Seeley's ANATOMY & PHYSIOLOGY

Twelfth Edition

VANPUTTE | REGAN | RUSSO

Mc Graw Hill Education

Seeley's ANATOMY & PHYSIOLOGY

Twelfth Edition

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ABOUT THE **Authors**

Courtesy of Leanna Rolla

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Cinnamon has been teaching biology and human anatomy and physiology since 1998. She is a member of the faculty at Southwestern Illinois College and is an active member of several professional societies, including the Human Anatomy & Physiology Society (HAPS). Her Ph.D. in zoology, with an emphasis in endocrinology, is from Texas A&M University. She worked in Dr. Duncan MacKenzie's lab, where she was indoctrinated in the major principles of physiology and the importance of critical thinking. The critical thinking component of the Seeley titles epitomizes Cinnamon's passion for the field of human anatomy and physiology; she is committed to maintaining this tradition of excellence. Cinnamon and her husband, Robb, have two children: a daughter, Savannah, and a son, Ethan. She and her family, including her parents, Tom and Bobbie Moore, live on a farm where they raise Simmental cattle, Suffolk sheep, and a flock of 20 chickens.

Courtesy of Bridget Reeves

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For over 20 years, Jennifer has taught introductory biology, human anatomy and physiology, and genetics at the university and community college level. She has received the Instructor of the Year Award at both the departmental and college level while teaching at USM. In addition, she has been recognized for her dedication to teaching by student organizations such as the Alliance for Graduate Education in Mississippi and Increasing Minority Access to Graduate Education. Jennifer has dedicated much of her career to improving lecture and laboratory instruction at her institutions. Critical thinking and lifelong learning are two characteristics Jennifer hopes to instill in her students. She appreciates the Seeley approach to learning and is excited about contributing to further development of the textbook. She received her Ph.D. in biology at the University of Houston, under the direction of Edwin H. Bryant and Lisa M. Meffert. She is an active member of several professional organizations, including the Human Anatomy and Physiology Society. During her free time, Jennifer enjoys spending time with her husband, Hobbie, and two sons, Patrick and Nicholas.

Courtesy of the University of Iowa

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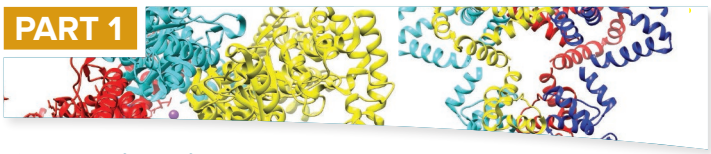
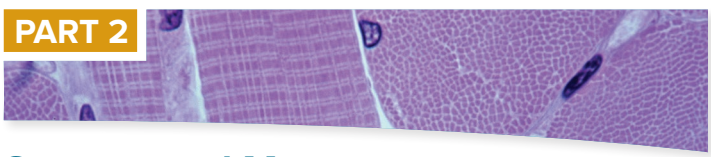
Andrew has over 30 years of classroom experience with human physiology, neurobiology, molecular biology, and cell biology courses at the University of Iowa. He is a recipient of the Collegiate Teaching Award and the J.P. Long Teaching Award in Basic Sciences. He is currently the course director for a new medical school course called Mechanisms of Health and Disease that integrates physiology, histology, and genetics. He is a member of several professional societies, including the Society for Neuroscience. Andrew received his Ph.D. in biochemistry from the University of California at Berkeley. His research interests are focused on the molecular basis of migraine. His decision to join the author team for *Seeley's Human Anatomy & Physiology* is the culmination of a passion for teaching that began in graduate school. He is excited about the opportunity to hook students' interest in learning by presenting cutting-edge clinical and scientific advances. Andy is married to Maureen, a physical therapist, and has three daughters, Erilynn, Becky, and Colleen, and six grandchildren. He enjoys all types of outdoor sports, especially bicycling, skiing, running, and open water swimming.

This text is dedicated to the students of human anatomy and physiology. Helping students develop a working knowledge of anatomy and physiology is a satisfying challenge, and we have a great appreciation for the effort and enthusiasm of so many who want to know more. It is difficult to imagine anything more exciting, or more important, than being involved in the process of helping people learn about the subject we love so much.

Brief Contents



PART 1 Organization of the Human Body



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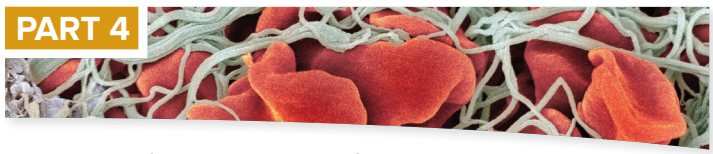

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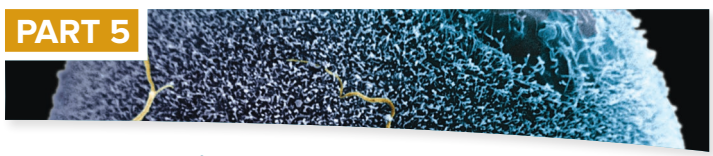

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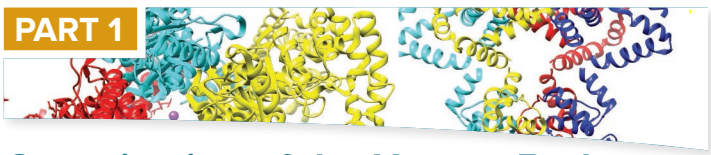
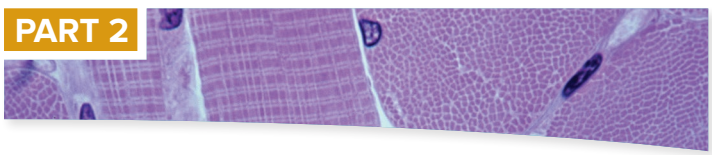
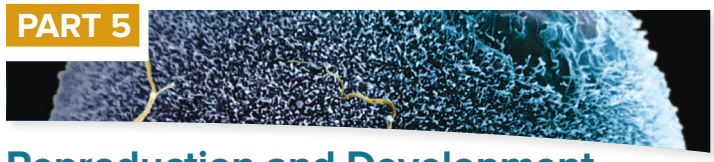


Organization of the Human Body



Support and Movement



WHAT SETS **Seeley's Anatomy & Physiology** APART?

Seeley's Anatomy & Physiology is written for the two-semester anatomy and physiology course. The writing is comprehensive enough to provide the depth necessary for those courses not requiring prerequisites, and is presented with such clarity that it nicely balances the thorough coverage. Clear descriptions and exceptional illustrations combine to help students develop a firm understanding of the concepts of anatomy and physiology and understand how to use that information.

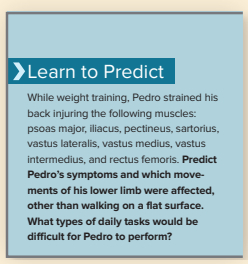
What Makes this Text a Market Leader?

Seeley's Learning System—*Emphasis on Critical Thinking*

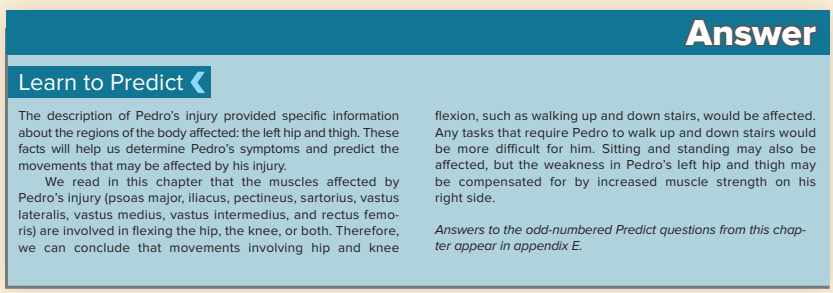
An emphasis on critical thinking is integrated throughout this textbook. This approach is found in questions that begin each chapter and those embedded within the narrative; in clinical material that is designed to bridge concepts explained in the text with real-life applications and scenarios; in end-of-chapter questions that go beyond rote memorization; and in a visual program that presents material in understandable, relevant images, with application questions that follow each Process Figure.

- Problem-solving perspective from the book's inception
- Pedagogy builds student comprehension from knowledge to application (**Learn to Predict** questions, Predict questions, Critical Thinking questions)

Chapter Opener pages provide a **Learn to Predict** question, with the corresponding answer located just before the end-of-chapter Summary.


Learn to Predict

While weight training, Pedro strained his back injuring the following muscles: psoas major, iliacus, pectineus, sartorius, vastus lateralis, vastus medius, vastus intermedius, and rectus femoris. **Predict Pedro's symptoms and which movements of his lower limb were affected, other than walking on a flat surface. What types of daily tasks would be difficult for Pedro to perform?**


Answer

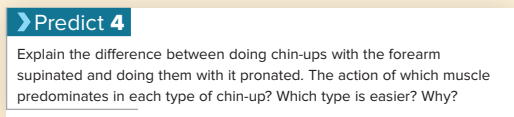
Learn to Predict

The description of Pedro's injury provided specific information about the regions of the body affected: the left hip and thigh. These facts will help us determine Pedro's symptoms and predict the movements that may be affected by his injury.

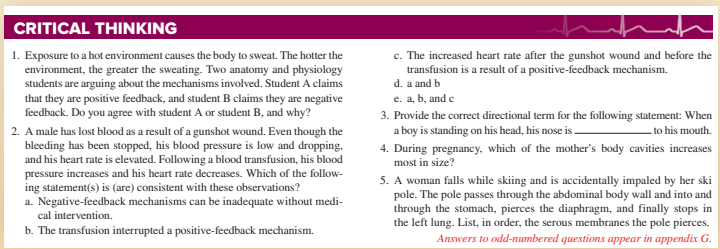
We read in this chapter that the muscles affected by Pedro's injury (psoas major, iliacus, pectineus, sartorius, vastus lateralis, vastus medius, vastus intermedius, and rectus femoris) are involved in flexing the hip, the knee, or both. Therefore, we can conclude that movements involving hip and knee flexion, such as walking up and down stairs, would be affected. Any tasks that require Pedro to walk up and down stairs would be more difficult for him. Sitting and standing may also be affected, but the weakness in Pedro's left hip and thigh may be compensated for by increased muscle strength on his right side.

Answers to the odd-numbered Predict questions from this chapter appear in appendix E.

Predict Questions challenge students to use their understanding of new concepts to solve a problem. Answers to the odd-numbered Predict questions are provided in Appendix E, allowing students to evaluate their responses and to understand the logic used to arrive at the correct answer. All Predict question answers have been written in teaching style format to model the answer for students, to help them learn how to think critically.


Predict 4

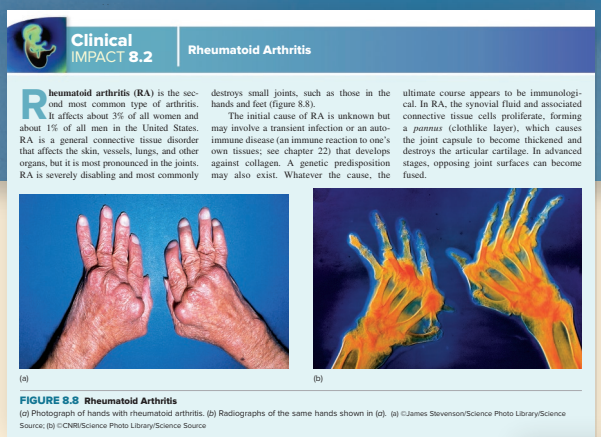
Explain the difference between doing chin-ups with the forearm supinated and doing them with it pronated. The action of which muscle predominates in each type of chin-up? Which type is easier? Why?


CRITICAL THINKING

1. Exposure to a hot environment causes the body to sweat. The hotter the environment, the greater the sweating. Two anatomy and physiology students are arguing about the mechanisms involved. Student A claims that they are positive feedback, and student B claims they are negative feedback. Do you agree with student A or student B, and why?
2. A male has lost blood as a result of a gunshot wound. Even though the bleeding has been stopped, his blood pressure is low and dropping, and his heart rate is elevated. Following a blood transfusion, his blood pressure increases and his heart rate decreases. Which of the following statement(s) is (are) consistent with these observations?
   a. Negative-feedback mechanisms can be inadequate without medical intervention.
   b. The transfusion interrupted a positive-feedback mechanism.
   c. The increased heart rate after the gunshot wound and before the transfusion is a result of a positive-feedback mechanism.
   d. a and b
   e. a, b, and c
3. Provide the correct directional term for the following statement: When a boy is standing on his head, his nose is _____ to his mouth.
4. During pregnancy, which of the mother's body cavities increases most in size?
5. A woman falls while skiing and is accidentally impaled by her ski pole. The pole passes through the abdominal body wall and into and through the stomach, pierces the diaphragm, and finally stops in the left lung. List, in order, the serous membranes the pole pierces.

