Thirteenth Edition

HOLE'S ESSENTIALS OF Human Anatomy & Physiology

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Mc Graw Hill Education

HOLE'S ESSENTIALS OF HUMAN ANATOMY & PHYSIOLOGY

THIRTEENTH EDITION

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BRIEF CONTENTS

ABOUT THE AUTHORS

DAVID SHIER has more than thirty years of experience teaching anatomy and physiology, primarily to premedical, nursing, dental, and allied health students. He has effectively incorporated his extensive teaching experience into another student-friendly revision *of Hole's Essentials of Human Anatomy and Physiology* and *Hole's Human Anatomy and Physiology.* His interest in physiology and teaching began with a job as a research assistant at Harvard Medical School from 1976-1979. He completed his Ph.D. at the University of Michigan in 1984, and served on the faculty of the Medical College of Ohio from 1985-1989. He began teaching at Washtenaw Community College in 1990. David has recent experience in online course delivery, including recording lectures for so-called "flipped" classrooms. He has also been interested in the relationship between pedagogy and assessment, and the use of tools traditionally associated with assessment (e.g. lab quizzes) as pedagogical tools, often associated with group activities.

JACKIE BUTLER'S professional background includes work at the University of Texas Health Science Center conducting research about the genetics of bilateral retinoblastoma. She later worked at Houston's M. D. Anderson Hospital investigating remission in leukemia patients. A popular educator for more than thirty years at Grayson College, Jackie has taught microbiology and human anatomy and physiology for health science majors. Her experience and work with students of various educational backgrounds have contributed significantly to another revision of *Hole's Essentials of Human Anatomy and Physiology* and *Hole's Human Anatomy and Physiology.* Jackie Butler received her B.S. and M.S. degrees from Texas A&M University, focusing on microbiology, including courses in immunology and epidemiology.

RICKI LEWIS's career communicating science began with earning a Ph.D. in Genetics from Indiana University in 1980. It quickly blossomed into writing for newspapers and magazines, and writing the introductory textbook *Life.* Since then she has taught a variety of life science courses and has authored the textbook *Human Genetics: Concepts and Applications* and books about gene therapy, stem cells, and scientific discovery. She is a genetic counselor for a large medical practice, teaches a graduate online course in "Genethics" at Albany Medical College, and writes for *Medscape Medical News* and *Rare Disease Report.* She writes the popular *DNA Science* blog at Public Library of Science and is a frequent public speaker. Ricki is a strong advocate for the rare disease community, specializing in communication and bringing families together.

DIGITAL AUTHORS

LESLIE DAY earned her B.S. in Exercise Physiology from UMass Lowell, an M.S. in Applied Anatomy & Physiology from Boston University, and a Ph.D. in Biology from Northeastern University. She currently works as an Associate Clinical Professor and Associate Chair in the Department of Physical Therapy, Movement and Rehabilitation Sciences at Northeastern University with her main teaching role in upper level Gross Anatomy and Neuroanatomy courses, but still loves teaching her introductory anatomy course. She has received five teaching awards at the universities, including the coveted University Excellence in Teaching Award. Her current research focuses on the effectiveness of different teaching pedagogies, including the flipped-classroom and various technology. She brings her love for anatomy and quest for trying new technology into the classroom to make for a dynamic evidence-based teaching style that is friendly to all students.

JULIE PILCHER began teaching during her graduate training in Biomedical Sciences at Wright State University, Dayton, Ohio. She found, to her surprise, that working as a teaching assistant held her interest more than her research. Upon completion of her Ph.D. in 1986, she embarked on her teaching career, working for many years as an adjunct in a variety of schools as she raised her four children. In 1998, she began full-time at the University of Southern Indiana, Evansville. Her work with McGraw-Hill began several years ago, doing reviews of textbook chapters and lab manuals. More recently, she has been involved in content development for LearnSmart. In her A&P course at USI, she has also used Connect and has enjoyed the challenge of writing some of her own assignments. When the opportunity arose to become more involved in the authoring of digital content for McGraw-Hill, she could not pass it up. Based on her own experience, students are using more and more online resources, and she is pleased to be part of that aspect of A&P education.

