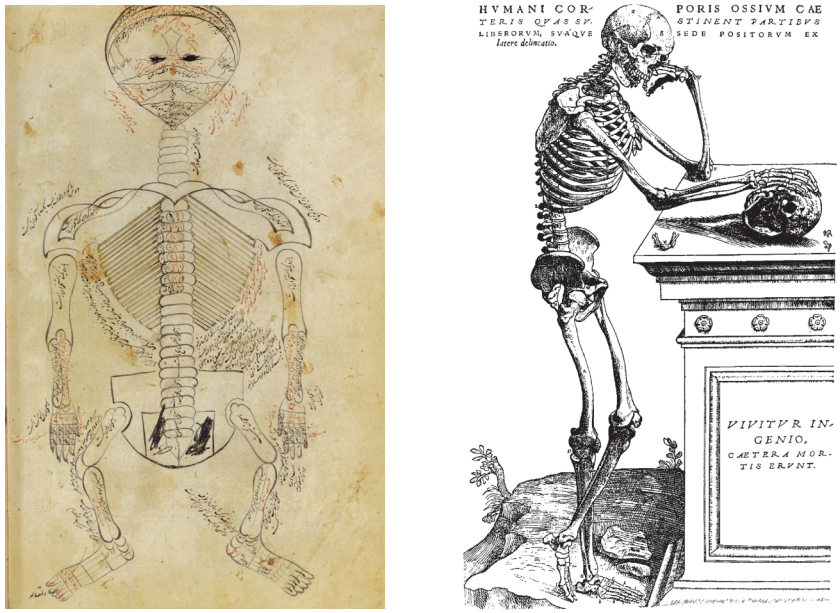
There are several ways to examine the structure of the human body. The simplest is **inspection**—simply looking at the body's appearance in careful detail, as in performing a physical examination or making a clinical diagnosis from surface appearance. Observations of the

[1] *morpho* = form, structure; *logy* = study of

[2] from *cadere* = to fall down or die

[3] *histo* = tissue; *patho* = disease; *logy* = study of

[4] *cyto* = cell; *logy* = study of



(a) (b)

Figure 1.1 **Evolution of Medical Art.** Two illustrations of the skeletal system made about 500 years apart. (a) From an eleventh-century work attributed to Persian physician Avicenna. (b) From *De Humani Corporis Fabrica* (1543) by Andreas Vesalius.

skin and nails, for example, can provide clues to such underlying problems as vitamin deficiencies, anemia, heart disease, and liver disease. Physical examinations involve not only looking at the body for signs of normalcy or disease, but also touching and listening to it. **Palpation**[5] means feeling a structure with the hands, such as palpating a swollen lymph node or taking a pulse. **Auscultation**[6] (AWS-cul-TAY-shun) is listening to the natural sounds made by the body, such as heart and lung sounds. In **percussion,** the examiner taps on the body, feels for abnormal resistance, and listens to the emitted sound for signs of abnormalities such as pockets of fluid, air, or scar tissue.

A deeper understanding of the body depends on **dissection** (dis-SEC-shun)—the careful cutting and separation of tissues to reveal their relationships. The very words *anatomy*[7] and *dissection*[8] both mean "cutting apart"; until the nineteenth century, dissection was called "anatomizing." In many schools of health science, cadaver dissection is one of the first steps in the training of students.

Dissection, of course, is not the method of choice when studying a living person! Not long ago, it was common to diagnose disorders through **exploratory surgery**—opening the body and taking a look inside to see what was wrong and what could be done about it. Any breach of the body cavities is risky, however, and most exploratory surgery has now been replaced by **medical imaging** techniques—methods of viewing the inside of the body without surgery. The branch of medicine concerned with imaging is called **radiology.** Anatomy learned in this way is called **radiologic anatomy,** and those who use radiologic methods for clinical purposes include **radiologists** and **radiologic technicians.**

Some radiologic methods involve high-energy **ionizing radiation** such as X-rays or particles called positrons. These penetrate the tissues and can be used to produce images on X-ray film or through electronic detectors. The benefits of ionizing radiation must always be weighed against its risks. It is called *ionizing* because it ejects electrons from the atoms and molecules it strikes. This effect can cause mutation and trigger cancer, so ionizing radiation cannot be used indiscriminately. Used judiciously, however, the benefits of a mammogram or dental X-ray substantially outweigh the small risk.

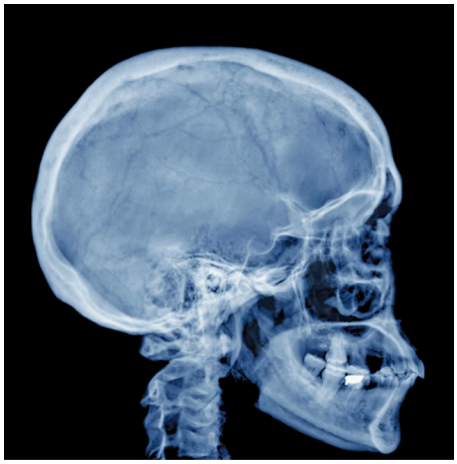
Some of the imaging methods to follow are considered *noninvasive* because they do not involve any penetration of the skin or body orifices. *Invasive* imaging techniques may entail inserting ultrasound probes into the esophagus, vagina, or rectum to get closer to the organ to be imaged, or injecting substances into the bloodstream or body passages to enhance image formation.

Any anatomy student today must be acquainted with the basic techniques of radiology and their respective advantages and limitations. Many of the images printed in this book have been produced by the following techniques.

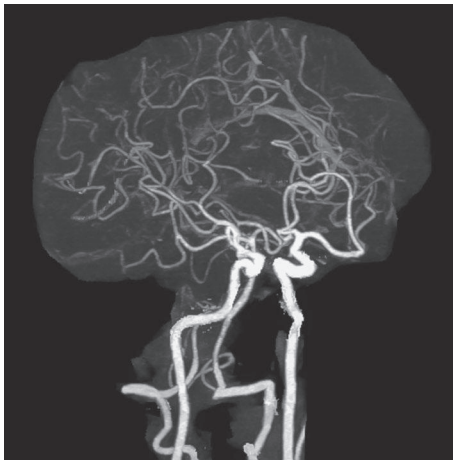
Radiography

Radiography, first performed in 1895, is the process of photographing internal structures with X-rays. Until the 1960s, this was the only widely available imaging method; even today, it accounts for more than 50% of all clinical imaging. X-rays pass through the soft tissues of the body to a photographic film or detector on the other side, where they produce relatively dark images. They are absorbed, however, by dense matter such as bones, teeth, tumors, and tuberculosis nodules, which leave the image lighter in these areas (fig. 1.2a). The term *X-ray* also applies to a photograph *(radiograph)* made by this method. Radiography is commonly used in dentistry, mammography, diagnosis of fractures, and examination of the chest. Hollow organs can be visualized by filling them with a **contrast medium** that absorbs X-rays. Barium sulfate, for example, is given orally for examination of the esophagus, stomach, and small intestine, or by enema for examination of the large

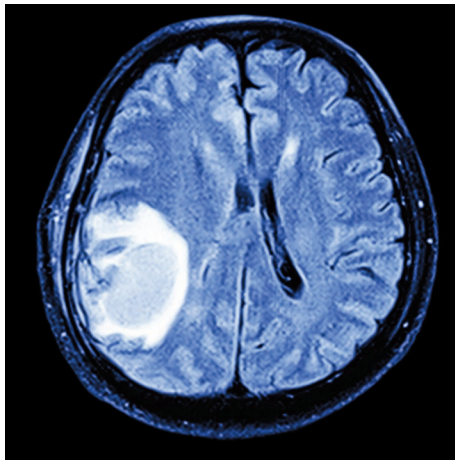
[5]*palp* = touch, feel; *ation* = process
[6]*auscult* = listen; *ation* = process
[7]*ana* = apart; *tom* = cut
[8]*dis* = apart; *sect* = cut



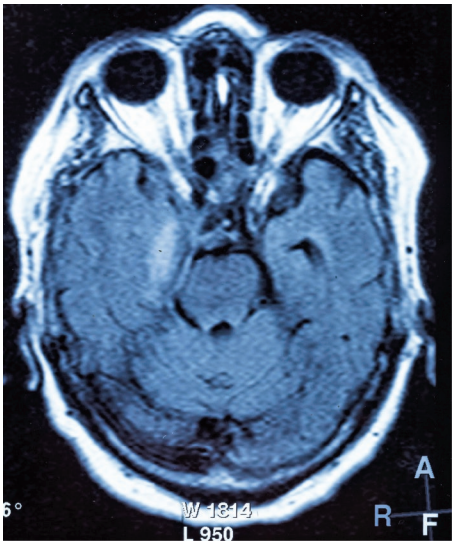
(a) X-ray (radiograph)



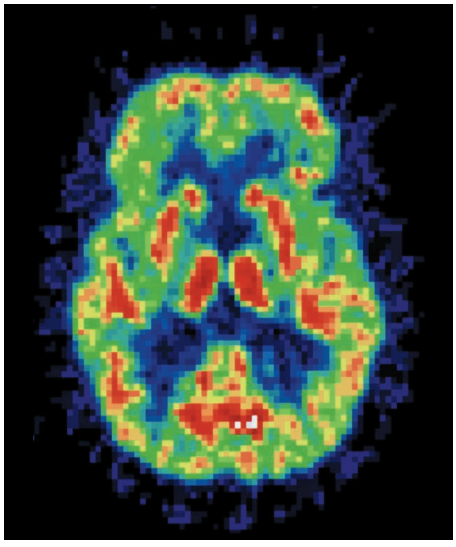
(b) Cerebral angiogram



(c) Computed tomographic (CT) scan



(d) Magnetic resonance image (MRI)



(e) Positron emission tomographic (PET) scan

Figure 1.2 Radiologic Images of the Head. (a) X-ray (radiograph) showing the bones and teeth. (b) An angiogram of the cerebral blood vessels. (c) A CT scan showing a brain tumor. (d) An MRI scan at the level of the eyes. (e) A PET scan of the brain. The metabolic activity of brain regions is indicated by colors from red (greatest activity) to yellow to green to blue (lowest activity, representing brain cavities filled with cerebrospinal fluid).
• *What structures are seen better by MRI than by X-ray? What structures are seen better by X-ray than by PET?*

(a) ©Science Photo Library/Alamy Stock Photo; (b) ©pang_oasis/Shutterstock; (c) ©Puwadol Jaturawutthichai/Alamy Stock Photo; (d) ©Alamy; (e) ©Lawrence Berkeley National Library/Getty Images

intestine. Other substances are given by injection for *angiography,* the examination of blood vessels (fig. 1.2b). Some disadvantages of radiography are that images of overlapping organs can be confusing and slight differences in tissue density are not easily detected.

Blood vessels can be seen much more sharply, however, with a new radiographic method called *digital subtraction angiography (DSA).* This entails taking X-rays before and after injecting a contrast medium into a vessel. A computer then "erases" the first image from the second, leaving a clear, dark image of just the injected vessels without the overlying and surrounding tissues. This is useful for showing vascular blockages and anatomical malformations, abnormalities of cerebral blood flow, and narrowing (stenosis) of renal arteries, and as an aid in threading catheters into blood vessels.

Computed Tomography

Computed tomography (a **CT scan**) is a more sophisticated application of X-rays. The patient is moved through a ring-shaped machine that emits low-intensity X-rays on one side and receives them with a detector on the opposite side. A computer analyzes signals from the detector and produces an image of a "slice" of the body about as thin as a coin (fig. 1.2c). The computer can "stack" a series of these images to construct a three-dimensional image of the body. CT scanning has the advantage of imaging thin sections of the body, so there is little organ overlap and the image is much sharper than a conventional X-ray. It requires extensive knowledge of cross-sectional anatomy to interpret the images. CT scanning is useful for identifying tumors, aneurysms, cerebral hemorrhages, kidney stones, and other abnormalities.

The **dynamic spatial reconstructor (DSR)** is a modified CT scanner that produces dynamic, three-dimensional video images rather than two-dimensional static ones. It shows organ motion and volume changes, and is valuable for visualizing heart movements and blood flow.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) (fig. 1.2d) is better than CT for visualizing soft tissues. The patient lies in either a tube or an open-sided scanner surrounded by a powerful electromagnet. Hydrogen atoms in the patient's tissues alternately align themselves with this magnetic field and with a radio-frequency field turned on and off by the technologist. These changes in hydrogen alignment generate signals that are analyzed by computer to produce an anatomical

image. MRI can "see" clearly through the skull and spine to produce images of the nervous tissue within, and it is better than CT for distinguishing between soft tissues such as the white and gray matter of the brain. It has some disadvantages, however, such as the claustrophobic feeling some patients experience in the scanner, loud noises generated by the machine, and long exposure times that prevent sharp images being made of the constantly moving stomach and intestines. Open-sided MRI machines are favored by some claustrophobic or obese patients, but have weaker magnetic fields, produce poorer images, and may miss important tissue abnormalities.

Functional MRI (fMRI) is a form of MRI that visualizes moment-to-moment changes in tissue physiology; fMRI scans of the brain, for example, show shifting patterns of activity as the brain applies itself to a specific task. This method has been very useful in clarifying which parts of the brain are involved in emotions, thought, language, sensation, and movement.

Positron Emission Tomography

Positron emission tomography (the **PET scan**) is used to assess the metabolic state of a tissue and to distinguish which tissues are most active at a given moment (fig. 1.2e). The procedure begins with an injection of radioactively labeled glucose, which emits positrons (electron-like particles with a positive charge). When a positron and electron meet, they annihilate each other and give off gamma rays that can be detected by sensors and processed by computer. The result is a color image that shows which tissues were using the most glucose. In cardiology, PET scans can show the extent of tissue death from a heart attack. Since damaged tissue consumes little or no glucose, it appears dark. In neuroscience, PET scans can similarly reveal the extent of brain damage from stroke or trauma. PET scans are also used to diagnose cancer and evaluate tumor status; they can often reveal small tumors earlier than they would be detected by CT or MRI. The PET scan is an example of **nuclear medicine**—the use of radioisotopes to treat disease or to form diagnostic images of the body.

Sonography

Sonography[9] is the second oldest and second most widely used method of imaging. A handheld device pressed against the skin emits high-frequency ultrasound waves and receives the signals reflected back from internal organs. Sonography avoids the harmful effects of X-rays, and the equipment is relatively inexpensive and portable. Its primary disadvantages are that it cannot penetrate bone and it usually does not produce a very sharp image. Although sonography was first used medically in the 1950s, images of significant clinical value had to wait until computer technology had developed enough to analyze differences in the way tissues reflect ultrasound. Sonography is not very useful for examining bones or lungs, but it is the method of choice in obstetrics, where the image *(sonogram)* can be used to locate the placenta and evaluate fetal age, position, and development (fig. 1.3). Sonography can also be used to view tissues in motion, such as fetal movements, a beating heart, and blood ejection from the heart. Sonographic imaging of the beating heart is called *echocardiography.* A *Doppler ultrasound scan* is a sonographic method for visualizing heart actions and the flow of blood through the vessels.

[9] *sono* = sound; *graphy* = recording process

Figure 1.3 **Fetal Sonography.** (a) A patient getting a fetal sonogram. (b) A three-dimensional fetal image made at 32 weeks of gestation.
• *Why is sonography safer for the fetus than radiography or computed tomography?*
(a) ©Keith Brofsky/Getty Images; (b) ©Kenneth Saladin

Apply What You Know

The concept of MRI was conceived in 1948 but could not be put into clinical practice until the 1970s. Speculate on a possible reason for this delay.

1.1c Variation in Human Structure

A quick look around any classroom is enough to show that no two humans look exactly alike; on close inspection, even identical twins exhibit differences. Anatomy atlases and textbooks can easily give you the impression that everyone's internal anatomy is the same, but this simply is not true. Books such as this one can teach you only the most common structure—the anatomy seen in approximately 70% or more of people. Someone who thinks that all human bodies are the same internally would make a confused medical student or an incompetent surgeon.

Some people completely lack certain organs. For example, most of us have a *palmaris longus* muscle in the forearm and a *plantaris* muscle in the leg, but not everyone. Most of us have five lumbar vertebrae (bones of the lower spine), but some have four and some have six. Most of us have one spleen, but some people have two. Most have two kidneys, but some have only one. Most kidneys are supplied by a single *renal artery* and drained by one *ureter,* but in some people, a single kidney has two renal arteries or ureters. Figure 1.4 shows some common variations in human anatomy, and Clinical Application 1.1 describes a particularly dramatic variation.

Apply What You Know

People who are allergic to penicillin or aspirin often wear bracelets or necklaces that note this fact in case they need emergency medical treatment and cannot communicate. Why would it be important for a person with situs inversus (see Clinical Application 1.1) to have this noted on a bracelet?

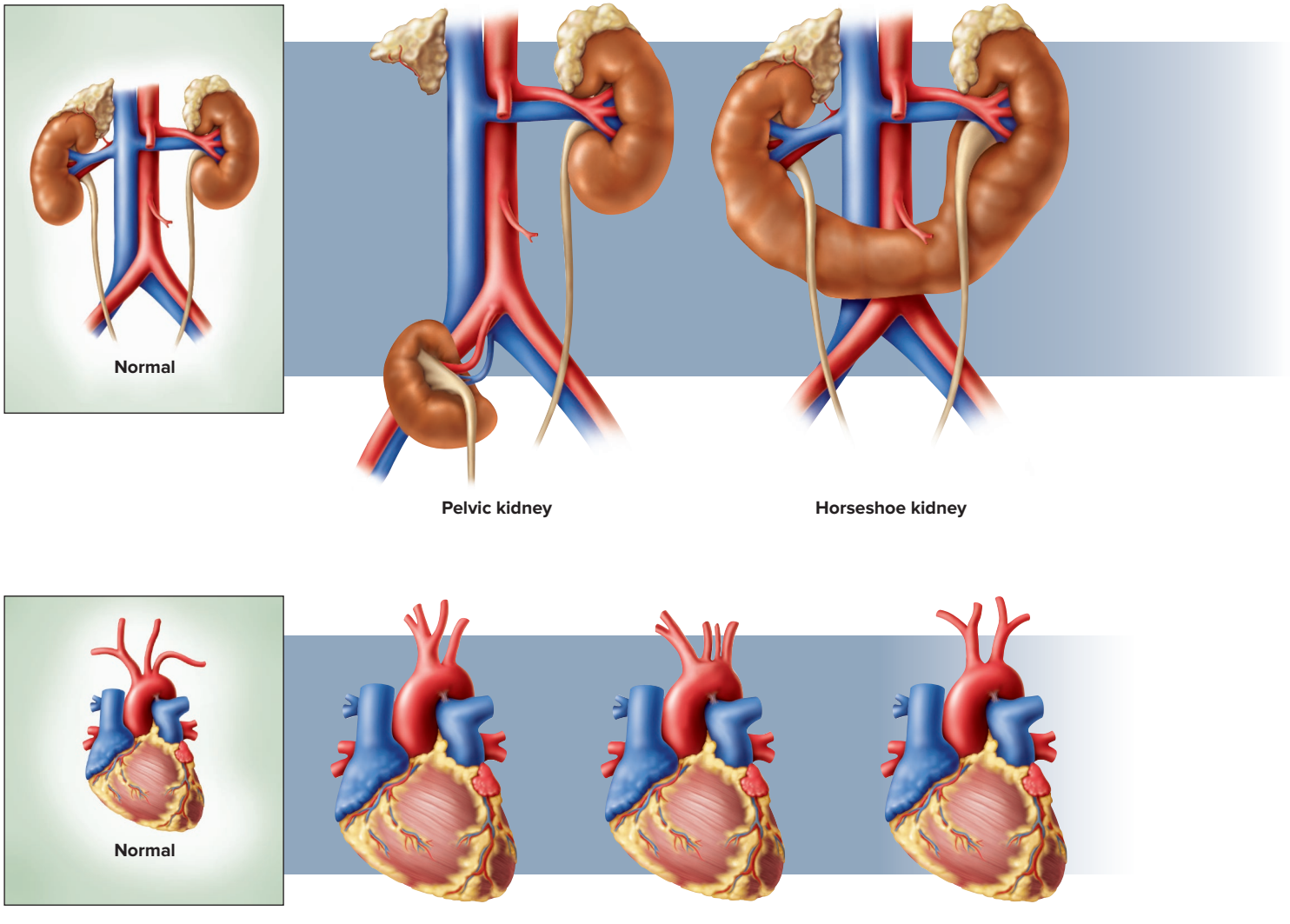


Figure 1.4 Variations in Anatomy of the Kidneys and Major Arteries near the Heart.