Answers to odd-numbered questions appear in appendix G.

Critical Thinking These innovative exercises encourage students to apply chapter concepts to solve a problem. These questions help build each student's knowledge of anatomy and physiology while developing reasoning and critical thinking skills. Answers to odd-numbered questions appear in Appendix G.



Clinical IMPACT 8.2 Rheumatoid Arthritis

Rheumatoid arthritis (RA) is the second most common type of arthritis. It affects about 3% of all women and about 1% of all men in the United States. RA is a general connective tissue disorder that affects the skin, vessels, lungs, and other organs, but it is most pronounced in the joints. RA is severely disabling and most commonly destroys small joints, such as those in the hands and feet (figure 8.8).

The initial cause of RA is unknown but may involve a transient infection or an autoimmune disease (an immune reaction to one's own tissues; see chapter 22) that develops against collagen. A genetic predisposition may also exist. Whatever the cause, the ultimate course appears to be immunological. In RA, the synovial fluid and associated connective tissue cells proliferate, forming a *pannus* (clothlike layer), which causes the joint capsule to become thickened and destroys the articular cartilage. In advanced stages, opposing joint surfaces can become fused.

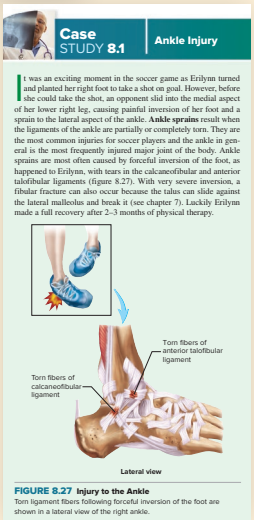
(a) (b)

FIGURE 8.8 Rheumatoid Arthritis
(*a*) Photograph of hands with rheumatoid arthritis. (*b*) Radiographs of the same hands shown in (*a*). (a) ©James Stevenson/Science Photo Library/Science Source; (b) ©CNRI/Science Photo Library/Science Source

Clinical Emphasis—*Case Studies Bring Relevance to the Reader*

- Chapter opening photos and scenarios have been correlated to provide a more complete story and begin critical thinking from the start of the chapter
- Learn to Predict and chapter Predict questions, with unique Learn to Predict answers
- Clinical Impact boxes (placed at key points in the text)
- Case Studies
- Clinical Genetics essays have been updated and streamlined for accuracy and impact
- Diseases and Disorders tables
- Systems Pathology boxes with System Interactions illustration

Clinical Impact boxes These in-depth boxed essays explore relevant topics of clinical interest. Subjects covered include pathologies, current research, sports medicine, exercise physiology, and pharmacology.

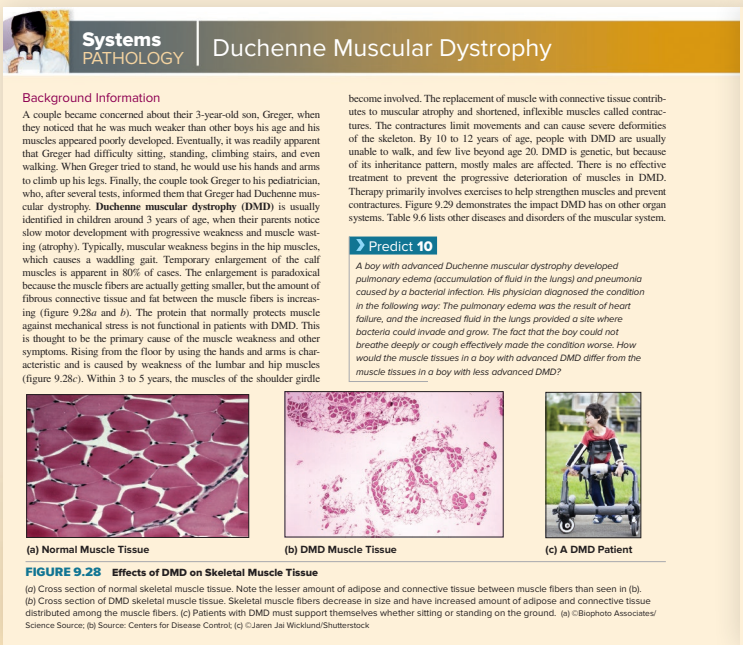


Case STUDY 8.1 Ankle Injury

It was an exciting moment in the soccer game as Erilynn turned and planted her right foot to take a shot on goal. However, before she could take the shot, an opponent slid into the medial aspect of her lower right leg, causing painful inversion of her foot and a sprain to the lateral aspect of the ankle. **Ankle sprains** result when the ligaments of the ankle are partially or completely torn. They are the most common injuries for soccer players and the ankle in general is the most frequently injured major joint of the body. Ankle sprains are most often caused by forceful inversion of the foot, as happened to Erilynn, with tears in the calcaneofibular and anterior talofibular ligaments (figure 8.27). With very severe inversion, a fibular fracture can also occur because the talus can slide against the lateral malleolus and break it (see chapter 7). Luckily Erilynn made a full recovery after 2–3 months of physical therapy.

Torn fibers of anterior talofibular ligament
Torn fibers of calcaneofibular ligament
Lateral view

FIGURE 8.27 Injury to the Ankle
Torn ligament fibers following forceful inversion of the foot are shown in a lateral view of the right ankle.



Systems PATHOLOGY Duchenne Muscular Dystrophy

Background Information

A couple became concerned about their 3-year-old son, Greger, when they noticed that he was much weaker than other boys his age and his muscles appeared poorly developed. Eventually, it was readily apparent that Greger had difficulty sitting, standing, climbing stairs, and even walking. When Greger tried to stand, he would use his hands and arms to climb up his legs. Finally, the couple took Greger to his pediatrician, who, after several tests, informed them that Greger had Duchenne muscular dystrophy. **Duchenne muscular dystrophy (DMD)** is usually identified in children around 3 years of age, when their parents notice slow motor development with progressive weakness and muscle wasting (atrophy). Typically, muscular weakness begins in the hip muscles, which causes a waddling gait. Temporary enlargement of the calf muscles is apparent in 80% of cases. The enlargement is paradoxical because the muscle fibers are actually getting smaller, but the amount of fibrous connective tissue and fat between the muscle fibers is increasing (figure 9.28*a* and *b*). The protein that normally protects muscle against mechanical stress is not functional in patients with DMD. This is thought to be the primary cause of the muscle weakness and other symptoms. Rising from the floor by using the hands and arms is characteristic and is caused by weakness of the lumbar and hip muscles (figure 9.28*c*). Within 3 to 5 years, the muscles of the shoulder girdle become involved. The replacement of muscle with connective tissue contributes to muscular atrophy and shortened, inflexible muscles called contractures. The contractures limit movements and can cause severe deformities of the skeleton. By 10 to 12 years of age, people with DMD are usually unable to walk, and few live beyond age 20. DMD is genetic, but because of its inheritance pattern, mostly males are affected. There is no effective treatment to prevent the progressive deterioration of muscles in DMD. Therapy primarily involves exercises to help strengthen muscles and prevent contractures. Figure 9.29 demonstrates the impact DMD has on other organ systems. Table 9.6 lists other diseases and disorders of the muscular system.

Predict 10

A boy with advanced Duchenne muscular dystrophy developed pulmonary edema (accumulation of fluid in the lungs) and pneumonia caused by a bacterial infection. His physician diagnosed the condition in the following way: The pulmonary edema was the result of heart failure, and the increased fluid in the lungs provided a site where bacteria could invade and grow. The fact that the boy could not breathe deeply or cough effectively made the condition worse. How would the muscle tissues in a boy with advanced DMD differ from the muscle tissues in a boy with less advanced DMD?

(a) Normal Muscle Tissue (b) DMD Muscle Tissue (c) A DMD Patient

FIGURE 9.28 Effects of DMD on Skeletal Muscle Tissue
(*a*) Cross section of normal skeletal muscle tissue. Note the lesser amount of adipose and connective tissue between muscle fibers than seen in (b). (*b*) Cross section of DMD skeletal muscle tissue. Skeletal muscle fibers decrease in size and have increased amount of adipose and connective tissue distributed among the muscle fibers. (*c*) Patients with DMD must support themselves whether sitting or standing on the ground. (a) ©Biophoto Associates/Science Source; (b) Source: Centers for Disease Control; (c) ©Jaren Jai Wicklund/Shutterstock

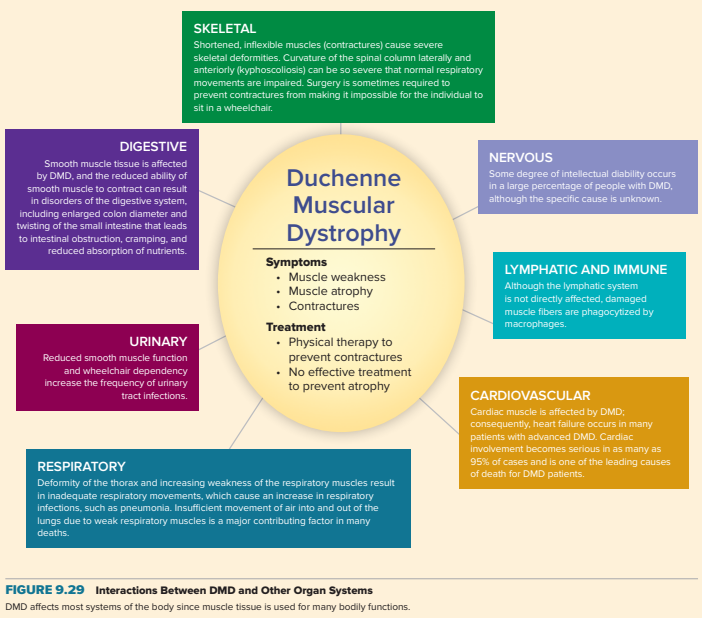


FIGURE 9.29 Interactions Between DMD and Other Organ Systems
DMD affects most systems of the body since muscle tissue is used for many bodily functions.

Systems Pathology boxes These 2-page spreads explore a specific condition or disorder related to a particular body system. Presented in a simplified case study format, each Systems Pathology vignette begins with a patient history, followed by background information about the featured topic.

Exceptional Art—*Always created from the student perspective*

A picture is worth a thousand words—especially when you're learning anatomy and physiology. Because words alone cannot convey the nuances of anatomy or the intricacies of physiology, *Seeley's Anatomy & Physiology* employs a dynamic program of full-color illustrations and photographs that support and further clarify the textual explanations:

- Fundamental figures teamed with special online support, with many figures linked to APR
- Homeostasis figures draw a correlation from the text description of feedback system components to the figure.
- All figures use consistent colors and arrows to represent cytoplasm in a cell, symbols for ions, and molecules, etc.
- Step-by-step process figures
- Atlas-quality cadaver images
- Illustrated tables
- Photos side-by-side with illustrations
- Color saturation of art makes the art more engaging
- Macro-to-micro art

Clearly labeled photos of dissected human cadavers provide detailed views of anatomical structures, capturing the intangible characteristics of actual human anatomy that can be appreciated only when viewed in human specimens.