NEW TO THIS EDITION

Global Changes

Learning Outline	Brief chapter outline at the beginning of each chapter
Learning Outcomes	Learning Outcomes now follow each major section heading.
Glossary	Many definitions updated

Specific Changes At-a-Glance

Chapter	Topic	Change
1	Scientific method	Chapter 1 introduces and revised Appendix B expands coverage
1	Body fluid compartments	Clearer connection between the extracellular fluid and the internal environment
1	Homeostasis	Clearer connection between the external environment and the outside world
1	Clinical Application 1.1	Figure orientations now correspond to each other
1	Abdominal regions	Figure 1.17 redone with model
2	Proteins	Levels of protein structure section rewritten
2	Atomic structure	Rewritten section on relationship between atoms and ions
2	Lipids	Terminology—"triglyceride" used preferentially to "fat"
3	Golgi apparatus	Figure 3.5 new micrograph with improved contrast
3	Centrioles	Figure 3.8 new micrograph with improved contrast
3	Nucleus	Figure 3.10 new micrograph with improved contrast
3	Diffusion	Figures 3.11 and 3.12 have better contrast
3	Facilitated diffusion	Figure 3.14 has better contrast
3	Organelles	Vesicles moved up in discussion to more realistically parallel activities within cells
4	Lipid terminology	Figures 4.2 and 4.10, "triglyceride" is predominant term, with "fat" in parentheses
4	Energy	Figure 4.9 total ATP equals 28, to be more consistent with recent calculations
4	Genetics Connection	Exome sequencing progress updated
5	Epithelial tissues	Labels in figs. 5.4 and 5.5 have been changed to clarify that microvilli and cilia are on the free surface of the tissues
5	Connective tissue cells	Figures 5.16 and 5.17 are new micrographs of a macrophage engulfing a cell and a mast cell, respectively
5	Adipose tissue	A blood vessel has been identified in fig. 5.20
6	Melanocyte	New micrograph in fig. 6.3*a* labeling melanosomes containing melanin
6	Clinical Application 6.1	Photograph of squamous cell carcinoma added to fig. 6A
6	Fingernails	Figure 6.4 redrawn to extend finger and show the detail of the joint between two phalanges
6	Skin functions	All of the skin functions are now under one major heading; 6.4 Skin Functions
7	Microscopic structure of bone	Added lamellae to the discussion
7	Ossification	Bold faced term moved to the introduction of the discussion of intramembranous and endochondral bone formation
7	Levers and movement	Discussion moved to chapter 8
7	Figures revised	Figure 7.13 has more detail added to the line art, figure 7.17 locator icon colored to match the a, b, c portion titles, figure 7.23 the leader for the anatomical neck ends in a circle surrounding the neck, figure 7.27 labels added for the medial and lateral surfaces
7	Pelvic outlet	Added to the discussion of the pelvis
7	Movements	Abduction, adduction, rotation, and pronation rewritten for clarification
8	Muscle structure	Figure 8.1 redrawn to better show the relationship among epimysium, perimysium, and endomysium
8	Connective tissue coverings	Section rewritten for clarity
8	Skeletal muscle fibers	Section on striations rewritten for clarity
8	Neuromuscular junction	Section rewritten for clarity