CLINICAL APPLICATION 1.1

Situs Inversus and Other Unusual Anatomy

In most people, the heart tilts toward the left, the spleen and sigmoid colon are on the left, the liver and gallbladder lie mainly on the right, the appendix is on the right, and so forth. This normal arrangement of the viscera is called *situs* (SITE-us) *solitus*. About 1 in 8,000 people is born, however, with a striking developmental abnormality called *situs inversus*—the organs of the thoracic and abdominal cavities are reversed between right and left. A selective left–right reversal of the heart is called *dextrocardia*. In *situs perversus*, a single organ occupies an atypical position, not necessarily a left–right reversal—for example, a kidney located low in the pelvic cavity instead of high in the abdominal cavity.

Some conditions, such as dextrocardia in the absence of complete situs inversus, can cause serious medical problems. Complete situs inversus, however, usually causes no functional problems because all of the viscera, though reversed, maintain their normal relationships to each other. Situs inversus is often diagnosed prenatally by sonography, but many people remain unaware of their condition for several decades until it is discovered by medical imaging, on physical examination, or in surgery. However, you can easily imagine the importance of such conditions in diagnosing appendicitis, performing gallbladder surgery, interpreting an X-ray, auscultating the heart valves, or recording an electrocardiogram.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

1. How does functional morphology differ from the sort of anatomy taught by a photographic atlas of the body?
2. Why would regional anatomy be a better learning approach than systemic anatomy for a cadaver dissection course?
3. What is the difference between radiology and radiography?
4. What are some reasons that sonography would be unsuitable for examining the size and location of a brain tumor?

1.2 The Human Body Plan

Expected Learning Outcomes

When you have completed this section, you should be able to

a. list in proper order the levels of structural complexity of the body, from organism down to atoms;
b. name the human organ systems and state the basic functions and components of each;
c. describe the anatomical position and explain why it is important in medical language;
d. identify the three primary anatomical planes of the body;
e. define several terms that describe the locations of structures relative to each other;
f. identify the major body regions and their subdivisions;
g. name and describe the body cavities and the membranes that line them; and
h. explain what a potential space is, and give some examples.

The chapters that follow assume a certain core, common language of human structure. You will need to know what we mean by the names for the major body cavities and regions, know the difference between a tissue and an organ, and know where to look if you read that structure X is distal or medial to structure Y, for example. This section introduces this core terminology.

1.2a Levels of Human Structure

Although this book is concerned mainly with gross anatomy, the study of human structure spans all levels from the whole organism down to the atomic level. Consider for a moment an analogy to human structure: The English language, like the human body, is very complex, yet an endless array of ideas can be conveyed with a limited number of words. All words in the English language are, in turn, composed of various combinations of just 26 letters. Between the alphabet and a book are successively more complex levels of organization: syllables, words, sentences, paragraphs, and chapters. Humans have an analogous hierarchy of complexity (fig. 1.5), as follows:

The organism is composed of organ systems,
organ systems are composed of organs,
organs are composed of tissues,
tissues are composed of cells,
cells are composed (in part) of organelles,
organelles are composed of molecules, and
molecules are composed of atoms.

The **organism** is a single, complete individual, capable of acting separately from other individuals.

An **organ system** is a group of organs that carries out a basic function of the organism such as circulation, respiration, or digestion (fig. 1.6). Usually, the organs of a system are physically interconnected, such as the kidneys, ureters, urinary bladder, and urethra that compose the urinary system.

An **organ** is any structure that has definite anatomical boundaries, is visually distinguishable from adjacent organs, and is composed of two or more tissue types working together to carry out a particular function. Most organs and higher levels of structure are within the domain of gross anatomy. However, there are organs within organs—the large organs visible to the naked eye contain

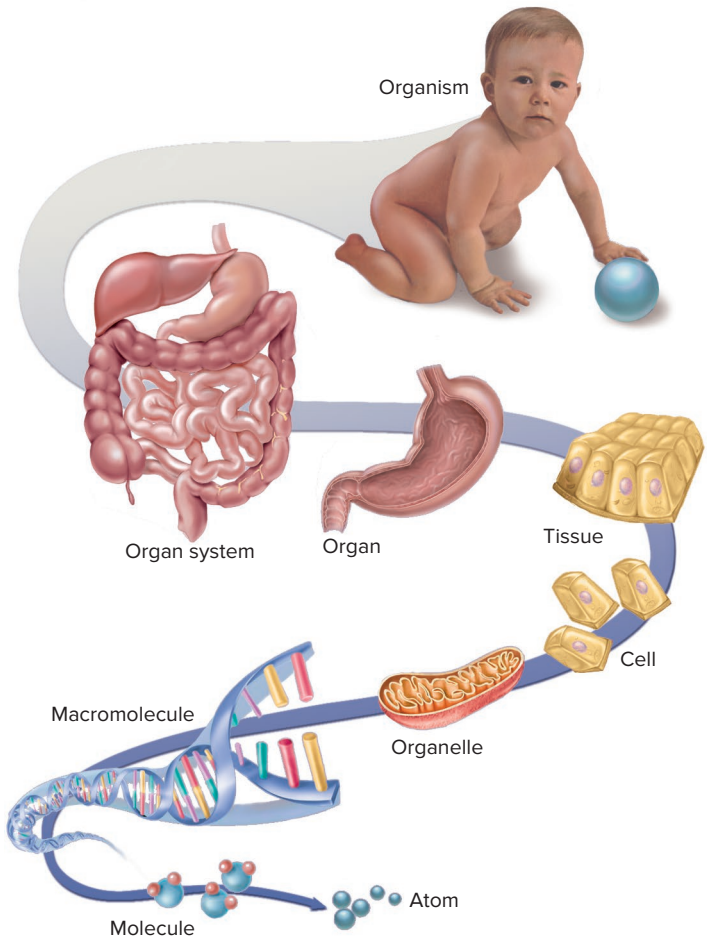


Figure 1.5 The Body's Structural Hierarchy from Organism to Atom.

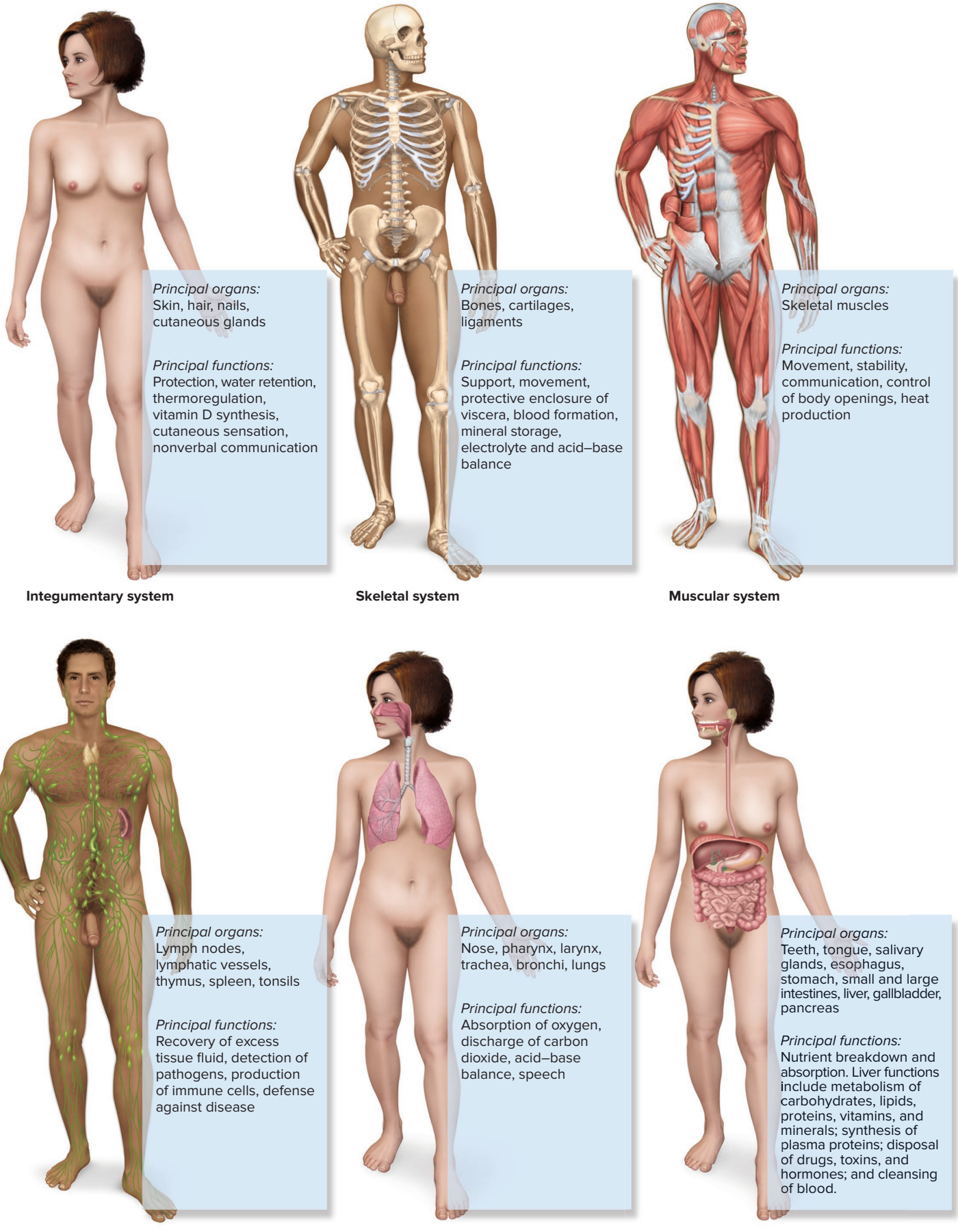
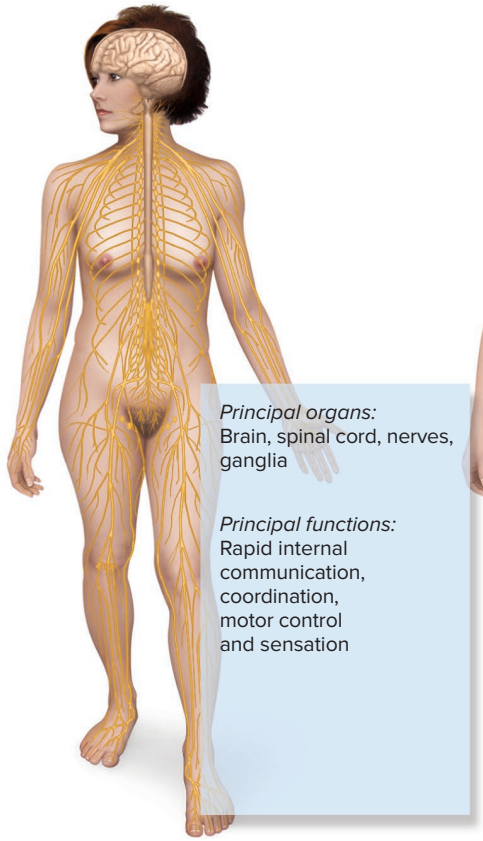


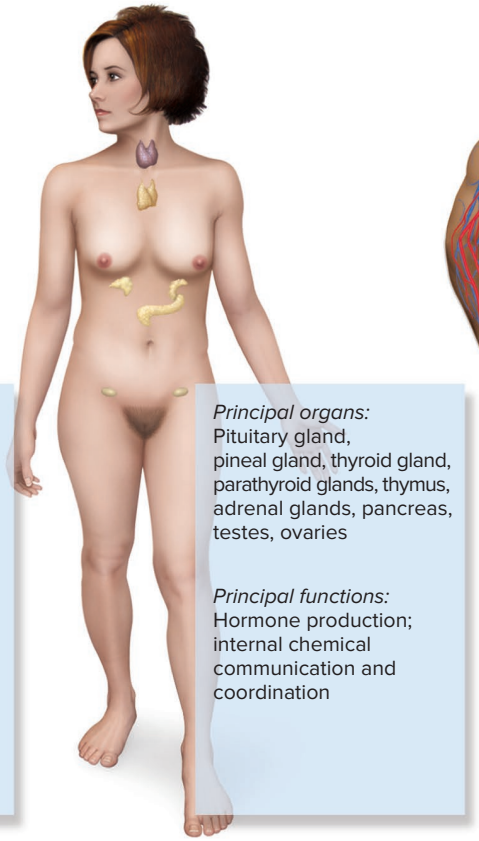
Figure 1.6 The 11 Human Organ Systems.



Principal organs:
Brain, spinal cord, nerves, ganglia

Principal functions:
Rapid internal communication, coordination, motor control and sensation

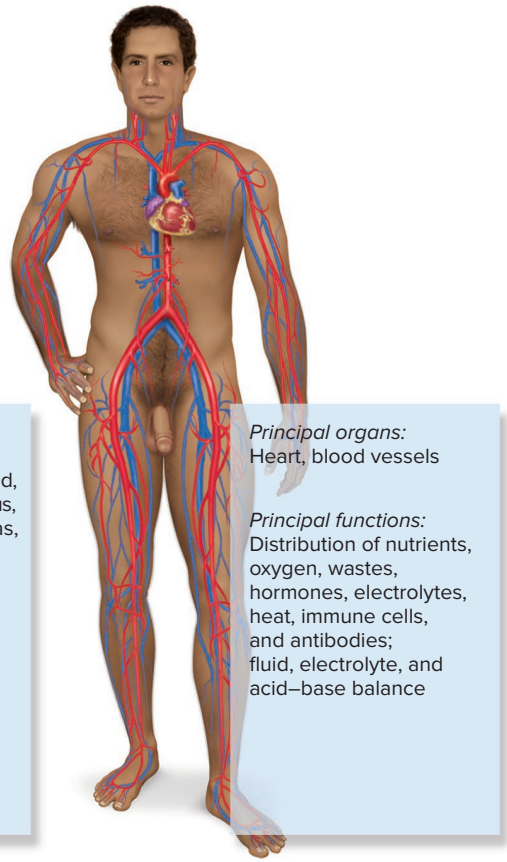
Nervous system



Principal organs:
Pituitary gland, pineal gland, thyroid gland, parathyroid glands, thymus, adrenal glands, pancreas, testes, ovaries

Principal functions:
Hormone production; internal chemical communication and coordination

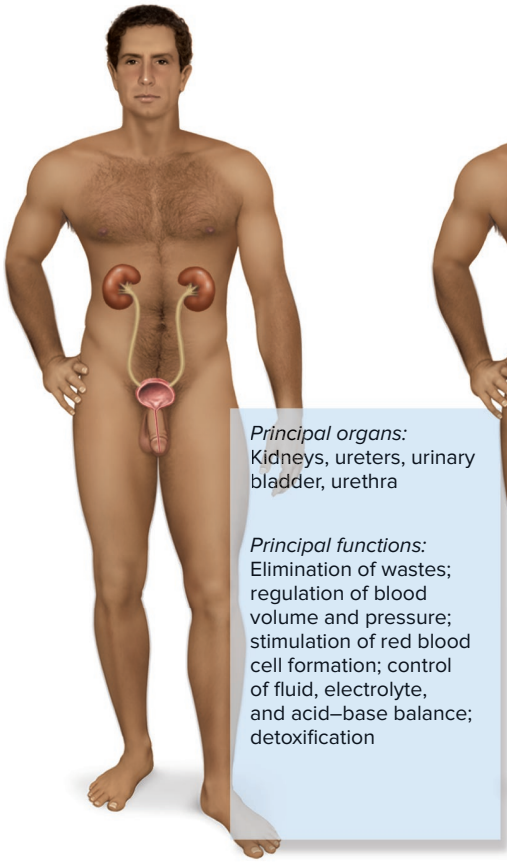
Endocrine system



Principal organs:
Heart, blood vessels

Principal functions:
Distribution of nutrients, oxygen, wastes, hormones, electrolytes, heat, immune cells, and antibodies; fluid, electrolyte, and acid–base balance

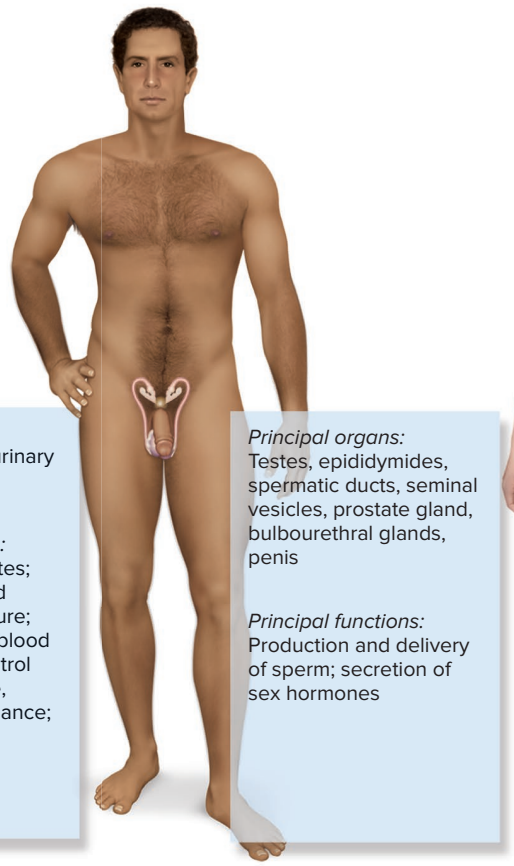
Circulatory system



Principal organs:
Kidneys, ureters, urinary bladder, urethra

Principal functions:
Elimination of wastes; regulation of blood volume and pressure; stimulation of red blood cell formation; control of fluid, electrolyte, and acid–base balance; detoxification

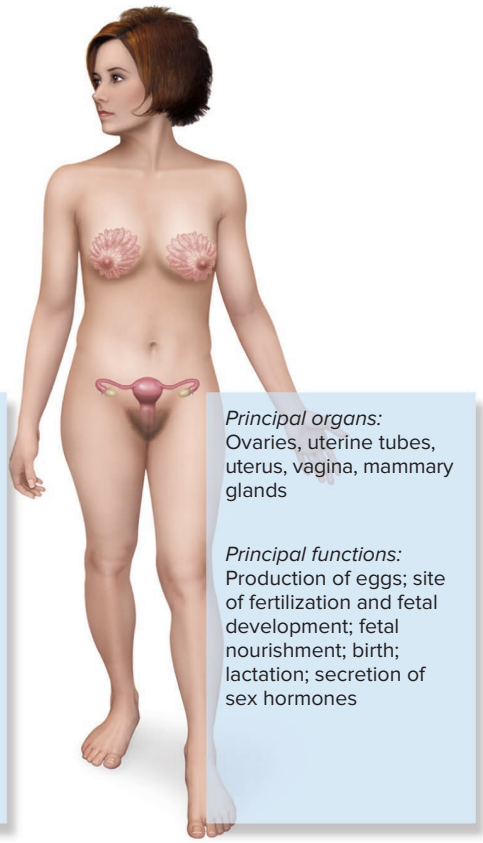
Urinary system



Principal organs:
Testes, epididymides, spermatic ducts, seminal vesicles, prostate gland, bulbourethral glands, penis

Principal functions:
Production and delivery of sperm; secretion of sex hormones

Male reproductive system



Principal organs:
Ovaries, uterine tubes, uterus, vagina, mammary glands

Principal functions:
Production of eggs; site of fertilization and fetal development; fetal nourishment; birth; lactation; secretion of sex hormones

Female reproductive system

smaller organs, some of which are visible only with the microscope. The skin, for example, is the body's largest organ. Included within it are thousands of smaller organs: Each hair follicle, nail, sweat gland, nerve, and blood vessel of the skin is an organ in itself.

A **tissue** is a mass of similar cells and cell products that forms a discrete region of an organ and performs a specific function. The body is composed of only four primary classes of tissue—epithelial, connective, nervous, and muscular tissue. *Histology,* the study of tissues, is the subject of chapter 3.

Cells are the smallest units of an organism considered to be alive. A cell is enclosed in a *plasma membrane* composed of lipids and protein, and it usually has one nucleus, an organelle that contains most of its DNA. *Cytology,* the study of cells and organelles, is the subject of chapter 2. The human body is estimated to have from 40 to 100 trillion cells of about 200 basic kinds.

Organelles[10] are microscopic structures in a cell that carry out its individual functions, much like organs such as the heart, liver, and kidneys carry out individual functions of the whole body. Organelles include the nucleus, mitochondria, lysosomes, centrioles, and others.