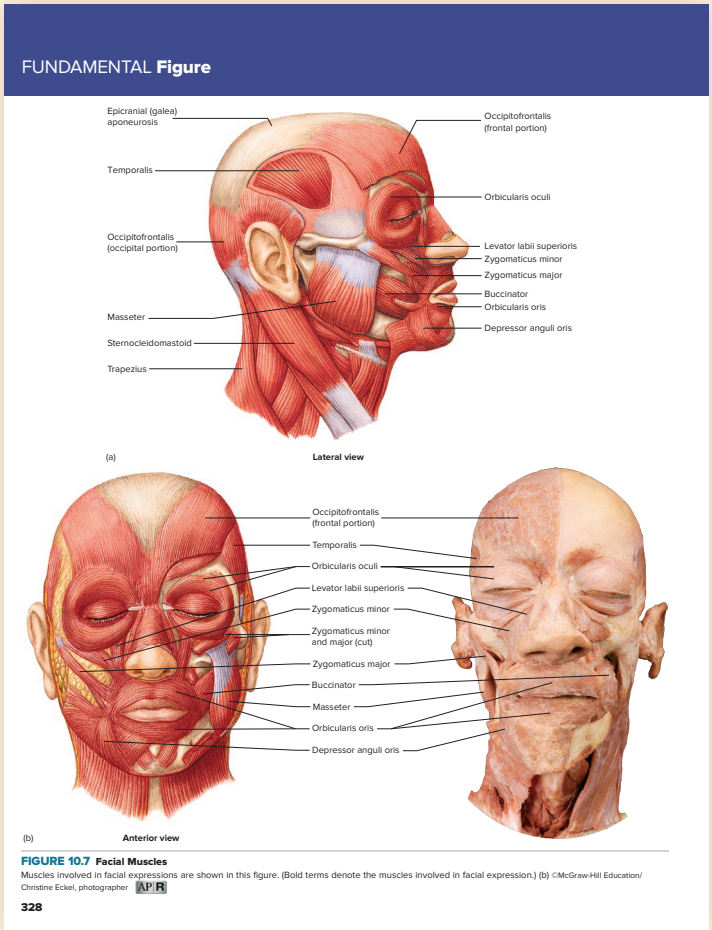


FIGURE 10.7 Facial Muscles
Muscles involved in facial expressions are shown in this figure. (Bold terms denote the muscles involved in facial expression.) (b) ©McGraw-Hill Education/Christine Eckel, photographer APR

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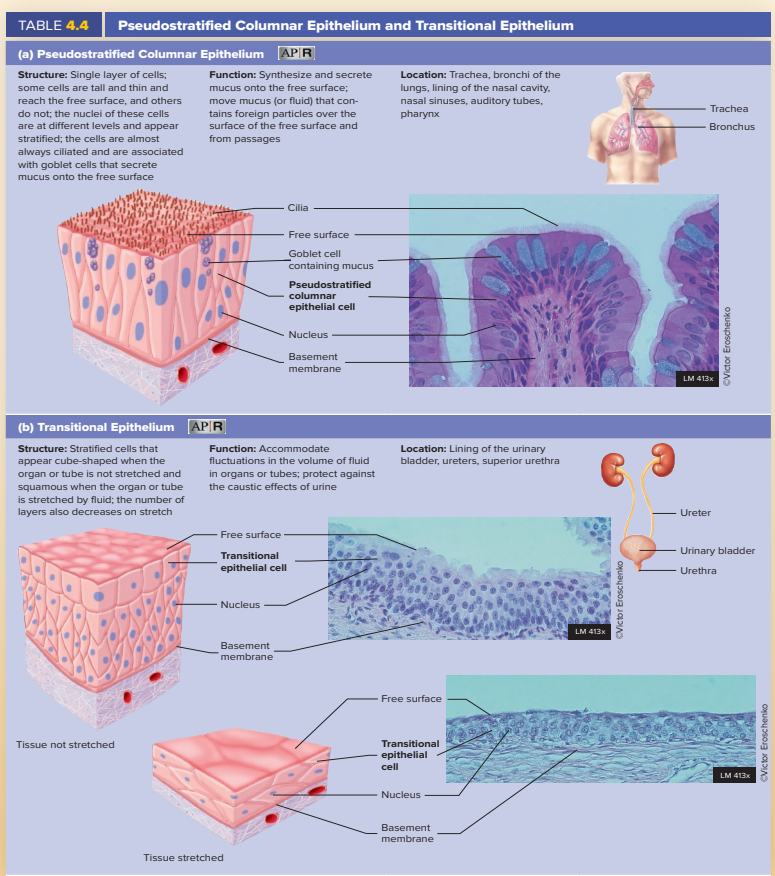
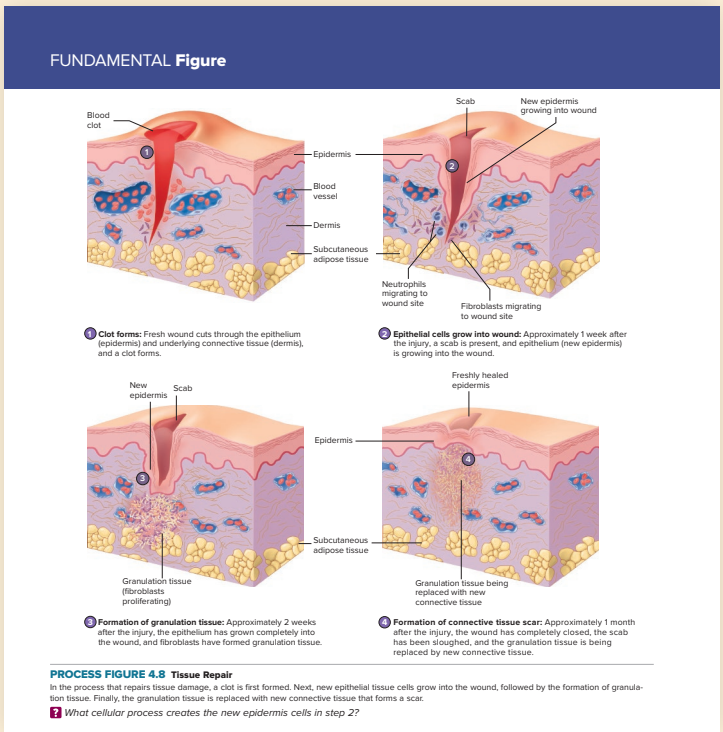


Specialized Figures Clarify Tough Concepts

Studying anatomy and physiology does not have to be an intimidating task mired in memorization. *Seeley's Anatomy & Physiology* uses two special types of illustrations to help students not only learn the steps involved in specific processes, but also to apply the knowledge as they predict outcomes in similar situations. Process figures organize the key occurrences of physiological processes in an easy-to-follow format. Homeostasis figures summarize the mechanisms of homeostasis by diagramming how a given system regulates a parameter within a narrow range of values.

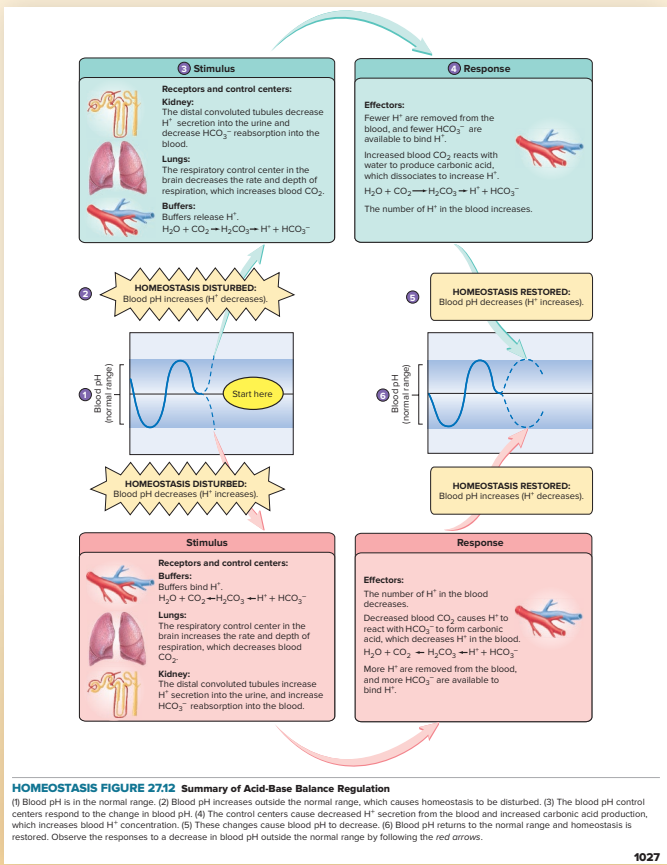


Step-by-Step Process Figures

Process figures break down physiological processes into a series of smaller steps, allowing readers to build their understanding by learning each important phase. Numbers are placed carefully in the illustrations, permitting students to zero right in to where the action described in each step takes place.

Homeostasis figures with in-art explanations and organ icons

- These specialized flowcharts with succinct explanations illustrate the mechanisms that body systems employ to maintain homeostasis.
- Small icon illustrations depict the organ or structure being discussed.
- All homeostasis figures correlate the text description of feedback components to the figure, and are consistent throughout each organ system.



- Microbes In Your Body features discuss the many important and sometimes little-known roles of microbes and the physiology of homeostasis.

MICROBES In Your Body 22.1 — Do Our Gut Bacteria Drive Immune Development and Function?

"All disease begins in the gut." This quote from Hippocrates (460–377 B.C.), the father of Western medicine, is still relevant today. Over the last four decades, increasing numbers of people have suffered from allergies and autoimmune disorders. Researchers hypothesize that the increase in these conditions stems from inadequate development of immune function. In turn, they hypothesize that underdeveloped immune function is due to deficiencies in our gut microbiota. This has led to the Hygiene Hypothesis, which states that the increased use of antibiotics and antimicrobial chemicals damages the normal gut microbiota and other microbiota that are critical for immune system development and function.

Could the Hygiene Hypothesis explain the observed increases in allergies and autoimmune disorders? Much of the evidence for the importance of gut microbiota for immune function is derived from studies with germ-free mice. These lab-raised mice lack the natural microorganisms in their gut and in their body. As a result, the mice have multiple defects with their lymphatic tissues, such as fewer and smaller Peyer patches in the gut and fewer B and T lymphocytes. However, if scientists place intestinal or fecal microbiota from normal mice into the gut of germ-free mice, the immune tissues of the germ-free mice begin developing and functioning normally.

The importance of the gut in immune development is further supported by the fact that it contains the largest concentration of lymphatic tissue and microbiota in the human body. In the gut there are between 500 and 1000 species of bacteria compared to a few hundred associated with the skin or fewer than 10 species associated with the conjunctiva of the eye. In humans, the gut microbiota begin to appear just before birth. As the baby passes through the birth canal, more microorganisms are transferred from the mother to the baby. The makeup of a baby's microbiota is influenced by many factors, including genetics, the mode of delivery (vaginal or C-section), antibiotic use, stress, and the mother's diet during late pregnancy. The first year of life is the most critical for the accumulation of gut bacteria, but this process continues through childhood. At about 10 years of age, a person's gut microbiota are established and remain similar in composition throughout life. Humans and their gut microbiota have a symbiotic relationship, in that the gut provides space and nutrients for the microbiota, which in turn provide their host with specialized nutrition, physiological regulators, and protection against pathogens. Because of these ever-present microbiota ("good" bacteria), human gut epithelial and immune cells must maintain tolerance to them yet still protect against invading gut pathogens ("bad" bacteria).

How do our cells distinguish between "good" and "bad" bacteria? As it turns out, gut microbiota help stimulate the development of immune cells by triggering the production of different receptors. These receptors are found in the plasma membranes of white blood cells, such as macrophages and neutrophils, as well as in the plasma membranes of intestinal epithelial cells. The surface of all bacterial cells has bacteria-specific molecules that can be recognized by the receptors of defense cells, which is what allows for distinction between "good" and "bad" microorganisms. Activation of the receptors triggers a cascade of events, which result in immune responses such as T-lymphocyte activation and the production of immunity chemicals. In addition, the "good" bacteria attack invading "bad" bacteria by secreting antimicrobial substances against them and competing with them for nutrients and space. Thus, without appropriate amounts and/or types of gut microbiota, the body's immune system may not have all of the messages that are essential for producing specific immune cells and chemicals that kill pathogenic intestinal microorganisms.

Medical professionals are interested in manipulating gut microbiota to reduce allergies and other diseases and to promote healing. First, and perhaps most importantly, is to get the desired population of gut microbiota started immediately in infancy through breastfeeding. Human breast milk contains carbohydrates that stimulate the growth of specific intestinal microbiota while preventing infection by some pathogens. And the use of prebiotics (nondigestible carbohydrates that promote the growth of healthy microbiota) and probiotics (live normal gut microbiota) is being actively explored for the treatment of problems that arise later in life. However, there is still much work to be done before we fully understand the extent to which gut microbiota are involved in human immune function.

Predict 2

In some underdeveloped countries, children are nutritionally deprived. Studies of twins in these countries have demonstrated that sometimes one of the twins thrives, whereas the other twin is malnourished. In the malnourished twin, the gut microbiota population is far less diverse and much smaller than that of the thriving twin. Using what you have learned about the role of gut microbiota in immune function, predict a possible developmental repercussion in the malnourished twin. Propose some possible solutions that might result in both twins having a normal gut microbe population.

- The Clinical Genetics feature has been updated and streamlined to provide the newest and most accurate information available.
- Online clinical study questions are based on clinical features within the text including Microbes in Your Body and Systems Pathology vignettes, and are correlated with Learning Outcomes and HAPS Learning Objectives to further develop and measure higher-level thinking and application of learned content.

Clinical GENETICS 25.1 — Newborn Screening of Metabolic Disorders

Metabolic disorders, sometimes called inborn errors of metabolism, are a large class of genetic disorders that result in biochemical defects. Metabolic disorders affect the body's ability to break down or use nutrients needed for energy, growth, and repair. Too little synthesis of certain substances or a buildup of toxic compounds can cause significant health problems. Although the frequency of any given individual disorder is rare, the overall incidence of metabolic disorders is estimated to be up to 1 in 1000 births.