continued next page—

NEW TO THIS EDITION

Specific Changes At-a-Glance—*Continued*

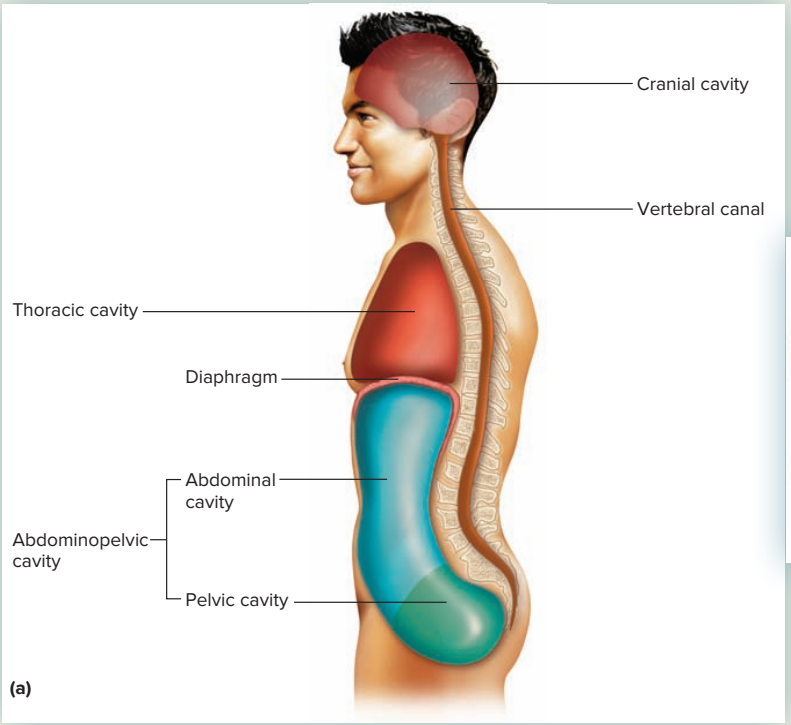
Chapter	Topic	Change
8	Creatine phosphate	Figure 8.9 revised—cells eliminated for accuracy and clarity
8	Oxygen supply and aerobic reactions	Figure 8.10 revised—ATP from citric acid cycle added
8	Oxygen debt and muscle fatigue	ATP yield from cellular respiration updated
8	Summation	Clarification on the role of partial tetanic contractions
8	Smooth muscle	Section revised and terminology replaces smooth muscle "fibers" with smooth muscle "cells"
8	Body movement	Figure 8.14 supports the discussion of levers, now moved to this chapter
8	Major skeletal muscles	Paragraph added to clarify appropriate use of technical terms as opposed to popular terms
8	Tables describing muscle, origin, insertion, and action	Revised for accuracy and use of correct anatomical terminology
8	Muscles that move the head	Ligamentum nuchae added to discussion and to figure 8.18
8	Muscle illustrations	Figures redrawn throughout
8	Muscles that move the thigh	Text reorganized for clarity
9	Neural pathways	Term replaces "nerve pathways"
9	Introduction	Discussion of the synapse moved to earlier in the section
9	Neuroglia	Section on blood-brain barrier rewritten for clarity
9	Resting potential and action potentials	Sections rewritten for clarity
9	Impulse conduction	Clarification of role of Schwann cells in PNS and oligodendrocytes in CNS
9	Removal of neurotransmitter	Section reorganized for clarity
9	Facilitation	Mechanism updated
9	Sensory, motor, and mixed nerves	Description rewritten for clarity
9	Spinal cord	Figure 9.24 redrawn to better show structure of cauda equina and dura
9	Tracts	Figures 9.26 and 9.27 redrawn to more clearly show neural pathways
9	Brain	Figure 9.28 revised
10	Pain	Section rewritten in terms of fast and slow pain fibers
10	Pain pathways	Central destinations of pain fibers rewritten
10	Spiral organ	Figure 10.9 has improved drawings of innervation
10	Iris	Discussion includes pupillary dilators and pupillary constrictors
11	Target cells	Figure 11.1 redrawn to emphasize that hormones reach all cells, but only target cells respond
11	Pituitary hormones	Clarification regarding why secretions from hypothalamic neurons reaching the posterior pituitary are considered hormones
11	Thyroid hormones	Section rewritten
11	Pineal gland	Section on melatonin rewritten
12	Vignette	Updated to be more current
12	Blood volume	Rewritten to indicate the values for males and females
12	Blood cell formation	Figure 12.4 the late erythroblast redrawn for clarification
12	Albumins in plasma	Rewritten to emphasize their role in colloid osmotic pressure
12	Edema box	Rewritten for clarification
12	Vascular spasm	Wording changed from blood vessel spasm to vascular spasm and rewritten for clarification
13	Heart transplantation box	Updated paragraph on LVADs
13	ECG	Replaced figure 13.14*a* and labeled all of the waves on figure 13.14*b*
13	Blood vessels micrographs	Replaced figures 13.20 and 13.22
13	Arterial blood pressure	Rewritten to indicate that normal is no greater than 119/79
14	Vignette	Rewritten to update and clarify
14	MALT	Discussion rewritten for clarification
14	Thymus	Figure 14.9*a* redrawn to better illustrate the size of the thymus
14	Lymphocyte activation	Figure 14.14 revised with numbers added to clarify step sequence

