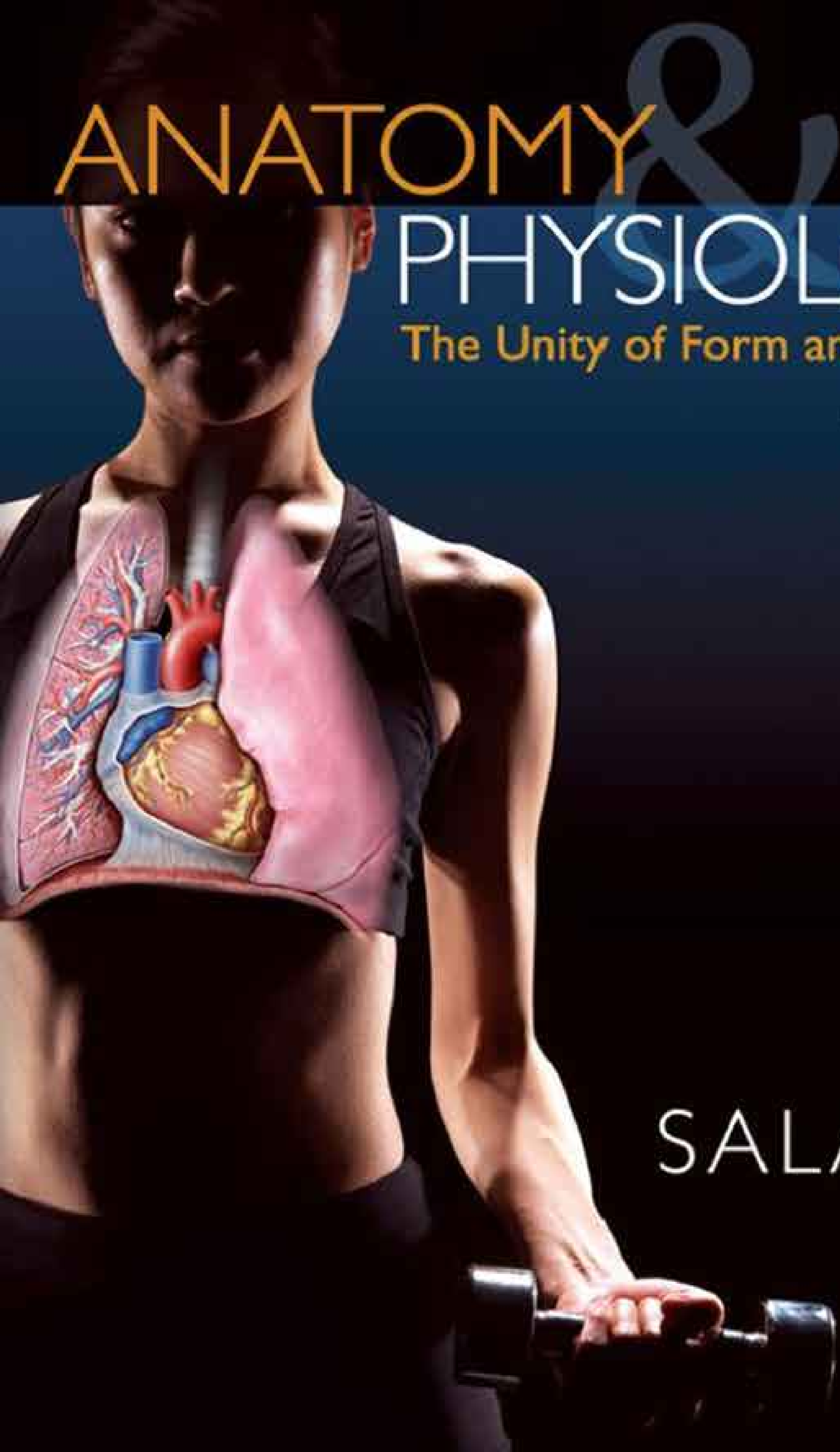
ANATOMY & PHYSIOLOGY

The Unity of Form and Function

Seventh Edition



SALADIN

ANATOMY & PHYSIOLOGY

The Unity of Form and Function

Seventh Edition

KENNETH S. SALADIN
Georgia College & State University

Digital Authors

STEPHEN J. SULLIVAN
Bucks County Community College

CHRISTINA A. GAN
Highline Community College

Mc Graw Hill Education

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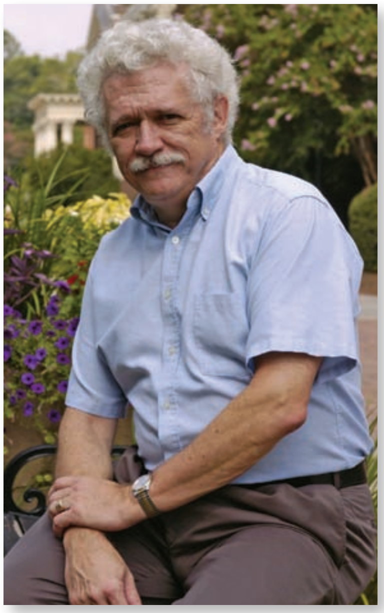


KENNETH S. SALADIN has taught since 1977 at Georgia College & State University in Milledgeville, Georgia. He earned a B.S. in zoology at Michigan State University and a Ph.D. in parasitology at Florida State University, with interests especially in the sensory ecology of freshwater invertebrates. In addition to human anatomy and physiology, his teaching experience includes histology, parasitology, animal behavior, sociobiology, introductory biology, general zoology, biological etymology, and study abroad in the Galápagos Islands. Ken has been recognized as "most significant undergraduate mentor" nine times over the years by outstanding students inducted into Phi Kappa Phi. He received the university's Excellence in Research and Publication Award for the first edition of this book, and was named Distinguished Professor in 2001.

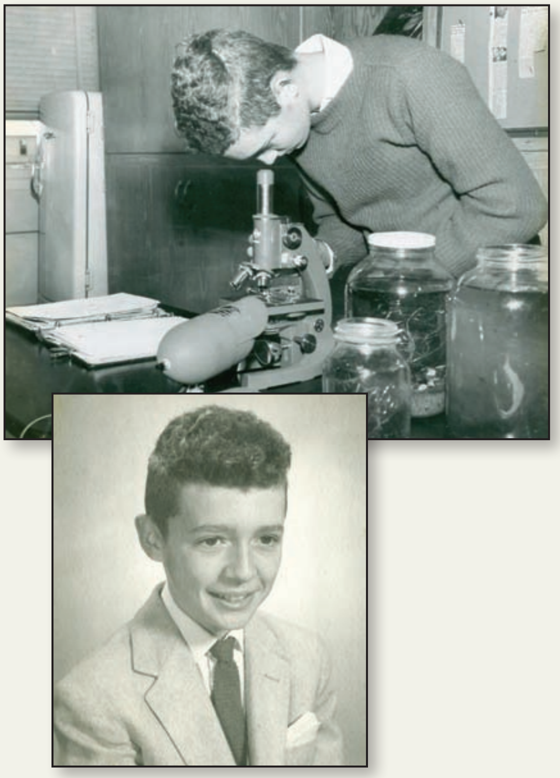
Ken is a member of the Human Anatomy and Physiology Society, the Society for Integrative and Comparative Biology, the American Association of Anatomists, American Physiological Society, and the American Association for the Advancement of Science. He served as a developmental reviewer and wrote supplements for several other McGraw-Hill anatomy and physiology textbooks for a number of years before becoming a textbook writer.

Ken's outside interests include the Big Brothers/Big Sisters program for single-parent children, the Galápagos Conservancy, and student scholarships. Ken is married to Diane Saladin, a registered nurse. They have two adult children.

STEPHEN J. SULLIVAN, digital coauthor for Connect, has been teaching anatomy and physiology at Bucks County Community College in Pennsylvania since 2002. Steve started consulting with McGraw-Hill on the development of digital tools in 2009. His goal for Connect is to create digital assessments that directly reflect the content and style of Ken Saladin's text, provide student access, and foster student success. Steve is a member of the Human Anatomy and Physiology Society and the American Association of Anatomists, and is a 2013 recipient of the Lindback Award for Distinguished Teaching.

CHRISTINA A. GAN, digital coauthor for Connect, has been teaching anatomy and physiology, microbiology, and general biology at Highline Community College in Des Moines, WA since 1994. Before that she taught at Rogue Community College in Medford, OR for six years. She earned her MA 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.

THE EVOLUTION OF A STORYTELLER

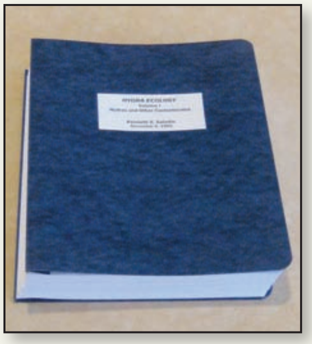


Ken in 1964

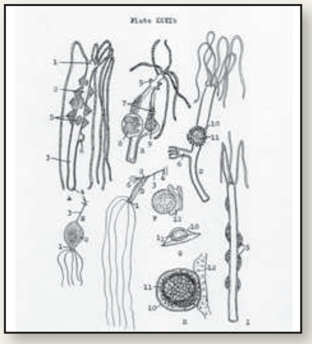
Ken Saladin's first step into authoring was a 318-page paper on the ecology of hydras written for his 10th-grade biology class. With his "first book," featuring 53 original India ink drawings and photomicrographs, a true storyteller was born.

When I first became a textbook writer, I found myself bringing the same enjoyment of writing and illustrating to this book that I first discovered when I was 15.

—Ken Saladin

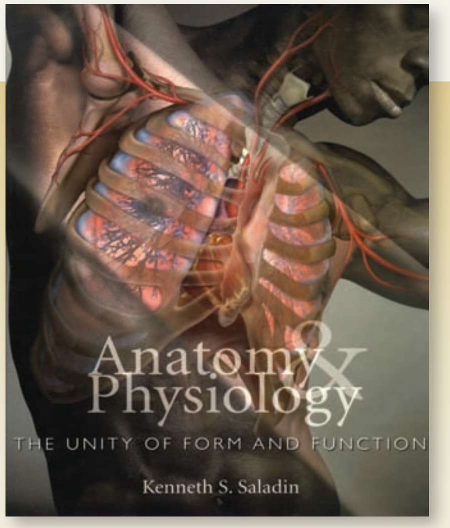


Ken's "first book," *Hydra Ecology*, 1965

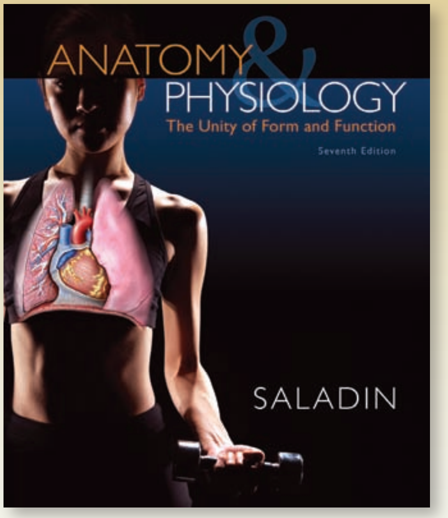


One of Ken's drawings from *Hydra Ecology*

Ken began working on his first book for McGraw-Hill in 1993, and in 1997 the first edition of *The Unity of Form and Function* was published. In 2014 the story continues with the seventh edition of Ken's best-selling A&P textbook.



The first edition (1997)



The story continues (2014)

PREFACE

Anatomy & Physiology: The Unity of Form and Function tells a story made of many layers including the core science, clinical applications, the history of medicine, and the evolution of the human body. Saladin combines this humanistic perspective on anatomy and physiology with vibrant photos and art to convey the beauty and excitement of the subject to beginning students.

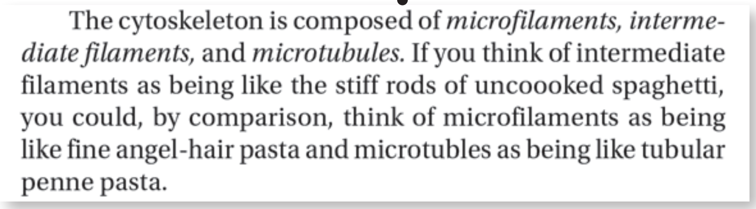
To help students manage the tremendous amount of information in this introductory course, the narrative is broken into short segments, each framed by expected learning outcomes and self-testing review questions. This presentation strategy works as a whole to create a more efficient and effective way for students to learn A&P.

WRITING STYLE AND LEVEL

Saladin's text is written using plain language for A&P students who may be taking this course early in their curricula. Careful attention has been given to word selection and paragraph structure to maintain the appropriate level for students, while avoiding the appearance of dumbed down content. This writing level makes the text accessible for *all* audiences (international readers, English-as-a-second-language students, and nontraditional students).

Students say the enlightening analogies, clinical applications, historical notes, biographical vignettes, and evolutionary insights make the book not merely informative, but a pleasure to read. Even instructors say they often learn something new and interesting from Saladin's innovative perspectives.

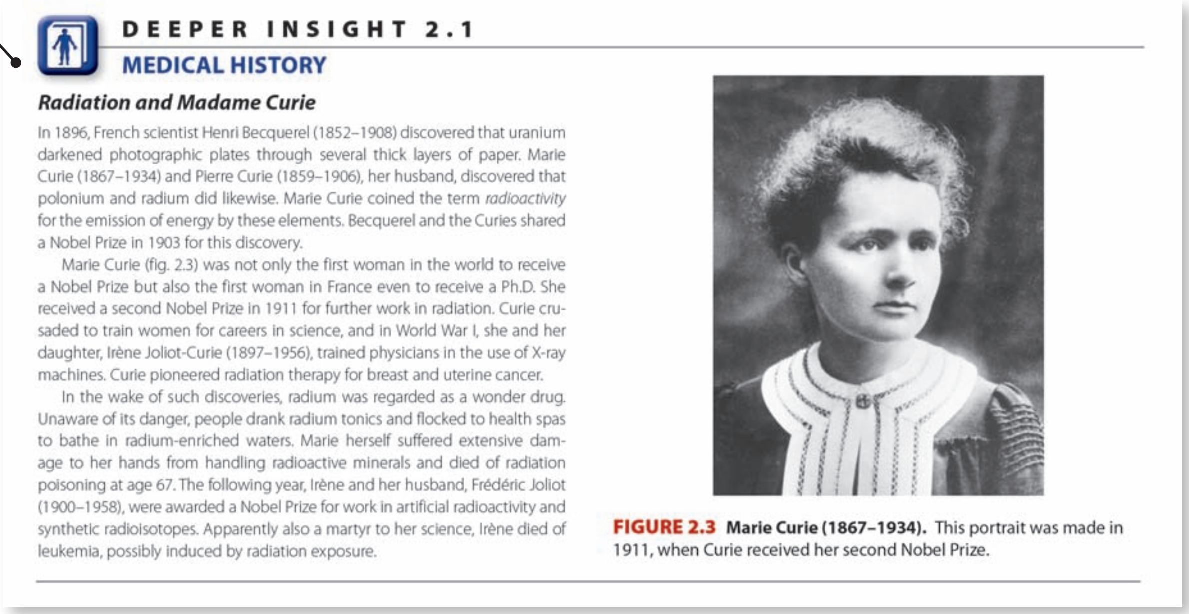
Analogies explain tough scientific content in a way students can understand.



The cytoskeleton is composed of *microfilaments, intermediate filaments,* and *microtubules.* If you think of intermediate filaments as being like the stiff rods of uncoooked spaghetti, you could, by comparison, think of microfilaments as being like fine angel-hair pasta and microtubles as being like tubular penne pasta.