Early detection through newborn screening is vital. Metabolic disorders can hinder early mental and physical development. Depending on the disorder, specific treatment can prevent or limit harm if it is started early. In the United States, most states require the screening of newborns. However, there is no national standard for newborn screening, so the specific disorders for which tests are performed vary from state to state. Although over several hundred genetic disorders are known, most are so rare that it is not cost-effective to test for them.

Table 25.5 lists the most common blood tests performed for metabolic disorders. All of the disorders listed are autosomal recessive.

TABLE 25.5 Metabolic Disorders

Disorder	Description	Effect	Treatment
Phenylketonuria (PKU)	Inability to metabolize the amino acid phenylalanine (see chapter 29)	Intellectual disability	Restrict dietary phenylalanine.
Galactosemia	Inability to convert the sugar galactose to glucose, resulting in a buildup of galactose	Intellectual disability, growth deficiency, cataracts, severe infections, death	Eliminate milk and other dairy products from the diet. Galactose is one of two sugars in lactose (milk sugar).
Biotinidase deficiency	Inability to separate the vitamin biotin from other chemicals, resulting in a biotin deficiency	Seizures, hearing loss, optic atrophy, intellectual disability, poor muscle control	Take oral biotin supplements.
Maple syrup urine disease	Deficiency in an enzyme complex, resulting in an inability to metabolize the amino acids leucine, isoleucine, and valine	Intellectual disability in those surviving past 3 months of age	Restrict dietary intake of the affected amino acids.
Homocystinuria	Defect in methionine metabolism, leading to an accumulation of homocysteine	Dislocated lenses of the eyes, intellectual disability, skeletal abnormalities, abnormal blood clotting	Take high doses of vitamin B_6; eat methionine-restricted diet supplemented with cysteine.
Tyrosinemia	Deficiency in a series of enzymes that break down the amino acid tyrosine	Mild intellectual disability, language skill difficulties, liver and kidney failure	Restrict dietary tyrosine and phenylalanine.

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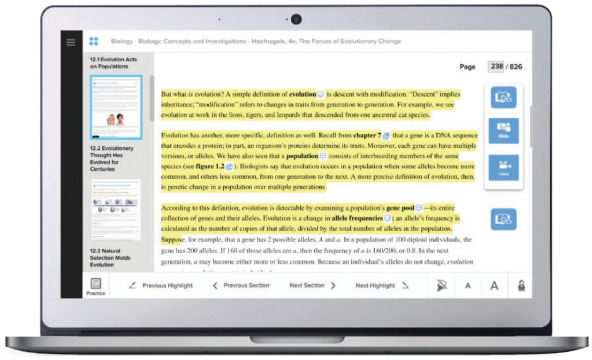

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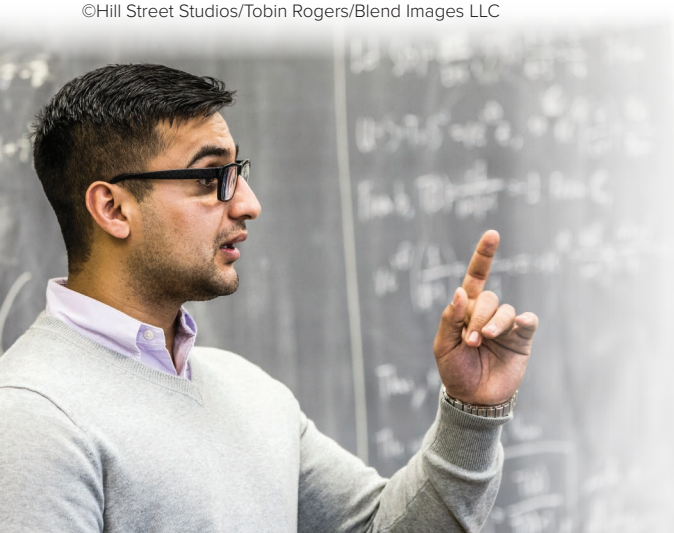

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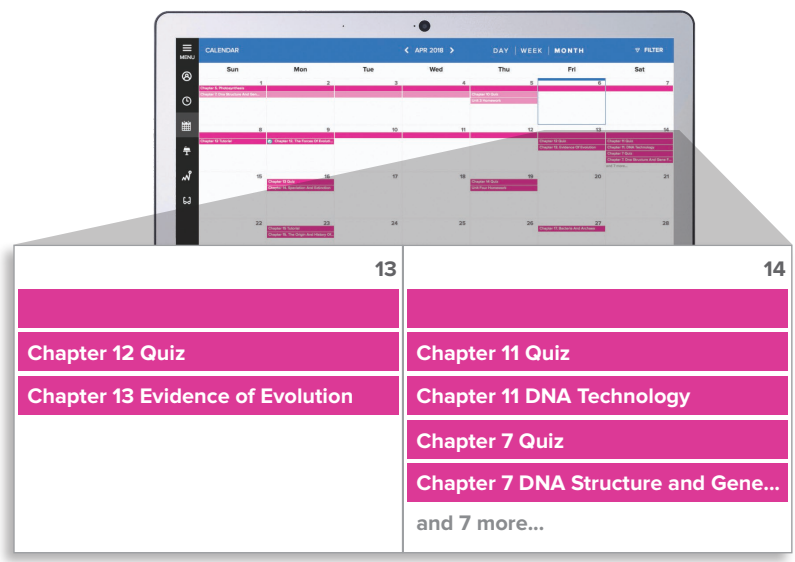

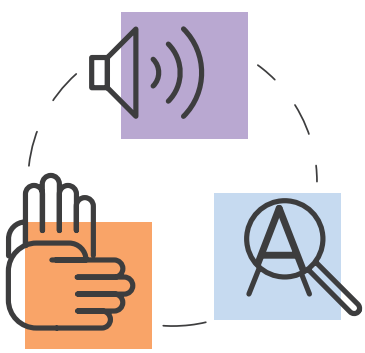

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Chapter-by-Chapter Changes

Global Changes

- Each **Process Figure** now includes a question following the figure legend to help students think about and apply the knowledge into everyday context. The **answers** to these Process Figure questions are found in Appendix D, which is new to the Twelfth Edition.
- **Figure legends** were updated throughout the text to be more descriptive of the figure content.
- Answers to even-numbered **Predict** questions can now be accessed by instructors in Connect, allowing instructors to assign these questions if desired. Answers to odd-numbered Predict questions appear in Appendix E.
- Answers to even-numbered **Critical Thinking** questions can now be accessed by instructors in Connect, allowing these questions to be assigned if desired. Answers to odd-numbered Critical Thinking questions appear in Appendix F.
- **Appendix C: Genetic Code** is new to the Twelfth Edition.

Chapter 1

- New chapter opening photo; revised figures 1.2, 1.3, 1.8, 1.10, 1.14, and 1.16
- Body cavities section has been reorganized into dorsal and ventral.

Chapter 2

- Figure 2.15 is revised to show conjugate acid and base forms of buffer.
- Figure 2.14 is recast as a graph to clarify the concept of pH and how it correlates to hydrogen ion concentration, and show the correlation of pH with hydrogen ion concentration in both decimal and scientific notation formats.
- A new Case Study is included on cyanide poisoning from house fires, from a firefighter's perspective.
- New Clinical Impact on clinical uses of atomic particles, which includes CT and MRI figures
- Incorporation of planetary models into atomic representations in figures 2.2 and 2.5, and clearer representation of partial charges on water molecules (figures 2.7 and 2.8, table 2.4)
- Revision of electronegativity text and figure 2.4 to better describe covalent bonds
- Includes an expanded definition of hydrophilic and hydrophobic properties of molecules in the water section
- Clarification that H bonds are important for both adhesion and cohesion—important for both intramolecular bonds and intermolecular bonds

Chapter 3

- Section 3.2 How We See Cells has been revised to provide more thorough coverage of electron microscopy.
- Process figures now have questions to probe further understanding of concepts.

Chapter 4

- Clarification of the distinct cell surfaces of epithelial cells
- Clarified that stereocilia are specialized microvilli, not cilia
- Revised figure 4.4 to add illustrative example of location of the three types of exocrine glands in the skin
- Reorganized the cells of connective tissue to emphasize the category of framework of connective tissue cells
- Added image of platelets to the blood micrograph in table 4.12
- Simplified proteoglycan aggregate in figure 4.5
- Rewrote tissue damage and inflammation section to clarify how inflammation helps the healing process; simplified organization of the inflammatory response into three steps
- Clarified and expanded discussion on the regeneration abilities of labile, stable, and permanent cells, and the potential of stem cell therapy for tissue regeneration and replacement
- Rewrote the tissue repair section to simplify organization of repair into four steps

Chapter 5

- Added a description of alopecia areata
- Description of fourth-degree burns added

Chapter 6

- New opening photo; revised figures 6.11, 6.13, and 6.14
- Chapter opening Learning to Predict box now covers Paget disease
- Coverage of bone shapes is moved to chapter 7.
- Revised table 6.2 Comparison of Intramembranous and Endochondral Ossification
- Added section on bone fracture classification, with table showing x-rays of fracture type
- Section 6.9 is rewritten.

Chapter 7

- The discussion on bone shapes is inserted into section 7.1 Skeletal Anatomy Overview

- Removed the terms *neurocranium*, *viscerocranium,* and *braincase*
- Revised table 7.2 to include examples of bone features
- Section 7.2 is reorganized by bone, from cranial bones to facial bones.
- Vertebral Column section now has subheadings for vertebra type/region.
- The term *rib cage* is now *thoracic cage*.
- Appendicular Skeleton section now has bone names added to subheadings.

Chapter 8

- Table 8.1 has been divided into two separate tables on Fibrous Joints (table 8.1) and Cartilaginous Joints (table 8.2), with illustrated examples of each class of joint. Includes the defining feature of cartilaginous joints in the table.
- Redesigned figure 8.8 on synovial joints into a table to match the organization of fibrous and cartilaginous joints tables; the tables include examples and the degree of axial movement.
- Expanded description of functional classification of joints
- Revised several Assess Your Progress questions
- Clarified costrochondral joint description
- Revised definitions of articular disk and meniscus
- Clarification of pronation and supination and other movements of the elbow joint
- Added emphasis on factors that dictate range of motion
- Reorganized tables to list major ligaments first
- Revised Clinical Impact to focus on only knee ligament injuries
- New Case Study on ankle injury to a soccer player
- Removed Clinical Impacts on joint replacement and gingivitis, with incorporation of key points into text body
- Addition of chondromalacia of the knee to the Representative Diseases and Disorders table

Chapter 9

- Clarified that myoblasts are uninucleate
- Section 9.3 reorganized
- The term *myokinase* is replaced with *adenylate cyclase*.
- New figure 9.23 on production of ATP in skeletal muscle
- The term *recovery oxygen consumption* is replaced with *excess post-exercise consumption.*

Chapter 10

- Revised figures 10.2 and 10.19; combined figures 10.31 and 10.32
- Added cadaver photos to figures 10.17 and 10.29
- The term *pelvic diaphragm* replaces *floor.*

Chapter 11

- Section 11.2 is reorganized.
- New table 11.1; new figure 11.2; revised figure 11.8
- Table 11.2 (formerly table 11.1) added composite drawing of glial cells
- Changing the Resting Membrane Potential section is reorganized by depolarization vs. hyperpolarization.

Chapter 12

- Added overview of meninges
- New introduction to reflexes, and revised description of the stretch reflex
- Clinical Impact on Spinal Cord Injury condensed and updated to include computer-controlled electrical stimulation
- Moved coverage of the “funny bone” from a Clinical Impact box to chapter text
- Revised figures 12.3 and 12.4 to use dorsal and ventral labels for spinal cord horns
- Clarified nerves to and from the brain in figure 12.6, including a description of the gamma motor neuron
- Included spinal stenosis in Representative Diseases and Disorders table

Chapter 13

- Revised chapter opener to note the myth that humans use only 10% of their brains is false
- Section 13.3 Cerebellum is reorganized.
- Clinical Impact 13.1 Traumatic Brain Injuries has been updated to focus on clinical consequences.
- Case Study 13.1 has been revised to focus on Subdural Hematoma.
- Revised table 13.1 to include structural regions of cerebrum
- Revised Limbic System section to clarify it is a major contributor to motivation, emotion, learning, and memory, and influences the endocrine and autonomic nervous systems
- Revised figure 13.7 to add arcuate nucleus, showing hypothalamic nuclei
- Simplified table 13.3 by removing hypothalamic nuclei; select examples added to text
- Expanded coverage of the role of the hypothalamus in setting the biological clock
- Role of habenula updated to emphasize its role in motivation and reward behavior

Chapter 14

- Chapter opener revised to emphasize the brain as a challenging and exciting area for further study
- Clinical Impact box on pain revised into Pain Pathways section within chapter text; Clinical Impact 14.1 covers phantom pain
- Responses of Sensory Receptors section revised to clarify roles of tonic and phasic receptors for multiple sensory receptors
- Revised table 14.1 to include all the proprioception receptors
- Added photos of healthy brain compared to brain of Alzheimer patient in Clinical Genetics 14.1
- Figure 14.24 on long-term potentiation mechanism has been simplified.