Specific Changes At-a-Glance—*Continued*

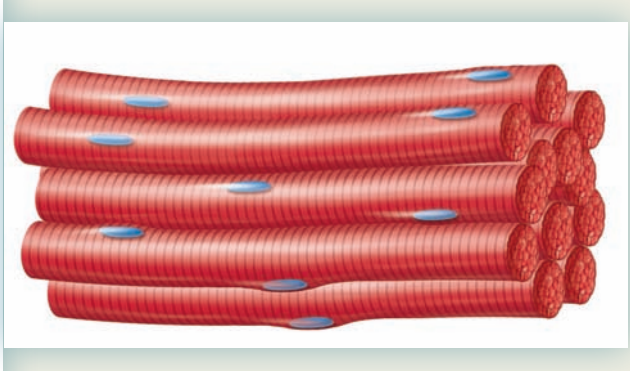
Chapter	Topic	Change
14	Allergic reactions	Section rewritten and title changed from allergic reactions to hypersensitivity to clarify that allergic reactions are just one type of hypersensitivity reaction
14	Immunosuppressive drugs	Rewritten to update
15	Vignette	Updated the discussion of fecal microbiota transplantation
15	Stomach	Rewritten discussion of parts to clarify the pylorus
15	Pancreas	Pancreatic duct portion rewritten to clarify
15	Gallbladder radiograph	Figure 15.20 replaced
15	Triglyceride absorption	Figure 15.26 revised to reflect the use of the term triglycerides (instead of fats) in the rewritten discussion
15	Colonoscopy box	Added the alternative stool sample method to update
16	Organs of the respiratory system	New discussion on bronchoconstriction and bronchodilation
16	Inspiration	Text reworked for clarity with new examples of pressure gradients
16	Respiratory volumes and capacities	New box with tidal volume analogy
16	Gas transport	Improved description of histotoxic hypoxia
17	Location of the kidneys	Figure 17.1 redrawn, vertebrae labeled as markers
17	Kidney structure	Redrawn figure 17.3
17	Nephrons	Redrawn diagrammatic part of figure 17.6
17	Glomerular filtration	Clearer distinction between glomerular filtrate and tubular fluid
17	Urine formation	Figure 17.9 redrawn in more diagrammatic fashion for clarity
17	Tubular reabsorption and tubular secretion	Figures 17.14 and 17.15 updated for accuracy and clarity
18	Vignette	Updated
18	Figure revisions	Figures 18.4, 18.5, and 18.14 revised for clarification
18	Clinical Application 18.1	Rewritten water intoxication for clarification
18	Electrolyte balance	Reworded to emphasize keeping ions in appropriate concentrations within the plasma and interstitial fluid
18	Acidosis and alkalosis	Discussions reorganized to describe the symptoms first, followed by the causes
19	Figures revised	Figures 19.2, 19.4, 19.7, and 19.13 revised for changes in terminology and accuracy
19	Oogenesis	Rewritten for clarification
19	Follicle maturation	Figure 19.9 revised with the addition of locator icons for the developing follicle
19	Carcinoma *in situ* box	Updated
19	Reproductive cycle and ovulation	Rewritten to emphasize LH acting with FSH to induce complex interactions, adding accuracy but not detail
19	Birth control	Figure 19.16 revised and the text discussion rewritten to reflect methods currently in use
20	Vignette	Rewritten for clarification
20	Sperm cells on oocyte	Figure 20.1 micrograph replaced
20	Figures revised	Figures 20.3, 20.5, and 20.10 revised for clarification
20	Chapter reorganized	Pregnancy and the Prenatal Period section includes a changed sequence for flow in the Embryonic Stage (Period of Cleavage, Extraembryonic Membrane Formation, Gastrulation and Organogenesis), the Fetal Stage, Fetal Blood and Circulation, Maternal Changes During Pregnancy, Birth Process, and Milk Production and Secretion
20	Genetics Connection 20.1	Figure 20C revised for clarification
20	Multifactorial traits	Figure 20.20 replaced with a more current figure
20	New box	Added to distinguish the difference between genetic disease and inherited disease