Medical History

Saladin "puts the human in human A&P" with his occasional vignettes on the people behind the science. Students say these stories make learning A&P more fun and stimulating.



DEEPER INSIGHT 2.1

MEDICAL HISTORY

Radiation and Madame Curie

In 1896, French scientist Henri Becquerel (1852–1908) discovered that uranium darkened photographic plates through several thick layers of paper. Marie Curie (1867–1934) and Pierre Curie (1859–1906), her husband, discovered that polonium and radium did likewise. Marie Curie coined the term *radioactivity* for the emission of energy by these elements. Becquerel and the Curies shared a Nobel Prize in 1903 for this discovery.

Marie Curie (fig. 2.3) was not only the first woman in the world to receive a Nobel Prize but also the first woman in France even to receive a Ph.D. She received a second Nobel Prize in 1911 for further work in radiation. Curie crusaded to train women for careers in science, and in World War I, she and her daughter, Irène Joliot-Curie (1897–1956), trained physicians in the use of X-ray machines. Curie pioneered radiation therapy for breast and uterine cancer.

In the wake of such discoveries, radium was regarded as a wonder drug. Unaware of its danger, people drank radium tonics and flocked to health spas to bathe in radium-enriched waters. Marie herself suffered extensive damage to her hands from handling radioactive minerals and died of radiation poisoning at age 67. The following year, Irène and her husband, Frédéric Joliot (1900–1958), were awarded a Nobel Prize for work in artificial radioactivity and synthetic radioisotopes. Apparently also a martyr to her science, Irène died of leukemia, possibly induced by radiation exposure.

FIGURE 2.3 **Marie Curie (1867–1934).** This portrait was made in 1911, when Curie received her second Nobel Prize.

DEEPER INSIGHT 20.4

CLINICAL APPLICATION

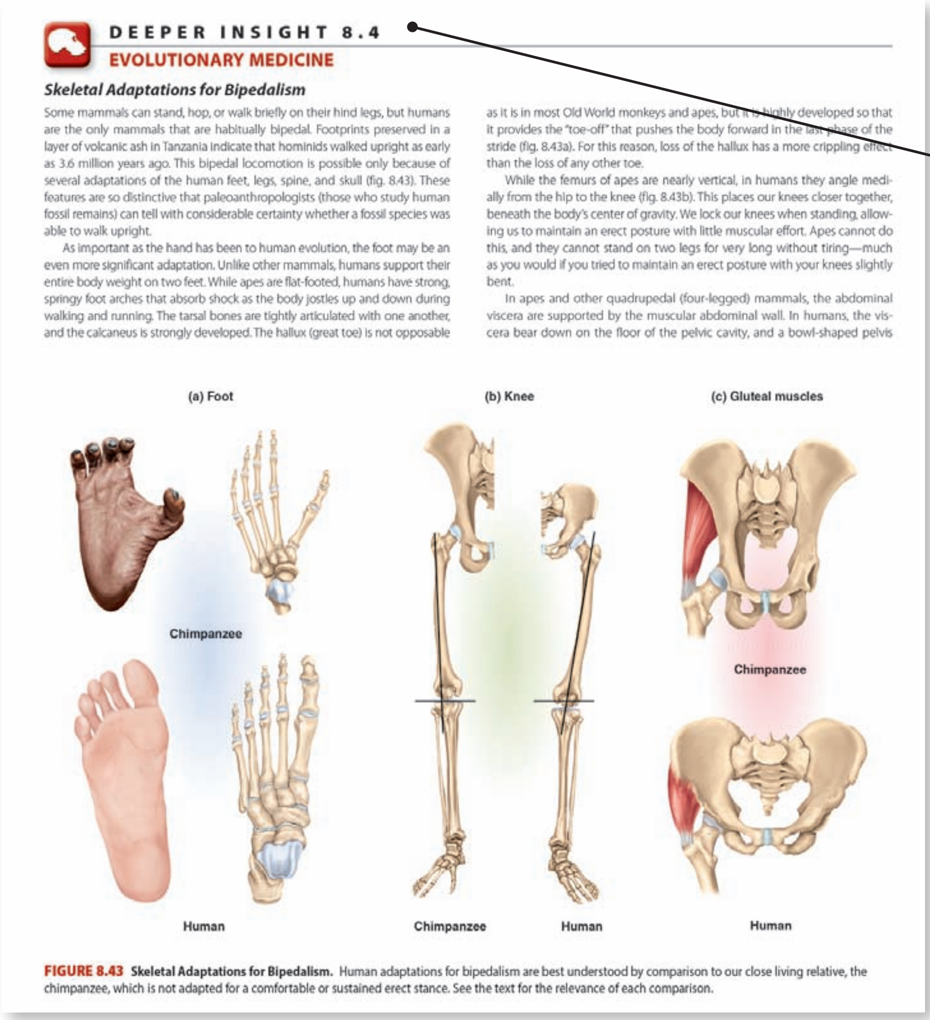
Portal Hypertension and Ascites

Liver diseases that obstruct the hepatic circulation can cause blood pressure to back up into the hepatic portal system with multiple effects on the upstream organs that it drains. An example is *schistosomiasis* (SHIS-to-so-MY-ah-sis), one of the world's most prevalent tropical diseases, occurring in South America, the Caribbean, Africa, the Mideast, and Asia. In the intestinal forms of the disease, parasitic worms called blood flukes live in the small veins of mesenteries and the intestinal wall. Some of their eggs wash up the mesenteric veins into the hepatic portal circulation and lodge in venules of the liver. Here, they cause severe inflammation that results in a knot or *granuloma* of fibrous scar tissue around each egg. As these granulomas accumulate and the liver becomes more and more fibrous, they obstruct blood flow and cause portal hypertension, a backup of pressure into the hepatic portal system. For lack of drainage, the spleen can become tremendously enlarged *(splenomegaly)* (fig. 20.33). Normally weighing 150 g, the spleen can grow to 1,000 g or more and extend even into the pelvic cavity. Increased capillary blood pressure causes the spleen, liver, and mesenteries to "weep" serous fluid into the peritoneal cavity. As much as 10 to 20 L of fluid can accumulate and cause great distension of the abdomen, a state called *ascites* (ah-SY-teez). Portal hypertension and ascites can also occur in many other obstructive liver diseases such as alcoholic cirrhosis.

FIGURE 20.33 **Ascites.** The abdomen is distended with accumulated serous fluid that has filtered from the liver, spleen, and intestinal blood vessels.

Clinical Applications make the abstract science more relevant.

> *More than a few distinguished scientists and clinicians say they found their inspiration in reading of the lives of their predecessors. Maybe these stories will inspire some of our own students to go on to do great things.*
>
> —Ken Saladin



DEEPER INSIGHT 8.4

EVOLUTIONARY MEDICINE

Skeletal Adaptations for Bipedalism

Some mammals can stand, hop, or walk briefly on their hind legs, but humans are the only mammals that are habitually bipedal. Footprints preserved in a layer of volcanic ash in Tanzania indicate that hominids walked upright as early as 3.6 million years ago. This bipedal locomotion is possible only because of several adaptations of the human feet, legs, spine, and skull (fig. 8.43). These features are so distinctive that paleoanthropologists (those who study human fossil remains) can tell with considerable certainty whether a fossil species was able to walk upright.

As important as the hand has been to human evolution, the foot may be an even more significant adaptation. Unlike other mammals, humans support their entire body weight on two feet. While apes are flat-footed, humans have strong, springy foot arches that absorb shock as the body jostles up and down during walking and running. The tarsal bones are tightly articulated with one another, and the calcaneus is strongly developed. The hallux (great toe) is not opposable as it is in most Old World monkeys and apes, but it is highly developed so that it provides the "toe-off" that pushes the body forward in the last phase of the stride (fig. 8.43a). For this reason, loss of the hallux has a more crippling effect than the loss of any other toe.

While the femurs of apes are nearly vertical, in humans they angle medially from the hip to the knee (fig. 8.43b). This places our knees closer together, beneath the body's center of gravity. We lock our knees when standing, allowing us to maintain an erect posture with little muscular effort. Apes cannot do this, and they cannot stand on two legs for very long without tiring—much as you would if you tried to maintain an erect posture with your knees slightly bent.

In apes and other quadrupedal (four-legged) mammals, the abdominal viscera are supported by the muscular abdominal wall. In humans, the viscera bear down on the floor of the pelvic cavity, and a bowl-shaped pelvis

FIGURE 8.43 **Skeletal Adaptations for Bipedalism.** Human adaptations for bipedalism are best understood by comparison to our close living relative, the chimpanzee, which is not adapted for a comfortable or sustained erect stance. See the text for the relevance of each comparison.

Evolutionary Medicine provides novel and intriguing ways of looking at:

- menopause
- the sweet tooth
- bipedalism
- the origin of mitochondria
- skin color
- body hair
- lactose intolerance
- the kidney and life on dry land
- the palate
- theories of aging and death

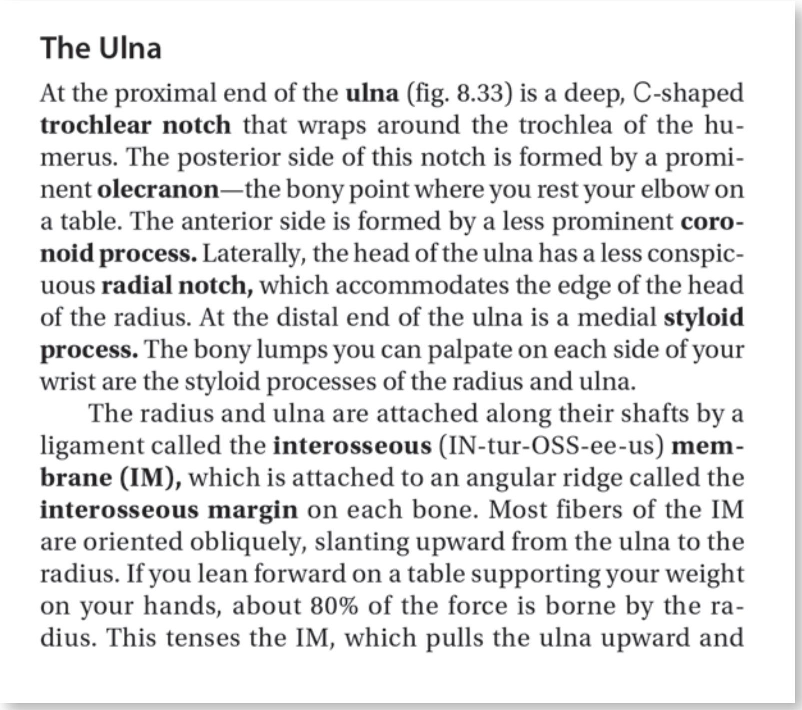
INTERACTIVE MATERIAL

Review activities are integrated into each chapter. Self-teaching prompts and simple experiments are liberally seeded throughout the narrative. Learning aids such as pronunciation guides and insights into the origins and root meanings of medical terms are sprinkled liberally throughout the text to help students retain meaning and spelling of terms.

Self-teaching prompts make reading more active.

Pro-NUN-see-AY-shun guides help beginning students master A&P.

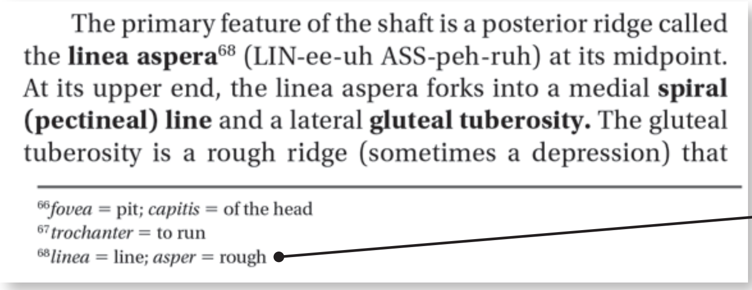
Word origins are footnoted.



The Ulna

At the proximal end of the **ulna** (fig. 8.33) is a deep, C-shaped **trochlear notch** that wraps around the trochlea of the humerus. The posterior side of this notch is formed by a prominent **olecranon**—the bony point where you rest your elbow on a table. The anterior side is formed by a less prominent **coronoid process.** Laterally, the head of the ulna has a less conspicuous **radial notch,** which accommodates the edge of the head of the radius. At the distal end of the ulna is a medial **styloid process.** The bony lumps you can palpate on each side of your wrist are the styloid processes of the radius and ulna.

The radius and ulna are attached along their shafts by a ligament called the **interosseous** (IN-tur-OSS-ee-us) **membrane (IM),** which is attached to an angular ridge called the **interosseous margin** on each bone. Most fibers of the IM are oriented obliquely, slanting upward from the ulna to the radius. If you lean forward on a table supporting your weight on your hands, about 80% of the force is borne by the radius. This tenses the IM, which pulls the ulna upward and



The primary feature of the shaft is a posterior ridge called the **linea aspera**[68] (LIN-ee-uh ASS-peh-ruh) at its midpoint. At its upper end, the linea aspera forks into a medial **spiral (pectineal) line** and a lateral **gluteal tuberosity.** The gluteal tuberosity is a rough ridge (sometimes a depression) that

---

[66] *fovea* = pit; *capitis* = of the head

[67] *trochanter* = to run

[68] *linea* = line; *asper* = rough

Familiarity with word origins helps students retain meaning and spelling.

WHAT'S NEW IN THE SEVENTH EDITION?

New Content

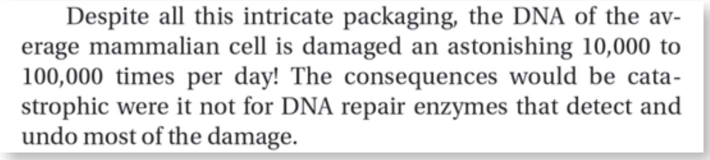
Several sections include new content, especially

- Gradients and flow as another unifying concept of physiology (chapter 1)
- Pseudopods as another class of cell surface features (chapter 3)
- New table of art and descriptions of the hierarchy of muscle structure (chapter 11)
- New Deeper Insight on portal hypertension and ascites (chapter 20)
- Updated treatment of chronic obstructive pulmonary disease (COPD) (chapter 22)
- New section on magnesium homeostasis (chapter 24)
- History's youngest mother, pregnant at age 4 (chapter 28)
- Deeper Insight on endometriosis (chapter 28)

New Science

Other new content in Saladin's *Anatomy & Physiology* updates the book to stay abreast of new developments in science. Some of the more significant examples are listed here.

- The high frequency of everyday DNA damage (chapter 4)
- The proteome as a new frontier in cytology (chapter 4)
- Epigenetic inheritance and disease (chapter 4)



Despite all this intricate packaging, the DNA of the average mammalian cell is damaged an astonishing 10,000 to 100,000 times per day! The consequences would be catastrophic were it not for DNA repair enzymes that detect and undo most of the damage.