Chapter 15

- Reduced level of detail in text and in figure 15.6 on olfactory receptor types
- Content from Clinical Impact: Visual Acuity box has been incorporated into regular text.

Chapter 16

- Modified entry for urinary wall in table 16.3 to note that sympathetic affect is relaxation; receptor type is β_3

Chapter 17

- Sections on Characteristics of the Endocrine System and Comparison of the Nervous and Endocrine Systems are moved to precede the section on Classes of Chemical Messengers

Chapter 18

- Clarified that prolactin-releasing hormone's identity is not known
- Changed the term *Caucasian* to *white.*
- Case Study 18.1 Negative Feedback and Hypothyroidism is moved from Chapter 17 to this chapter.

Chapter 19

- Added a new column for Average Abundance for each of the formed elements in table 19.2
- Revised figure 19.7 Hemoglobin Breakdown
- Removed Factor VI from table 19.3 (the information is now a footnote at the bottom of the table)
- Deleted figure 19.12

Chapter 20

- Pericarditis and Cardiac Tamponade box has moved to chapter 1.
- Content from Clinical Impact: Alterations in the Electrocardiogram is now incorporated into the text.
- Table 20.2 Summary of the Events of the Cardiac Cycle is deleted.

Chapter 21

- Section 21.2 is reorganized to place the Structure of Blood Vessels and Types of Arteries sections before Capillaries.
- Content from Trauma and the Aorta Clinical Impact box is incorporated into regular text.
- Table 21.14 Blood Pressure Classification in Adults is updated with 2017 recommendations.

Chapter 22

- The summary table is now divided into two tables—one for innate immunity and one for adaptive immunity.
- Clarified the difference between plasma cells and memory B cells
- Updated discussion of monoclonal antibody use in immunotherapy

Chapter 23

- Complete chapter reorganization and rewrite for more coherent flow of information
- Combined discussion of ventilation and gas laws
- Organized physiology discussion into respiration versus gas transport, with a separate section on metabolic factors affecting gas transport

Chapter 24

- Reorganized and consolidated structures and functions of the digestive tract (in text and in table 14.1)
- Clarification of the definition of tooth crown as the anatomical crown in text and in figure 24.8
- Reorganization of saliva constituents and functions
- Expansion of description of lingual lipase and gastric lipase functions, including their relative importance in neonates
- Simplification of segmental contractions process in figure 24.3, which allows easier comparison with peristalsis steps
- New information added to table 24.2, including large intestine secretions
- Revised presentation of stomach anatomy, histology, and secretions
- Inclusion of gastric lipase in the Secretions of the Stomach section
- Reorganization of the Secretions of the Small Intestine and Motility in the Small Intestine sections
- Revised figures 24.20, 24.21, 24.23, and 24.24 to simplify the arrow paths
- Eliminated three Clinical Impact boxes
- Revised Pancreatic Secretions and Regulation of Pancreatic Secretion sections
- Emphasize that pancreatic lipase is the major carbohydrate digestive enzyme, but that the brush border disaccharidases are required before sugars can be absorbed
- Addition of cholesterol lipase and its role in digesting dietary cholesteryl esters
- Added that lack of intrinsic factor can also lead to peripheral neuropathy
- Content from Clinical Impact: Rehydration has been moved into the main text.

Chapter 25

- New USDA food label presented in figure 25.2
- Updated description of cellular respiration to use the terms *pyruvate* and *lactate*
- Use of *aerobic glycolysis* has been updated to *aerobic respiration.*
- Updated ATP estimate from glucose metabolism to more current number of 32

Chapter 26

- Altered figure 26.1 to more accurately reflect the anatomical position of the kidneys
- Reorganized section 26.1 to more clearly state kidney function early
- Reorganized The Renal Corpuscle in section 26.2
- Numbered equations for logical flow of information
- Reorganized section on Regulation of Glomerular Filtration Rate for sequential presentation
- Reorganized section on Reabsorption in the Proximal Convoluted Tubule for clarity

- Updated Urine Concentration Mechanism with a discussion of the two parts of the countercurrent mechanism: countercurrent exchanger and countercurrent multiplier
- Revised Hormonal Mechanisms section for clarity
- Added homeostasis figure 26.20 on regulation of blood volume

Chapter 27

- Revised chapter introduction
- Converted 11/e introduction into a Clinical Impact box on water intoxication
- Added a new figure on review of osmotic pressure and osmosis
- Revised Regulation of Extracellular Fluid Osmolality section for clarity
- Added discussion of hypokalemia to section on Regulation of Potassium Ions section
- Reorganized section on Mechanisms of Acid-Base Balance Regulation for clarity
- Added some clinical correlations to discussion of Acidosis and Alkalosis, especially diabetic ketoacidosis

Chapter 28

- Updated terminology to use *female* and *male* throughout
- Included new Clinical Impact on Gender and Sex
- Revised the description of sexual karyotype for clarity
- Updated the description of progesterone release from the corpus luteum
- Added new recommendations for HPV vaccination for males in Microbes in Your Body box
- Revised the Puberty in Females section to provide additional information
- Revised the description of the length of the menstrual cycle to clarify the use of "average" duration of the cycle
- Revised the description of the ovarian cycle in section 28.6 Physiology of Female Reproduction
- Revised table 28.2 to include the ovarian cycle
- Clinical Impact Birth Control Methods greatly revised for currency and accuracy

Chapter 29

- Updated Clinical Impact 29.1 Stem Cell Research
- Revised description of hormones associated with lactation to include dopamine
- Revised the description of the development of the urinary system for clarity

Acknowledgments

A great deal of effort is required to produce a heavily illustrated textbook like *Seeley's Anatomy & Physiology*. Many hours of work are required to organize and develop the components of the textbook while also creating and designing illustrations, but no text is solely the work of the authors. It is not possible to adequately acknowledge the support and encouragement provided by our loved ones. They have had the patience and understanding to tolerate our absences and our frustrations. They have also been willing to provide assistance and unwavering support.

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Finally, we sincerely thank the past reviewers and instructors who have provided us time and time again with remarkable feedback. We have continued their recommendations in this edition, while remaining true to our overriding goal of writing a text that is comprehensive enough to provide the depth necessary for a two semester course, yet ensuring it is presented with such clarity that it nicely balances the thorough coverage to be more student centered. Each feature incorporated into this edition has been carefully considered in how it may be used to support student learning and understanding.

Also, in this edition, we are very pleased to have been able to incorporate real student data points and input, derived from thousands of our LearnSmart users, to help guide our revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With this data, we were able to hone not only our text content but also the LearnSmart probes.

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Just as the dancer in the photo works to balance his body's position, homeostasis works to balance the body's internal environment. ©Elnur/Shutterstock

1

The Human Organism

What lies ahead is an astounding adventure—learning about the structure and function of the human body and the intricate checks and balances that regulate it. Renzo's (the dancer featured in this chapter's "Learn to Predict") blood sugar disorder is a good example of how important this system of checks and balances is in the body. Perhaps you have had the experience of oversleeping, rushing to your 8 a.m. class, and missing breakfast. Afterwards, on the way to Anatomy & Physiology class, you bought an energy bar from the vending machine. Eating the energy bar helped you feel better. The explanation for these experiences is the process of homeostasis, the maintenance of a relatively constant internal environment, despite fluctuations in the external environment. For you, homeostasis was maintained, but for Renzo, there was a disruption in homeostasis. Throughout this book, the major underlying theme is homeostasis. As you think about Renzo's case, you will come to realize just how capable the human body is of an incredible coordination of thousands upon thousands of processes. Knowing human anatomy and physiology is also the basis for understanding disease. The study of human anatomy and physiology is important for students who plan a career in the health sciences because health professionals need a sound knowledge of structure and function in order to perform their duties. In addition, understanding anatomy and physiology prepares all of us to evaluate recommended treatments, critically review advertisements and reports in the popular literature, and rationally discuss the human body with health professionals and nonprofessionals.

Learn to Predict

Renzo, the dancer in the photo, is perfectly balanced, yet a slight movement in any direction would cause him to adjust his position. The human body adjusts its balance among all its parts through a process called homeostasis.

Let's imagine that Renzo is unknowingly suffering from a blood sugar disorder. Normally, tiny collections of cells embedded in the pancreas increase blood sugar by secreting the chemical insulin. Insulin increases the movement of sugar from the blood into his cells. However, Renzo has been losing a lot of weight, despite eating the same amount of food as always. He noticed that he's been fatigued, very thirsty, and urinating more than normal. Renzo went to see his doctor, who ordered some tests, including a blood glucose challenge. The results showed Renzo's blood sugar was higher than normal. After trying several treatments such as diet and prescription oral medication with little effect, Renzo was outfitted with an insulin pump. Now, his blood sugar levels are more consistent.

Develop an explanation for Renzo's blood sugar levels before and after his visit to the doctor.

1.1 Anatomy and Physiology

LEARNING OUTCOMES

After reading this section, you should be able to

A. **Define *anatomy* and describe the levels at which anatomy can be studied.**

B. **Define *physiology* and describe the levels at which physiology can be studied.**

C. **Explain the importance of the relationship between structure and function.**

Anatomy is the scientific discipline that investigates the body's structures—for example, the shape and size of bones. The word *anatomy* means to dissect or cut apart and separate the parts of the body for study. In addition, anatomy examines the relationship between the structure of a body part and its function. Thus, the fact that bone cells are surrounded by a hard, mineralized substance enables the bones to provide strength and support. Understanding the relationship between structure and function makes it easier to understand and appreciate anatomy. Anatomy can be studied at different levels. **Developmental anatomy** studies the structural changes that occur between conception and adulthood. **Embryology** (em-brē-ol′ō-jē), a subspecialty of developmental anatomy, considers changes from conception to the end of the eighth week of development.

Some structures, such as cells, are so small that they must be studied using a microscope. **Cytology** (sī-tol′ō-jē; *cyto,* cell) examines the structural features of cells, and **histology** (his-tol′ō-jē; *hist,* tissue) examines tissues, which are composed of cells and the materials surrounding them.

Gross anatomy, the study of structures that can be examined without the aid of a microscope, can be approached either systemically or regionally. A **system** is a group of structures that have one or more common functions, such as the cardiovascular, nervous, respiratory, skeletal, or muscular systems. In systemic anatomy, the body is studied system by system. In regional anatomy, the body is studied area by area. Within each region, such as the head, abdomen, or arm, all systems are studied simultaneously. The regional approach is taken in most graduate programs at medical and dental schools. The systemic approach is used in this and most other introductory textbooks.

Surface anatomy involves looking at the exterior of the body to visualize structures deeper inside the body. For example, the sternum (breastbone) and parts of the ribs can be seen and palpated (felt) on the front of the chest. Health professionals use these structures as anatomical landmarks to identify regions of the heart and points on the chest where certain heart sounds can best be heard. **Anatomical imaging** uses radiographs (x-rays), ultrasound, magnetic resonance imaging (MRI), and other technologies to create pictures of internal structures (table 1.1). Anatomical imaging has revolutionized medical science. Anatomical imaging allows medical personnel to look inside the body with amazing accuracy and without the trauma and risk of exploratory surgery. Although most of the technology used in anatomical imaging is very new, the concept and earliest technology are quite old. In 1895, Wilhelm Roentgen (1845–1923) became the first medical scientist to use **x-rays** to see inside the body. The rays were called x-rays because no one knew what they were. Whenever the human body is exposed to x-rays, ultrasound, electromagnetic fields, or radioactively labeled substances, a potential risk exists. This risk must be weighed against the medical benefit. Numerous studies have been conducted and are still being done to determine the effects of diagnostic and therapeutic exposure to x-rays. The risk of anatomical imaging is minimized by using the lowest possible doses providing the necessary information. No known risks exist from ultrasound or electromagnetic fields at the levels used for diagnosis. Both surface anatomy and anatomical imaging provide important information for diagnosing disease.

However, no two humans are structurally identical. **Anatomical anomalies** are physical characteristics that differ from the normal pattern. Anatomical anomalies can vary in severity from relatively harmless to life-threatening. For example, each kidney is normally supplied by one blood vessel, but in some individuals a kidney is supplied by two blood vessels. Either way, the kidney receives adequate blood. On the other hand, in the condition called "blue baby" syndrome, certain blood vessels arising from an infant's heart are not attached in their correct locations; blood is not effectively pumped to the lungs, and so the tissues do not receive adequate oxygen.