DYNAMIC ART PROGRAM

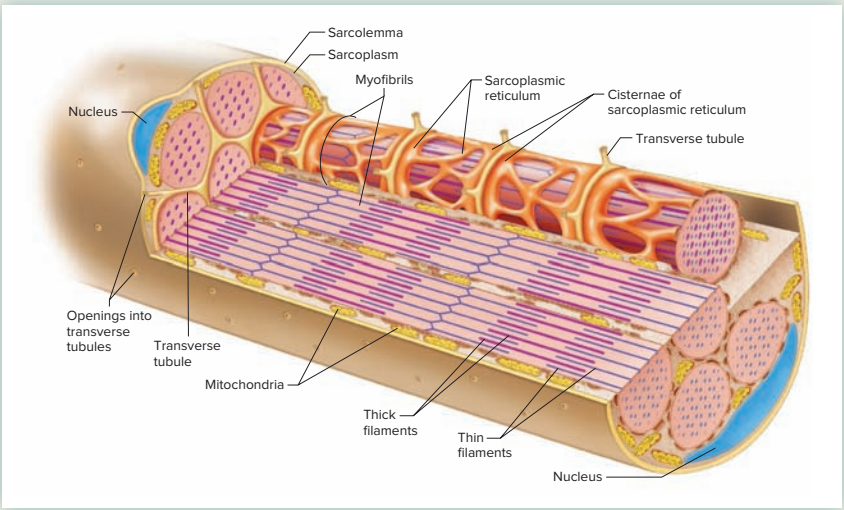
Art is vibrant, three-dimensional, and instructional. The authors examined every piece to ensure it was engaging and accurate. The thirteenth edition's art program will help students understand the key concepts of anatomy and physiology.



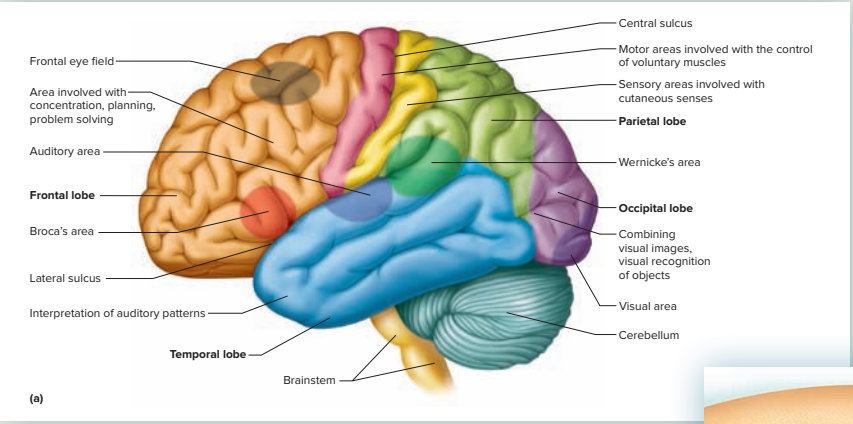
Realistic, three-dimensional figures provide depth and orientation.