- Umbrella cells and protective role of transitional epithelium (chapter 5)
- Reinterpretation of pelvic floor muscle compartments based on new medical imaging techniques (chapter 10)
- Updates in muscle physiology on the length–tension relationship, the size principle in recruitment, tetanus, fatigue, muscle fiber types, and smooth muscle caveolae (chapter 11)
- Autoimmune pathogenesis of pernicious anemia (chapter 18)
- New biomechanical interpretations of papillary muscles and trabeculae carneae (chapter 19)
- New insights on functions of the spleen (chapter 21)
- Update on the status of reproductive effects of endocrine disrupting chemicals (chapter 27)
- New understanding of the 209-day timetable of ovarian follicle and oocyte development (chapter 28)
- Update on free radical–DNA damage theory of aging (chapter 29)

New Photographs

- Figure A.8: intestinal mesentery
- Figure 17.11: histology of the adrenal cortex
- Figure 21.7: macrophages attacking bacteria
- Figure 21.24: T cells attacking cancer cell
- Figure 28.9d: SEM of acini and myoepithelial cells of the mammary gland

New Art

- Figure 3.13: pseudopods as cell surface features
- Figure 3.31: the proteasome as an organelle
- Figure 4.23: cancer metastasis
- Figure 5.32: comparison of merocrine, apocrine, and holocrine secretion
- Figure 14.39: full-page summary flowchart of cranial nerve pathways
- Figure 17.18: hormone actions on their target cells
- Figure 17.23: antagonistic effects of insulin and glucagon on a hepatocyte
- Figure 18.22: enhanced presentation of blood-clotting cascade
- Figure 25.31: full-page summary figure of macronutrient digestion and absorption
- Figure 26.1: simplified flowchart of gut–brain peptides and appetite regulation

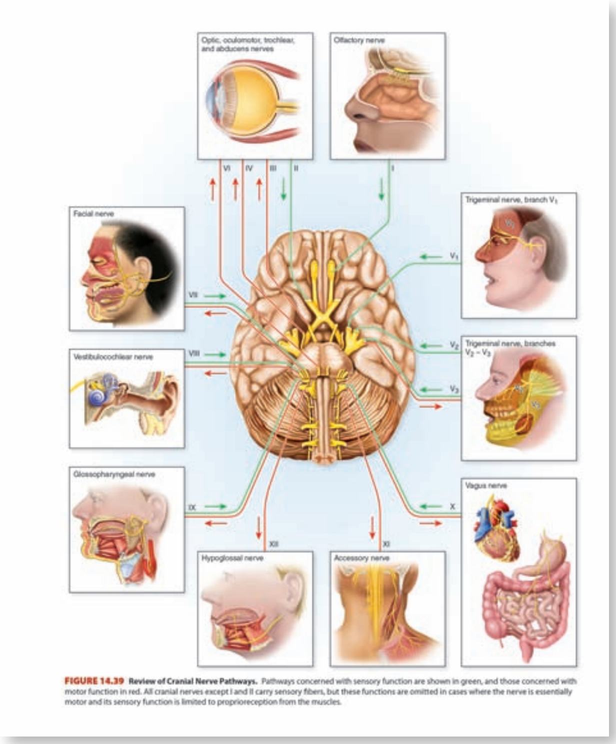


FIGURE 14.39 Review of Cranial Nerve Pathways. Pathways concerned with sensory function are shown in green, and those concerned with motor function in red. All cranial nerves except I and II carry sensory fibers, but these functions are omitted in cases where the nerve is essentially motor and its sensory function is limited to proprioreception from the muscles.

New Pedagogy

- Appendix E: a table of the complete genetic code

GUIDED TOUR

MAKING *Anatomy & Physiology* INTRIGUING AND INSPIRING

INNOVATIVE CHAPTER SEQUENCING

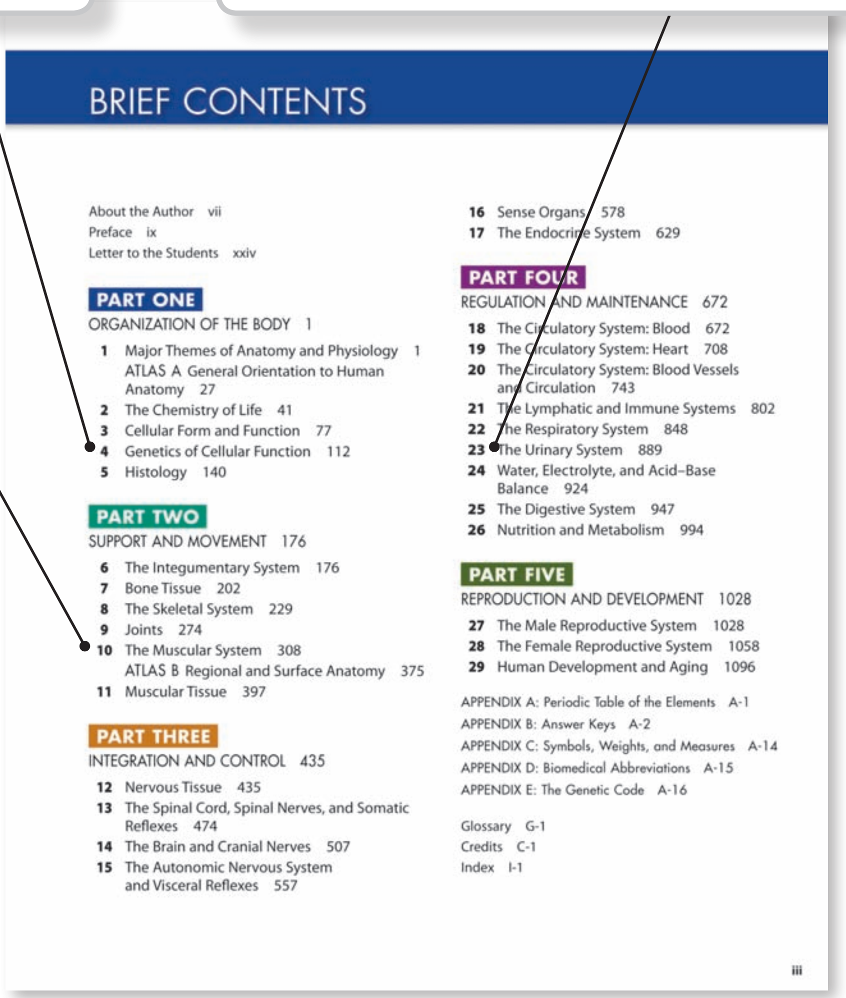
Some chapters and topics are presented in a sequence that is more instructive than the conventional order.

Early Presentation of Heredity

Fundamental principles of heredity are presented in the last few pages of chapter 4 rather than at the back of the book to better integrate molecular and Mendelian genetics. This organization also prepares students to learn about such genetic traits and conditions as cystic fibrosis, color blindness, blood types, hemophilia, cancer genes, and sickle-cell disease by first teaching them about dominant and recessive alleles, genotype and phenotype, and sex linkage.

Urinary System Presented Close to Circulatory and Respiratory Systems

Most textbooks place this system near the end of the book because of its anatomical and developmental relationships with the reproductive system. However, its physiological ties to the circulatory and respiratory systems are much more important. Except for a necessary digression on lymphatics and immunity, the circulatory system is followed almost immediately with the respiratory and urinary systems, which regulate blood composition and whose functional mechanisms rely on recently covered principles of blood flow and capillary exchange.



BRIEF CONTENTS

iii

Muscle Anatomy and Physiology Follow Skeleton and Joints

The functional morphology of the skeleton, joints, and muscles is treated in three consecutive chapters, 8 through 10, so when students learn muscle origins and insertions, these come only two chapters after the names of the relevant bone features. When they learn muscle actions, it is in the first chapter after learning the terms for the joint movements. This order brings another advantage: the physiology of muscle and nerve cells is treated in two consecutive chapters (11 and 12), which are thus closely integrated in their treatment of synapses, neurotransmitters, and membrane electrophysiology.

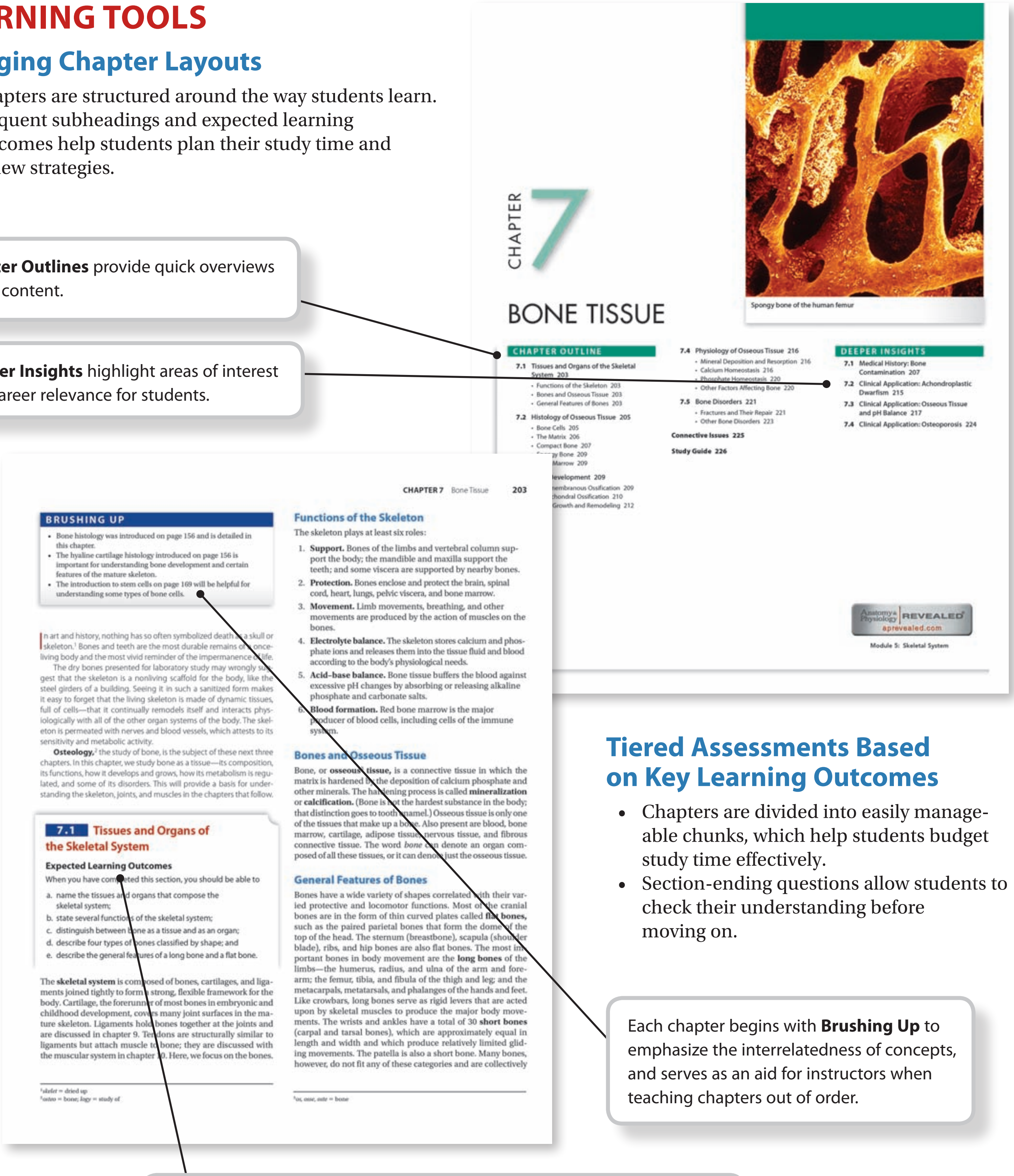
LEARNING TOOLS

Engaging Chapter Layouts

- Chapters are structured around the way students learn.
- Frequent subheadings and expected learning outcomes help students plan their study time and review strategies.

Chapter Outlines provide quick overviews of the content.

Deeper Insights highlight areas of interest and career relevance for students.



CHAPTER 7

BONE TISSUE

Spongy bone of the human femur

CHAPTER OUTLINE

- **7.1** Tissues and Organs of the Skeletal System 203
  - Functions of the Skeleton 203
  - Bones and Osseous Tissue 203
  - General Features of Bones 203
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- **7.1** Medical History: Bone Contamination 207
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Module 5: Skeletal System

CHAPTER 7 Bone Tissue 203

BRUSHING UP

- Bone histology was introduced on page 156 and is detailed in this chapter.
- The hyaline cartilage histology introduced on page 156 is important for understanding bone development and certain features of the mature skeleton.
- The introduction to stem cells on page 169 will be helpful for understanding some types of bone cells.

In art and history, nothing has so often symbolized death as a skull or skeleton.[1] Bones and teeth are the most durable remains of a once-living body and the most vivid reminder of the impermanence of life.

The dry bones presented for laboratory study may wrongly suggest that the skeleton is a nonliving scaffold for the body, like the steel girders of a building. Seeing it in such a sanitized form makes it easy to forget that the living skeleton is made of dynamic tissues, full of cells—that it continually remodels itself and interacts physiologically with all of the other organ systems of the body. The skeleton is permeated with nerves and blood vessels, which attests to its sensitivity and metabolic activity.

Osteology,[2] the study of bone, is the subject of these next three chapters. In this chapter, we study bone as a tissue—its composition, its functions, how it develops and grows, how its metabolism is regulated, and some of its disorders. This will provide a basis for understanding the skeleton, joints, and muscles in the chapters that follow.

7.1 Tissues and Organs of the Skeletal System

Expected Learning Outcomes

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

a. name the tissues and organs that compose the skeletal system;
b. state several functions of the skeletal system;
c. distinguish between bone as a tissue and as an organ;
d. describe four types of bones classified by shape; and
e. describe the general features of a long bone and a flat bone.

The **skeletal system** is composed of bones, cartilages, and ligaments joined tightly to form a strong, flexible framework for the body. Cartilage, the forerunner of most bones in embryonic and childhood development, covers many joint surfaces in the mature skeleton. Ligaments hold bones together at the joints and are discussed in chapter 9. Tendons are structurally similar to ligaments but attach muscle to bone; they are discussed with the muscular system in chapter 10. Here, we focus on the bones.

Functions of the Skeleton

The skeleton plays at least six roles:

1. **Support.** Bones of the limbs and vertebral column support the body; the mandible and maxilla support the teeth; and some viscera are supported by nearby bones.
2. **Protection.** Bones enclose and protect the brain, spinal cord, heart, lungs, pelvic viscera, and bone marrow.
3. **Movement.** Limb movements, breathing, and other movements are produced by the action of muscles on the bones.
4. **Electrolyte balance.** The skeleton stores calcium and phosphate ions and releases them into the tissue fluid and blood according to the body's physiological needs.
5. **Acid–base balance.** Bone tissue buffers the blood against excessive pH changes by absorbing or releasing alkaline phosphate and carbonate salts.
6. **Blood formation.** Red bone marrow is the major producer of blood cells, including cells of the immune system.

Bones and Osseous Tissue

Bone, or **osseous**[3] **tissue,** is a connective tissue in which the matrix is hardened by the deposition of calcium phosphate and other minerals. The hardening process is called **mineralization** or **calcification.** (Bone is not the hardest substance in the body; that distinction goes to tooth enamel.) Osseous tissue is only one of the tissues that make up a bone. Also present are blood, bone marrow, cartilage, adipose tissue, nervous tissue, and fibrous connective tissue. The word *bone* can denote an organ composed of all these tissues, or it can denote just the osseous tissue.

General Features of Bones

Bones have a wide variety of shapes correlated with their varied protective and locomotor functions. Most of the cranial bones are in the form of thin curved plates called **flat bones,** such as the paired parietal bones that form the dome of the top of the head. The sternum (breastbone), scapula (shoulder blade), ribs, and hip bones are also flat bones. The most important bones in body movement are the **long bones** of the limbs—the humerus, radius, and ulna of the arm and forearm; the femur, tibia, and fibula of the thigh and leg; and the metacarpals, metatarsals, and phalanges of the hands and feet. Like crowbars, long bones serve as rigid levers that are acted upon by skeletal muscles to produce the major body movements. The wrists and ankles have a total of 30 **short bones** (carpal and tarsal bones), which are approximately equal in length and width and which produce relatively limited gliding movements. The patella is also a short bone. Many bones, however, do not fit any of these categories and are collectively

---

[1] *skelet* = dried up
[2] *osteo* = bone; *logy* = study of
[3] *os, osse, oste* = bone

Tiered Assessments Based on Key Learning Outcomes

- Chapters are divided into easily manageable chunks, which help students budget study time effectively.
- Section-ending questions allow students to check their understanding before moving on.