Physiology is the scientific investigation of the processes or functions of living things. The major goals when studying human physiology are to understand and predict the body's responses to stimuli and to understand how the body maintains conditions within a narrow range of values in a constantly changing environment.

Like anatomy, physiology can be considered at many levels. **Cell physiology** examines the processes occurring in cells such as energy production from food, and **systemic physiology** considers the functions of organ systems. Types of systemic physiology are **cardiovascular physiology,** which focuses on the heart and blood vessels, and **neurophysiology,** which focuses on the function of the nervous system. Physiology often examines systems rather than regions because a particular function can involve portions of a system in more than one region.

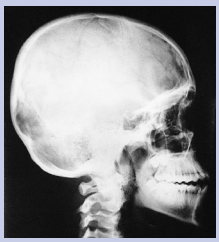
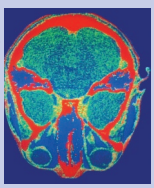
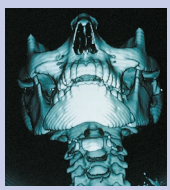
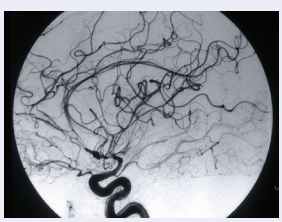
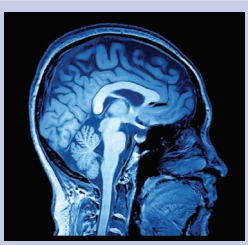
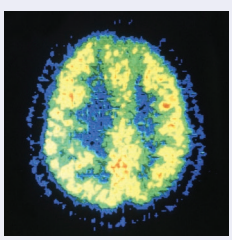
Studies of the human body must encompass both anatomy and physiology because structures, functions, and processes are interwoven. **Pathology** (pa-thol′ō-jē) is the medical science dealing with all aspects of disease, with an emphasis on the cause and development of abnormal conditions, as well as the structural and functional changes resulting from disease. **Exercise physiology** focuses on the changes in function and structure caused by exercise.

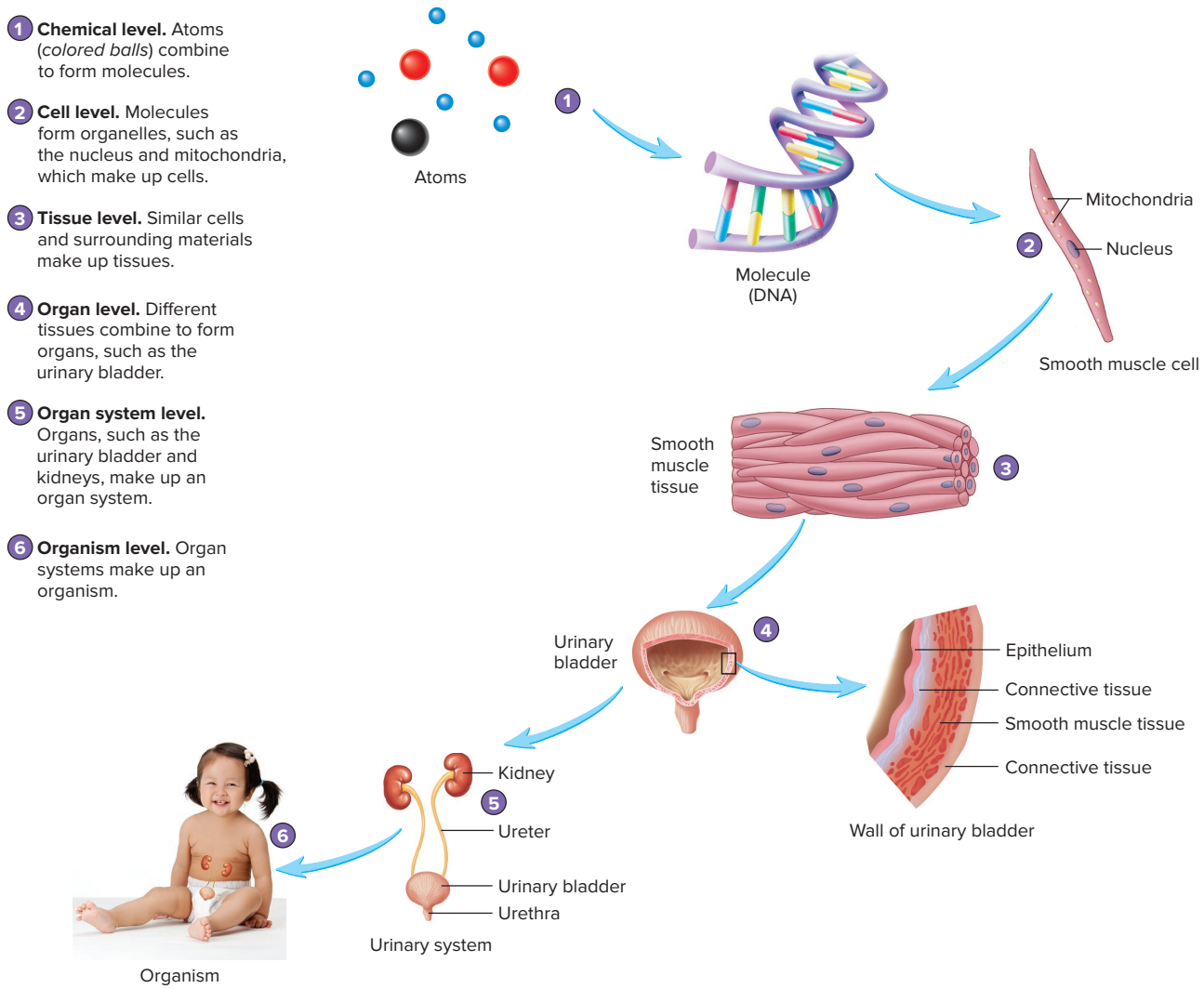
ASSESS YOUR PROGRESS

Answers to these questions are found in the section you have just completed. Re-read the section if you need help in answering these questions.

1. *How does the study of anatomy differ from the study of physiology?*
2. *What is studied in gross anatomy? In surface anatomy?*
3. *What type of physiology is employed when studying the endocrine system?*
4. *Why are anatomy and physiology normally studied together?*

TABLE 1.1 Anatomical Imaging

Imaging Technique	Image	Clinical Examples
X-ray	 ©Omikron/Science Source	This extremely shortwave electromagnetic radiation (see chapter 2) moves through the body, exposing a photographic plate to form a **radiograph** (rā′dē-ō-graf). Bones and radiopaque dyes absorb the rays and create underexposed areas that appear white on the photographic film. A major limitation of radiographs is that they give only flat, two-dimensional (2-D) images.
Ultrasound	 ©Bernard Benoit/Science Photo Library/Science Source	**Ultrasound,** the second-oldest imaging technique, was first developed in the early 1950s from World War II sonar technology. It uses high-frequency sound waves, which are emitted from a transmitter-receiver placed on the skin over the area to be scanned. The sound waves strike internal organs and bounce back to the receiver on the skin. Even though the basic technology is fairly old, the most important advances in this field occurred only after it became possible to analyze the reflected sound waves by a computer. The computer analyzes the pattern of reflected sound waves and transfers the information to a monitor to be visualized as a **sonogram** (son′ō-gram) image. One of the more recent advances in ultrasound technology is the ability of more advanced computers to analyze changes in position through "real-time" movements. Among other medical applications, ultrasound is commonly used to evaluate the condition of the fetus during pregnancy.
Computed Tomography (CT)	©RGB Ventures/SuperStock/Alamy  (a)  (b) ©Ribotsky D.P.M./Custom Medical Stock Photo	**Computed tomographic** (tō′mō-graf′ik) **(CT) scans,** developed in 1972 and originally called computerized axial tomographic (CAT) scans, are computer-analyzed x-ray images. A low-intensity x-ray tube is rotated through a 360-degree arc around the patient, and the images are fed into a computer. The computer then constructs the image of a "slice" through the body at the point where the x-ray beam was focused and rotated (*a*). Some computers are able to take several scans short distances apart and stack the slices to produce a 3-D image of a body part (*b*).
Digital Subtraction Angiography (DSA)	 ©Living Art Enterprises, LLC/Science Source	**Digital subtraction angiography** (an-jē-og′ră-fē) **(DSA)** is one step beyond CT scanning. A 3-D radiographic image of an organ, such as the brain, is made and stored in a computer. Then a radiopaque dye is injected into the blood, and a second radiographic computer image is made. The first image is subtracted from the second one, greatly enhancing the differences revealed by the injected dye. These dynamic computer images are the most common way angioplasty is performed. Angioplasty uses a tiny balloon to unclog an artery.
Magnetic Resonance Imaging (MRI)	 ©MriMan/Shutterstock	**Magnetic resonance imaging (MRI)** directs radio waves at a person lying inside a large electromagnetic field. The magnetic field causes the protons of various atoms to align (see chapter 2). Because of the large amount of water in the body, the alignment of hydrogen atom protons is most important in this imaging system. Radio waves of certain frequencies, which change the alignment of the hydrogen atoms, then are directed at the patient. When the radio waves are turned off, the hydrogen atoms realign in accordance with the magnetic field. The time it takes the hydrogen atoms to realign is different for various body tissues. These differences can be analyzed by computer to produce very clear sections through the body. An MRI is more effective at detecting some forms of cancer than a CT scan.
Positron Emission Tomography (PET)	 ©Science Source	**Positron emission tomographic (PET) scans** can identify the metabolic states of various tissues. This technique is particularly useful in analyzing the brain. When cells are active, they are using energy. The energy they need is supplied by the breakdown of glucose (blood sugar). If radioactively treated ("labeled") glucose is given to a patient, the active cells take up the labeled glucose. As the radioactivity in the glucose decays, positively charged subatomic particles called positrons are emitted. When the positrons collide with electrons, the two particles annihilate each other and gamma rays are given off. The gamma rays can be detected, pinpointing the cells that are metabolically active.



PROCESS FIGURE 1.1 Levels of Organization for the Human Body

The simplest level of organization in the human body is the atom. Atoms combine to form molecules. Molecules aggregate into cells. Cells form tissues, which combine with other tissues to form organs. Organs work in groups called organ systems. All organ systems work together to form an organism.

Why is the skin considered an organ? What characterizes the integumentary system as an organ system?

1.2 Structural and Functional Organization of the Human Body

LEARNING OUTCOMES

After reading this section, you should be able to

A. **Name the six levels of organization of the body and describe the major characteristics of each level.**

B. **List the 11 organ systems, identify their components, and describe the major functions of each system.**

The body can be studied at six levels of organization: chemical, cell, tissue, organ, organ system, and whole organism (figure 1.1).

1. *Chemical level.* The structural and functional characteristics of all organisms are determined by their chemical makeup. The chemical level of organization involves how atoms, such as hydrogen and carbon, interact and combine into molecules. This is important because a molecule's structure determines its function. For example, collagen molecules are strong ropelike protein fibers that give skin structural strength and flexibility. With old age, the structure of collagen changes, and the skin becomes fragile and more easily torn during everyday activities. We present a brief overview of chemistry in chapter 2.
2. *Cell level.* **Cells** are the basic structural and functional units of all living organisms. Cells contain smaller structures inside called **organelles** (or′gă-nelz; little organs). Organelles carry out particular functions, such as digestion and movement, for the cell. For example, the nucleus is an organelle that contains the cell's

MICROBES In Your Body 1.1

Getting to Know Your Bacteria

Did you know that you have more microbial cells than human cells in your body? Astoundingly, for every cell in your body, there is one microbial cell. That's as many as 40 trillion microbial cells, which can collectively account for between 2 and 6 pounds of your body weight! A microbe is any life form that can only be seen with a microscope (for example, bacteria, fungi, and protozoa). The total population of microbial cells on the human body is referred to as the microbiota, while the collection of all the microbial cell genes is known as the microbiome. The microbiota includes so-called good bacteria, which do not cause disease and may even help us. It also includes pathogenic, or "bad," bacteria.

With that many microbes in and on our bodies, you might wonder how they affect our health. To answer that question, the National Institutes of Health (NIH) initiated the Human Microbiome Project. Five significant regions of the human body were examined: the airway, skin, mouth, gastrointestinal tract, and vagina. This project identified over 5000 species and sequenced over 20 million unique microbial genes.