Organelles and other cellular components are composed of **molecules**—particles of at least two **atoms** joined by chemical bonds. The largest molecules, such as proteins, fats, and DNA, are called *macromolecules.*

1.2b The Human Organ Systems

As remarked earlier, human structure can be learned from the perspective of regional anatomy or systemic anatomy. This book takes the systemic approach, in which we will fully examine one organ system at a time. There are 11 organ systems in the human body, as well as an *immune system,* which is better described as a population of cells that inhabit multiple organs rather than as an organ system. The organ systems are illustrated and summarized in figure 1.6 in the order that they are covered by this book. They are classified in the following list by their principal functions, although this is an unavoidably flawed classification. Some organs belong to two or more systems—for example, the male urethra is part of both the urinary and reproductive systems; the pharynx is part of the digestive and respiratory systems; and the mammary glands belong to both the integumentary and female reproductive systems.

Systems of Protection, Support, and Movement
- Integumentary system
- Skeletal system
- Muscular system

Systems of Internal Communication and Integration
- Nervous system
- Endocrine system

Systems of Fluid Transport
- Circulatory system
- Lymphatic system

Systems of Intake and Output
- Respiratory system
- Digestive system
- Urinary system

Systems of Reproduction
- Male reproductive system
- Female reproductive system

Some medical terms combine the names of two functionally related systems—for example, the *musculoskeletal system, cardiopulmonary system,* and *urogenital (genitourinary) system.* Such terms serve to call attention to the close anatomical or physiological relationship between two systems, but these are not literally individual organ systems.

1.2c The Terminology of Body Orientation

When anatomists describe the body, they must indicate where one structure is relative to another, the direction in which a nerve or blood vessel travels, the directions in which body parts move, and so forth. Clear communication on such points requires a universal terminology and frame of reference.

Anatomical Position

In describing the human body, anatomists assume that it is in **anatomical position**—that of a person standing upright with the feet flat on the floor and close together, arms at the sides, and the palms and face directed forward (fig. 1.7) (see the history of this in Clinical Application 8.3). Without such a frame of reference, to say that a structure such as the sternum, thymus, or aorta is "above the heart" would be vague, since it would depend on whether the subject was standing, lying face down, or lying face up. From the perspective of anatomical position, however, we can describe the thyroid gland as *superior* to the heart, the sternum as *anterior (ventral)* to it, and the aorta as *posterior (dorsal)* to it. These descriptions remain valid regardless of the subject's position. Even if the body is lying down, such as a cadaver on the medical student's dissection table, to say that the sternum is anterior to the heart invites the viewer to imagine the body standing in anatomical position and not to call it "above the heart" simply because that is the way the body happens to be lying.

Unless stated otherwise, assume that all anatomical descriptions refer to anatomical position. Bear in mind that if a subject is facing you in anatomical position, the subject's left will be on your right and vice versa. In most anatomical illustrations, for example, the left atrium of the heart appears toward the right side of the page, and although the appendix is located in the right lower quadrant of the abdomen, it appears on the left side of most illustrations.

The forearm is said to be **supinated** when the palms face up or anteriorly and **pronated** when they face down or posteriorly (see fig. 9.13); in anatomical position, the forearm is supinated. The words *prone* and *supine* seem similar to these but have an entirely different meaning. A person is **prone** if lying face down, and **supine** if lying face up.

[10] *elle* = little

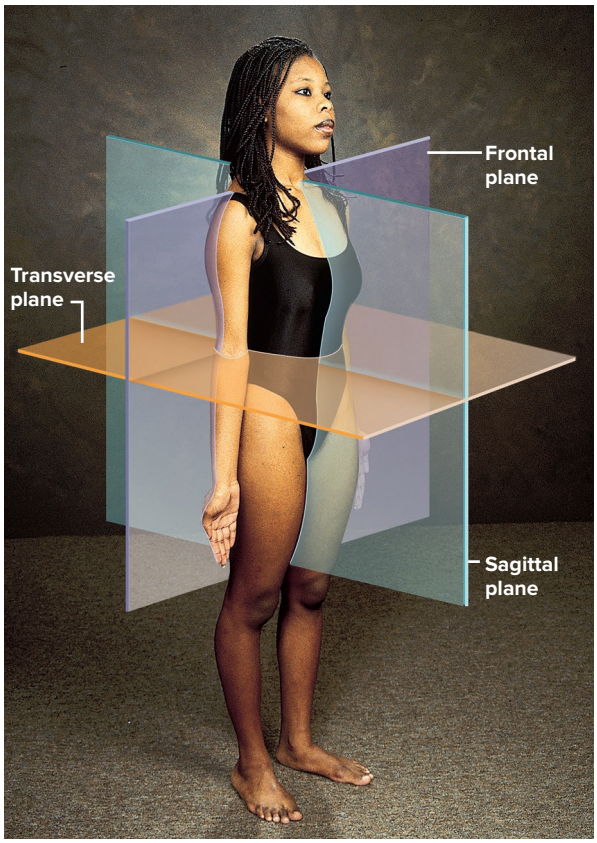


Figure 1.7 **A Person Standing in Anatomical Position and Bisected Along the Three Primary Planes of Reference.**
• *What is another name for the specific sagittal plane shown here?*

Anatomical Planes

Many views of the body are based on real or imaginary "slices" called sections or planes. *Section* implies an actual cut or slice to reveal internal anatomy, whereas *plane* implies an imaginary flat surface passing through the body. The three primary anatomical planes are *sagittal, frontal,* and *transverse* (fig. 1.7).

A **sagittal**[11] **plane** (SADJ-ih-tul) extends vertically and divides the body or an organ into right and left portions. The **median (midsagittal) plane** passes through the midline of the body and divides it into *equal* right and left halves. Other sagittal planes parallel to this (off center), called **parasagittal**[12] **planes,** divide the body into unequal right and left portions. The head and pelvic organs are commonly illustrated on the median plane (fig. 1.8a).

A **frontal (coronal**[13]**) plane** also extends vertically, but it is perpendicular to the sagittal plane and divides the body into anterior (front) and posterior (back) portions. A frontal section of the head, for example, would divide it into one portion bearing the face and another bearing the back of the head. Contents of the thoracic and abdominal cavities are commonly shown in frontal section (fig. 1.8b).

A **transverse (horizontal) plane** passes across the body or an organ perpendicular to its long axis (fig. 1.8c); it divides the body into superior (upper) and inferior (lower) portions. CT scans are typically transverse sections (see fig. 1.2c), but not always.

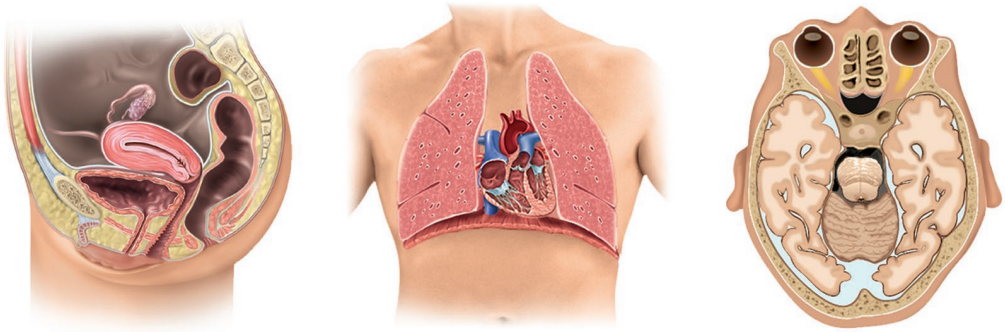
Directional Terms

In navigating the human body and describing the locations of structures, anatomists use a set of standard **directional terms** (table 1.1). You will need to be familiar with these in order to understand anatomical descriptions later in this book. The terms assume that the body is in anatomical position.

Most of these terms exist in pairs with opposite meanings: *anterior* versus *posterior, superior* versus *inferior, medial* versus *lateral, proximal* versus *distal,* and *superficial* versus *deep.* Intermediate directions are often indicated by combinations of these terms. For example, one structure may be described as *anterolateral* to another (toward the front and side).

The terms **proximal** and **distal** are used especially in the anatomy of the limbs, with *proximal* used to denote something relatively close to the limb's point of attachment (the shoulder or hip joint) and *distal* to denote something farther away. These terms do have

[11] *sagitta* = arrow
[12] *para* = next to
[13] *corona* = crown; *al* = like



(a) Sagittal section (b) Frontal section (c) Transverse section

Figure 1.8 **Sections of the Body in the Three Primary Anatomical Planes.** (a) Sagittal section of the pelvic region. (b) Frontal section of the thoracic region. (c) Transverse section of the head at the level of the eyes.

TABLE 1.1 Directional Terms in Human Anatomy

Term	Meaning	Examples of Usage
Anterior	Toward the front of the body	The sternum is *anterior* to the heart.
Posterior	Toward the back of the body	The esophagus is *posterior* to the trachea.
Ventral	Toward the anterior side*	The abdomen is on the *ventral* side of the body.
Dorsal	Toward the posterior side*	The scapulae are *dorsal* to the rib cage.
Superior	Above	The heart is *superior* to the diaphragm.
Inferior	Below	The liver is *inferior* to the diaphragm.
Cephalic	Toward the head or superior end	The *cephalic* end of the embryonic neural tube develops into the brain.
Rostral	Toward the forehead or nose	The forebrain is *rostral* to the brainstem.
Caudal	Toward the tail or inferior end	The spinal cord is *caudal* to the brain.
Medial	Toward the midline of the body	The heart is *medial* to the lungs.
Lateral	Away from the midline of the body	The eyes are *lateral* to the nose.
Proximal	Closer to the point of attachment or origin	The elbow is *proximal* to the wrist.
Distal	Farther from the point of attachment or origin	The fingernails are at the *distal* ends of the fingers.
Ipsilateral	On the same side of the body (right or left)	The liver is *ipsilateral* to the appendix.
Contralateral	On opposite sides of the body (right and left)	The spleen is *contralateral* to the liver.
Superficial	Closer to the body surface	The skin is *superficial* to the muscles.
Deep	Farther from the body surface	The bones are *deep* to the muscles.

*In humans only; definition differs for other animals. In human anatomy, *anterior* and *posterior* are usually used in place of *ventral* and *dorsal*.

some applications to anatomy of the trunk of the body—for example, in referring to certain aspects of the intestines and the microscopic structure of the kidneys. But when describing the trunk and referring to a structure that lies above or below another in anatomical position, **superior** and **inferior** are the preferred terms. These terms are not usually used for the limbs. Although it may be technically correct, one would not generally say the elbow is superior to the wrist. Rather, it is proximal to the wrist.

Because of the bipedal, upright stance of humans, some directional terms have different meanings for humans than they do for other animals. **Anterior,** for example, denotes the region of the body that leads the way in normal locomotion. For a four-legged animal such as a cat, this is the head end of the body; for a human, however, it is the front of the chest and abdomen. What we call *anterior* in a human is called *ventral* in a cat. **Posterior** denotes the region that comes last in normal locomotion—the tail end of a cat but the back of a human. In the anatomy of most other animals, *ventral* denotes the surface of the body closest to the ground and *dorsal* denotes the surface farthest away from the ground. These two words are too entrenched in human anatomy to completely ignore them, but we will minimize their use in this book to avoid confusion. You must keep such differences in mind, however, when dissecting other animals for comparison to human anatomy.

See table 1.1 for additional pairs of terms with which you must be familiar before progressing very far into the study of anatomy.

1.2d Major Body Regions

Knowledge of the external anatomy and landmarks of the body is important in performing a physical examination and many other clinical procedures. For purposes of study, the body is divided into two major regions called the *axial* and *appendicular regions.* Smaller areas within the major regions are described in the following paragraphs and illustrated in figure 1.9.

Axial Region

The **axial region** consists of the **head, neck (cervical[14] region),** and **trunk.** The trunk is further divided into the **thoracic region** above the diaphragm and the **abdominal region** below it.

[14] *cervic* = neck

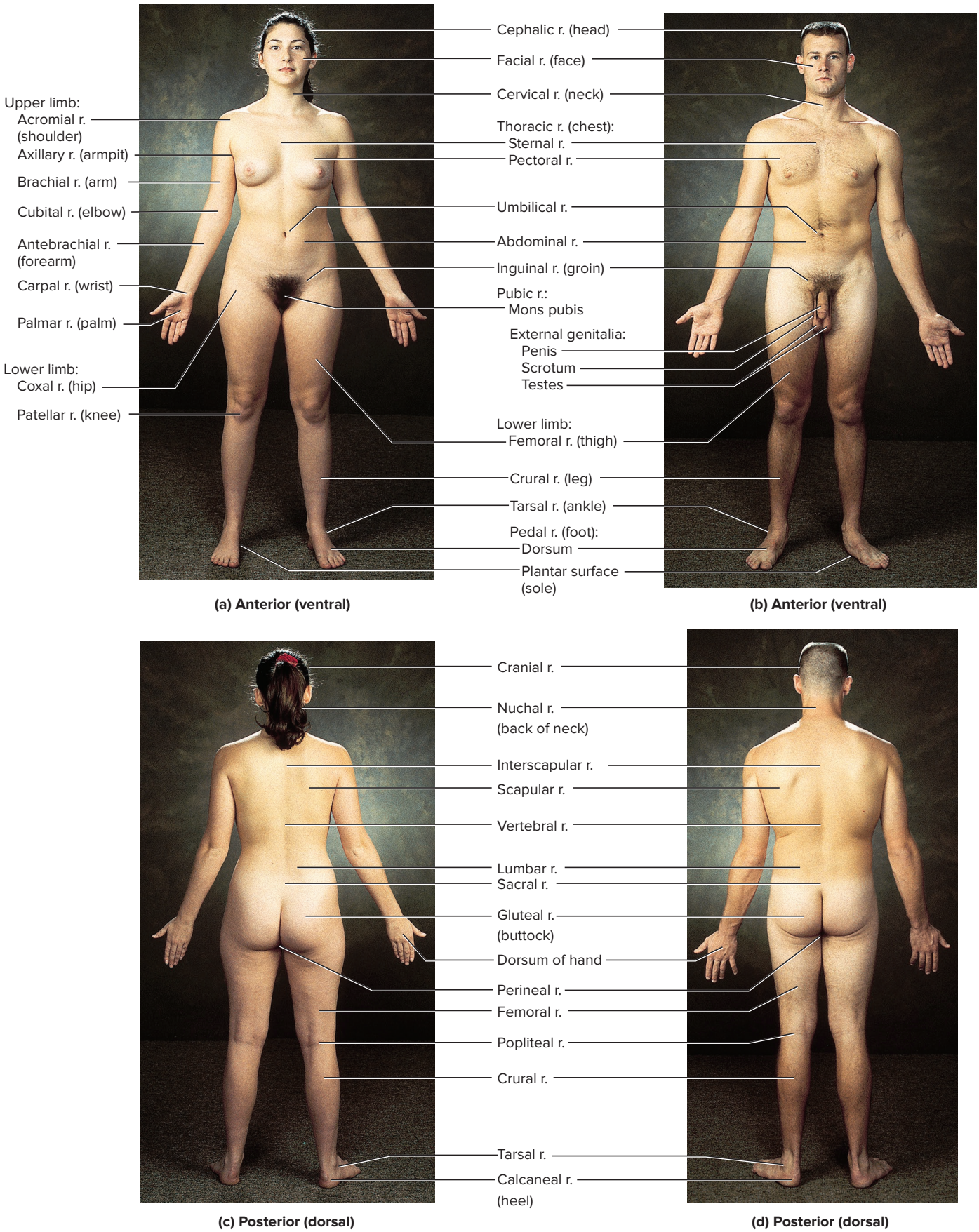


Figure 1.9 **The Adult Female and Male Body Regions.** (r. = region)

One way of referring to the locations of abdominal structures is to divide the region into quadrants. Two perpendicular lines intersecting at the umbilicus (navel) divide the abdomen into a **right upper quadrant (RUQ), right lower quadrant (RLQ), left upper quadrant (LUQ),** and **left lower quadrant (LLQ)** (fig. 1.10a, b). The quadrant scheme is often used to describe the site of an abdominal pain or abnormality.

The abdomen also can be divided into nine regions defined by four lines that intersect like a tic-tac-toe grid (fig. 1.10c, d). Each vertical line is called a *midclavicular line* because it passes through the midpoint of the clavicle (collarbone). The superior horizontal line is called the *subcostal*[15] *line* because it connects the inferior borders of the lowest costal cartilages (cartilages connecting the tenth rib on each side to the inferior end of the sternum). The inferior horizontal line is called the *intertubercular*[16] *line* because it passes from left to right between the tubercles *(anterior superior spines)* of the hip bones—two points of bone located about

[15] *sub* = below; *cost* = rib
[16] *inter* = between; *tubercul* = little swelling

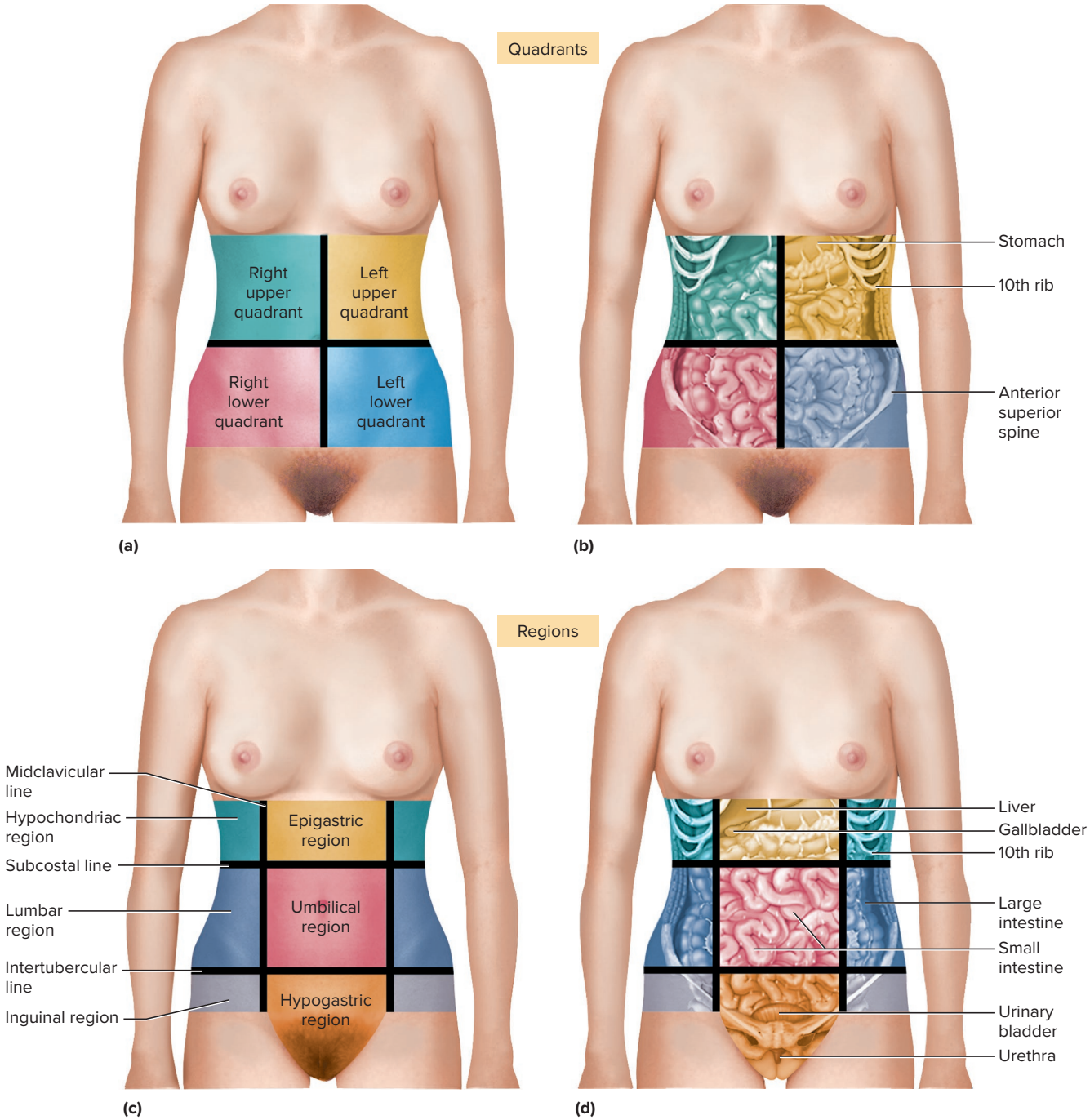


Figure 1.10 The Four Quadrants and Nine Regions of the Abdomen. (a) External division into four quadrants. (b) Internal anatomy correlated with the quadrants. (c) External division into nine regions. (d) Internal anatomy correlated with the nine regions.

where the front pockets open on most pants. The three lateral regions of this grid, from upper to lower, are the left and right **hypochondriac,**[17] **lumbar,** and **inguinal**[18] **regions.** The three medial regions from upper to lower are the **epigastric,**[19] **umbilical,** and **hypogastric (pubic)** regions.