Each chapter begins with **Brushing Up** to emphasize the interrelatedness of concepts, and serves as an aid for instructors when teaching chapters out of order.

Each numbered section begins with **Expected Learning Outcomes** to help focus the reader's attention on the larger concepts and make the course outcome-driven. This also assists instructors in structuring their courses around expected learning outcomes.

Questions in figure legends and **Apply What You Know** items prompt students to think more deeply about the implications and applications of what they have learned.

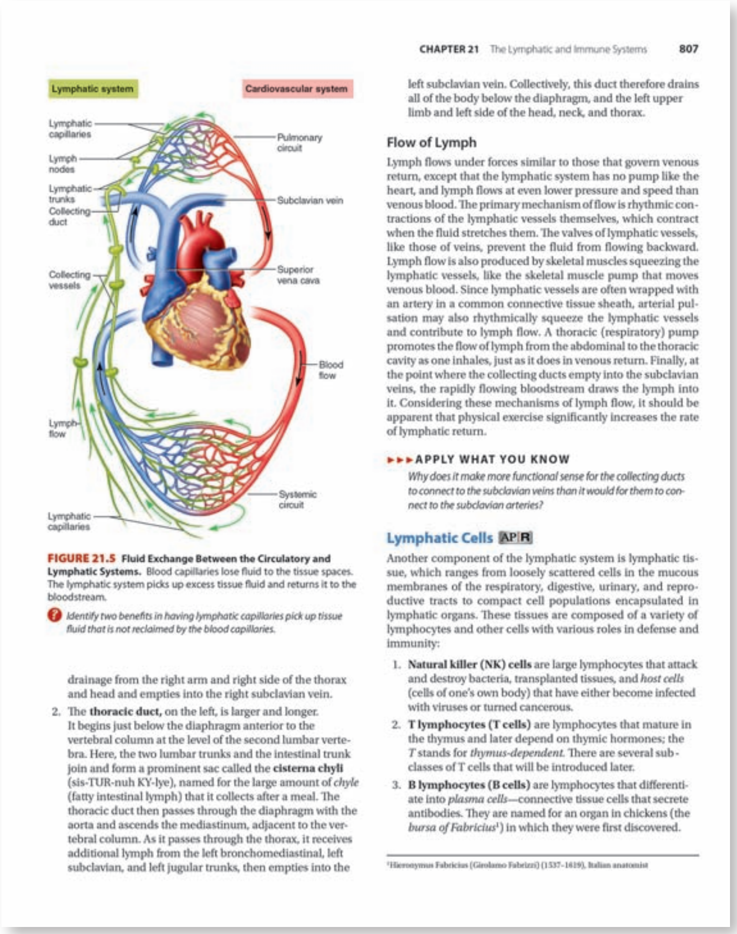

CHAPTER 21 The Lymphatic and Immune Systems 807

FIGURE 21.5 Fluid Exchange Between the Circulatory and Lymphatic Systems. Blood capillaries lose fluid to the tissue spaces. The lymphatic system picks up excess tissue fluid and returns it to the bloodstream.

? *Identify two benefits in having lymphatic capillaries pick up tissue fluid that is not reclaimed by the blood capillaries.*

drainage from the right arm and right side of the thorax and head and empties into the right subclavian vein.

2. The **thoracic duct,** on the left, is larger and longer. It begins just below the diaphragm anterior to the vertebral column at the level of the second lumbar vertebra. Here, the two lumbar trunks and the intestinal trunk join and form a prominent sac called the **cisterna chyli** (sis-TUR-nuh KY-lye), named for the large amount of *chyle* (fatty intestinal lymph) that it collects after a meal. The thoracic duct then passes through the diaphragm with the aorta and ascends the mediastinum, adjacent to the vertebral column. As it passes through the thorax, it receives additional lymph from the left bronchomediastinal, left subclavian, and left jugular trunks, then empties into the left subclavian vein. Collectively, this duct therefore drains all of the body below the diaphragm, and the left upper limb and left side of the head, neck, and thorax.

Flow of Lymph

Lymph flows under forces similar to those that govern venous return, except that the lymphatic system has no pump like the heart, and lymph flows at even lower pressure and speed than venous blood. The primary mechanism of flow is rhythmic contractions of the lymphatic vessels themselves, which contract when the fluid stretches them. The valves of lymphatic vessels, like those of veins, prevent the fluid from flowing backward. Lymph flow is also produced by skeletal muscles squeezing the lymphatic vessels, like the skeletal muscle pump that moves venous blood. Since lymphatic vessels are often wrapped with an artery in a common connective tissue sheath, arterial pulsation may also rhythmically squeeze the lymphatic vessels and contribute to lymph flow. A thoracic (respiratory) pump promotes the flow of lymph from the abdominal to the thoracic cavity as one inhales, just as it does in venous return. Finally, at the point where the collecting ducts empty into the subclavian veins, the rapidly flowing bloodstream draws the lymph into it. Considering these mechanisms of lymph flow, it should be apparent that physical exercise significantly increases the rate of lymphatic return.

►►►**APPLY WHAT YOU KNOW**

Why does it make more functional sense for the collecting ducts to connect to the subclavian veins than it would for them to connect to the subclavian arteries?

Lymphatic Cells APR

Another component of the lymphatic system is lymphatic tissue, which ranges from loosely scattered cells in the mucous membranes of the respiratory, digestive, urinary, and reproductive tracts to compact cell populations encapsulated in lymphatic organs. These tissues are composed of a variety of lymphocytes and other cells with various roles in defense and immunity:

1. **Natural killer (NK) cells** are large lymphocytes that attack and destroy bacteria, transplanted tissues, and *host cells* (cells of one's own body) that have either become infected with viruses or turned cancerous.
2. **T lymphocytes (T cells)** are lymphocytes that mature in the thymus and later depend on thymic hormones; the *T* stands for *thymus-dependent.* There are several subclasses of T cells that will be introduced later.
3. **B lymphocytes (B cells)** are lymphocytes that differentiate into *plasma cells*—connective tissue cells that secrete antibodies. They are named for an organ in chickens (the *bursa of Fabricius*[1]) in which they were first discovered.

---

[1] Hieronymus Fabricius (Girolamo Fabrizzi) (1537–1619), Italian anatomist

The end-of-chapter **Study Guide** offers several methods for assessment that are useful to both students and instructors.

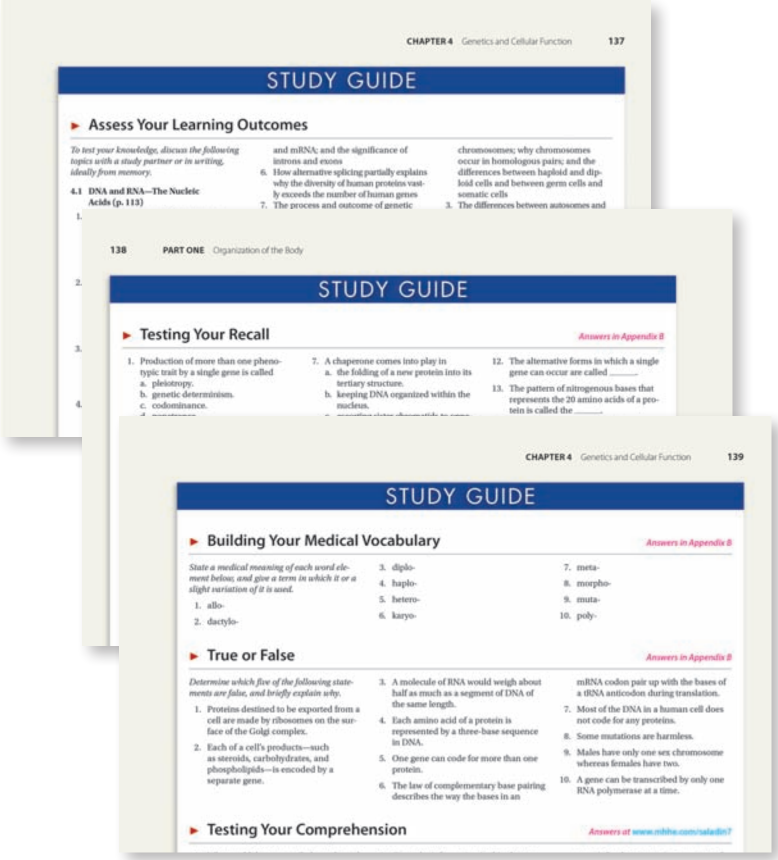
Assess Your Learning Outcomes provides students a study outline for review, and addresses the needs of instructors whose colleges require outcome-oriented syllabi and assessment of student achievement of the expected learning outcomes.

End-of-chapter questions build on all levels of Bloom's taxonomy in sections to

1. assess learning outcomes
2. test simple recall and analytical thought
3. build medical vocabulary
4. apply the basic knowledge to new clinical problems and other situations

True or False questions further address Bloom's taxonomy by asking the student to explain *why* the false statements are untrue.

Testing Your Comprehension questions address Bloom's Taxonomy in going beyond recall to application of ideas.


CHAPTER 4 Genetics and Cellular Function 137

STUDY GUIDE

► Assess Your Learning Outcomes

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

4.1 DNA and RNA—The Nucleic Acids (p. 113)

and mRNA; and the significance of introns and exons

6. How alternative splicing partially explains why the diversity of human proteins vastly exceeds the number of human genes
7. The process and outcome of genetic

chromosomes; why chromosomes occur in homologous pairs; and the differences between haploid and diploid cells and between germ cells and somatic cells

3. The differences between autosomes and

138 PART ONE Organization of the Body

STUDY GUIDE

► Testing Your Recall *Answers in Appendix B*

1. Production of more than one phenotypic trait by a single gene is called
   a. pleiotropy.
   b. genetic determinism.
   c. codominance.

7. A chaperone comes into play in
   a. the folding of a new protein into its tertiary structure.
   b. keeping DNA organized within the nucleus.

12. The alternative forms in which a single gene can occur are called ______.

13. The pattern of nitrogenous bases that represents the 20 amino acids of a protein is called the ______.

CHAPTER 4 Genetics and Cellular Function 139

STUDY GUIDE

► Building Your Medical Vocabulary *Answers in Appendix B*

State a medical meaning of each word element below, and give a term in which it or a slight variation of it is used.

1. allo-
2. dactylo-
3. diplo-
4. haplo-
5. hetero-
6. karyo-
7. meta-
8. morpho-
9. muta-
10. poly-

► True or False *Answers in Appendix B*

Determine which five of the following statements are false, and briefly explain why.

1. Proteins destined to be exported from a cell are made by ribosomes on the surface of the Golgi complex.
2. Each of a cell's products—such as steroids, carbohydrates, and phospholipids—is encoded by a separate gene.
3. A molecule of RNA would weigh about half as much as a segment of DNA of the same length.
4. Each amino acid of a protein is represented by a three-base sequence in DNA.
5. One gene can code for more than one protein.
6. The law of complementary base pairing describes the way the bases in an mRNA codon pair up with the bases of a tRNA anticodon during translation.
7. Most of the DNA in a human cell does not code for any proteins.
8. Some mutations are harmless.
9. Males have only one sex chromosome whereas females have two.
10. A gene can be transcribed by only one RNA polymerase at a time.

► Testing Your Comprehension *Answers at www.mhhe.com/saladin7*

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The incredible art program in this textbook sets the standard in A&P. The stunning portfolio of art and photos was created with the aid of art focus groups, and with feedback from hundreds of accuracy reviews.

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- Easy-to-understand process figures
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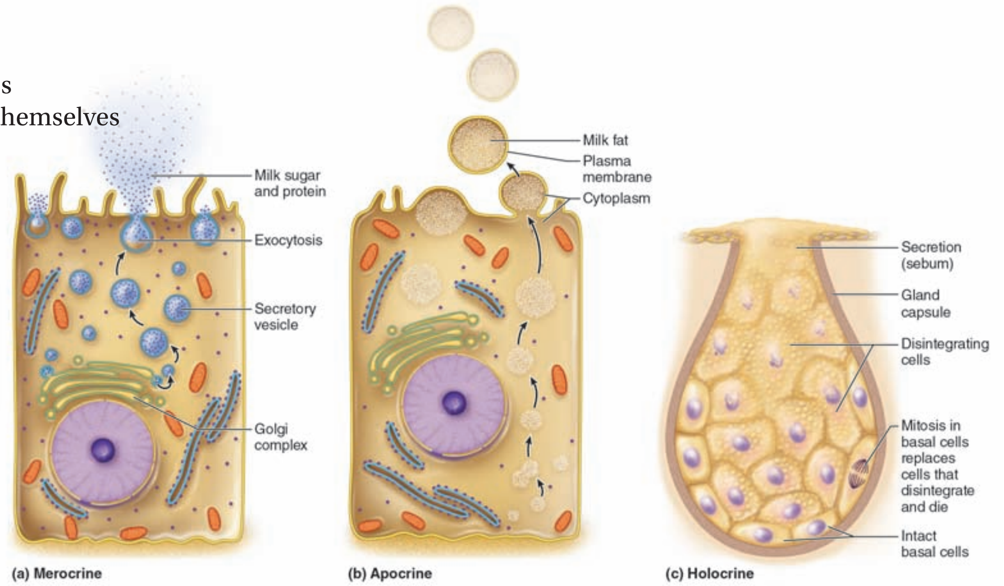


(a) Merocrine (b) Apocrine (c) Holocrine

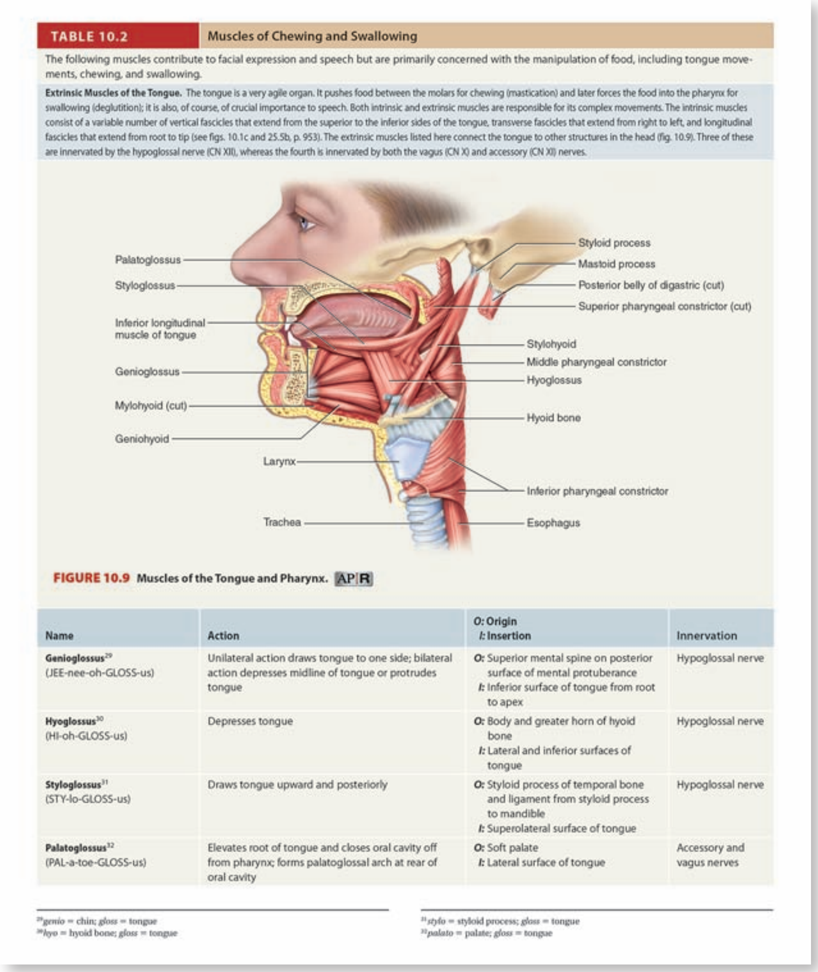


TABLE 10.2 Muscles of Chewing and Swallowing

The following muscles contribute to facial expression and speech but are primarily concerned with the manipulation of food, including tongue movements, chewing, and swallowing.