What did scientists learn from the Human Microbiome Project? Human health is dependent upon the health of our microbiota, especially the "good" bacteria. More specifically, the human microbiome is intimately involved in the development and maintenance of the immune system. And more evidence is mounting for a correlation between a host's microbiota, digestion, and metabolism. Researchers have suggested that microbial genes are more responsible for our survival than human genes. There are even a few consistent pathogens that are present without causing disease, suggesting that their presence may be good for us. However, there does not seem to be a universal healthy human microbiome. Rather, the human microbiome varies across lifespan, ethnicity, nationality, culture, and geographic location. Instead of being a detriment, this variation may actually be very useful for predicting disease. There seems to be a correlation between autoimmune and inflammatory diseases (Crohn's disease, asthma, multiple sclerosis), which have become more prevalent, and a "characteristic microbiome community." Early research seems to indicate that any significant change in the profile of the microbiome of the human gut may increase a person's susceptibility to autoimmune diseases. It has been proposed that these changes may be associated with exposure to antibiotics, particularly in infancy. Fortunately, newer studies of microbial transplantations have shown that the protective and other functions of bacteria can be transferred from one person to the next. However, this work is all very new, and much research remains to be done.

Throughout this text, we will highlight specific instances in which our microbes influence our body systems. In light of the importance of our bodies' bacteria and other microbes, the prevalence of antibacterial soap and hand gel usage in everyday life may be something to think about.

Predict 1

Predict some possible consequences of high-dose, intravenous (IV) antibiotic administration on the homeostasis of a person's digestive function.

hereditary information, and mitochondria are organelles that manufacture adenosine triphosphate (ATP), a molecule cells use for energy. Although cell types differ in their structure and function, they have many characteristics in common. Knowledge of these characteristics, as well as their variations, is essential to understanding anatomy and physiology. We discuss the cell in chapter 3.

3. *Tissue level.* A **tissue** is composed of a group of similar cells and the materials surrounding them. The characteristics of the cells and surrounding materials determine the functions of the tissue. The body is made up of four basic tissue types: (1) epithelial, (2) connective, (3) muscle, and (4) nervous. We discuss tissues in chapter 4.
4. *Organ level.* An **organ** is composed of two or more tissue types that perform one or more common functions. Examples of organs include: the urinary bladder, heart, stomach, and lung (figure 1.2).
5. *Organ system level.* An **organ system** is a group of organs that together perform a common function or set of functions and are therefore viewed as a unit. For example, the urinary system consists of the kidneys, ureter, urinary bladder, and urethra. The kidneys produce urine, which the ureters transport to the urinary bladder, where it is stored until being eliminated from the body through the urethra. In this text, we consider 11 major organ systems: (1) integumentary, (2) skeletal, (3) muscular, (4) nervous, (5) endocrine, (6) cardiovascular, (7) lymphatic, (8) respiratory, (9) digestive, (10) urinary, and (11) reproductive. Figure 1.3 presents a brief summary of these organ systems and their functions. Throughout this text, Systems Pathology essays consider interactions of the organ systems.
6. *Organism level.* An **organism** is any living thing considered as a whole—whether composed of one cell, such as a bacterium, or of trillions of cells, such as a human. The human organism is a network of organ systems, all mutually dependent on one another.

Predict 2

In one type of diabetes, the pancreas fails to produce insulin, a chemical normally made by pancreatic cells and released into the blood. List as many levels of organization as you can at which this disorder could be corrected.

ASSESS YOUR PROGRESS

5. *From simplest to complex, list and define the body's six levels of organization.*
6. *What are the four basic types of tissues?*
7. *Referring to figure 1.3, which two organ systems are responsible for regulating the other organ systems? Which two are responsible for support and movement?*

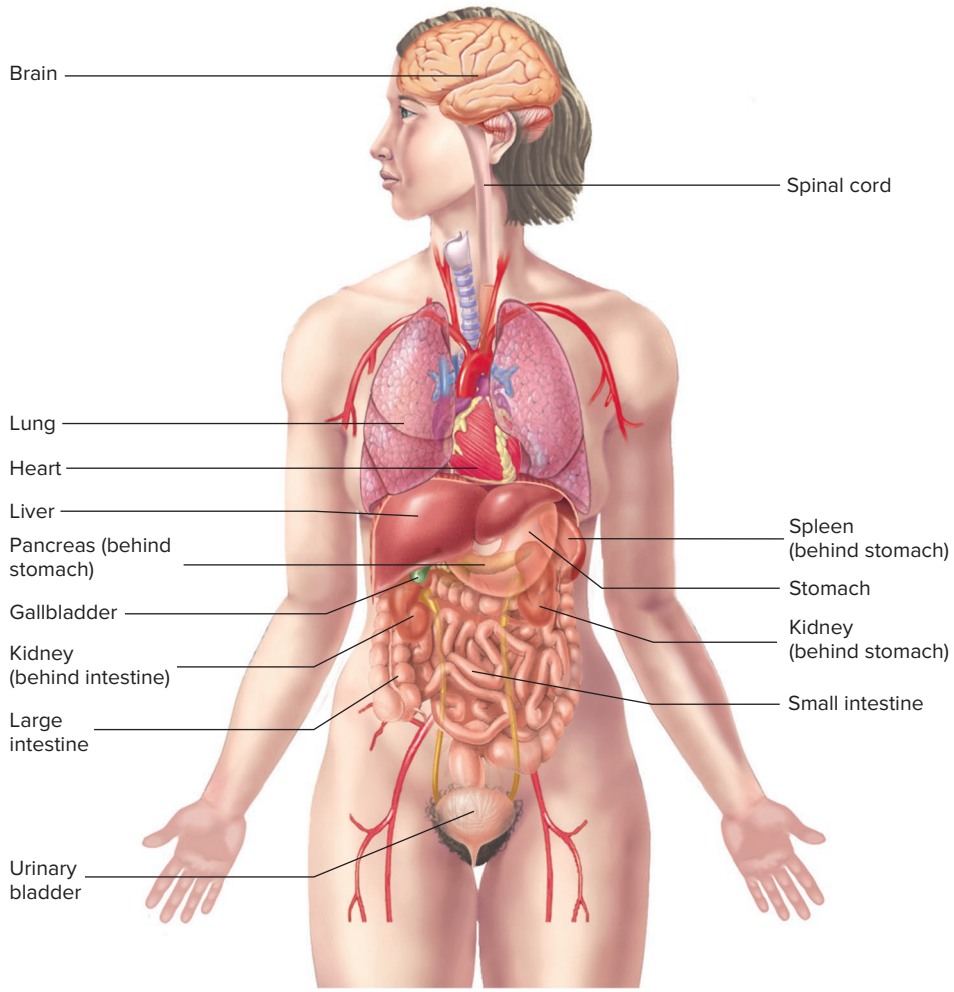


FIGURE 1.2 Major Organs of the Body
The body's major organs include the brain, lungs, heart, liver, pancreas, spleen, stomach, gallbladder, kidneys, large intestine, small intestine, urinary bladder, and urethra. AP|R

1.3 Characteristics of Life

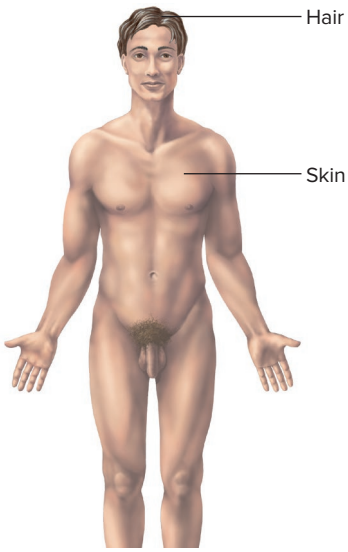
LEARNING OUTCOME

After reading this section, you should be able to

A. **List and define the six characteristics of life.**

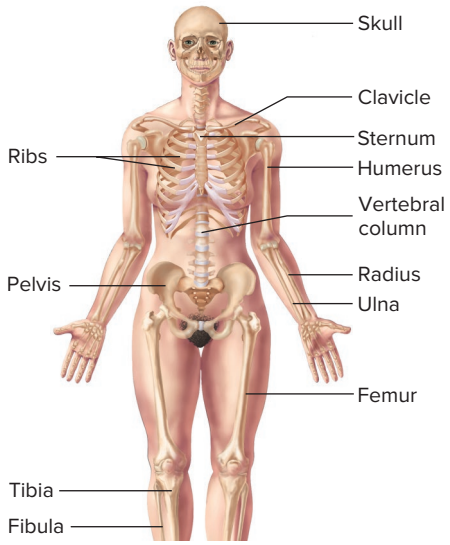
Humans are organisms, sharing characteristics with other organisms. The most important common feature of all organisms is life. This text recognizes six essential characteristics of life:

1. **Organization** refers to the specific interrelationships among the parts of an organism and how those parts interact to perform specific functions. Living things are highly organized. All organisms are composed of one or more cells. In turn, cellular function depends on the precise organization of large molecules. Disruption of this organized state can result in loss of functions, or even death.
2. **Metabolism** (mĕ-tab′ō-lizm) is the ability to use energy and to perform vital functions. Metabolism refers to all of the chemical reactions taking place in the cells and internal environment of an organism. Organisms possess specialized proteins that break down food molecules. The organism then uses the nutrients from the food as a source of energy and raw materials to synthesize new molecules. Energy is also used to rearrange the shape of molecules. The shape of a molecule determines its function. Some changes in molecular shape can allow certain cells to change shape. For example, specialized white blood cells can surround and engulf potentially dangerous foreign invaders, such as certain bacteria. Metabolism is necessary for other vital functions, such as responsiveness, growth, development, and reproduction.
3. **Responsiveness** is an organism's ability to sense changes in its external or internal environment and adjust to those changes. Responses include actions such as moving toward food or water and moving away from danger or poor environmental conditions. Organisms can also make adjustments that maintain their internal environment. For example, if the external environment causes the body temperature to rise, sweat glands produce sweat, which can lower body temperature down to the normal range.



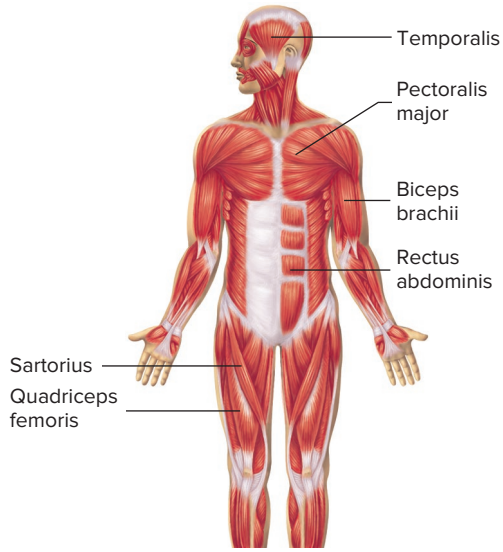
Integumentary System

Provides protection, regulates temperature, prevents water loss, and helps produce vitamin D. Consists of skin, hair, nails, and sweat glands.



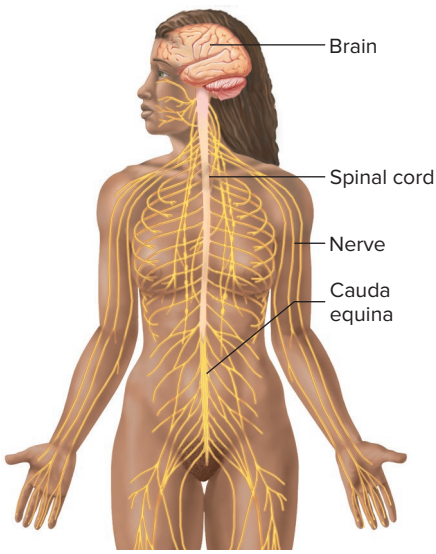
Skeletal System

Provides protection and support, allows body movements, produces blood cells, and stores minerals and adipose. Consists of bones, associated cartilages, ligaments, and joints.



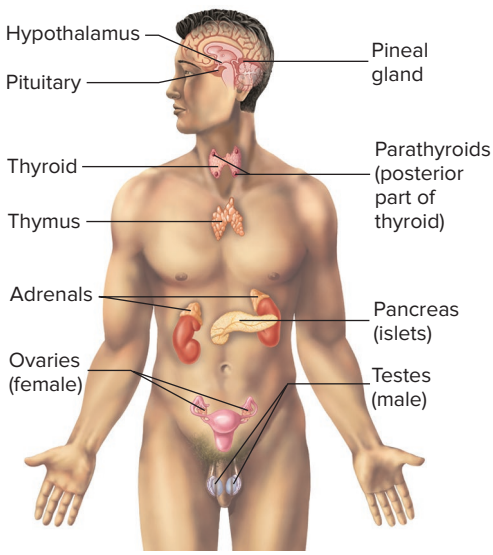
Muscular System

Produces body movements, maintains posture, and produces body heat. Consists of muscles attached to the skeleton by tendons.