Appendicular Region

The **appendicular region** (AP-en-DIC-you-lur) of the body consists of the **upper limbs** and **lower limbs** (also called *appendages* or *extremities*). The upper limb includes the **arm** (**brachial region,** BRAY-kee-ul), **forearm** (**antebrachial**[20] **region,** AN-teh-BRAY-kee-ul), **wrist (carpal region), hand,** and **fingers (digits).** The lower limb includes the **thigh (femoral region), leg** (**crural region,** CROO-rul), **ankle (tarsal region), foot,** and **toes (digits).** In strict anatomical terms, *arm* refers only to that part of the upper limb between the shoulder and elbow. *Leg* refers only to that part of the lower limb between the knee and ankle.

A **segment** of a limb is a region between one joint and the next. The arm, for example, is the segment between the shoulder and elbow joints, and the forearm is the segment between the elbow and wrist joints. Slightly flexing your fingers, you can easily see that your thumb has two segments (proximal and distal), whereas the other four digits have three segments (proximal, middle, and distal). The segment concept is especially useful in describing the locations of bones and muscles and the movements of the joints.

[17] *hypo* = below; *chondr* = cartilage
[18] *inguin* = groin
[19] *epi* = above, over; *gastr* = stomach
[20] *ante* = fore, before; *brachi* = arm

1.2e Body Cavities and Membranes

The body wall encloses several **body cavities,** each lined by a membrane and containing internal organs called the **viscera** (VISS-er-uh) (singular, *viscus*[21]) (fig. 1.11, table 1.2).

[21] *viscus* = body organ

TABLE 1.2 Body Cavities and Membranes

Name of Cavity	Associated Viscera	Membranous Lining
Cranial cavity	Brain	Meninges
Vertebral canal	Spinal cord	Meninges
Thoracic cavity		
Pleural cavities (2)	Lungs	Pleura
Pericardial cavity	Heart	Pericardium
Abdominopelvic cavity		
Abdominal cavity	Digestive organs, spleen, kidneys, ureters	Peritoneum
Pelvic cavity	Bladder, rectum, reproductive organs	Peritoneum

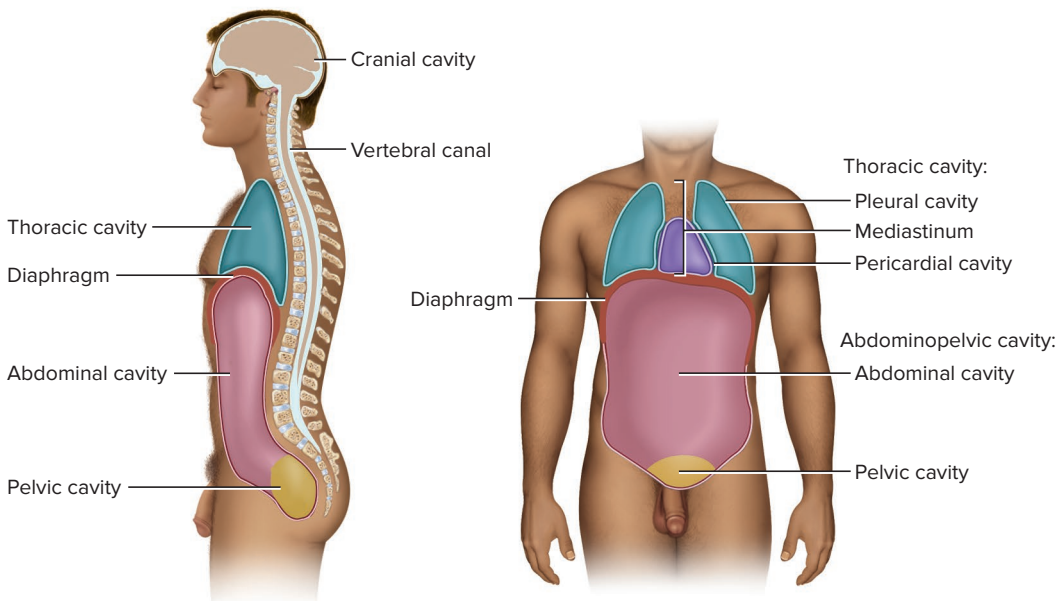


Figure 1.11 **The Major Body Cavities.** (a) Left lateral view. (b) Anterior view.

The Cranial Cavity and Vertebral Canal

The **cranial cavity** (CRAY-nee-ul) is enclosed by the cranial bones (braincase) of the skull and contains the brain. The **vertebral canal** is enclosed by the vertebral column (spine, backbone) and contains the spinal cord. The two are continuous with each other and lined by three membrane layers called the **meninges** (meh-NIN-jeez). Among other functions, the meninges protect the delicate nervous tissue from the hard protective bone that encloses it, and anchor the spinal cord to the vertebral column and limit its movement.

The Thoracic Cavity

The trunk of your body contains two major spaces, the thoracic cavity and abdominopelvic cavity, separated by a transverse muscular sheet, the **diaphragm.** Superior to the diaphragm, in your chest, is the **thoracic cavity,** and inferior to it, in your abdomen, is the **abdominopelvic cavity.** Both cavities are lined with thin **serous membranes,** which secrete a lubricating film of moisture similar to blood serum (hence their name).

The thoracic cavity is divided by a thick partition called the **mediastinum**[22] (ME-dee-ah-STY-num) (fig. 1.11b). This lies between the lungs, from the base of the neck to the diaphragm, and is occupied by the heart, the major blood vessels connected to it, the esophagus, the trachea and bronchi, and a gland called the *thymus*.

A two-layered serous membrane called the **pericardium**[23] wraps around the heart. The inner layer of the pericardium forms the surface of the heart itself and is called the **visceral pericardium (epicardium)** (VISS-er-ul). The outer layer is called the **parietal**[24] **pericardium (pericardial sac)** (pa-RY-eh-tul). It is separated from the visceral pericardium by a space called the **pericardial cavity** (fig. 1.12a) (see Clinical Application 1.2). This space is lubricated by a thin film of **pericardial fluid.**

[22] *mediastinum* = in the middle
[23] *peri* = around; *cardi* = heart
[24] *pariet* = wall

CLINICAL APPLICATION 1.2

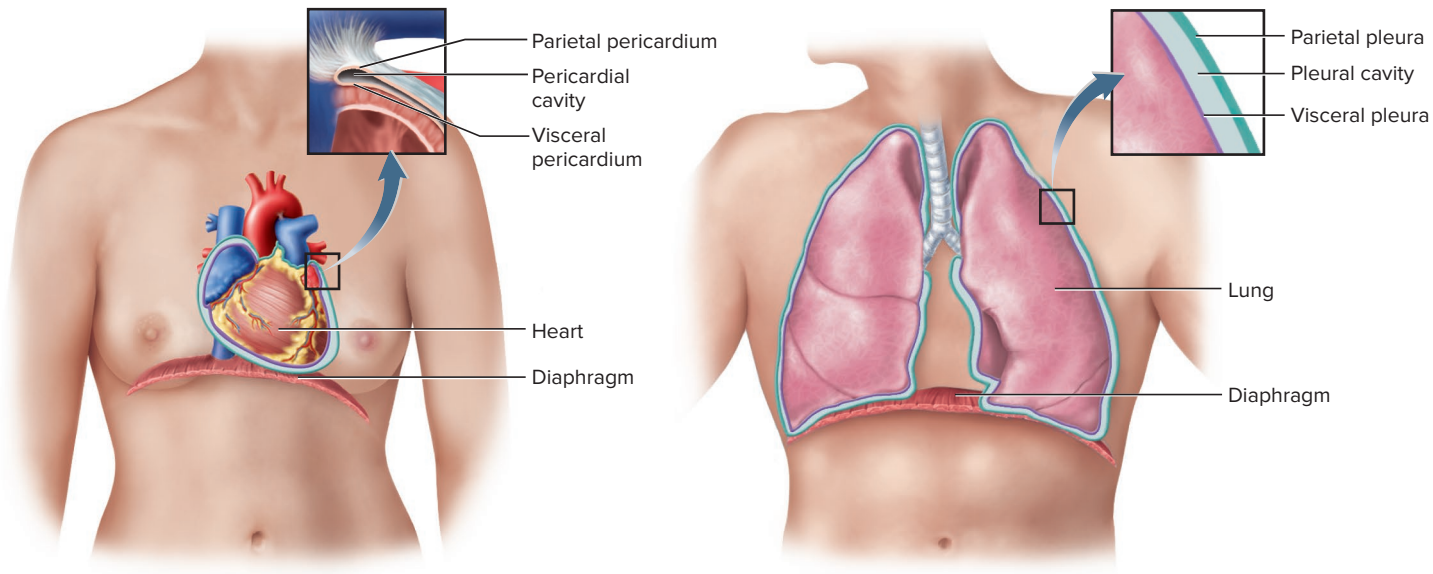
Cardiac Tamponade

Being confined by the pericardium can cause a problem for the heart under some circumstances. If a heart wall weakened by disease should rupture, or if it suffers a penetrating injury such as a knife or gunshot wound, blood spurts from the heart into the pericardial cavity, filling the cavity more and more with each heartbeat. Diseased hearts also sometimes seep serous fluid into the pericardial sac. Either way, the effect is the same: The pericardial sac has little room to expand, so the accumulating fluid puts pressure on the heart, squeezing it and preventing it from refilling between beats. This condition is called *cardiac tamponade*. If the heart chambers cannot refill, then cardiac output declines and a person may die of catastrophic circulatory failure. A similar situation occurs if serous fluid or air accumulates in the pleural cavity, causing collapse of a lung.

The right and left sides of the thoracic cavity contain the lungs. A serous membrane called the **pleura**[25] (PLOOR-uh) wraps around each lung (fig. 1.12b). Like the pericardium, it has visceral (inner) and parietal (outer) layers. The **visceral pleura** forms the external surface of the lung, and the **parietal pleura** lines the inside of the rib cage. The narrow space between them is called the **pleural cavity** (see atlas fig. A.11). It is lubricated by slippery **pleural fluid.**

Note that in both the pericardium and pleura, the visceral layer of the membrane *covers* the surface of an organ and the parietal layer *lines* the inside of a body cavity. We will see this pattern repeated elsewhere, including the abdominopelvic cavity.

[25] *pleur* = rib, side



(a) Pericardium (b) Pleurae

Figure 1.12 **Parietal and Visceral Layers of the Serous Membranes of the Thoracic Cavity.** (a) Pericardium. (b) Pleurae.

The Abdominopelvic Cavity

The abdominopelvic cavity consists of the **abdominal cavity** superiorly and the **pelvic cavity** inferiorly. The abdominal cavity contains most of the digestive organs as well as the spleen, kidneys, and ureters. It extends inferiorly to the level of a bony landmark called the *brim* of the pelvis (see figs. 8.6 and A.7). The pelvic cavity, below the brim, is continuous with the abdominal cavity (no wall separates them), but it is much narrower and tilts posteriorly (see fig. 1.11a). It contains the rectum, urinary bladder, urethra, and reproductive organs.

The abdominopelvic cavity contains a two-layered serous membrane called the **peritoneum**[26] (PERR-ih-toe-NEE-um). The **parietal peritoneum** lines the cavity wall. The **visceral peritoneum** turns inward from the body wall, wraps around the abdominal viscera, binds them to the body wall or suspends them from it, and holds them in their proper place. The **peritoneal cavity** is the space between the parietal and visceral layers. It is lubricated by **peritoneal fluid.**

Some organs of the abdominal cavity lie against the posterior body wall and are covered by peritoneum only on the side facing the peritoneal cavity. They are said to have a **retroperitoneal**[27] position (fig. 1.13). These include the kidneys; ureters; adrenal glands; most of the pancreas; and abdominal portions of two major blood vessels, the aorta and inferior vena cava (see fig. A.6). Organs that are encircled by peritoneum and connected to the posterior body wall by peritoneal sheets are described as **intraperitoneal.**[28]

The intestines are suspended from the posterior abdominal wall by a translucent membrane called the **posterior mesentery**[29] (MESS-en-tare-ee), an infolding of the peritoneum (fig. 1.14). The posterior mesentery of the large intestine is called the **mesocolon.** In some places, after wrapping around the intestines or other viscera, the mesentery continues toward the anterior body wall as the **anterior mesentery.** The most prominent example of this is a fatty membrane called the **greater omentum,**[30] which hangs like an apron from the inferolateral margin of the stomach and overlies the intestines (see fig. A.4). It is unattached at its inferior border and can be lifted to reveal the intestines. A smaller **lesser omentum** extends from the superomedial margin of the stomach to the liver.

Where the visceral peritoneum meets an organ such as the stomach or small intestine, it divides and wraps around it, forming an outer layer of the organ called the **serosa** (seer-OH-sa) (fig. 1.13). The visceral peritoneum thus consists of the mesenteries and serosae.

Potential Spaces

Some of the spaces between body membranes are considered to be **potential spaces,** so named because under normal conditions, the membranes are pressed firmly together and there is no actual space between them. The membranes are not physically attached, however, and under unusual conditions, they may separate and create a space filled with fluid or other matter. Thus, there is only a potential for the membranes to separate and create a space.

The pleural cavity is one example. Normally, the parietal and visceral pleurae are pressed together without a gap between them, but under pathological conditions, air or serous fluid can accumulate between the membranes and open up a space. Another example is the internal cavity *(lumen)* of the uterus. In a nonpregnant uterus, the mucous membranes of the opposite walls are pressed together, so there is little or no open space in the organ. In pregnancy, of course, a growing fetus occupies this space and pushes the mucous membranes apart.

[26] *peri* = around; *tone* = stretched
[27] *retro* = behind
[28] *intra* = within
[29] *mes* = in the middle; *enter* = intestine
[30] *omentum* = covering

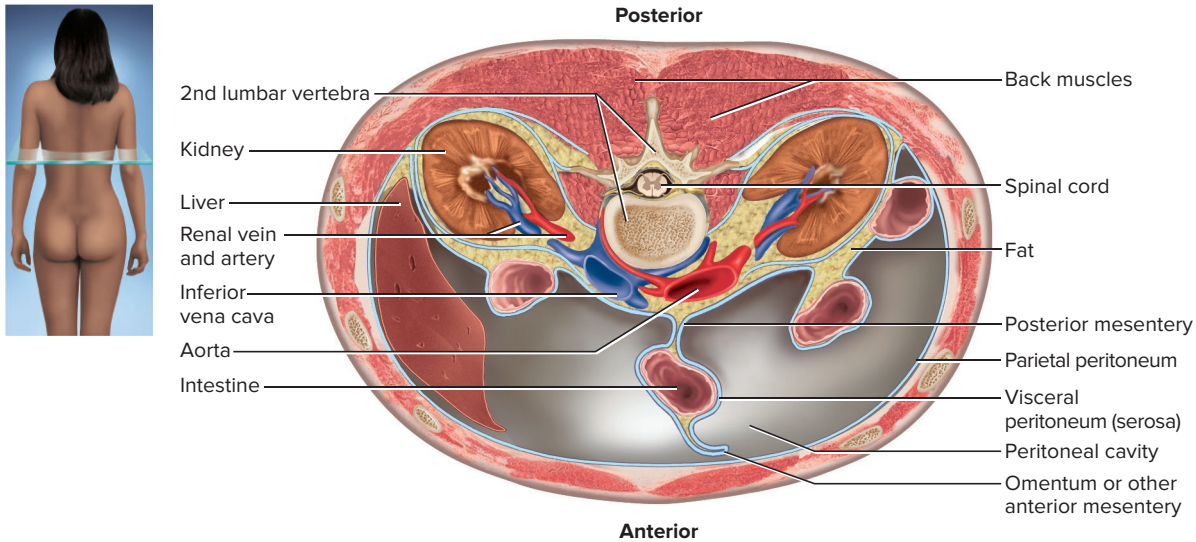
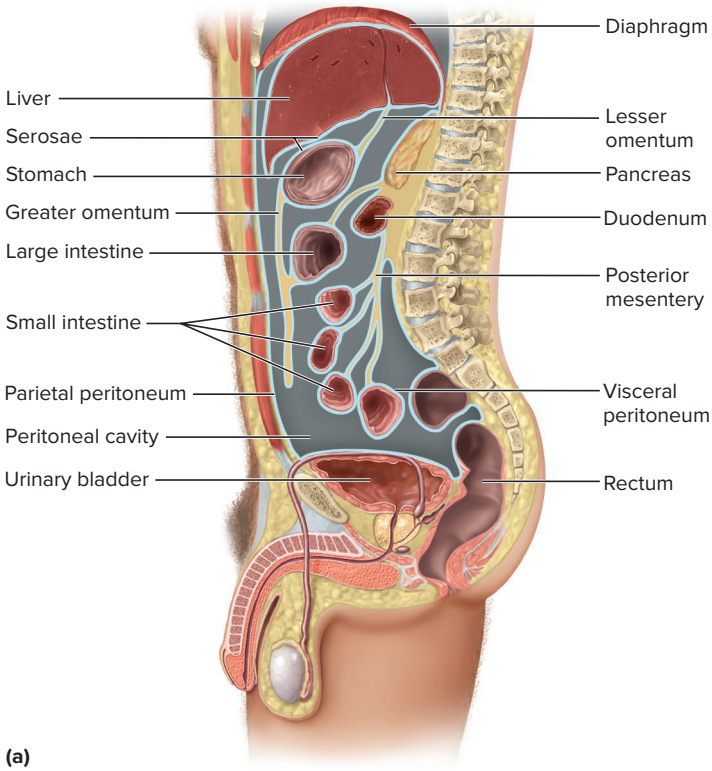


Figure 1.13 **Transverse Section Through the Abdomen.** Shows the peritoneum (thin blue line), peritoneal cavity (with most viscera omitted), and some retroperitoneal organs (between peritoneum and posterior body wall).



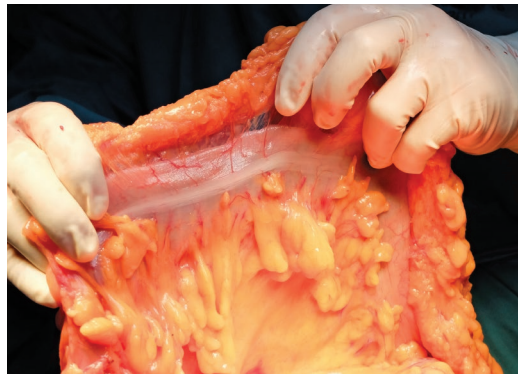


Figure 1.14 Serous Membranes of the Abdominal Cavity. (a) Diagram of the abdomen in sagittal section, left lateral view. (b) Surgical photograph of an intestinal mesentery. The yellow areas are mesenteric fat, where much of the extra body weight resides in obesity.
• *Is the urinary bladder in the peritoneal cavity?*

Before You Go On

Answer the following questions to test your understanding of the preceding section:

5. Put the following list in order from the largest and most complex to the smallest and least complex components of the human body: cells, molecules, organelles, organs, organ systems, tissues.
6. Name the organ system responsible for each of the following functions: (a) movement and distribution of blood; (b) water retention, sensation, and protection from infection; (c) hormone secretion; (d) nutrient breakdown and absorption; and (e) recovery of excess tissue fluid and detection of pathogens in the tissues.
7. State the directional term that describes the position of (a) the spinal cord relative to the heart; (b) the eyes relative to the nose; (c) the urinary bladder relative to the intestines; (d) the diaphragm relative to the liver; and (e) skin relative to the muscles.
8. State the alternative anatomical terms for the regions commonly known as the neck, the sole of the foot, the lower back, the buttocks, and the calf.
9. Name the membranes that enclose the brain, the heart, the lungs, and the abdominal cavity.