Extrinsic Muscles of the Tongue. The tongue is a very agile organ. It pushes food between the molars for chewing (mastication) and later forces the food into the pharynx for swallowing (deglutition); it is also, of course, of crucial importance to speech. Both intrinsic and extrinsic muscles are responsible for its complex movements. The intrinsic muscles consist of a variable number of vertical fascicles that extend from the superior to the inferior sides of the tongue, transverse fascicles that extend from right to left, and longitudinal fascicles that extend from root to tip (see figs. 10.1c and 25.5b, p. 953). The extrinsic muscles listed here connect the tongue to other structures in the head (fig. 10.9). Three of these are innervated by the hypoglossal nerve (CN XII), whereas the fourth is innervated by both the vagus (CN X) and accessory (CN XI) nerves.

FIGURE 10.9 Muscles of the Tongue and Pharynx. APR

Name	Action	*O:* Origin *I:* Insertion	Innervation
Genioglossus[29] (JEE-nee-oh-GLOSS-us)	Unilateral action draws tongue to one side; bilateral action depresses midline of tongue or protrudes tongue	*O:* Superior mental spine on posterior surface of mental protuberance *I:* Inferior surface of tongue from root to apex	Hypoglossal nerve
Hyoglossus[30] (HI-oh-GLOSS-us)	Depresses tongue	*O:* Body and greater horn of hyoid bone *I:* Lateral and inferior surfaces of tongue	Hypoglossal nerve
Styloglossus[31] (STY-lo-GLOSS-us)	Draws tongue upward and posteriorly	*O:* Styloid process of temporal bone and ligament from styloid process to mandible *I:* Superolateral surface of tongue	Hypoglossal nerve
Palatoglossus[32] (PAL-a-toe-GLOSS-us)	Elevates root of tongue and closes oral cavity off from pharynx; forms palatoglossal arch at rear of oral cavity	*O:* Soft palate *I:* Lateral surface of tongue	Accessory and vagus nerves

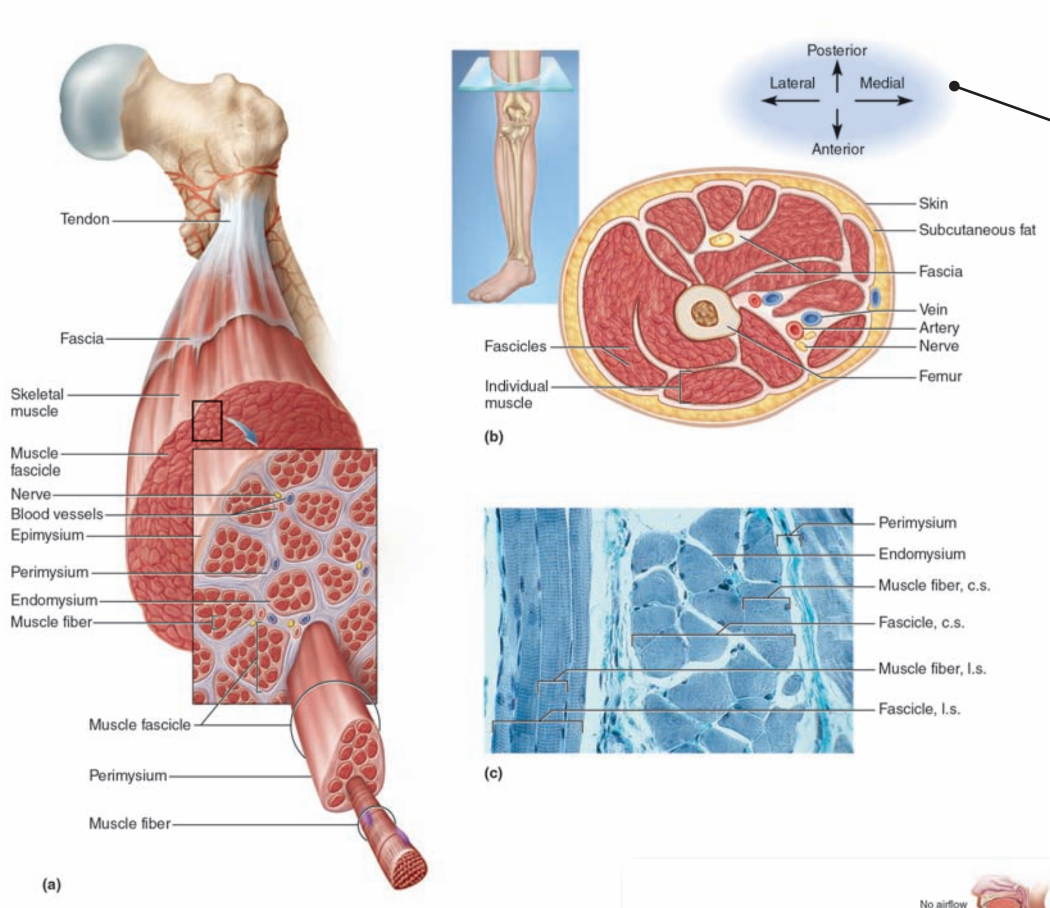
---

[29] *genio* = chin; *gloss* = tongue
[30] *hyo* = hyoid bone; *gloss* = tongue
[31] *stylo* = styloid process; *gloss* = tongue
[32] *palato* = palate; *gloss* = tongue

Muscle Tables

Muscle tables are organized into columnar format and enhanced with shading for easier reading and learning.

> *The visual appeal of nature is immensely important in motivating one to study it. We certainly see this at work in human anatomy—in the countless students who describe themselves as visual learners”, in the many laypeople who find anatomy atlases so intriguing, and in the enormous popularity of* Body Worlds *and similar exhibitions of human anatomy.*
>
> —Ken Saladin



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Saladin art integrates tools to help students quickly orient themselves within a figure and make connections between ideas.

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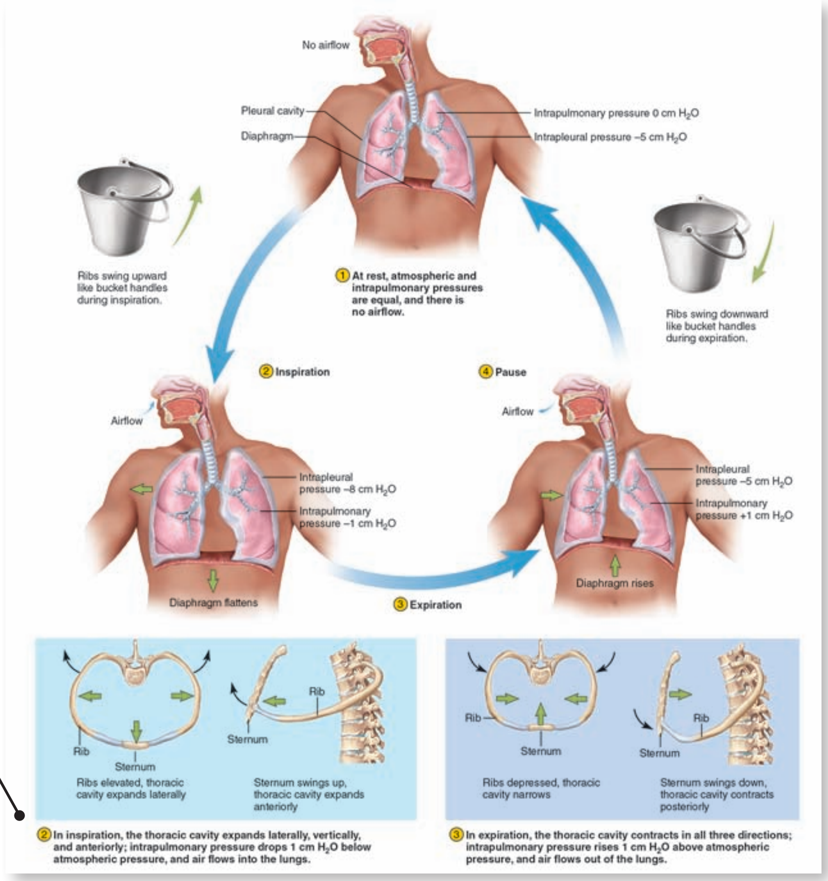

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Other question types, such as multiple choice, true/false, fill-in-the-blank, and "Before You Go On" essay, are included to ensure consistent and adequate depth and breadth of coverage for each Learning Outcome in the text. Many Connect questions include a hint to help students recall information, make meaningful connections between concepts, and connect words and visual structures, promoting long-term memory. Explanations are included for numerous questions to provide feedback and guidance, which is especially useful to students taking an online or hybrid course.

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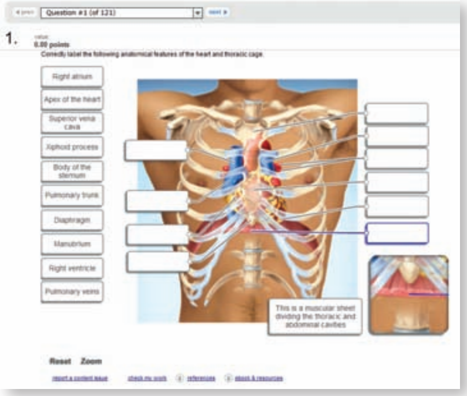

1. value: 6.00 points

Correctly label the following anatomical features of the heart and thoracic cage.

This is a muscular sheet dividing the thoracic and abdominal cavities

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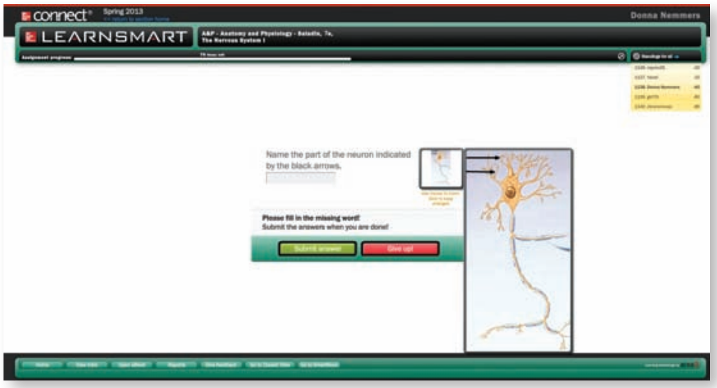

Name the part of the neuron indicated by the black arrows.

Please fill in the missing word!
Submit the answers when you are done!

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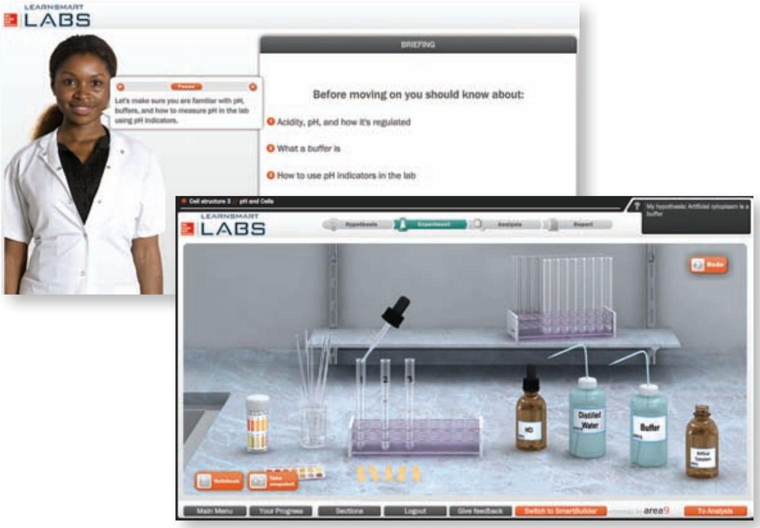

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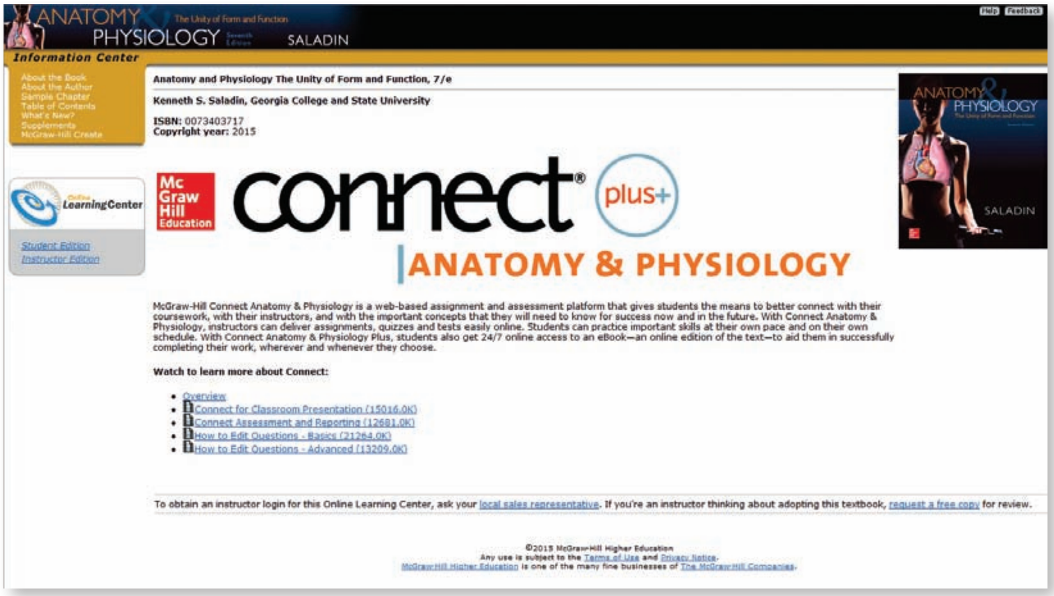

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Kenneth S. Saladin, Georgia College and State University