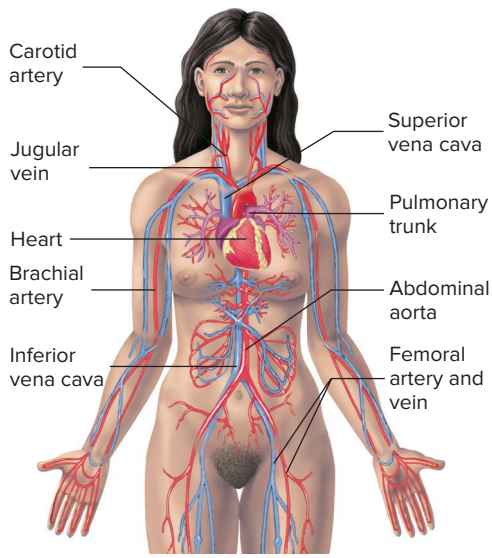
Nervous System

A major regulatory system that detects sensations and controls movements, physiological processes, and intellectual functions. Consists of the brain, spinal cord, nerves, and sensory receptors.



Endocrine System

A major regulatory system that influences metabolism, growth, reproduction, and many other functions. Consists of glands, such as the pituitary, that secrete hormones.



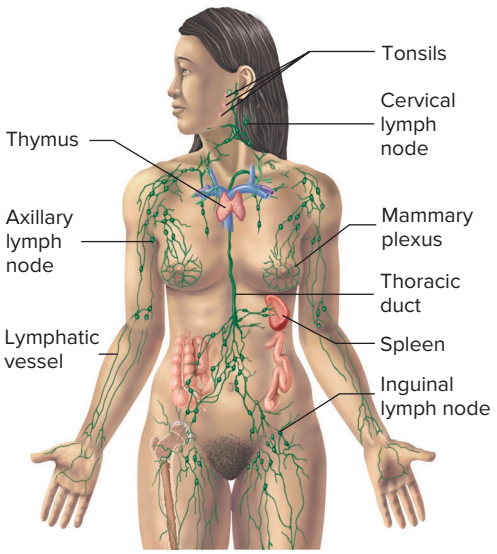
Cardiovascular System

Transports nutrients, waste products, gases, and hormones throughout the body; plays a role in the immune response and the regulation of body temperature. Consists of the heart, blood vessels, and blood.

FIGURE 1.3 Organ Systems of the Body

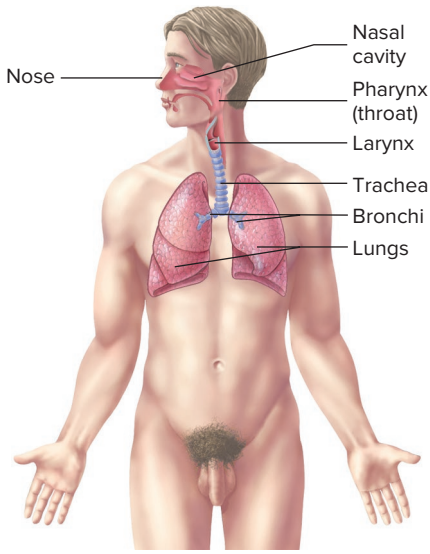
There are 11 body systems: integumentary, skeletal, muscular, lymphatic, respiratory, digestive, nervous, endocrine, cardiovascular, urinary, and reproductive.

4. **Growth** refers to an increase in the size or number of cells, which produces an overall enlargement of all or part of an organism. For example, a muscle enlarged by exercise is composed of larger muscle cells than those of an untrained muscle, and the skin of an adult has more cells than the skin of an infant. An increase in the materials surrounding cells can also contribute to growth. For instance, bone grows because of an increase in cell number and the deposition of mineralized materials around the cells.



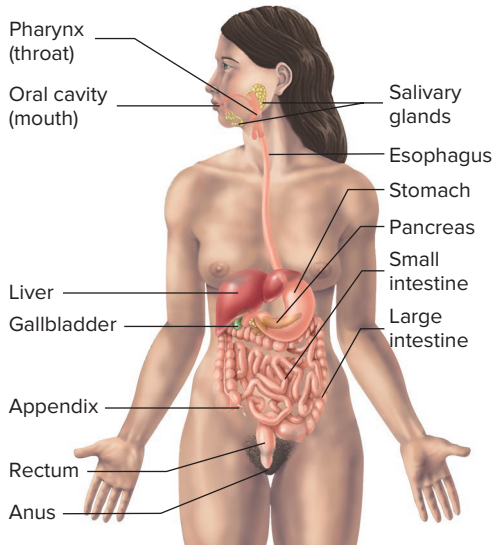
Lymphatic System

Removes foreign substances from the blood and lymph, combats disease, maintains tissue fluid balance, and absorbs dietary fats from the digestive tract. Consists of the lymphatic vessels, lymph nodes, and other lymphatic organs.



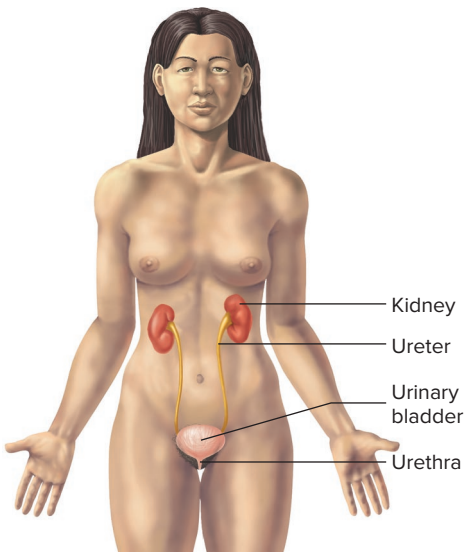
Respiratory System

Exchanges oxygen and carbon dioxide between the blood and air and regulates blood pH. Consists of the lungs and respiratory passages.



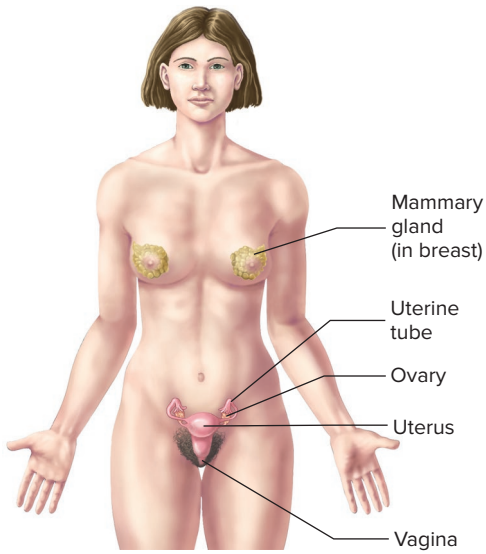
Digestive System

Performs the mechanical and chemical processes of digestion, absorption of nutrients, and elimination of wastes. Consists of the mouth, esophagus, stomach, intestines, and accessory organs.



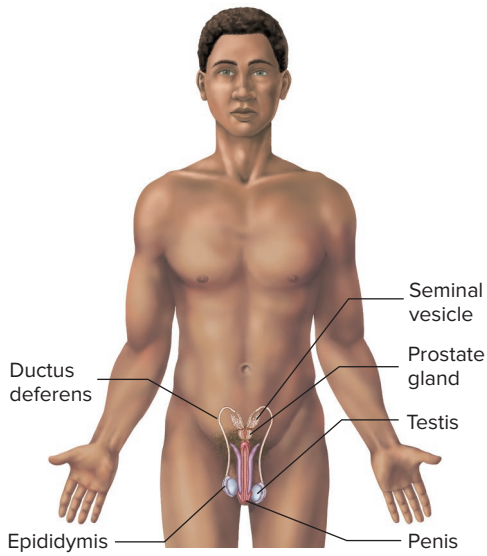
Urinary System

Removes waste products from the blood and regulates blood pH, ion balance, and water balance. Consists of the kidneys, urinary bladder, and ducts that carry urine.



Female Reproductive System

Produces oocytes and is the site of fertilization and fetal development; produces milk for the newborn; produces hormones that influence sexual function and behaviors. Consists of the ovaries, uterine tubes, uterus, vagina, mammary glands, and associated structures.



Male Reproductive System

Produces and transfers sperm cells to the female and produces hormones that influence sexual functions and behaviors. Consists of the testes, accessory structures, ducts, and penis.

FIGURE 1.3 (continued)

5. **Development** includes the changes an organism undergoes through time, beginning with fertilization and ending at death. The greatest developmental changes occur before birth, but many changes continue after birth, and some go on throughout life. Development usually involves growth, but it also involves differentiation and morphogenesis. **Differentiation** involves changes in a cell's structure and function from an immature, generalized state to a

mature, specialized state. For example, following fertilization, immature cells differentiate to become specific cell types, such as skin, bone, muscle, or nerve cells. These differentiated cells form tissues and organs. **Morphogenesis** (mōr-fō-jen′ĕ-sis) is the change in shape of tissues, organs, and the entire organism.

6. **Reproduction** is the formation of new cells or new organisms. Reproduction of cells allows for growth and development. All living organisms pass on their genes to their offspring.

ASSESS YOUR PROGRESS

8. *What are the six characteristics of living things? Briefly explain each.*

9. *How does differentiation differ from morphogenesis?*

1.4 Biomedical Research

LEARNING OUTCOME

After reading this section, you should be able to

A. **Explain why it is important to study other organisms along with humans.**

Studying other organisms has increased our knowledge about humans because humans share many characteristics with other organisms. For example, studying single-celled bacteria has allowed scientists to utilize bacteria to synthesize certain human medicines such as insulin. However, some biomedical research cannot be accomplished using single-celled organisms or isolated cells. Sometimes other mammals must be studied, as evidenced by the great progress in open-heart surgery and kidney transplantation made possible by perfecting surgical techniques on other mammals before attempting them on humans. Strict laws govern the use of animals in biomedical research; these laws are designed to ensure minimal suffering on the part of the animal and to discourage unnecessary experimentation.

Although much can be learned from studying other organisms, the ultimate answers to questions about humans can be obtained only from humans because other organisms differ from humans in significant ways. A failure to appreciate the differences between humans and other animals led to many misconceptions by early scientists. One of the first great anatomists was a Greek physician, Claudius Galen (ca. 130–201). Galen described a large number of anatomical structures supposedly present in humans but observed only in other animals. For example, he described the liver as having five lobes. This is true for rats, but not for humans, who have four-lobed livers. The errors introduced by Galen persisted for more than 1300 years until a Flemish anatomist, Andreas Vesalius (1514–1564), who is considered the first modern anatomist, carefully examined human cadavers and began to correct the textbooks. This example should serve as a word of caution: Some current knowledge in molecular biology and physiology has not been confirmed in humans.

ASSESS YOUR PROGRESS

10. *Why is it important to recognize that humans share many, but not all, characteristics with other animals?*

1.5 Homeostasis

LEARNING OUTCOMES

After reading this section, you should be able to

A. **Define *homeostasis* and explain why it is important for proper body function.**

B. **Describe a negative-feedback mechanism and give an example.**

C. **Describe a positive-feedback mechanism and give an example.**

Homeostasis (hō′mē-ō-stā′sis) is the existence and maintenance of a relatively constant environment within the body. To achieve homeostasis, the body must actively regulate conditions that are constantly changing. As our bodies undergo their everyday processes, we are continuously exposed to new conditions. Changes in our environmental conditions, such as hot or cold outdoor temperatures, are called **variables** because their values are not constant. For cells to function normally, the volume, temperature, and chemical content of their environment must be maintained within a narrow range.

One of the most well-known examples of homeostasis is body temperature. Body temperature is a variable that increases when you are too hot and decreases when you are too cold. Homeostatic mechanisms, such as sweating or shivering, normally maintain body temperature near an ideal normal value, or **set point** (figure 1.4). Note that these mechanisms are not able to maintain body temperature *precisely* at the set point. Instead, body temperature increases and decreases slightly around the set point to produce a **normal range** of values. As long as body temperature remains within this normal range, homeostasis is maintained. Keep in mind that the fluctuations are minimal, however. Note in figure 1.4 that the normal body temperature range is no more than 1 degree Fahrenheit above or below normal. Our *average* body temperature is 98.6 degrees Fahrenheit. Just as your home's thermostat does not keep the air temperature exactly at 75 degrees Fahrenheit at all times, your body's temperature does not stay perfectly stable.

The organ systems help keep the body's internal environment relatively constant. For example, the digestive, respiratory, cardiovascular, and urinary systems work together, so that each cell in the body receives adequate oxygen and nutrients while also ensuring that waste products do not accumulate to a toxic level. If body fluids deviate from homeostasis, body cells do not function normally and can even die. Disease disrupts homeostasis and sometimes results in death. Modern medicine attempts to understand disturbances in homeostasis and works to reestablish a normal range of values.

Negative Feedback

Most systems of the body are regulated by **negative-feedback** mechanisms, which maintain homeostasis. In everyday terms, the word *negative* is used to mean "bad" or "undesirable." In this