1.3 The Language of Anatomy

Expected Learning Outcomes

When you have completed this section, you should be able to

a. explain why modern anatomical terminology is so heavily based on Greek and Latin;
b. recognize eponyms when you see them;
c. describe the efforts to achieve an internationally uniform anatomical terminology;
d. discuss the Greek, Latin, or other derivations of medical terms;
e. state some reasons why the literal meaning of a word may not lend insight into its definition;
f. relate singular noun forms to their plural forms; and
g. discuss why accurate spelling is so important in medical communication.

One of the greatest challenges faced by anatomy students is the vocabulary. In this book, you will encounter such Latin terms as *corpus callosum* (a brain structure), *ligamentum arteriosum* (a small fibrous band near the heart), and *extensor carpi radialis*

longus (a forearm muscle). You may wonder why structures aren't named in "just plain English," and how you will ever remember such formidable names. This section will give you some answers to these questions and some useful tips on mastering anatomical terminology.

1.3a The Origins of Medical Terms

The major features of human gross anatomy have standard international names prescribed by a book titled *Terminologia Anatomica (TA).* The TA system was codified in 1998 by an international body of anatomists and approved by professional associations of anatomists in more than 50 countries.

About 90% of today's medical terms are formed from about 1,200 Greek and Latin roots. This hearkens back to the beginnings of scientific investigation in ancient Greece and Rome. Greek and Roman scholars coined many of the words still used in human anatomy today: *duodenum, uterus, prostate, cerebellum, diaphragm, sacrum, amnion,* and others. In the Renaissance, the fast pace of anatomical discovery required a profusion of new terms to describe things. Anatomists in different countries began giving different names to the same structures. Adding to the confusion, they often named new structures and diseases in honor of their esteemed teachers and predecessors, giving us such nondescriptive terms as the *fallopian tube* and *canal of Schlemm.* Terms coined from the names of people, called **eponyms,**[31] afford little clue as to what a structure or medical condition is.

In hopes of resolving this growing confusion, anatomists began meeting as early as 1895 to try to devise a uniform international terminology. This led in stages to the *Terminologia Anatomica (TA)* that we use today. The *TA* rejects all eponyms and provides recommended descriptive terms in Latin and English for gross anatomical structures. These terms are used worldwide, so even if you were to look at an anatomy atlas in Korean or Arabic, the illustrations might be labeled with the same Latin terms as in an English-language atlas. The *TA* is now accompanied by two similar volumes—the *Terminologia Histologica* for the structure of cells and tissues, and *Terminologia Embryologica* for prenatal anatomy. The terminology in this text book conforms to these guidelines except where undue confusion would result from abandoning widely used, yet unofficial terms. This book avoids most eponyms.

1.3b Analyzing Medical Terms

The task of learning anatomical terminology seems overwhelming at first, but as you study this book, there is a simple habit that can quickly make you more comfortable with the technical language of medicine—read the footnotes, which explain the roots and origins of the words. Students who find scientific terms confusing and difficult to pronounce, spell, and remember usually feel more confident once they realize the logic of how terms are composed. A term such as *hyponatremia* is less forbidding once we recognize that it is composed of three common word elements: *hypo-* (below normal), *natr-* (sodium), and *-emia* (blood condition). Thus, hyponatremia is a deficiency of sodium in the blood. Those three word elements appear over and over in many other medical terms: *hypothermia, natriuretic, anemia,* and so on. Once you learn the meanings of *hypo-, natri-,* and *-emia,* you already have the tools to at least partially understand hundreds of other biomedical terms. In appendix B, you will find a lexicon of word elements commonly footnoted in this book.

Scientific terms are typically composed of one or more of the following elements:

- At least one *root (stem)* that bears the core meaning of the word. In *cardiology,* for example, the root is *cardi* (heart). Many words have two or more roots. In *adipocyte,* the roots are *adip* (fat) and *cyte* (cell).
- *Combining vowels,* which are often inserted to join roots and make the word easier to pronounce. The letter *o* is the most common combining vowel (as in *adipocyte*), but all vowels are used in this way, such as *a* in *ligament, e* in *vitreous, i* in *fusiform, u* in *ovulation,* and *y* in *tachycardia.* Some words have no combining vowels. A combination of a root and combining vowel is called a *combining form:* for example, *odont* (tooth) + *o* (the combining vowel) make the combining form *odonto,* as in *odontoblast* (a cell that produces the dentin of a tooth).
- A *prefix* may be present to modify the core meaning of the word. For example, *gastric* (pertaining to the stomach or to the belly of a muscle) takes on a wide variety of new meanings when prefixes are added: *epigastric* (above the stomach), *hypogastric* (below the stomach), *endogastric* (within the stomach), and *digastric* (a muscle with two bellies).
- A *suffix* may be added to the end of a word to modify its core meaning. For example, *microscope, microscopy, microscopic,* and *microscopist* have different meanings because of their suffixes alone. Often two or more suffixes, or a root and suffix, occur together so often that they are treated jointly as a *compound suffix;* for example, *log* (study) + *y* (process) form the compound suffix *-logy* (the study of).

To summarize these basic principles, consider the word *gastroenterology,* denoting a branch of medicine dealing with the stomach and small intestine. It breaks down into gastro/entero/logy:

gastro = a combining form meaning "stomach"
entero = a combining form meaning "small intestine"
logy = a compound suffix meaning "the study of"

"Dissecting" words in this way and paying attention to the word-origin footnotes throughout this book will help make you more comfortable with the language of anatomy. Knowing how a word breaks down and knowing the meaning of its elements make it easier to pronounce a word, spell it, and remember its definition.

There are a few unfortunate exceptions, however. The path from original meaning to current usage has often become obscured by history. *Amnion,* the transparent membrane around a fetus, originally meant a bowl for catching the sacrificial blood of lambs; the *acetabulum* (socket) of the hip literally means "vinegar cup"; and *testicles* literally means "little witnesses." The history of medical terms is full of twists and turns that say much about the history of the whole of human culture, but they can create confusion for students. The foregoing word-dissection approach also is no help with eponyms or with **acronyms**—words composed of the first letter, or first few letters, of a series of words. *PET,* for example, is an acronym for *positron emission tomography.* Note that *PET* is a pronounceable word,

[31] *epo* = after, related to; *nym* = name

hence a true acronym. Acronyms are not to be confused with simple abbreviations such as DNA or MRI, in which each letter must be pronounced separately; these are properly called *initialisms.*

1.3c Variant Forms of Medical Terms

A point of confusion for many beginning students is how to recognize the plural forms of medical terms. Few people would fail to recognize that *ovaries* is the plural of *ovary,* but the connection is harder to make in other cases: For example, the plural of *cortex* is *cortices* (COR-ti-sees), the plural of *corpus* is *corpora,* and the plural of *ganglion* is *ganglia*. Table 1.3 will help you make the connection between common singular and plural noun terminals.

In some cases, what appears to the beginner to be two completely different words may be only the noun and adjective forms of the same word. For example, *brachium* denotes the arm, and *brachii* (as in the muscle name *biceps brachii*) means "of the arm." *Carpus* denotes the wrist, and *carpi,* a word used in several muscle names, means "of the wrist." Adjectives can also take different forms for the singular and plural and for different degrees of comparison. The *digits* are the fingers and toes. The word *digiti* in a muscle name means "of a single finger (or toe)," whereas *digitorum* is the plural, meaning "of multiple fingers (or toes)." Thus the *extensor digiti minimi* muscle extends only the little finger, whereas the *extensor digitorum* muscle extends all fingers except the thumb.

The English words *large, larger,* and *largest* are examples of the positive, comparative, and superlative degrees of comparison. In Latin, these are *magnus, major* (from *maior*), and *maximus.* We find these in the muscle names *adductor magnus* (a *large* muscle of the thigh), the *pectoralis major* (the *larger* of two *pectoralis* muscles of the chest), and *gluteus maximus* (the *largest* of the three gluteal muscles of the buttock).

Some noun variations indicate the possessive, such as the *rectus abdominis,* a straight *(rectus)* muscle of the abdomen (*abdominis,* "of the abdomen"), and the *erector spinae,* a muscle that straightens *(erector)* the spinal column (*spinae,* "of the spine").

Anatomical terminology also follows the Greek and Latin practice of placing the adjective after the noun. Thus, we have such names as the *stratum lucidum* for a clear *(lucidum)* layer *(stratum)* of the epidermis, the *foramen magnum* for a large *(magnum)* hole *(foramen)* in the skull, and the aforementioned *pectoralis major* muscle of the chest.

This is not to say that you must be conversant in Latin or Greek grammar to proceed with your study of anatomy. These few examples, however, may alert you to some patterns to watch for in the terminology you study and, ideally, will make your encounters with anatomical terminology less confusing.

TABLE 1.3 Singular and Plural Forms of Some Noun Terminals

Singular Ending	Plural Ending	Examples
-a	-ae	axilla, axillae
-ax	-aces	thorax, thoraces
-en	-ina	lumen, lumina
-ex	-ices	cortex, cortices
-is	-es	diagnosis, diagnoses
-is	-ides	epididymis, epididymides
-ix	-ices	appendix, appendices
-ma	-mata	carcinoma, carcinomata
-on	-a	ganglion, ganglia
-um	-a	septum, septa
-us	-era	viscus, viscera
-us	-i	villus, villi
-us	-ora	corpus, corpora
-x	-ges	phalanx, phalanges
-y	-ies	ovary, ovaries
-yx	-yces	calyx, calyces

1.3d The Importance of Accuracy

A final word of advice for your study of anatomy: Be accurate in your spelling of anatomical terms. It may seem trivial if you misspell *trapezius* as *trapezium,* but in doing so, you would be changing the name of a back muscle to the name of a wrist bone. Similarly, changing *occipitalis* to *occipital* or *zygomaticus* to *zygomatic* changes other muscle names to bone names. Changing *malleolus* to *malleus,* omitting a small and perhaps trivial-seeming syllable, changes the name of the bony protuberance of your ankle to the name of a tiny middle-ear bone. A "little" error such as misspelling *ileum* as *ilium* changes the name of part of the small intestine to the name of a hip bone. Again, a "mere" one-letter difference distinguishes gustation (the sense of taste) from gestation (pregnancy).

The health professions demand the utmost attention to detail and precision—people's lives may one day be in your hands. The habit of carefulness must extend to your use of language as well. Many patients die because of tragic miscommunication in the hospital. Compared to this, it is hardly tragic if an instructor deducts a point or two for a small error in spelling. It should be considered a lesson learned about the importance of accuracy.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

10. Explain why modern anatomical terminology is so heavily based on Greek and Latin.
11. Distinguish between an eponym and an acronym, and explain why both of these present difficulties for interpreting anatomical terms.
12. Break the following words down into their roots, prefixes, and suffixes and state their meanings, following the example of *gastroenterology* analyzed earlier: *pericardium, appendectomy, subcutaneous, arteriosclerosis, hypercalcemia.* Consult the list of word elements in appendix B for help.
13. Write the singular form of each of the following words: *pleurae, gyri, lumina, ganglia, fissures.* Write the plural form of each of the following: *villus, tibia, encephalitis, cervix, stoma.*

STUDY GUIDE

Assess Your Learning Outcomes

To test your knowledge, discuss the following topics with a study partner or in writing, ideally from memory.

1.1 The Scope of Human Anatomy

1. The distinction between the sciences of anatomy and physiology, and the way functional morphology unites the two
2. The distinctions between gross, microscopic, surface, radiologic, systemic, and regional anatomy
3. Examples of what a physician might be looking for when he or she employs inspection, palpation, auscultation, and percussion with a patient
4. Ways in which dissection differs from exploratory surgery, and why exploratory surgery is far less common now than it was in the 1950s
5. The principles behind radiography, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and sonography
6. Differences between invasive and noninvasive methods of medical imaging
7. Reasons why the anatomy presented in this book may not apply to every human being

1.2 The Human Body Plan

1. The successive levels of human structural complexity from atom to organism
2. Correlation between the levels of human structure and the sciences of gross anatomy, histology, cytology, and ultrastructure
3. The 11 human organ systems, including the basic functions and major organs of each
4. Anatomical position and why it is important in anatomical communication
5. What it means to say the forearm is pronated or supinated, and how this differs from the meanings of *prone* and *supine*
6. The three primary anatomical planes, and what a given region of the body (such as midthoracic) would look like in each of these planes
7. The distinctions between *anterior* and *posterior; cephalic, rostral,* and *caudal; superior* and *inferior; medial* and *lateral; proximal* and *distal; ipsilateral* and *contralateral;* and *superficial* and *deep;* and the ability to use these terms correctly in descriptive anatomical sentences
8. Why the words *anterior* and *posterior* are preferable to *ventral* and *dorsal* for most purposes in human anatomy, and why *ventral* and *dorsal* would be more relevant to dissection of a cat than to dissection of the human cadaver
9. The principal body parts of the axial region and the appendicular region
10. The landmarks used to divide the abdomen into four quadrants, and the name of each quadrant
11. The landmarks used to divide the abdomen into a 3 × 3 grid, and the names of each of the 9 resulting regions
12. Names of the cavities that house the brain and spinal cord, and of the membranes that line these cavities
13. Landmarks that divide the thoracic, abdominal, and pelvic cavities from each other
14. The names of the cavities that enfold the heart and lungs; names of the membranes that line these cavities; names of the relatively superficial and deep layers of each of these two-layered membranes; and names of the fluids that lubricate these membranes and allow for painless heart and lung movements
15. The name of the membrane that lines the abdominal cavity; the name of its lubricating fluid; and the defining characteristic of organs described as retroperitoneal
16. The name of the serous membranes that suspend and bind the abdominal organs, and the name for the outer surface of an organ formed by this membrane passing around it
17. The meaning of *potential spaces,* and some examples

1.3 The Language of Anatomy

1. The reason so many medical terms are based on Latin and Greek
2. The role of *Terminologia Anatomica (TA)* in modern medical terminology, and the problems that it is meant to solve
3. How to divide medical terms such as *histology, cardiovascular, anatomy, endometrium, pseudostratified, subcutaneous, corticospinal,* and *hypodermic* into their prefixes, roots, combining forms, and suffixes, and how to recognize combining vowels where they exist
4. The differences between an eponym and an acronym, and between an acronym and an initialism (abbreviation) with medical examples of each
5. Recognition of the singular and plural forms of the same term, as in *extensor digiti* and *extensor digitorum*
6. Recognition of the positive, comparative, and superlative forms of the same term, as in the second word of *adductor magnus, pectoralis major,* and *gluteus maximus*
7. The importance of accurate spelling; why even one-letter or other trivial-seeming errors may be very significant in clinical practice; and examples of where this may apply

Testing Your Recall

1. Structure that can be observed with the naked eye is called
   a. gross anatomy.
   b. ultrastructure.
   c. microscopic anatomy.
   d. macroscopic anatomy.
   e. cytology.
2. Which of the following techniques requires an injection of radioisotopes into a patient's bloodstream?
   a. sonography
   b. a PET scan
   c. radiography
   d. a CT scan
   e. an MRI scan
3. The simplest structures considered to be alive are
   a. organs.
   b. tissues.
   c. cells.
   d. organelles.
   e. proteins.

4. The tarsal region is _____ to the popliteal region.
   a. medial
   b. superficial
   c. superior
   d. dorsal
   e. distal
5. The _____ region is immediately medial to the coxal region.
   a. inguinal
   b. hypochondriac
   c. umbilical
   d. popliteal
   e. cubital
6. Which of these regions is *not* part of the upper limb?
   a. plantar
   b. carpal
   c. cubital
   d. brachial
   e. palmar
7. Which of these organs is intraperitoneal?
   a. urinary bladder
   b. kidney
   c. heart
   d. small intestine
   e. brain
8. Which of these is *not* an organ system?
   a. muscular system
   b. integumentary system
   c. endocrine system
   d. lymphatic system
   e. immune system
9. The term *histology* is most nearly equivalent to
   a. histopathology.
   b. microscopic anatomy.
   c. cytology.
   d. ultrastructure.
   e. systemic anatomy.
10. An imaging technique that exposes the patient to no harmful radiation is
    a. radiography.
    b. positron emission tomography (PET).
    c. computed tomography (CT).
    d. magnetic resonance imaging (MRI).
    e. angiography.
11. Cutting and separating tissues to reveal their structural relationships is called _____.
12. The forearm is said to be _____ when the palms are facing forward.
13. The relatively superficial layer of the pleura is called the _____ pleura.
14. Abdominal organs that lie against the posterior abdominal wall and are covered with peritoneum only on the anterior side are said to have a/an _____ position.
15. _____ is a science that doesn't merely describe bodily structure but interprets structure in terms of its function.
16. When a doctor presses on the upper abdomen to feel the size and texture of the liver, he or she is using a technique of physical examination called _____.
17. _____ is a method of medical imaging that uses X-rays and a computer to generate images of thin slices of the body.
18. A/An _____ is the simplest body structure to be composed of two or more types of tissue.
19. The left hand and left foot are _____ to each other, whereas the left hand and right hand are _____ to each other.
20. The anterior pit of the elbow is called the _____ region, whereas the corresponding (but posterior) pit of the knee is called the _____ region.

Answers in appendix A

Building Your Medical Vocabulary

State a meaning of each word element and give a medical term from this chapter that uses it or a slight variation of it.

1. ana-
2. -graphy
3. morpho-
4. hypo-
5. -ation
6. -elle
7. palp-
8. ante-
9. intra-
10. auscult-

Answers in appendix A

What's Wrong with These Statements?

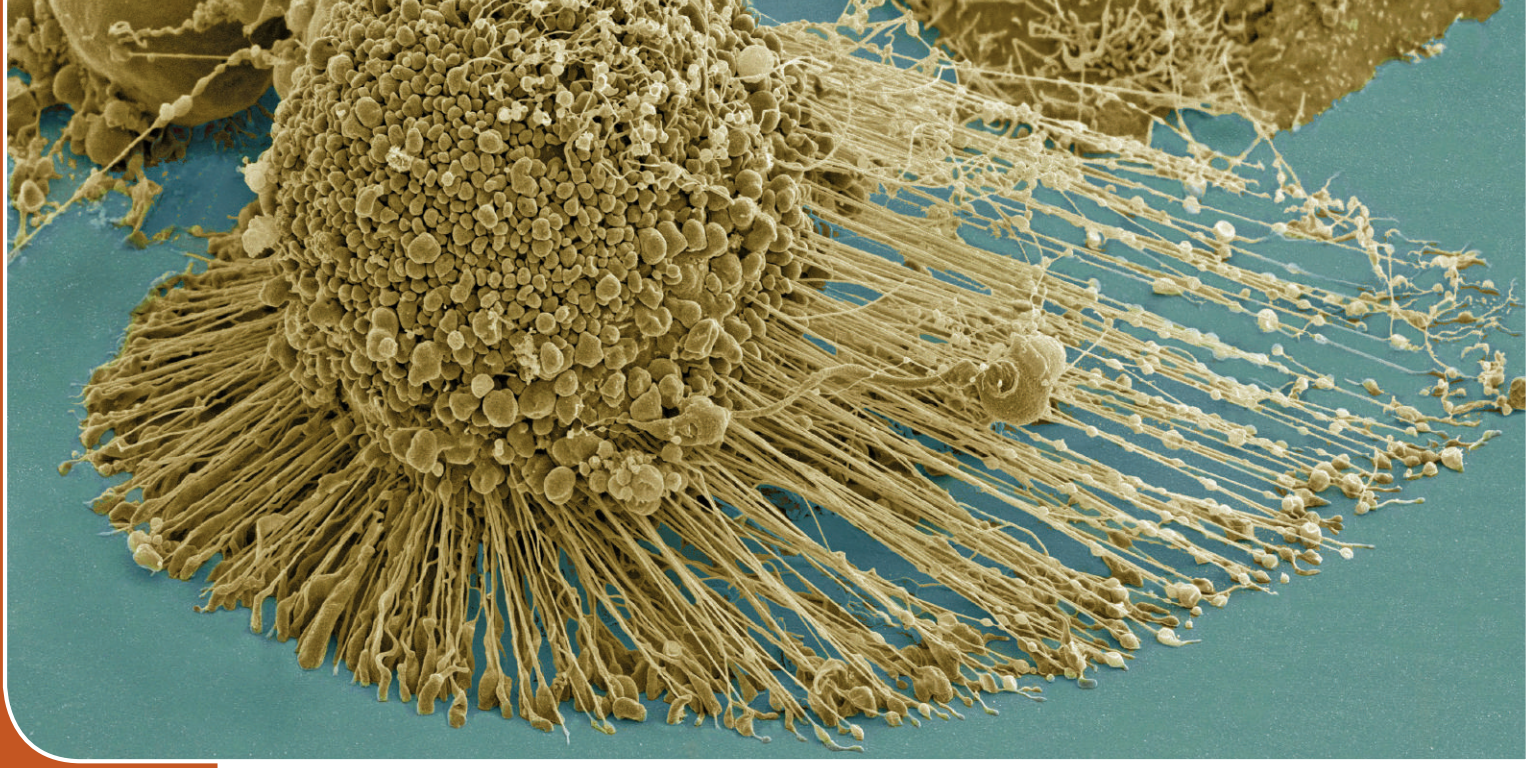
Briefly explain why each of the following statements is false, or reword it to make it true.