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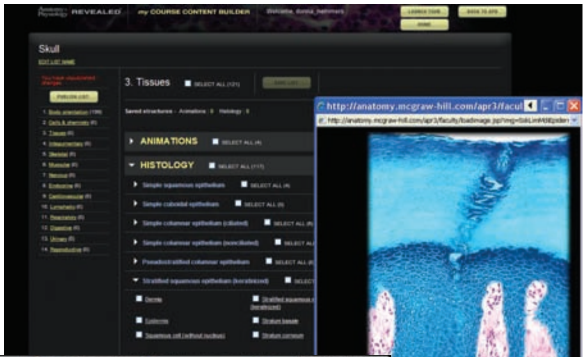
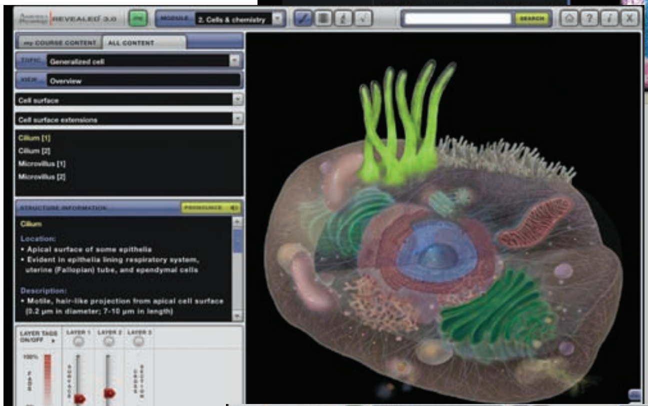
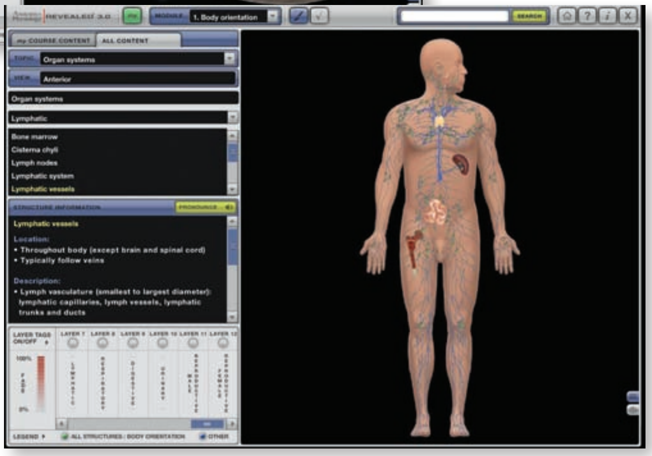




Cilium

Location:
• Apical surface of some epithelia
• Evident in epithelia lining respiratory system, uterine (Fallopian) tube, and ependymal cells

Description:
• Motile, hair-like projection from apical cell surface (0.2 µm in diameter; 7-10 µm in length)



Lymphatic vessels

Location:
• Throughout body (except brain and spinal cord)
• Typically follow veins

Description:
• Lymph vasculature (smallest to largest diameter): lymphatic capillaries, lymph vessels, lymphatic trunks and ducts

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- Outcomes and assessments format
- Clear, concise writing style

The *Clinical Applications Manual to Accompany Anatomy and Physiology* is correlated to the Saladin text. The first six chapters introduce general aspects of patient examination, diagnosis, and treatment, as well as pathologies at the cell, tissue, and genetic levels. All later chapters explain disorders and procedures specific to each body system, elaborating on some clinical conditions described in the text, and introducing additional conditions that are especially common or interesting.

Solve Saladin Crossword Puzzle Supplement by Greg Reeder of Broward Community College contains crossword puzzles tailored to each section of Saladin's chapters, including a "Quiz" puzzle to summarize the most important concepts in each chapter. This excellent anatomy and physiology study aid contains all puzzle answers in the back of the book.

OTHER RESOURCES AVAILABLE

Student Study Guide

This comprehensive study guide written by experienced instructor Jacque Homan in collaboration with Ken Saladin contains vocabulary-building and content-testing exercises, labeling exercises, and practice exams.

Physiology Tutorials

MediaPhys offers detailed explanations, high-quality illustrations, and animations to provide students with a thorough introduction to the world of physiology—giving them a virtual tour of physiological processes.

Physiology Interactive Lab Simulations

Ph.I.L.S. offers 42 lab simulations that may be used to supplement or substitute for wet labs. Users may adjust variables, view outcomes, make predictions, draw conclusions, and print lab reports.

Osmosis and Diffusion
1. Varying Extracellular Concentration

Metabolism
2. Size and Basal Metabolic Rate
3. Respiratory Quotient
4. Cyanide and Electron Transport

Skeletal Muscle Function
5. Stimulus-Dependent Force Generation
6. Weight & Contraction
7. The Length-Tension Relationship
8. Principles of Summation and Tetanus
9. EMG and Twitch Amplitude

Resting Potentials
10. Resting Potential and External $[K^+]$
11. Resting Potential and External $[Na^+]$

Action Potentials
12. The Compound Action Potential
13. Conduction Velocity and Temperature
14. Refractory Periods
15. Measuring Ion Currents

Synaptic Potentials
16. Facilitation and Depression
17. Temporal Summation of EPSPs
18. Spatial Summation of EPSPs

Endocrine Function
19. Thyroid Gland and Metabolic Rate
20. Insulin and Glucose Tolerance

Frog Heart Function
21. Thermal and Chemical Effects
22. Refractory Period of the Heart
23. Starling's Law of the Heart
24. Heart Block

ECG and Heart Function
25. ECG and Exercise
26. The Meaning of Heart Sounds
27. ECG and Finger Pulse
28. Electrical Axis of the Heart
29. ECG and Heart Block
30. Abnormal ECGs

Circulation
31. Cooling and Peripheral Blood Flow
32. Blood Pressure and Gravity
33. Blood Pressure and Body Position

Blood
34. pH and Hb-Oxygen Binding
35. DPG and Hb-Oxygen Binding
36. Blood Typing

Respiration
37. Altering Body Position
38. Altering Airway Volume
39. Exercise-Induced Changes
40. Deep Breathing and Cardiac Function

Digestion
41. Glucose Transport

Human Kidney Function
42. Anti-Diuretic Hormone

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Michele D. Alexandre
Durham Technical Community College

Tami Asplin
North Dakota State University

Seher Atamturktur
Bronx Community College

Tim Ballard
University of North Carolina–Wilmington

Patricia Bernard
Trocaire College

Christopher Brandon Jr.
Georgia Gwinnett College, School of Science & Technology

Winnifred Bryant
University of Wisconsin–Eau Claire

Wayne Busch
Riverland Community College

Juliann Chmielecki
Bunker Hill Community College

Roger Choate
Oklahoma City Community College

Thomas F. Chubb
Villanova University

Tracy Curtis
Broome Community College

Patricia DeLeon
BMCC/CUNY

Mathew Edick
Grand Valley State University

Amy Fenech Sandy
Columbus Technical College

Julie Fischer
Wallace Community College

Teresa Fischer
Indian River State College

Ted Fleming
Bradley University

Clifford Fontenot
Southeastern Louisiana University

Seth Gardner
Bowling Green State University–Firelands Campus

Carrie Gaynor
Macomb Community College

Mike Gehner
Xavier University

Christine Griffiths
Jackson State Community College

Matthew Halter
Cabrillo College

Steven B. Hammer
Indian River State College

Judy Y. Harris
Kennebec Valley Community College

DeLoris Hesse
University of Georgia

William Hopkins
Whatcom Community College

Melinda Hutton
McNeese State University

Kathy Jo Ann Jackson
McNeese State University

Judy Jiang
Triton College

Astagik Kalashnikova
Broward College

Steve Kash
Oklahoma City Community College

Raymond Larsen
Bowling Green State University

Deborah Lawson
Maryville University–St. Louis

Carlos Liachovitzky
Bronx Community College of The City University of New York

Sarah Liechty
Ivy Tech Community College

David Barry Markillie
Cape Fear Community College

Tiffany McFalls
Elizabethtown Community & Technical College

Abraham Miller
University of Tampa

Robert Moldenhauer
St. Clair County Community College

April Murphy
Columbus Technical College

Keith (Dan) Murray
South Texas College

Ellen Ott-Reeves
Blinn College–Bryan

Kjerstin Owens
Trocaire College

James Palmer
Southeastern Louisiana University

Maria Pereira
Hunter College, CUNY

Jocelyn Ramos
Ivy Tech Community College–Franklin

Cynthia P. Robison
Wallace Community College–Dothan

Susan Rohde
Triton College

Donald Shaw
University of Tennessee–Martin

Gidi Shemer
University of North Carolina–Chapel Hill

Hollis Smith
Kennebec Valley Community College

Michelle Smith
Columbus Technical College

Kimberly Sonanstine
Wallace Community College

Christopher Sorenson
St. Cloud Technical and Community College

Jeff Spencer
The University of Akron

William Stewart
Middle Tennessee State University

Justin St. Juliana
Ivy Tech Community College–Wabash Valley

Diana Sturges
Georgia Southern University

Pete Sutliff
Wayne County Community College District

Mohamad Termos
South Texas College

Diane Tice
Morrisville State College

Todd Tolar
Wallace Community College

Janice Webster
Ivy Tech Community College

Andrzej Wieraszko
The College of Staten Island/CUNY

Daniel B. Williams
Winston Salem State University

Sonya J. Williams
Oklahoma City Community College

Vanessa Williams
University of Georgia

Madelyn Wilson
Three Rivers College

Kerby Winters
Treasure Valley Community College

Jen Wortham
University of Tampa

Catherine Young
Bunker Hill Community College

Jeffrey Zuiderveen
Columbus State University

LETTER TO THE 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 teaching myself by 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 ink as a medium. My "first book" was a 318-page paper on some little pond animals called hydras, with 53 India ink 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 the first edition of this book you are now holding. 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 his scientific, storytelling prose and his concept of the way things should be illustrated to spark interest and facilitate understanding.

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 its 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.

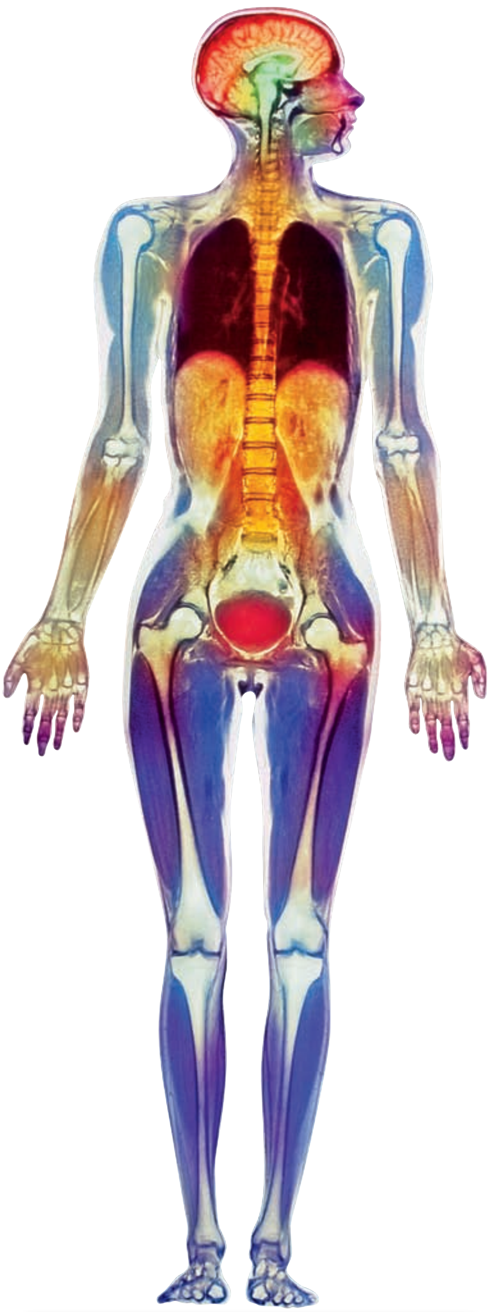
Each chapter is broken down into short, digestible bits with a set of Expected Learning Outcomes at the beginning of each section, and self-testing questions (Before You Go On) just a few pages later. Even if you have just 30 minutes to read during a lunch break or a bus ride, you can easily read or review one of these brief sections. There are also numerous self-testing questions in a Study Guide at the end of each chapter, in some of the figure legends, and the occasional Apply What You Know questions dispersed throughout 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.

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 a lot with students and would enjoy hearing from you.

Ken Saladin
Georgia College & State University
Milledgeville, GA 31061 (USA)
ken.saladin@gcsu.edu

Dedicated to the memory of
Libbie Henrietta Hyman
who patiently indulged my adolescent zoological questions
and, unknowingly, taught me how to write

PART ONE: ORGANIZATION OF THE BODY



A colorized MRI scan of the human body

CHAPTER 1

MAJOR THEMES OF ANATOMY AND PHYSIOLOGY

CHAPTER OUTLINE

DEEPER INSIGHTS

Anatomy & Physiology REVEALED®
aprevealed.com

Volume 1 Skeletal and Muscular Systems

No branch of science hits as close to home as the science of our own bodies. We're grateful for the dependability of our hearts; we're awed by the capabilities of muscles and joints displayed by Olympic athletes; and we ponder with philosophers the ancient mysteries of mind and emotion. We want to know how our body works, and when it malfunctions, we want to know what is happening and what we can do about it. Even the most ancient writings of civilization include medical documents that attest to humanity's timeless drive to know itself. You are embarking on a subject that is as old as civilization, yet one that grows by thousands of scientific publications every week.

This book is an introduction to human structure and function, the biology of the human body. It is meant primarily to give you a foundation for advanced study in health care, exercise physiology, pathology, and other fields related to health and fitness. Beyond that purpose, however, it can also provide you with a deeply satisfying sense of self-understanding.

As rewarding and engrossing as this subject is, the human body is highly complex, and understanding it requires us to comprehend a great deal of detail. The details will be more manageable if we relate them to a few broad, unifying concepts. The aim of this chapter, therefore, is to introduce such concepts and put the rest of the book into perspective. We consider the historical development of anatomy and physiology, the thought processes that led to the knowledge in this book, the meaning of human life, some central concepts of physiology, and how to better understand medical terminology.

1.1 The Scope of Anatomy and Physiology

Expected Learning Outcomes

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

a. define *anatomy* and *physiology* and relate them to each other;
b. describe several ways of studying human anatomy; and
c. define a few subdisciplines of human physiology.

Anatomy is the study of structure, and **physiology** is the study of function. These approaches are complementary and never entirely separable. Together, they form the bedrock of the health sciences. When we study a structure, we want to know, What does it do? Physiology thus lends meaning to anatomy; and, conversely, anatomy is what makes physiology possible. This *unity of form and function* is an important point to bear in mind as you study the body. Many examples of it will be apparent throughout the book—some of them pointed out for you, and others you will notice for yourself.

Anatomy—The Study of Form

There are several ways to examine the structure of the human body. The simplest is **inspection**—simply looking at the body's appearance, as in performing a physical examination or making a clinical diagnosis from surface appearance. Physical examinations also involve touching and listening to the body. **Palpation**[1] means feeling a structure with the hands, such as palpating a swollen lymph node or taking a pulse. **Auscultation**[2] (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 or air.

But a deeper understanding of the body depends on **dissection** (dis-SEC-shun)—carefully cutting and separating tissues to reveal their relationships. The very words *anatomy*[3] and *dissection*[4] both mean "cutting apart"; until the nineteenth century, dissection was called "anatomizing." In many schools of health science, one of the first steps in training students is dissection of the **cadaver,**[5] a dead human body. Many insights into human structure are obtained from **comparative anatomy**—the study of multiple species in order to examine similarities and differences and analyze evolutionary trends. Anatomy students often begin by dissecting other animals with which we share a common ancestry and many structural similarities. Many of the reasons for human structure become apparent only when we look at the structure of other animals.

Dissection, of course, is not the method of choice when studying a living person! It was once 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, discussed at the end of this chapter (see Deeper Insight 1.5). The branch of medicine concerned with imaging is called **radiology.** Structure that can be seen with the naked eye—whether by surface observation, radiology, or dissection—is called **gross anatomy.**

Ultimately, the functions 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**[6] **(microscopic anatomy). Histopathology** is the microscopic examination of tissues for signs of disease. **Cytology**[7] is the study of the structure and function of individual cells. **Ultrastructure** refers to fine detail, down to the molecular level, revealed by the electron microscope.