1. The technique for taking one's pulse at the wrist is called *auscultation*.
2. Both lungs could be seen in a single sagittal section of the body.
3. Abnormal skin color or dryness could be one piece of diagnostic information gained by auscultation.
4. Radiology refers only to those medical imaging methods that use radioisotopes.
5. Sonography is a better method than MRI for visualizing a tumor of the brain.
6. There are more cells than organelles in the body.
7. The diaphragm is ventral to the lungs.
8. Pregnant women should avoid MRI scans because of the potential harmful effects of ionizing radiation on the fetus.
9. Each lung is enclosed in a space between the parietal and visceral pleurae.
10. *DNA* is an acronym for *deoxyribonucleic acid.*

Answers in appendix A

Testing Your Comprehension

1. Classify each of the following radiologic techniques as invasive or noninvasive and explain your reasoning for each: angiography, sonography, CT, MRI, and PET.
2. Beginning medical students are always told to examine multiple cadavers and not confine their study to just one. Other than the obvious purpose of studying both male and female anatomy, why is this instruction so important in medical education?
3. Identify which anatomical plane—sagittal, frontal, or transverse—is the only one that could *not* show (a) both the brain and tongue; (b) both eyes; (c) both the heart and uterus; (d) both the hypogastric and gluteal regions; (e) both kidneys; and (f) both the sternum and vertebral column.
4. Lay people often misunderstand medical terminology. Drawing on this chapter's terminology of body regions, what do you think people really mean when they say they have "planter's warts"?
5. Why do you think the writers of *Terminologia Anatomica* decided to reject eponyms? Do you agree with that decision? Why do you think they decided to name structures in Latin? Do you agree with that decision? Explain your reasons for agreeing or disagreeing with each.



A dying HeLa cancer cell (SEM)

CHAPTER

2

CYTOLOGY— THE STUDY OF CELLS

CHAPTER OUTLINE

CLINICAL APPLICATIONS

BRUSHING UP

To understand this chapter, you may find it helpful to review the following concept:

- Levels of human structure (section 1.2a)

Module 2: Cells and Chemistry
Module 3: Tissues

The most important revolution in the history of medicine was the realization that all bodily functions result from cellular activity. By extension, nearly every dysfunction of the body is now recognized as stemming from a dysfunction at the cellular level. Numerous medical research articles on cellular function appear every week, and all drug development is based on an intimate knowledge of how cells work. The cellular perspective has thus become indispensable to any true understanding of the structure and function of the human body, the mechanisms of disease, and the rationale of therapy.

This chapter therefore begins our study of anatomy at the cellular level. We will see how continued developments in microscopy have deepened our insight into cell structure, examine the structural components of cells, and briefly survey two aspects of cellular function—transport through the plasma membrane and the cell life cycle. It is the derangement of that life cycle that gives rise to one of the most dreaded of human diseases, cancer.

2.1 The Study of Cells

Expected Learning Outcomes

When you have completed this section, you should be able to

a. state some tenets of the cell theory;
b. discuss how developments in microscopy have changed our view of cell structure;
c. outline the major structural components of a cell;
d. identify cell shapes from their descriptive terms; and
e. state the size range of human cells and explain why cell size is limited.

Cells are the smallest entities considered to be alive. No protein is alive, and DNA is not alive—only cells and the larger structures they compose are alive. But why? Because nothing smaller than a cell has all of the following characteristics and abilities essential to the meaning of life:

- **Organization.** Cells have a far more organized and complex structure than any nonliving objects, and continually expend energy to maintain this organization.
- **Assimilation.** Cells selectively take up chemicals from their environment and incorporate them into their own structure.
- **Metabolism.** Cells don't simply use whatever materials are available to them in their existing form, but chemically convert assimilated molecules to new compounds needed for their own maintenance. *Metabolism* is the sum of all such chemical conversions in a cell or organism.
- **Excretion.** Metabolism generates wastes, and cells selectively eliminate (excrete) these rather than allow them to accumulate internally.
- **Responsiveness.** Cells respond to changes in their environment, often by changes in the electrical polarity of their surface membrane, in their metabolism, or by movement.
- **Movement.** Cells move materials within them in purposeful (not random) ways, move substances through their cellular membranes, and, in some cases such as muscle cells and white blood cells, the entire cell can move.
- **Self-replication.** Cells reproduce themselves rather than being produced from nonliving matter by external agents; all cells come from preexisting cells.

The scientific study of cellular structure and function is called **cytology.**[1] Some historians date the birth of this science to 15 April 1663, when English inventor Robert Hooke employed his newly created microscope to observe the little boxes formed by the cell walls of cork. He named them *cellulae.* Cytology was greatly advanced by refinements in microscope technology and techniques of histology (tissue preparation) in the nineteenth century. By 1900, it was established beyond reasonable doubt that every living organism is made of cells; that cells now arise only through the division of preexisting cells rather than springing spontaneously from nonliving matter; and that all cells have the same basic chemical components, such as carbohydrates, lipids, proteins, and nucleic acids. These and other principles have been codified as the **cell theory.**

2.1a Microscopy

The smallest things we can see without magnification are about 100 **micrometers (μm)** in size—that is, about 0.1 mm. This is approximately one-quarter the size of the period at the end of a sentence in typical printed text. A few human cells fall within this range, such as the egg cell and some fat cells, but most human cells are only 10 to 15 μm wide. The longest are nerve cells (sometimes over a meter long) and muscle cells (up to 30 cm long), but both are usually too slender to be seen with the naked eye. Therefore, to study cells or even to see them requires a microscope; cytology would not exist without the microscope.

Throughout this book, you will find many **photomicrographs**—photos of tissues and cells taken through the microscope. The microscopes used to produce them fall into three basic categories: the light microscope, transmission electron microscope, and scanning electron microscope.

The **light microscope (LM)** uses visible light to produce its images. It is the least expensive type of microscope, the easiest to use, and the most often used. In addition to these advantages, it enables us to observe living cells and to see colors. However, it is also the most limited in the amount of useful magnification it can produce. Light microscopes today magnify up to 1,200 times. There are several varieties of light microscopes, including the fluorescence microscope used to produce figure 2.16b.

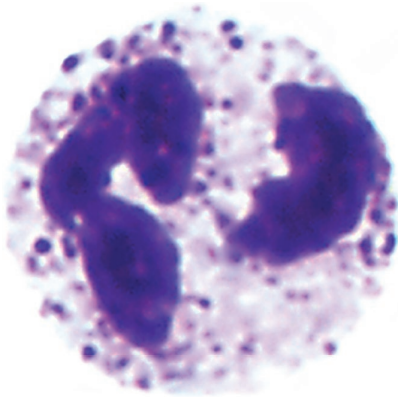
Most of the structure we study in this chapter is invisible to the LM, not because the LM cannot magnify enough but because it cannot reveal enough detail. The most important thing about a good microscope is not magnification but **resolution**—the ability to reveal detail. Any image can be photographed and enlarged as much as we wish, but if enlargement fails to reveal greater detail, it is useless *empty magnification.* A large blurry image is not nearly as informative as one that is small and sharp. For reasons of physics beyond the scope of this chapter, it is the wavelength of light that places a limit on resolution. At the wavelengths of

[1] *cyto* = cell; *logy* = study of

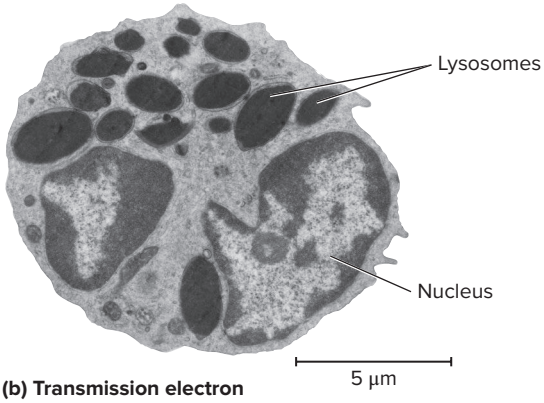
visible light (about 400 to 700 nanometers, or nm), the LM cannot distinguish between two objects any closer together than 200 nm (0.2 micrometers, or μm).

Resolution improves when objects are viewed with radiation of shorter wavelengths. *Electron microscopes* achieve higher resolution by using not visible light but a beam of electrons with very short wavelength (0.005 nm). The **transmission electron microscope (TEM),** invented in the mid-twentieth century, is usually used to study specimens that have been sliced ultrathin with diamond knives and stained with heavy metals such as osmium, which absorbs electrons. The TEM resolves details as small as 0.5 nm and attains useful magnifications of biological material up to 600,000 times. This is good enough to see even things as small as proteins, nucleic acids, and other large molecules. Such fine detail is called cell *ultrastructure.* Even at the same magnifications as the LM, the TEM reveals far more detail (fig. 2.1). It usually produces two-dimensional black-and-white images, but electron photomicrographs are often colorized for instructional purposes.

The **scanning electron microscope (SEM)** uses a specimen coated with vaporized metal (usually gold). The electron beam strikes the specimen and discharges secondary electrons from the metal coating. These electrons then strike a fluorescent screen and produce an image. The SEM yields less resolution than the TEM and is used at lower magnification, but it produces dramatic three-dimensional images that are sometimes more informative than TEM images, and it does not require that the specimen be cut into thin slices. The SEM can view only the surfaces of specimens; it does not see through an object as the LM or TEM does. Cell interiors can be viewed, however, by a *freeze-fracture* method in which a cell is frozen, cracked open, coated with gold vapor, and then viewed by either TEM or SEM. Figure 2.2 compares red blood cells photographed with the LM, TEM, and SEM.

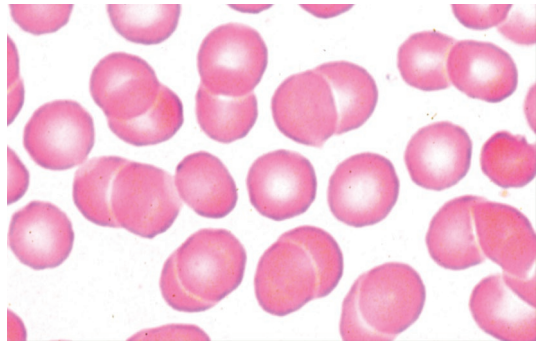


(a) Light microscope (LM)

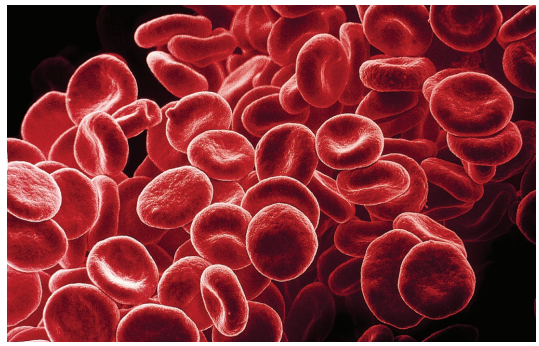


(b) Transmission electron microscope (TEM)

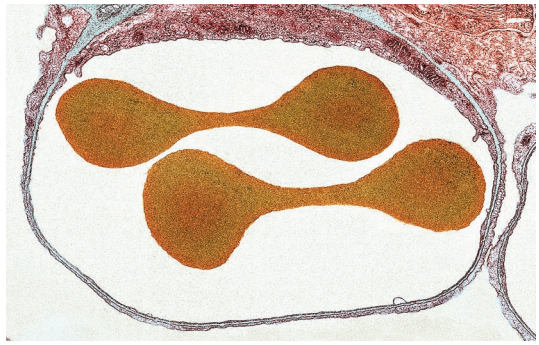
Figure 2.1 **Magnification Versus Resolution.** Two white blood cells (neutrophils) shown at the same magnification. (a) Photographed with the light microscope (LM). (b) Photographed with the transmission electron microscope (TEM). Note the finer detail (resolution) attained with the TEM.



(a) Light microscope (LM) — 10.0 μm



(b) Scanning electron microscope (SEM) — 10.0 μm



(c) Transmission electron microscope (TEM) — 2.0 μm

Figure 2.2 **Images of Red Blood Cells (Erythrocytes) Produced by Three Kinds of Microscopes.** (a) Light microscope. (b) Scanning electron microscope. (c) Transmission electron microscope (two cells encircled by a blood capillary).

• *Based on images (b) and (c), can you explain why the cells in image (a) have such pale centers?*

A visually stunning application of SEM, often seen in this book, is the *vascular corrosion cast* of an organ's blood vessels. This is made by injecting a resin into the blood vessels, then dissolving away the actual tissue with a corrosive agent, leaving only the resin cast. The cast is then photographed with an SEM. The resulting images are not only strikingly beautiful, but give great insight into the blood supply of an organ (see the opening page of chapter 18 and figs. 10.5 and 25.9, for example).

Apply What You Know

List all of the photomicrographs in this chapter that were made by LM, TEM, and SEM. For each photo, describe how you would know which type of microscope was used if that information had not already been provided.

2.1b Cell Shapes and Sizes

We will shortly examine the structure of a generic cell, but the generalizations we draw should not blind you to the diversity of cellular form and function in humans. There are about 200 kinds of cells in the human body, with a variety of shapes, sizes, and functions.

Descriptions of organ and tissue structure often refer to the shapes of cells by the following terms (fig. 2.3):

- *Squamous*[2] (SQUAY-mus)—a thin, flat, scaly shape, often with a bulge where the nucleus is—much like the shape of a fried egg "sunny side up." Squamous cells line the esophagus and form the surface layer (epidermis) of the skin.
- *Cuboidal*[3] (cue-BOY-dul)—squarish-looking in frontal sections and about equal in height and width; liver cells are a good example.
- *Columnar*—distinctly taller than wide, such as the inner lining cells of the stomach and intestines.
- *Polygonal*[4]—having irregularly angular shapes with four, five, or more sides. Cells that look cuboidal or columnar in frontal view are commonly polygonal in an end view, like a quartz crystal.
- *Stellate*[5]—having multiple pointed processes projecting from the body of a cell, giving it a somewhat starlike shape. The cell bodies of many nerve cells are stellate.
- *Spheroidal* to *ovoid*—round to oval, as in egg cells and white blood cells.
- *Discoidal*—disc-shaped, as in red blood cells.
- *Fusiform*[6] (FEW-zih-form)—spindle- or toothpick-shaped; elongated, with a thick middle and tapered ends, as in smooth muscle cells.
- *Fibrous*—long, slender, and threadlike, as in skeletal muscle cells and the axons (nerve fibers) of nerve cells.

In some cells, it is important to distinguish one surface from another, because cell surfaces may differ in function and membrane composition. This is especially true in *epithelia,* cell layers that cover organ surfaces. An epithelial cell rests on a lower **basal surface** often attached to an extracellular *basement membrane* (see section 3.2). The upper surface of the cell is called the **apical surface.** Its sides are **lateral surfaces.** You could compare these to the floor, roof, and walls of a house, respectively.

[2] *squam* = scale; *ous* = characterized by

[3] *cub* = cube-shaped; *oidal* = like, resembling

[4] *poly* = many; *gon* = angles

[5] *stell* = star; *ate* = characterized by

[6] *fusi* = spindle; *form* = shape

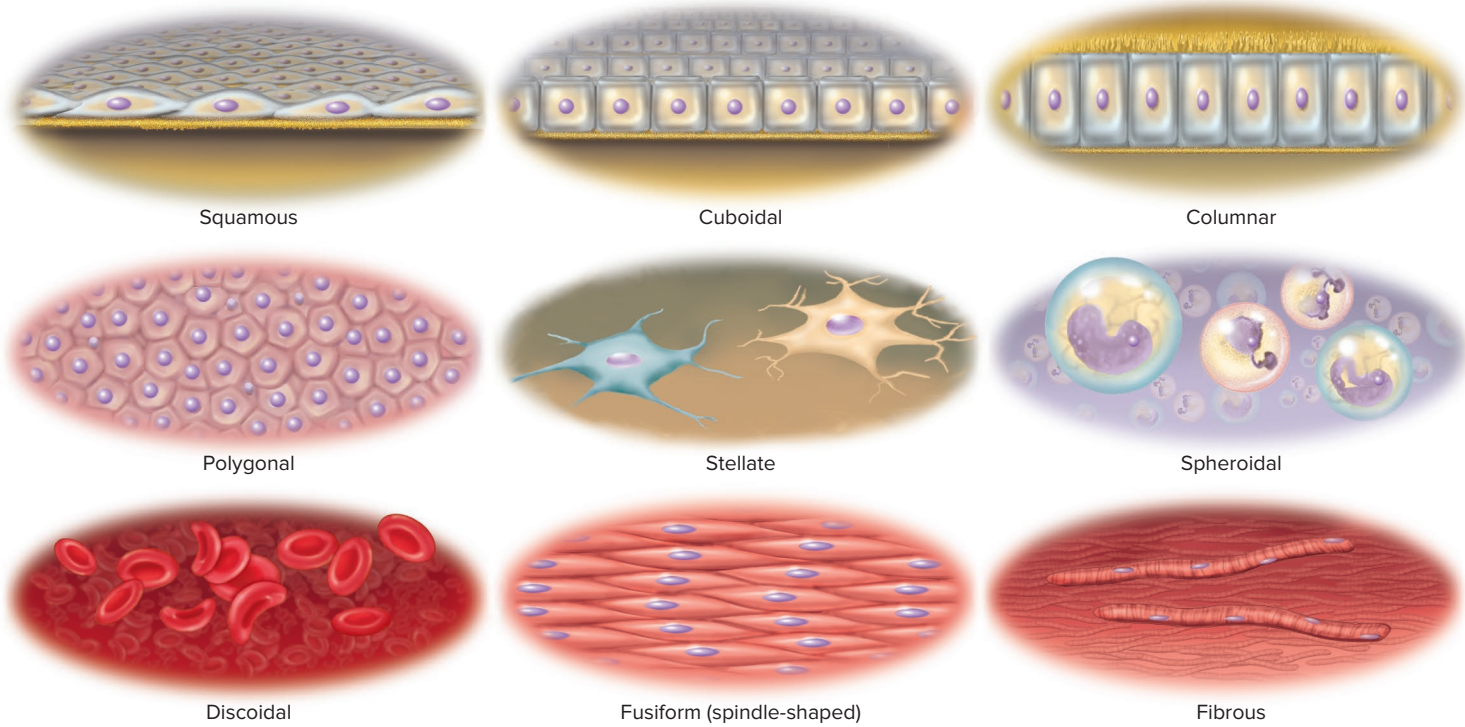


Figure 2.3 Common Cell Shapes. AP|R

There are several factors that limit the size of cells. If a cell swells to excessive size, it ruptures like an overfilled water balloon. In addition, cell size is limited by the relationship between its volume and surface area. The surface area of a cell is proportional to the square of its diameter, while volume is proportional to the cube of diameter. Thus, for a given increase in diameter, cell volume increases much faster than surface area. Picture a cuboidal cell 10 µm on each side (fig. 2.4). It would have a surface area of 600 μm^2 (10 µm × 10 µm × 6 sides) and a volume of 1,000 μm^3 (10 × 10 × 10 µm). Now, suppose it grew by another 10 µm on each side. Its new surface area would be 20 µm × 20 µm × 6 = 2,400 μm^2, and its volume would be 20 × 20 × 20 µm = 8,000 μm^3. The 20 µm cell has eight times as much cytoplasm needing nourishment and waste removal, but only four times as much membrane surface through which wastes and nutrients can be exchanged. In short, a cell that is too big cannot support itself.

Also, if a cell were too large, molecules could not diffuse from place to place fast enough to support its metabolism. The time required for diffusion is proportional to the square of distance, so if cell diameter doubled, the travel time for molecules within the cell would increase fourfold. For example, if it took 10 seconds for a molecule to diffuse from the surface to the center of a cell with a 10 µm radius, then we increased this cell to a radius of 1 mm, it would take 278 hours to reach the center—far too slow to support the cell's life activities.

Having organs composed of many small cells instead of fewer large ones has another advantage: The death of one or a few cells has less effect on the structure and function of the whole organ.

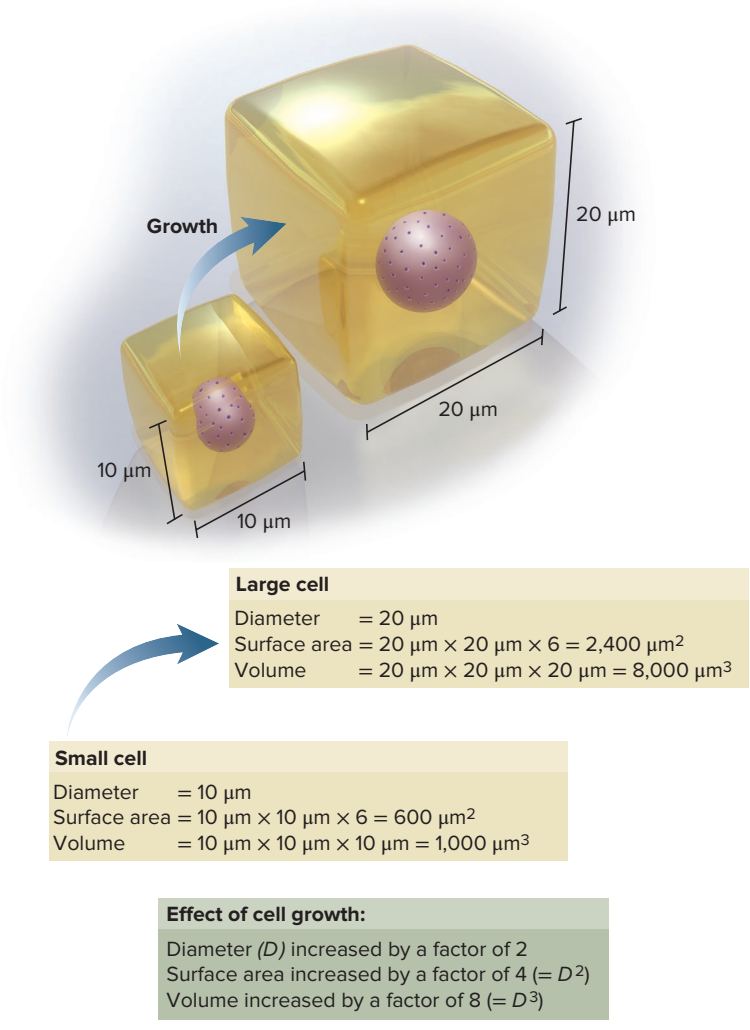


Figure 2.4 The Relationship Between Cell Surface Area and Volume. As a cell doubles in width, its volume increases eightfold, but its surface area increases only fourfold. A cell that is too large may have too little plasma membrane to support the metabolic needs of its volume of cytoplasm.

2.1c Basic Components of a Cell

Before electron microscopy, little was known about structural cytology except that cells were enclosed in a membrane and contained a nucleus. The material between the nucleus and surface membrane was thought to be little more than a gelatinous mixture of chemicals and vaguely defined particles. But the electron microscope revealed that the cytoplasm is crowded with a maze of passages, compartments, and filaments (fig. 2.5). Earlier microscopists were little aware of this detail simply because most of these structures are too small to be resolved by the light microscope (table 2.1).

We now regard cells as having the following major components:

- Plasma membrane
- Cytoplasm
  - Cytoskeleton
  - Organelles (including the nucleus)
  - Inclusions
  - Cytosol

TABLE 2.1 Sizes of Biological Structures in Relation to the Resolution of the Eye, Light Microscope, and Transmission Electron Microscope

Object	Size
Visible with the Eye (Resolution 70–100 µm)	
Human egg, diameter	100 µm
Visible with the Light Microscope (Resolution 200 nm)	
Most human cells, diameter	10–15 µm
Cilia, length	7–10 µm
Mitochondria, width × length	0.2 × 4 µm
Bacteria (*Escherichia coli*), length	1–3 µm
Microvilli, length	1–2 µm
Visible with the Transmission Electron Microscope (Resolution 0.5 nm)	
Nuclear pores, diameter	30–100 nm
Ribosomes, diameter	15 nm
Globular proteins, diameter	5–10 nm
Plasma membrane, thickness	7.5 nm
DNA molecule, diameter	2.0 nm
Plasma membrane channels, diameter	0.8 nm

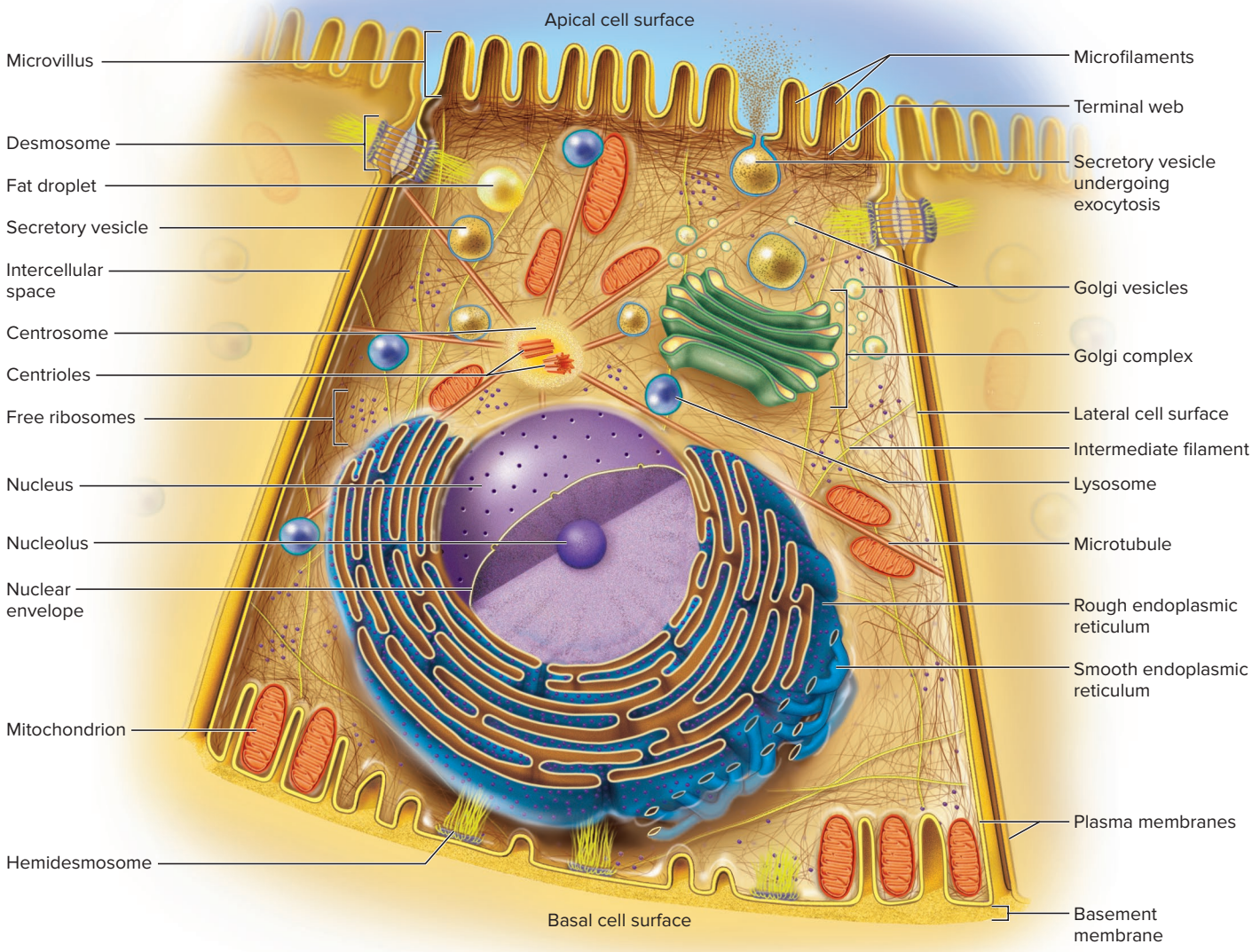


Figure 2.5 **Structure of a Generalized Cell.** The organelles are not all drawn to the same scale. Cytoplasm is more densely crowded with organelles than shown here.

The **plasma membrane (cell membrane)** forms the cell's surface boundary. The material enclosed by the plasma membrane is the **cytoplasm,**[7] and the material within the nucleus (usually the cell's largest organelle) is the **nucleoplasm.** The cytoplasm contains the *cytoskeleton,* a supportive framework of protein filaments and tubules; an abundance of *organelles,* diverse structures that perform various metabolic tasks for the cell; and *inclusions,* which are foreign matter or stored cell products. The cytoskeleton, organelles, and inclusions are embedded in a clear gel called the **cytosol.**

The cytosol is also called the **intracellular fluid (ICF).** All body fluids not contained in the cells are collectively called the **extracellular fluid (ECF).** The ECF located between the cells is also called **tissue (interstitial) fluid.** Some other extracellular fluids include blood plasma, lymph, and cerebrospinal fluid.

[7] *cyto* = cell; *plasm* = formed, molded

Before You Go On

Answer the following questions to test your understanding of the preceding section:

1. State some tenets of the cell theory.
2. What is the main advantage of an electron microscope over a light microscope?
3. Explain why cells cannot grow to unlimited size.
4. Define *cytoplasm, cytosol,* and *organelle.*

2.2 The Cell Surface

Expected Learning Outcomes

When you have completed this section, you should be able to

a. describe the structure of the plasma membrane;
b. explain the functions of the lipid, protein, and carbohydrate components of the plasma membrane;
c. describe the processes for moving material into and out of a cell; and
d. describe the structure and function of microvilli, cilia, flagella, pseudopods, and cell junctions.

A great deal of human physiology takes place at the cell surface—for example, the binding of signaling molecules such as hormones, the stimulation of cellular activity, the attachment of cells to each other, and the transport of materials into and out of cells. This, then, is where we begin our study of cellular structure and function. Like explorers of a new continent, we will examine the interior only after we have investigated its coastline.

2.2a The Plasma Membrane

The plasma membrane defines the boundaries of the cell, governs its interactions with other cells, and controls the passage of materials into and out of the cell. Similar membranes enclose most of the cell's organelles and control their uptake and release of chemicals. The side of a plasma membrane that faces the cytoplasm is its **intracellular face,** and the side that faces outward is the **extracellular face.**

Membrane Lipids

The plasma membrane is an oily, two-layered lipid film with proteins embedded in it (fig. 2.6). By weight, it is about half lipid and half protein. Since the lipid molecules are smaller and lighter, however, they constitute about 90% to 99% of the molecules in the membrane.

About 75% of the membrane lipid molecules are phospholipids. A **phospholipid** (fig. 2.7) consists of a three-carbon backbone called glycerol, with fatty acid tails attached to two of the carbons and a phosphate-containing head attached to the third. The two fatty acid tails are *hydrophobic*[8] (water-repellent) and the head is *hydrophilic*[9] (attracted to water). The heads of the phospholipids face the ECF and ICF, whereas the tails form the middle of the "sandwich," as far away from the surrounding water as possible. The phospholipids are not stationary but highly fluid—drifting laterally from place to place, vibrating, spinning on their axes, and flexing their tails.

Cholesterol, found near the membrane surfaces amid the phospholipids, constitutes about 20% of the membrane's lipid molecules. By interacting with the phospholipids and holding them in place, cholesterol can stiffen the membrane (make it less fluid) in spots. Higher concentrations of cholesterol, however, can increase membrane fluidity by preventing the phospholipids from packing as closely together as normal.

The remaining 5% of the lipids are **glycolipids**—phospholipids with short carbohydrate chains bound to them. Glycolipids occur only on the extracellular face of the membrane. They contribute to the **glycocalyx,** a sugary cell coating discussed later.

An important quality of the plasma membrane is its capacity for self-repair. When a physiologist inserts a probe into a cell, it doesn't pop the cell like a balloon. The probe slips through the oily film and the membrane seals itself around it. When cells take in matter by endocytosis (described later), they pinch off bits of their own membrane, which form bubblelike vesicles in the cytoplasm. As these vesicles pull away from the membrane, they don't leave gaping holes; the lipids immediately flow together to seal the break.

Membrane Proteins

Proteins constitute from 1% to 10% of the membrane molecules. They fall into two broad classes called *integral* and *peripheral proteins.* **Integral proteins** penetrate at least partially into the phospholipid bilayer, and if they pass all the way through, they are also called **transmembrane proteins.** They have hydrophilic regions in contact with the cytoplasm and extracellular fluid, and hydrophobic regions that pass back and forth through the membrane lipid, sometimes repeatedly, like a thread through fabric (fig. 2.8). Most of the transmembrane proteins are **glycoproteins,** which, like glycolipids, have carbohydrate chains linked to them and help form the glycocalyx. **Peripheral proteins** are those that don't protrude into the phospholipid layer but adhere to either face of the membrane, usually the intracellular face. Some transmembrane proteins drift about freely in the plasma membrane, while others are anchored to the cytoskeleton and thus held in one place. Most peripheral proteins are anchored to the cytoskeleton and associated with transmembrane proteins.

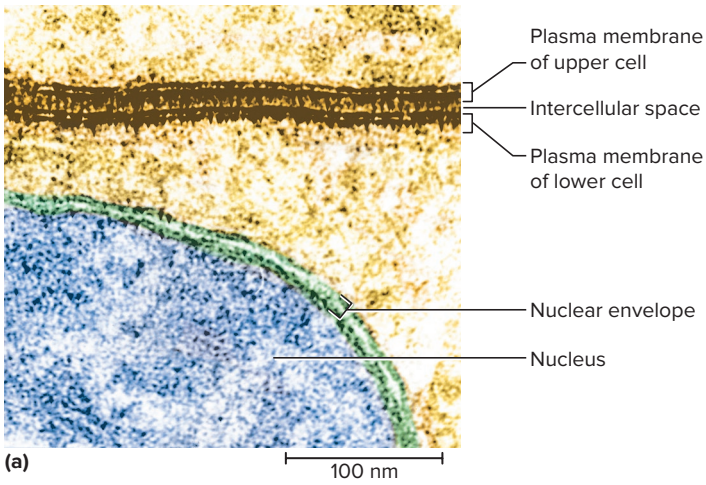
The functions of membrane proteins are very diverse and are among the most interesting aspects of cell physiology. These proteins serve in the following roles:

- **Receptors** (fig. 2.9a). Cells communicate with each other by chemical signals such as hormones and neurotransmitters. Some of these messengers (epinephrine, for example) cannot enter their target cells but can only "knock on the door" with their message. They bind to a membrane protein called a receptor, and the receptor triggers physiological changes inside the cell. Some of these have a dual function as receptor and transport proteins—they bind chemicals from the extracellular fluid and transport them into the cell.
- **Enzymes** (fig. 2.9b). Some membrane proteins are enzymes that carry out chemical reactions at the cell surface. Some of these break down chemical messengers after the message has been received. Enzymes in the plasma membranes of intestinal cells carry out the final stages of starch and protein digestion.
- **Channel proteins** (fig. 2.9c). These are individual proteins or aggregates of proteins enclosing a channel that allows water and hydrophilic solutes to enter or leave a cell. Some channels are always open, whereas others, called **gates** or **gated channels** (fig. 2.9d), open or close when they are stimulated and thus allow things to enter or leave the cell only at appropriate times. Membrane gates are responsible for firing of the heart's

[8] *hydro* = water; *phobic* = fearing, repelled by
[9] *hydro* = water; *philic* = loving, attracted to

pacemaker, muscle contraction, and most of our sensory processes, among other functions.

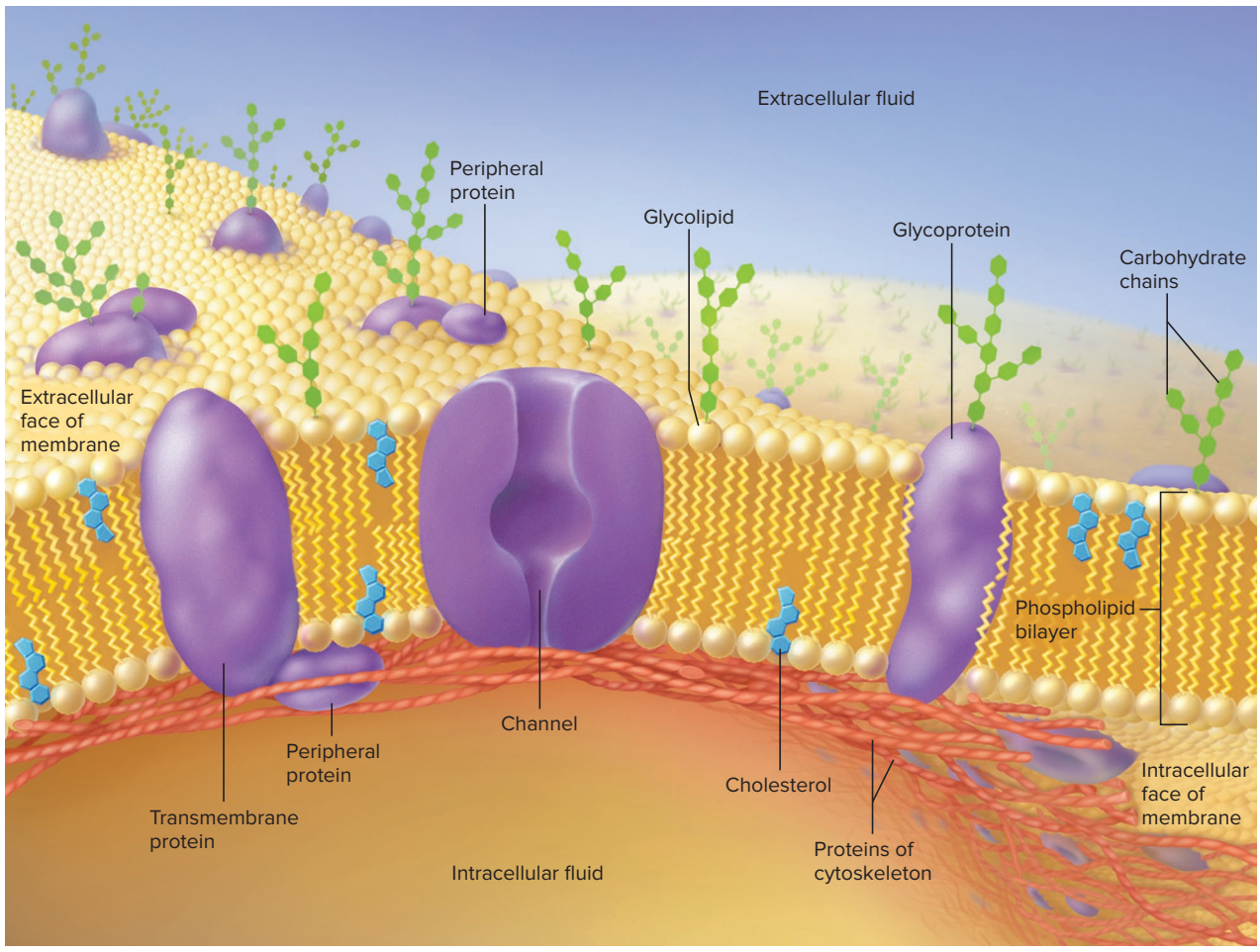
- **Transport proteins (carriers)** (see fig. 2.10c, d). Transport proteins don't merely open to allow substances through—they actively bind to a substance on one side of the membrane and release it on the other side. Carriers are responsible for transporting glucose, amino acids, sodium, potassium, calcium, and many other substances into and out of cells.
- **Cell-identity markers** (fig. 2.9e). The glycoproteins and glycolipids of the membrane are like genetic identification tags, unique to an individual (or to identical twins). They enable the body to distinguish what belongs to it from what does not—especially from foreign invaders such as bacteria and parasites.
- **Cell-adhesion molecules (CAMs)** (fig. 2.9f). Cells adhere to each other and to extracellular material through membrane proteins called cell-adhesion molecules. With few exceptions (such as blood cells and metastasizing cancer cells), cells don't grow or survive normally unless they are mechanically linked to the extracellular material. Special events such as sperm–egg binding and the binding of an immune cell to a cancer cell also require CAMs.