Physiology—The Study of Function

Physiology[8] uses the methods of experimental science discussed later. It has many subdisciplines such as *neurophysiology* (physiology of the nervous system), *endocrinology* (physiology

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[1] *palp* = touch, feel; *ation* = process
[2] *auscult* = listen; *ation* = process
[3] *ana* = apart; *tom* = cut
[4] *dis* = apart; *sect* = cut
[5] from *cadere* = to fall down or die
[6] *histo* = tissue; *logy* = study of
[7] *cyto* = cell; *logy* = study of
[8] *physio* = nature; *logy* = study of

of hormones), and *pathophysiology* (mechanisms of disease). Partly because of limitations on experimentation with humans, much of what we know about bodily function has been gained through **comparative physiology,** the study of how different species have solved problems of life such as water balance, respiration, and reproduction. Comparative physiology is also the basis for the development of new drugs and medical procedures. For example, a cardiac surgeon may learn animal surgery before practicing on humans, and a vaccine cannot be used on human subjects until it has been demonstrated through animal research that it confers significant benefits without unacceptable risks.

BEFORE YOU GO ON

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

1. What is the difference between anatomy and physiology? How do these two sciences support each other?
2. Name the method that would be used for each of the following: listening to a patient for a heart murmur; studying the microscopic structure of the liver; microscopically examining liver tissue for signs of hepatitis; learning the blood vessels of a cadaver; and performing a breast self-examination.

1.2 The Origins of Biomedical Science

Expected Learning Outcomes

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

a. give examples of how modern biomedical science emerged from an era of superstition and authoritarianism; and
b. describe the contributions of some key people who helped to bring about this transformation.

Any science is more enjoyable if we consider not just the current state of knowledge, but how it compares to past understandings of the subject and how our knowledge was gained. Of all sciences, medicine has one of the most fascinating histories. Medical science has progressed far more in the last 50 years than in the 2,500 years before that, but the field did not spring up overnight. It is built upon centuries of thought and controversy, triumph and defeat. We cannot fully appreciate its present state without understanding its past—people who had the curiosity to try new things, the vision to look at human form and function in new ways, and the courage to question authority.

The Greek and Roman Legacy

As early as 3,000 years ago, physicians in Mesopotamia and Egypt treated patients with herbal drugs, salts, physical therapy, and faith healing. The "father of medicine," however, is usually considered to be the Greek physician **Hippocrates** (c. 460–c. 375 BCE). He and his followers established a code of ethics for physicians, the Hippocratic Oath, that is still recited in modern form by graduating physicians at some medical schools. Hippocrates urged physicians to stop attributing disease to the activities of gods and demons and to seek their natural causes, which could afford the only rational basis for therapy.

Aristotle (384–322 BCE) was one of the first philosophers to write about anatomy and physiology. He believed that diseases and other natural events could have either supernatural causes, which he called *theologi,* or natural ones, which he called *physici* or *physiologi*. We derive such terms as *physician* and *physiology* from the latter. Until the nineteenth century, physicians were called "doctors of physic." In his anatomy book, *On the Parts of Animals,* Aristotle tried to identify unifying themes in nature. Among other points, he argued that complex structures are built from a smaller variety of simple components—a perspective that we will find useful later in this chapter.

►►►APPLY WHAT YOU KNOW

When you have completed this chapter, discuss the relevance of Aristotle's philosophy to our current thinking about human structure.

Claudius Galen (c. 130–c. 200), physician to the Roman gladiators, wrote the most influential medical textbook of the ancient era—a book worshipped to excess by medical professors for centuries to follow. Cadaver dissection was banned in Galen's time because of some horrid excesses that preceded him, including public dissection of living slaves and prisoners. Aside from what he could learn by treating gladiators' wounds, Galen was therefore limited to dissecting pigs, monkeys, and other animals. Because he was not permitted to dissect cadavers, he had to guess at much of human anatomy and made some incorrect deductions from animal dissections. He described the human liver, for example, as having five fingerlike lobes, somewhat like a baseball glove, because that is what he had seen in baboons. But Galen saw science as a method of discovery, not as a body of fact to be taken on faith. He warned that even his own books could be wrong and advised his followers to trust their own observations more than any book. Unfortunately, his advice was not heeded. For nearly 1,500 years, medical professors dogmatically taught what they read in Aristotle and Galen, seldom daring to question the authority of these "ancient masters."

The Birth of Modern Medicine

In the Middle Ages, the state of medical science varied greatly from one religious culture to another. Science was severely repressed in the Christian culture of Europe until about the sixteenth century, although some of the most famous medical schools of Europe were founded during this era. Their professors, however, taught medicine primarily as a dogmatic commentary on Galen and Aristotle, not as a field of original research. Medieval medical illustrations were crude representations of the body intended more to decorate a page than to depict the body realistically (fig. 1.1a). Some were astrological charts that showed which sign of the zodiac was thought to influence each organ of the body. From such pseudoscience came the word *influenza,* Italian for "influence."

Free inquiry was less inhibited in Jewish and Muslim culture during this time. Jewish physicians were the most esteemed practitioners of their art—and none more famous than *Moses ben Maimon* (1135–1204), known in Christendom as **Maimonides.** Born in Spain, he fled to Egypt at age 24 to escape antisemitic persecution. There he served the rest of his life as physician to the court of the sultan, Saladin. A highly admired rabbi, Maimonides wrote voluminously on Jewish law and theology, but also wrote 10 influential medical books and numerous treatises on specific diseases.

Among Muslims, probably the most highly regarded medical scholar was *Ibn Sina* (980–1037), known in the West as **Avicenna** or "the Galen of Islam." He studied Galen and Aristotle, combined their findings with original discoveries, and questioned authority when the evidence demanded it. Medicine in the Mideast soon became superior to European medicine. Avicenna's textbook, *The Canon of Medicine,* was the leading authority in European medical schools for over 500 years.

Chinese medicine had little influence on Western thought and practice until relatively recently; the medical arts evolved in China quite independently of European medicine. Later chapters of this book describe some of the insights of ancient China and India.

Modern Western medicine began around the sixteenth century in the innovative minds of such people as the anatomist Andreas Vesalius and the physiologist William Harvey.

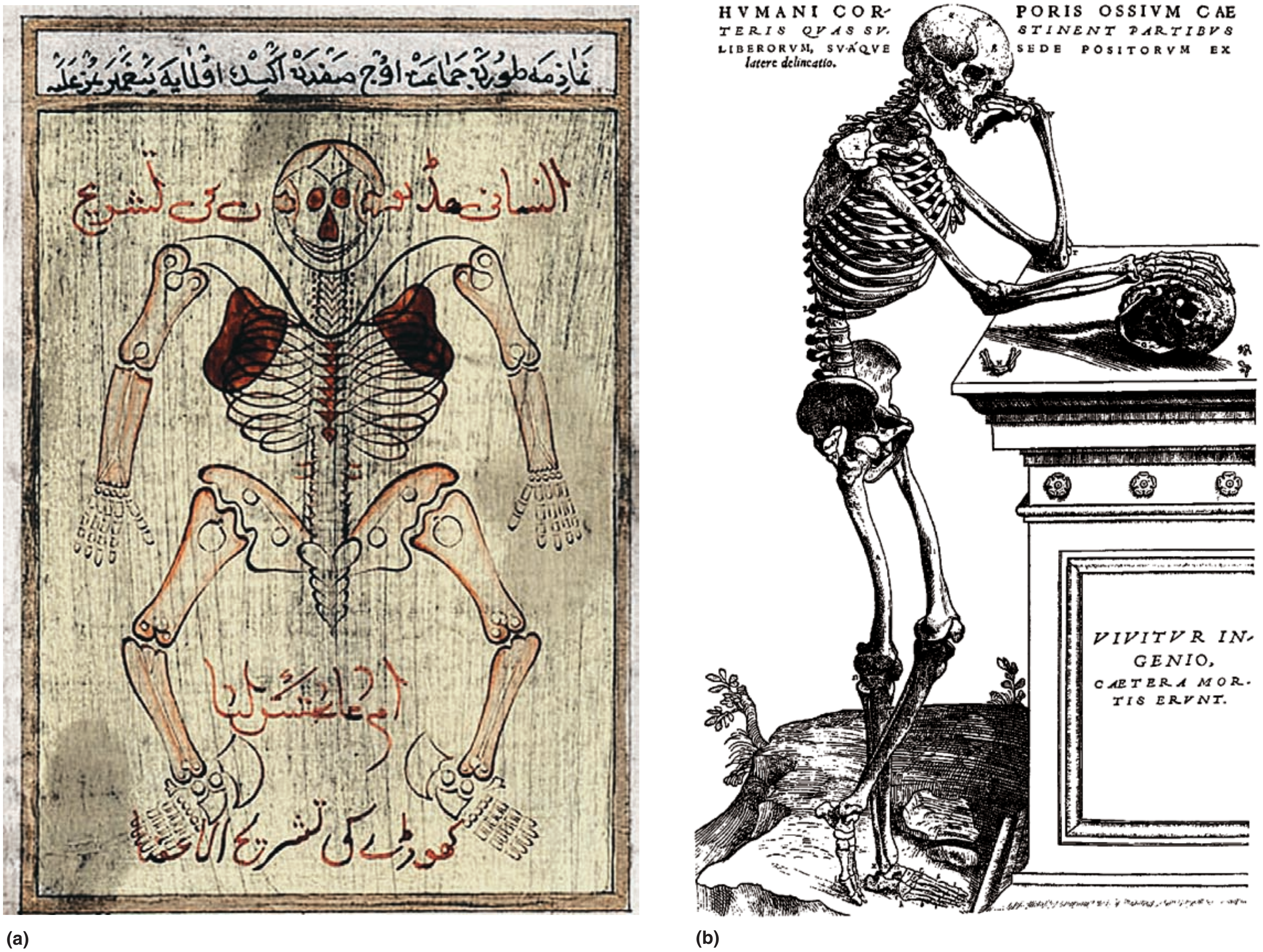

FIGURE 1.1 Evolution of Medical Art. Two illustrations of the skeletal system made about 500 years apart. (a) From an eleventh-century work attributed to Persian physician Avicenna. (b) From *De Humani Corporis Fabrica* by Andreas Vesalius, 1543.

Andreas Vesalius (1514–64) taught anatomy in Italy. In his time, the Catholic Church relaxed its prohibition against cadaver dissection, in part to allow autopsies in cases of suspicious death. Furthermore, the Italian Renaissance created an environment more friendly to innovative scholarship. Dissection gradually found its way into the training of medical students throughout Europe. It was an unpleasant business, however, and most professors considered it beneath their dignity. In those days before refrigeration or embalming, the odor from the decaying cadaver was unbearable. Dissections were a race against decay. Bleary medical students had to fight the urge to vomit, lest they incur the wrath of an overbearing professor. Professors typically sat in an elevated chair, the cathedra, reading dryly in Latin from Galen or Aristotle while a lower-ranking *barber–surgeon* removed putrefying organs from the cadaver and held them up for the students to see. Barbering and surgery were considered to be "kindred arts of the knife"; today's barber poles date from this era, their red and white stripes symbolizing blood and bandages.

Vesalius broke with tradition by coming down from the cathedra and doing the dissections himself. He was quick to point out that much of the anatomy in Galen's books was wrong, and he was the first to publish accurate illustrations for teaching anatomy (fig. 1.1b). When others began to plagiarize them, Vesalius published the first atlas of anatomy, *De Humani Corporis Fabrica (On the Structure of the Human Body),* in 1543. This book began a rich tradition of medical illustration that has been handed down to us through such milestones as *Gray's Anatomy* (1856) and the vividly illustrated atlases and textbooks of today.

Anatomy preceded physiology and was a necessary foundation for it. What Vesalius was to anatomy, the Englishman **William Harvey** (1578–1657) was to physiology. Harvey is remembered especially for his studies of blood circulation and a little book he published in 1628, known by its abbreviated title *De Motu Cordis (On the Motion of the Heart)*. He and **Michael Servetus** (1511–53) were the first Western scientists to realize that blood must circulate continuously around the body, from the heart to the other organs and back to the heart again. This flew in the face of Galen's belief that the liver converted food to blood, the heart pumped blood through the veins to all other organs, and those organs consumed it. Harvey's colleagues, wedded to the ideas of Galen, ridiculed him for his theory, though we now know he was correct (see p. 744). Despite persecution and setbacks, Harvey lived to a ripe old age, served as physician to the kings of England, and later did important work in embryology. Most importantly, Harvey's contributions represent the birth of experimental physiology—the method that generated most of the information in this book.

Modern medicine also owes an enormous debt to two inventors from this era, Robert Hooke and Antony van Leeuwenhoek, who extended the vision of biologists to the cellular level.

Robert Hooke (1635–1703), an Englishman, designed scientific instruments of various kinds, including the compound microscope. This is a tube with a lens at each end—an *objective lens* near the specimen, which produces an initial magnified image, and an *ocular lens (eyepiece)* near the observer's eye, which magnifies the first image still further. Although crude compound microscopes had existed since 1595, Hooke improved the optics and invented several of the helpful features found in microscopes today—a stage to hold the specimen, an illuminator, and coarse and fine focus controls. His microscopes magnified only about 30 times, but with them, he was the first to see and name cells. In 1663, he observed thin shavings of cork and observed that they "consisted of a great many little boxes," which he called *cellulae* (little cells) after the cubicles of a monastery (fig. 1.2). He later observed living cells "filled with juices." Hooke became particularly interested in microscopic examination of such material as insects, plant tissues, and animal parts. He published the first comprehensive book of microscopy, *Micrographia,* in 1665.

Antony van Leeuwenhoek (an-TOE-nee vahn LAY-wen-hook) (1632–1723), a Dutch textile merchant, invented a *simple* (single-lens) *microscope,* originally for the purpose of examining the weave of fabrics. His microscope was a bead-like lens mounted in a metal plate equipped with a movable

FIGURE 1.2 **Hooke's Compound Microscope.** (a) The compound microscope had a lens at each end of a tubular body. (b) Hooke's drawing of cork cells, showing the thick cell walls characteristic of plants.

specimen clip. Even though his microscopes were simpler than Hooke's, they achieved much greater useful magnification (up to 200×) owing to Leeuwenhoek's superior lens-making technique. Out of curiosity, he examined a drop of lake water and was astonished to find a variety of microorganisms—"little animalcules," he called them, "very prettily a-swimming." He went on to observe practically everything he could get his hands on, including blood cells, blood capillaries, sperm, muscular tissue, and bacteria from tooth scrapings. Leeuwenhoek began submitting his observations to the Royal Society of London in 1673. He was praised at first, and his observations were eagerly read by scientists, but enthusiasm for the microscope did not last. By the end of the seventeenth century, it was treated as a mere toy for the upper classes, as amusing and meaningless as a kaleidoscope. Leeuwenhoek and Hooke had even become the brunt of satire. But probably no one in history had looked at nature in such a revolutionary way. By taking biology to the cellular level, the two men had laid an entirely new foundation for the modern medicine to follow centuries later.

The Hooke and Leeuwenhoek microscopes produced poor images with blurry edges *(spherical aberration)* and rainbowlike distortions *(chromatic aberration)*. These problems had to be solved before the microscope could be widely used as a biological tool. In the nineteenth century, German inventors greatly improved the compound microscope, adding the condenser and developing superior optics. With improved microscopes, biologists began eagerly examining a wider variety of specimens. By 1839, botanist **Matthias Schleiden** (1804–81) and zoologist **Theodor Schwann** (1810–82) concluded that all organisms were composed of cells. Although it took another century for this idea to be generally accepted, it became the first tenet of the **cell theory,** added to by later biologists and summarized in chapter 3. The cell theory was perhaps the most important breakthrough in biomedical history; all functions of the body are now interpreted as the effects of cellular activity.

Although the philosophical foundation for modern medicine was largely established by the time of Leeuwenhoek, Hooke, and Harvey, clinical practice was still in a dismal state. Few doctors attended medical school or received any formal education in basic science or human anatomy. Physicians tended to be ignorant, ineffective, and pompous. Their practice was heavily based on expelling imaginary toxins from the body by bleeding their patients or inducing vomiting, sweating, or diarrhea. They performed operations with filthy hands and instruments, spreading lethal infections from one patient to another and refusing, in their vanity, to believe that they themselves were the carriers of disease. Countless women died of infections acquired during childbirth from their obstetricians. Fractured limbs often became gangrenous and had to be amputated, and there was no anesthesia to lessen the pain. Disease was still widely attributed to demons and witches, and many people felt they would be interfering with God's will if they tried to treat it.

Living in a Revolution

This short history brings us only to the threshold of modern biomedical science; it stops short of such momentous discoveries as the germ theory of disease, the mechanisms of heredity, and the structure of DNA. In the twentieth century, basic biology and biochemistry yielded a much deeper understanding of how the body works. Advances in medical imaging enhanced our diagnostic ability and life-support strategies. We witnessed monumental developments in chemotherapy, immunization, anesthesia, surgery, organ transplants, and human genetics. By the close of the twentieth century, we had discovered the chemical "base sequence" of every human gene and begun attempting gene therapy to treat children born with diseases recently considered incurable. As future historians look back on the turn of this century, they may exult about the Genetic Revolution in which you are now living.

Several discoveries of the nineteenth and twentieth centuries, and the men and women behind them, are covered in short historical sketches in later chapters. Yet, the stories told in this chapter are different in a significant way. The people discussed here were pioneers in establishing the scientific way of thinking. They helped to replace superstition with an appreciation of natural law. They bridged the chasm between mystery and medication. Without this intellectual revolution, those who followed could not have conceived of the right questions to ask, much less a method for answering them.

BEFORE YOU GO ON

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

3. In what way did the followers of Galen disregard his advice? How does Galen's advice apply to you and this book?

4. Describe two ways in which Vesalius improved medical education and set standards that remain relevant today.

5. How is our concept of human form and function today affected by inventors from the seventeenth to the nineteenth century?

1.3 Scientific Method

Expected Learning Outcomes

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

a. describe the inductive and hypothetico–deductive methods of obtaining scientific knowledge;

b. describe some aspects of experimental design that help to ensure objective and reliable results; and

c. explain what is meant by *hypothesis, fact, law,* and *theory* in science.

Prior to the seventeenth century, science was done in a haphazard way by a small number of isolated individuals.

The philosophers **Francis Bacon** (1561–1626) in England and **René Descartes** (1596–1650) in France envisioned science as a far greater, systematic enterprise with enormous possibilities for human health and welfare. They detested those who endlessly debated ancient philosophy without creating anything new. Bacon argued against biased thinking and for more objectivity in science. He outlined a systematic way of seeking similarities, differences, and trends in nature and drawing useful generalizations from observable facts. You will see echoes of Bacon's philosophy in the discussion of scientific method that follows.

Though the followers of Bacon and Descartes argued bitterly with one another, both men wanted science to become a public, cooperative enterprise, supported by governments and conducted by an international community of scholars rather than a few isolated amateurs. Inspired by their vision, the French and English governments established academies of science that still flourish today. Bacon and Descartes are credited with putting science on the path to modernity, not by discovering anything new in nature or inventing any techniques—for neither man was a scientist—but by inventing new habits of scientific thought.

When we say "scientific," we mean that such thinking is based on assumptions and methods that yield reliable, objective, testable information about nature. The assumptions of science are ideas that have proven fruitful in the past—for example, the idea that natural phenomena have natural causes and nature is therefore predictable and understandable. The methods of science are highly variable. **Scientific method** refers less to observational procedures than to certain habits of disciplined creativity, careful observation, logical thinking, and honest analysis of one's observations and conclusions. It is especially important in health science to understand these habits. This field is littered with more fads and frauds than any other. We are called upon constantly to judge which claims are trustworthy and which are bogus. To make such judgments depends on an appreciation of how scientists think, how they set standards for truth, and why their claims are more reliable than others.

The Inductive Method

The **inductive method,** first prescribed by Bacon, is a process of making numerous observations until one feels confident in drawing generalizations and predictions from them. What we know of anatomy is a product of the inductive method. We describe the normal structure of the body based on observations of many bodies.

This raises the issue of what is considered proof in science. We can never prove a claim beyond all possible refutation. We can, however, consider a statement as proven *beyond reasonable doubt* if it was arrived at by reliable methods of observation, tested and confirmed repeatedly, and not falsified by any credible observation. In science, all truth is tentative; there is no room for dogma. We must always be prepared to abandon yesterday's truth if tomorrow's facts disprove it.

The Hypothetico–Deductive Method

Most physiological knowledge was obtained by the **hypothetico–deductive method.** An investigator begins by asking a question and formulating a **hypothesis**—an educated speculation or possible answer to the question. A good hypothesis must be (1) consistent with what is already known and (2) capable of being tested and possibly falsified by evidence. **Falsifiability** means that if we claim something is scientifically true, we must be able to specify what evidence it would take to prove it wrong. If nothing could possibly prove it wrong, then it is not scientific.

►►►APPLY WHAT YOU KNOW

The ancients thought that gods or invisible demons caused epilepsy. Today, epileptic seizures are attributed to bursts of abnormal electrical activity in nerve cells of the brain. Explain why one of these claims is falsifiable (and thus scientific), whereas the other claim is not.

The purpose of a hypothesis is to suggest a method for answering a question. From the hypothesis, a researcher makes a deduction, typically in the form of an "if–then" prediction: *If* my hypothesis on epilepsy is correct and I record the brain waves of patients during seizures, *then* I should observe abnormal bursts of activity. A properly conducted experiment yields observations that either support a hypothesis or require the scientist to modify or abandon it, formulate a better hypothesis, and test that one. Hypothesis testing operates in cycles of conjecture and disproof until one is found that is supported by the evidence.

Experimental Design

Doing an experiment properly involves several important considerations. What shall I measure and how can I measure it? What effects should I watch for and which ones should I ignore? How can I be sure my results are due to the variables that I manipulate and not due to something else? When working on human subjects, how can I prevent the subject's expectations or state of mind from influencing the results? How can I eliminate my own biases and be sure that even the most skeptical critics will have as much confidence in my conclusions as I do? Several elements of experimental design address these issues:

- **Sample size.** The number of subjects (animals or people) used in a study is the sample size. An adequate sample size controls for chance events and individual variations in response and thus enables us to place more confidence in the outcome. For example, would you rather trust your health to a drug that was tested on 5 people or one tested on 5,000? Why?
- **Controls.** Biomedical experiments require comparison between treated and untreated individuals so that we can judge whether the treatment has any effect. A **control group** consists of subjects that are as much like the **treatment group** as possible except with respect to the variable being tested. For example, there is evidence that

garlic lowers blood cholesterol levels. In one study, volunteers with high cholesterol were each given 800 mg of garlic powder daily for 4 months and exhibited an average 12% reduction in cholesterol. Was this a significant reduction, and was it due to the garlic? It is impossible to say without comparison to a control group of similar people who received no treatment. In this study, the control group averaged only a 3% reduction in cholesterol, so garlic *seems* to have made a difference.

- **Psychosomatic effects.** Psychosomatic effects (effects of the subject's state of mind on his or her physiology) can have an undesirable effect on experimental results if we do not control for them. In drug research, it is therefore customary to give the control group a **placebo** (pla-SEE-bo)—a substance with no significant physiological effect on the body. If we were testing a drug, for example, we could give the treatment group the drug and the control group identical-looking sugar tablets. Neither group must know which tablets it is receiving. If the two groups showed significantly different effects, we could feel confident that it did not result from a knowledge of what they were taking.
- **Experimenter bias.** In the competitive, high-stakes world of medical research, experimenters may want certain results so much that their biases, even subconscious ones, can affect their interpretation of the data. One way to control for this is the **double-blind method.** In this procedure, neither the subject to whom a treatment is given nor the person giving it and recording the results knows whether that subject is receiving the experimental treatment or placebo. A researcher might prepare identical-looking tablets, some with the drug and some with placebo; label them with code numbers; and distribute them to participating physicians. The physicians themselves do not know whether they are administering drug or placebo, so they cannot give the subjects even accidental hints of which substance they are taking. When the data are collected, the researcher can correlate them with the composition of the tablets and determine whether the drug had more effect than the placebo.
- **Statistical testing.** If you tossed a coin 100 times, you would expect it to come up about 50 heads and 50 tails. If it actually came up 48:52, you would probably attribute this to random error rather than bias in the coin. But what if it came up 40:60? At what point would you begin to suspect bias? This type of problem is faced routinely in research—how great a difference must there be between control and experimental groups before we feel confident that it was due to the treatment and not merely random variation? What if a treatment group exhibited a 12% reduction in cholesterol level and the placebo group a 10% reduction? Would this be enough to conclude that the treatment was effective? Scientists are well grounded in **statistical tests** that can be applied to the data—the chi-square test, the *t* test, and analysis of variance, for example. A typical outcome of a statistical test might be expressed, "We can be 99.5% sure that the difference between group A and group B was due to the experimental treatment and not to random variation." Science is grounded not in statements of absolute truth, but in statements of probability.

Peer Review

When a scientist applies for funds to support a research project or submits results for publication, the application or manuscript is submitted to **peer review**—a critical evaluation by other experts in that field. Even after a report is published, if the results are important or unconventional, other scientists may attempt to reproduce them to see if the author was correct. At every stage from planning to postpublication, scientists are therefore subject to intense scrutiny by their colleagues. Peer review is one mechanism for ensuring honesty, objectivity, and quality in science.

Facts, Laws, and Theories

The most important product of scientific research is understanding how nature works—whether it be the nature of a pond to an ecologist or the nature of a liver cell to a physiologist. We express our understanding as *facts, laws,* and *theories* of nature. It is important to appreciate the differences among these.

A scientific **fact** is information that can be independently verified by any trained person—for example, the fact that an iron deficiency leads to anemia. A **law of nature** is a generalization about the predictable ways in which matter and energy behave. It is the result of inductive reasoning based on repeated, confirmed observations. Some laws are expressed as concise verbal statements, such as the *law of complementary base pairing:* In the double helix of DNA, a chemical base called adenine always pairs with one called thymine, and a base called guanine always pairs with cytosine (see p. 114). Other laws are expressed as mathematical formulae, such as *Boyle's law,* used in respiratory physiology: Under specified conditions, the volume of a gas (V) is inversely proportional to its pressure (P)—that is, $V \propto 1/P$.

A **theory** is an explanatory statement or set of statements derived from facts, laws, and confirmed hypotheses. Some theories have names, such as the *cell theory,* the *fluid-mosaic theory* of cell membranes, and the *sliding filament theory* of muscle contraction. Most, however, remain unnamed. The purpose of a theory is not only to concisely summarize what we already know but, moreover, to suggest directions for further study and to help predict what the findings should be if the theory is correct.

Law and *theory* mean something different in science than they do to most people. In common usage, a law is a rule created and enforced by people; we must obey it or risk a penalty. A law of nature, however, is a description; laws do not *govern* the universe—they *describe* it. Laypeople tend to use the word *theory* for what a scientist would call a hypothesis—for example, "I have a theory why my car won't start." The difference in meaning causes significant confusion when it leads people to think that a scientific theory (such as the theory of evolution) is merely a guess or conjecture, instead of recognizing it as a summary of conclusions drawn from a large body of observed facts. The concepts of gravity and electrons are theories, too, but this does not mean they are merely speculations.

►►►APPLY WHAT YOU KNOW

Was the cell theory proposed by Schleiden and Schwann more a product of the hypothetico–deductive method or of the inductive method? Explain your answer.

BEFORE YOU GO ON

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

6. Describe the general process involved in the inductive method.

7. Describe some sources of potential bias in biomedical research. What are some ways of minimizing such bias?

8. Is there more information in an individual scientific fact or in a theory? Explain.

1.4 Human Origins and Adaptations

Expected Learning Outcomes

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

a. explain why evolution is relevant to understanding human form and function;

b. define *evolution* and *natural selection;*

c. describe some human characteristics that can be attributed to the tree-dwelling habits of earlier primates; and

d. describe some human characteristics that evolved later in connection with upright walking.

If any two theories have the broadest implications for understanding the human body, they are probably the *cell theory* and the *theory of natural selection*. As an explanation of how species originate and change through time, natural selection was the brainchild of **Charles Darwin** (1809–82)—certainly the most influential biologist who ever lived. His book, *On the Origin of Species by Means of Natural Selection* (1859), has been called "the book that shook the world." In presenting the first well-supported theory of how evolution works, *On the Origin of Species* not only caused the restructuring of all of biology but also profoundly changed the prevailing view of our origin, nature, and place in the universe. In *The Descent of Man* (1871), Darwin directly addressed the issue of human evolution and emphasized features of anatomy and behavior that reveal our relationship to other animals. No understanding of human form and function is complete without an understanding of our evolutionary history. Here we will touch just briefly on how natural selection helps explain some of the distinctive characteristics seen in *Homo sapiens* today.

Evolution, Selection, and Adaptation

Evolution simply means change in the genetic composition of a population of organisms. Examples include the evolution of bacterial resistance to antibiotics, the appearance of new strains of the AIDS virus, and the emergence of new species of organisms.

Natural selection is the principal theory of how evolution works. It states essentially this: Some individuals within a species have hereditary advantages over their competitors—for example, better camouflage, disease resistance, or ability to attract mates—that enable them to produce more offspring. They pass these advantages on to their offspring, and such characteristics therefore become more and more common in successive generations. This brings about the genetic change in a population that constitutes evolution.

Natural forces that promote the reproductive success of some individuals more than others are called **selection pressures.** They include such things as climate, predators, disease, competition, and the availability of food. **Adaptations** are features of anatomy, physiology, and behavior that have evolved in response to these selection pressures and enable the organism to cope with the challenges of its environment.

Darwin could scarcely have predicted the overwhelming mass of genetic, molecular, fossil, and other evidence of human evolution that would accumulate in the twentieth century and further substantiate his theory. A technique called DNA hybridization, for example, suggests a difference of only 1.6% in DNA structure between humans and chimpanzees. Chimpanzees and gorillas differ by 2.3%. DNA structure thus suggests that a chimpanzee's closest living relative is not the gorilla or any other ape—it is us, *Homo sapiens*.

Several aspects of our anatomy make little sense without an awareness that the human body has a history (see Deeper Insight 1.1). Our evolutionary relationship to other species is also important in choosing animals for biomedical research. If there were no issues of cost, availability, or ethics, we might test drugs on our close living relatives, the chimpanzees, before

DEEPER INSIGHT 1.1

EVOLUTIONARY MEDICINE

Vestiges of Human Evolution

One of the classic lines of evidence for evolution, debated even before Darwin was born, is *vestigial organs*. These structures are the remnants of organs that apparently were better developed and more functional in the ancestors of a species. They now serve little or no purpose or, in some cases, have been converted to new functions.

Our bodies, for example, are covered with millions of hairs, each equipped with a useless little muscle called a *piloerector*. In other mammals, these muscles fluff the hair and conserve heat. In humans, they merely produce goose bumps. Above each ear, we have three *auricularis muscles*. In other mammals, they move the ears to receive sounds better or to repel flies and other pests, but most people cannot contract them at all. As Darwin said, it makes no sense that humans would have such structures were it not for the fact that we came from ancestors in which they were functional.