(a)

2.2b Membrane Transport

One of the most important functions of cellular membranes is to control the passage of materials into and out of the organelles and the cell as a whole. Figure 2.10 illustrates three methods of movement through



(b)

Figure 2.6 The Plasma Membrane. (a) Plasma membranes of two adjacent cells (TEM). Note also that the nuclear envelope is composed of a double membrane, each layer of which is similar to a plasma membrane. (b) Molecular organization of the plasma membrane.

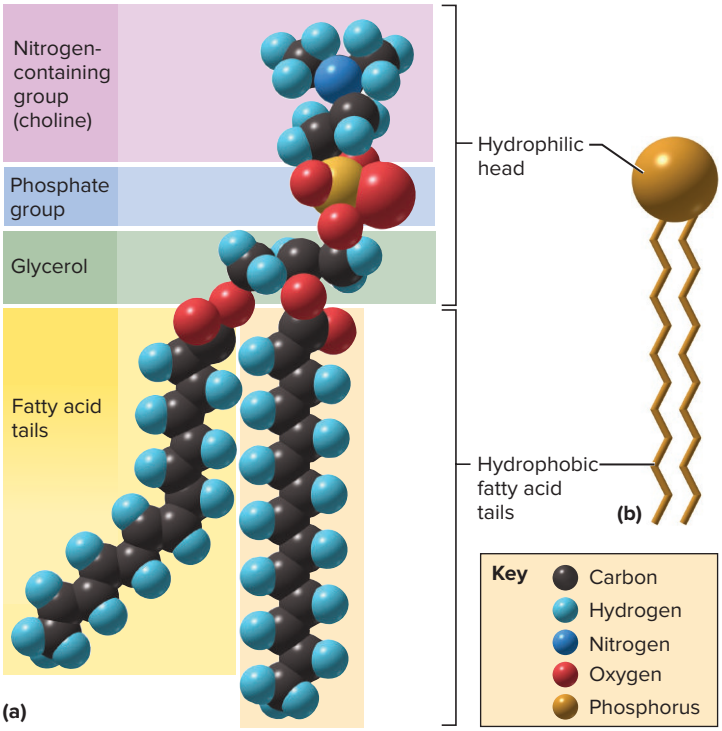


Figure 2.7 Phospholipid Structure and Symbol. (a) Molecular model of a phospholipid. (b) Common symbol used to represent phospholipids in diagrams of cell membranes.

the plasma membrane, as well as filtration, an important mode of transport across the walls of certain blood vessels.

Filtration

Filtration (fig. 2.10a) is a process in which a physical pressure forces fluid through a membrane, like the weight of water forcing it through the paper filter in a coffeemaker. In the body, the prime example of filtration is blood pressure forcing fluid to seep through the walls of the blood capillaries into the tissue fluid. This is how water, salts, organic nutrients, and other solutes pass from the bloodstream to the tissue fluid, where they can get to the cells surrounding a blood vessel. This is also how the kidneys filter wastes from the blood.

Simple Diffusion

Simple diffusion (fig. 2.10b) is the net movement of particles from a place of high concentration to a place of lower concentration—in other words, *down a concentration gradient.* Diffusion is how oxygen and steroid hormones enter cells and potassium ions leave, for example. The cell does not have to expend any energy to achieve this; all molecules are in spontaneous random motion, and this alone provides the energy for their diffusion through space. We say that the plasma membrane is *selectively permeable* because it lets some particles through but holds back larger ones.

Osmosis

Osmosis[10] (oz-MO-sis) is the net flow of water through a selectively permeable membrane from the "more watery" side (the one with less dissolved matter) to the "less watery" side (with more dissolved matter). Water molecules tend to cling to particles of dissolved matter and resist going back through the membrane in the opposite direction—hence the net accumulation of water on the side with more solute. Many cells have membrane channel proteins called **aquaporins** that allow water to pass easily through the membrane. Imbalances in osmosis underlie such problems as diarrhea, constipation, and edema. Osmosis is also a vital consideration in intravenous fluid therapy and kidney dialysis.

[10] *osm* = push, thrust; *osis* = process

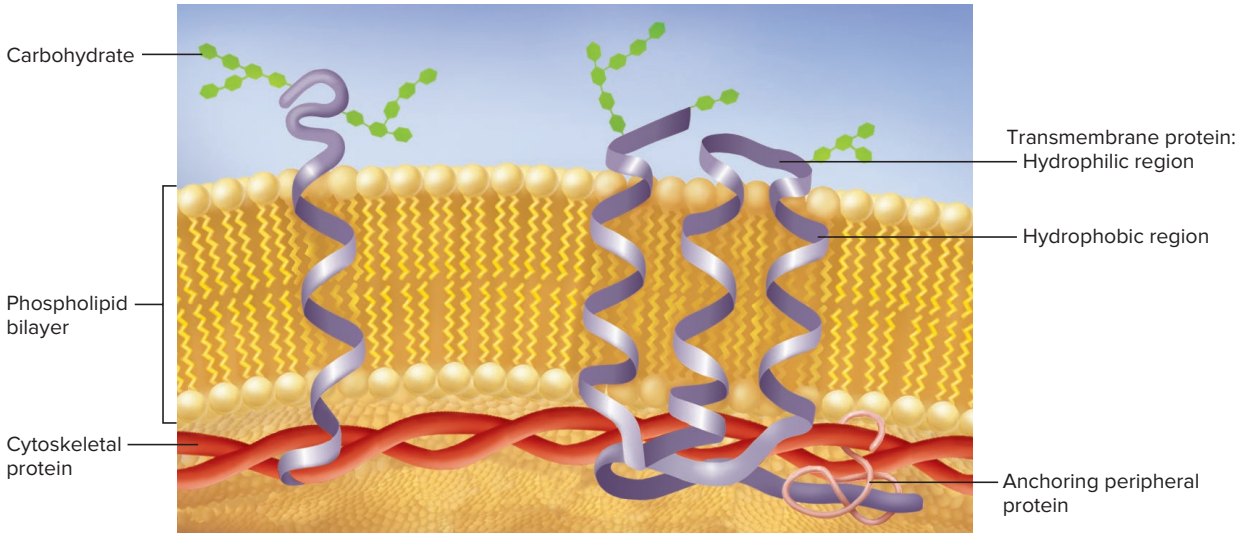


Figure 2.8 Transmembrane Proteins. A transmembrane protein has hydrophobic regions embedded in the phospholipid bilayer and hydrophilic regions projecting into the extracellular and intracellular fluids. The protein may cross the membrane once (left) or multiple times (right). The intracellular "domain" of the protein is often anchored to the cytoskeleton by peripheral proteins.

• *What other regions of the protein on the right would be hydrophilic in addition to the one labeled?*

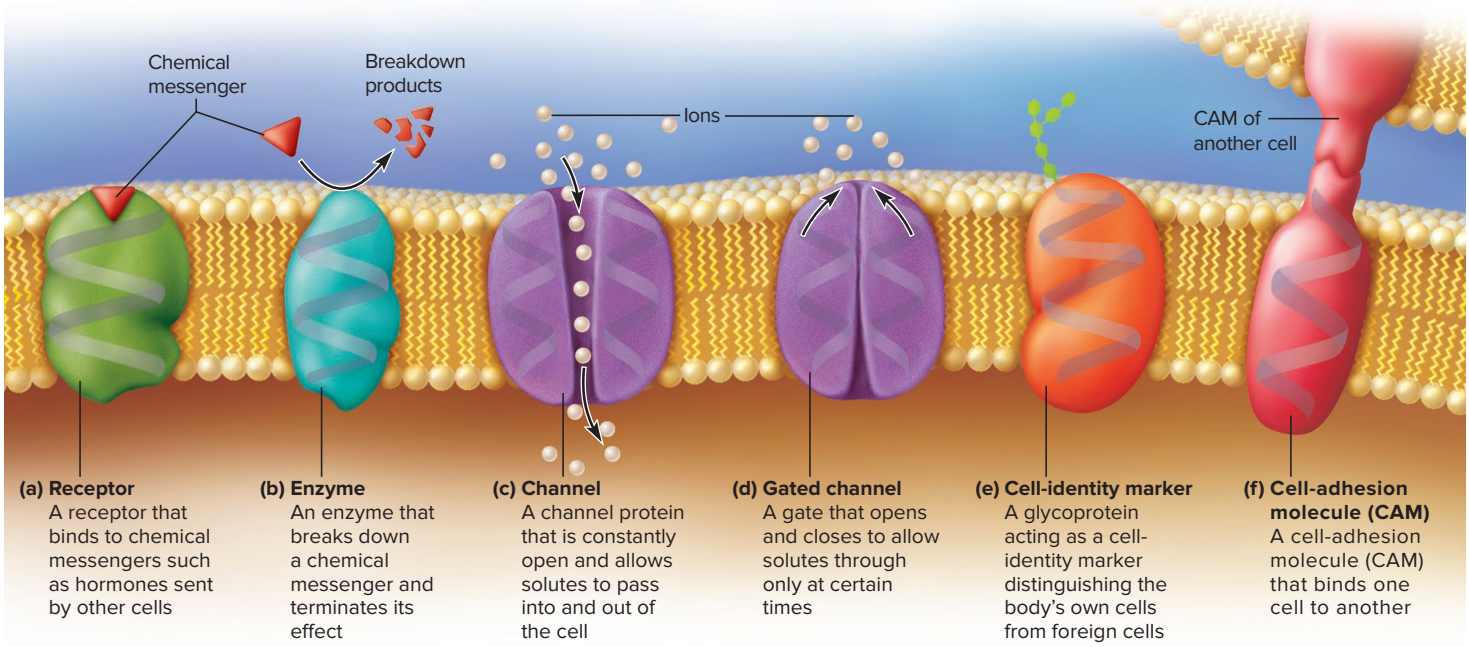


Figure 2.9 Some Functions of Plasma Membrane Proteins.

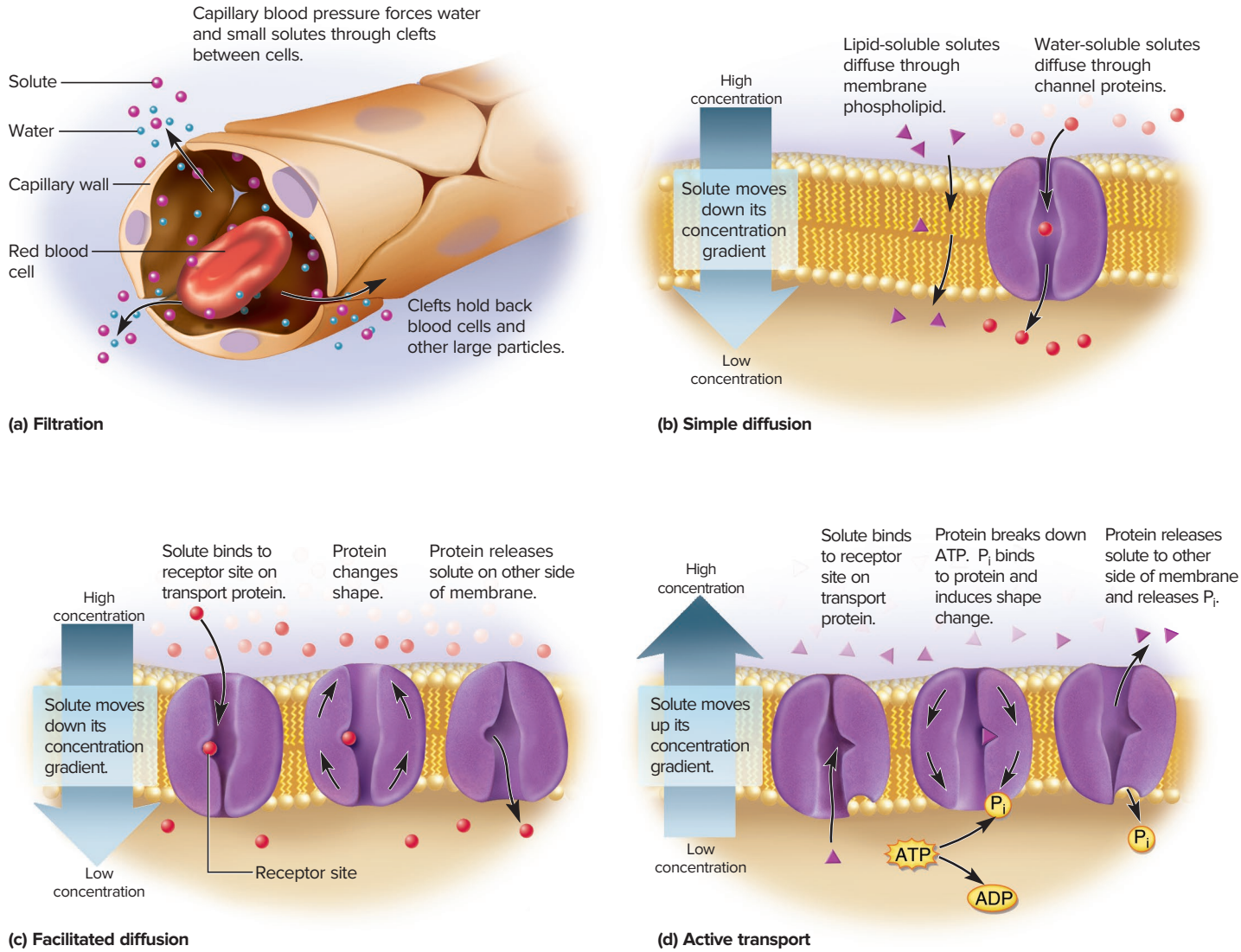


Figure 2.10 **Modes of Membrane Transport.** (a) Filtration. (b) Simple diffusion. (c) Facilitated diffusion. (d) Active transport.

Facilitated Diffusion

The next two processes, facilitated diffusion and active transport, are called *carrier-mediated transport* because they employ transport proteins in the plasma membrane. **Facilitated**[11] **diffusion** (fig. 2.10c) can be defined as the movement of a solute through a membrane, down its concentration gradient, with the aid of a carrier. The carrier transports solutes such as glucose that cannot pass through the membrane unaided. It binds to a particle on one side of a membrane, where the solute is more concentrated, and releases it on the other side, where it is less concentrated. The process requires no expenditure of metabolic energy by the cell. One use of facilitated diffusion is to absorb the sugars and amino acids from digested food.

Active Transport

Active transport (fig. 2.10d) is the carrier-mediated transport of a solute through a unit membrane *up its concentration gradient,* with the expenditure of energy provided by adenosine triphosphate (ATP). ATP is essential to this process because moving particles up a gradient requires an energy input, like getting a wagon to roll uphill. If a cell dies and stops producing ATP, active transport ceases immediately. One use of active transport is to pump calcium out of cells. Calcium is already more concentrated in the ECF than in the ICF, so pumping even more calcium into the ECF is an "uphill" movement.

An especially well-known active transport process is the **sodium–potassium (Na^+–K^+) pump,** which ejects sodium ions from the cell and brings potassium ions into it. The Na^+–K^+ pump plays roles in controlling cell volume; generating body heat; maintaining the electrical excitability of your nerves, muscles, and heart; and providing energy for other transport pumps to draw upon in moving such solutes as glucose through the plasma membrane. About half of the calories that you "burn" every day are used just to operate your Na^+–K^+ pumps.

Vesicular Transport

All of the processes discussed up to this point move molecules or ions individually through the plasma membrane. In **vesicular transport,** however, cells move much larger particles or droplets of fluid through the membrane in bubblelike *vesicles.* Vesicular processes that bring matter into a cell are called **endocytosis**[12] (EN-doe-sy-TOE-sis), and those that release material from a cell are called **exocytosis**[13] (EC-so-sy-TOE-sis). Like active transport, all forms of vesicular transport require ATP. There are three forms of endocytosis: *phagocytosis, pinocytosis,* and *receptor-mediated endocytosis* (fig. 2.11).

Pinocytosis[14] (PIN-oh-sy-TOE-sis), or "cell drinking," occurs in all human cells. In this process, dimples form in the plasma membrane and progressively sink in until they pinch off as *pinocytotic vesicles* containing droplets of ECF (fig. 2.11a). Kidney tubule cells use this method to reclaim the small amount of protein that filters out of the blood, thus preventing the protein from being lost in the urine.

Receptor-mediated endocytosis (fig. 2.11b) is more selective. It enables a cell to take in specific molecules from the ECF with a minimum of unnecessary fluid. Molecules in the ECF bind to specific receptor proteins on the plasma membrane. The receptors then cluster together and the membrane sinks in at this point, creating a pit. The pit soon pinches off to form a vesicle in the cytoplasm. Cells use receptor-mediated endocytosis to absorb cholesterol and insulin from the blood. Hepatitis, polio, and AIDS viruses trick our cells into admitting them by receptor-mediated endocytosis.

In **phagocytosis**[15] (FAG-oh-sy-TOE-sis), or "cell eating," a cell reaches out with footlike extensions called *pseudopods* (see fig. 2.14),

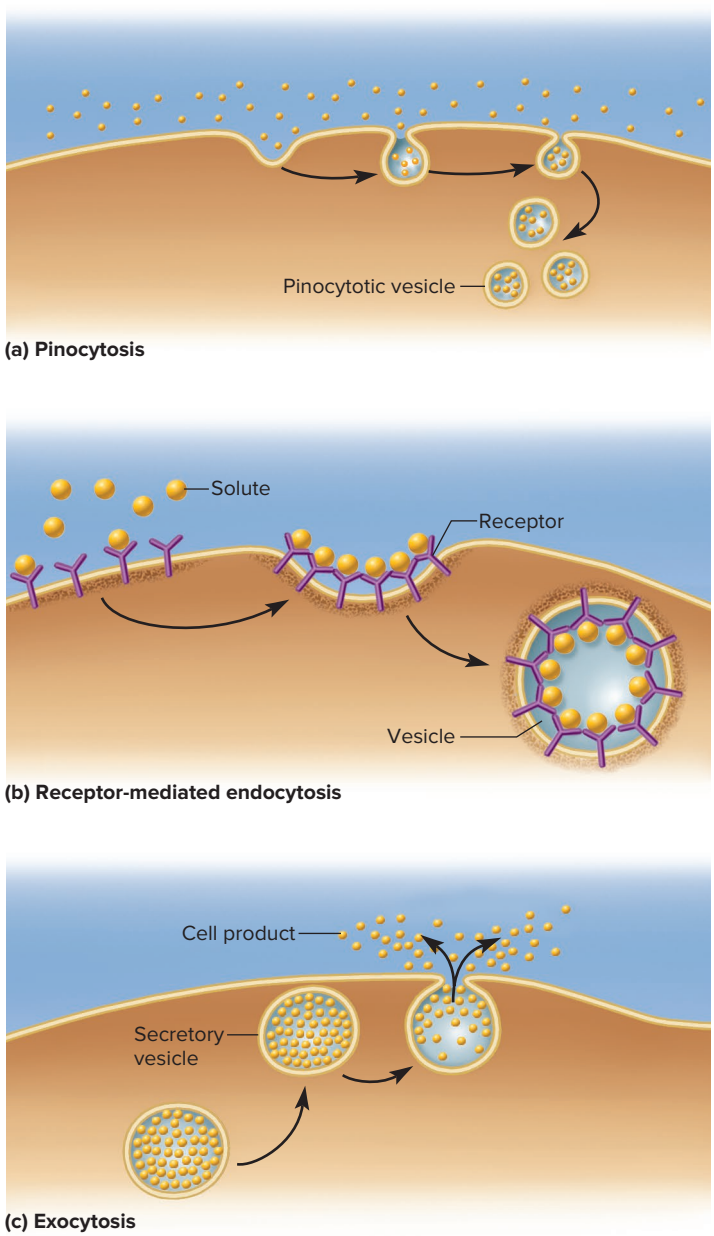


Figure 2.11 Modes of Vesicular Transport. (a) Pinocytosis. A cell imbibing droplets of extracellular fluid. (b) Receptor-mediated endocytosis. The Ys in the plasma membrane are membrane receptors that bind a solute in the extracellular fluid, then cluster together. The membrane sinks in at that point until a vesicle pinches off into the cytoplasm bearing the receptors and bound solute. (c) Exocytosis. A cell releasing a secretion or waste product. See also phagocytosis in figure 2.14 for a fourth mode of vesicular transport.

[11] *facil* = easy
[12] *endo* = into; *cyt* = cell; *osis* = process
[13] *exo* = out of; *cyt* = cell; *osis* = process
[14] *pino* = drinking; *cyt* = cell; *osis* = process
[15] *phago* = eating; *cyt* = cell; *osis* = process