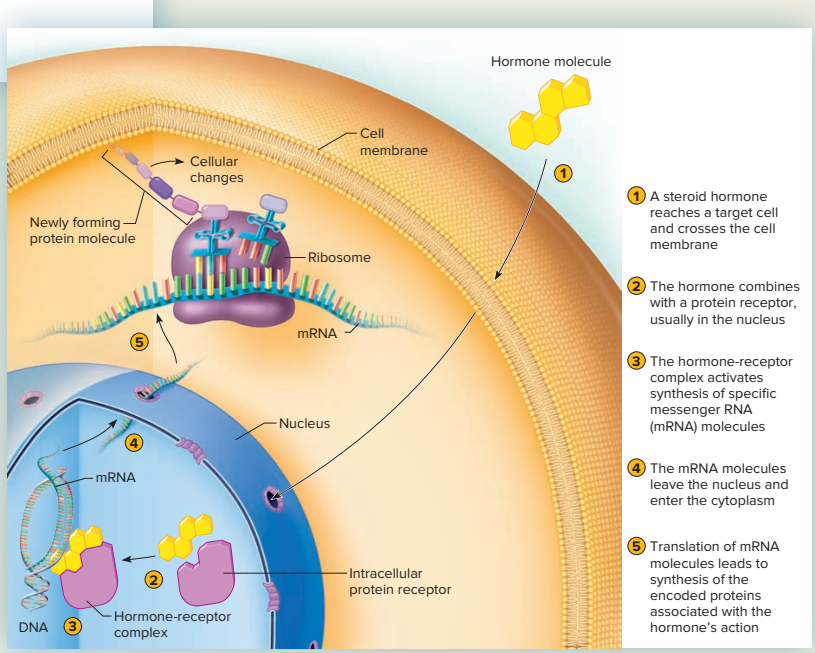
Line art for micrographs is three-dimensional to help students visualize more than just the flat microscopic sample.



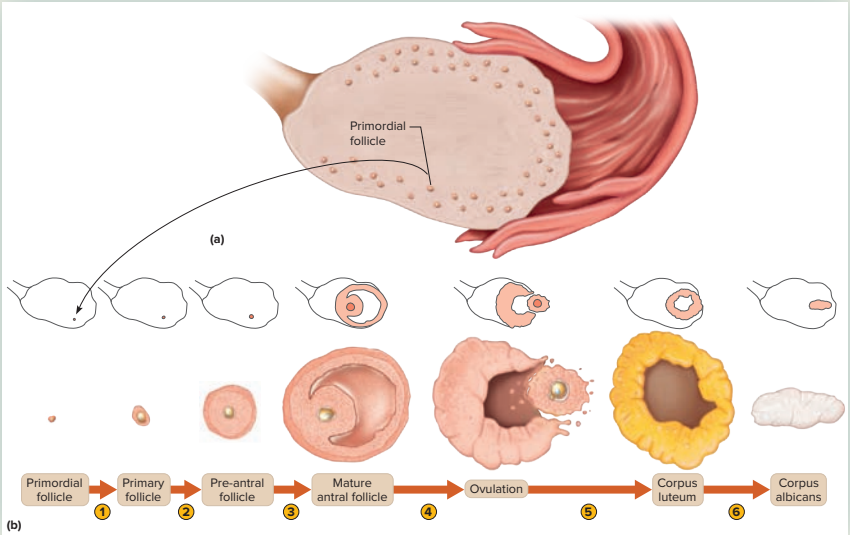
This longitudinal section shows the interior structures of a muscle fiber revealing detail of the myofibrils, and thick and thin filaments.



Colors readily distinguish functional areas.



The explanation is part of the figure, not lost in the legend.



Locator icons help portray the process more accurately.

Learn, Practice, Assess!

Learn

Learning Outcomes have been moved! They now follow the appropriate heading within the chapter. They continue to be closely linked to Chapter Assessments and Integrative Assessments/Critical Thinking questions found at the end of each chapter.

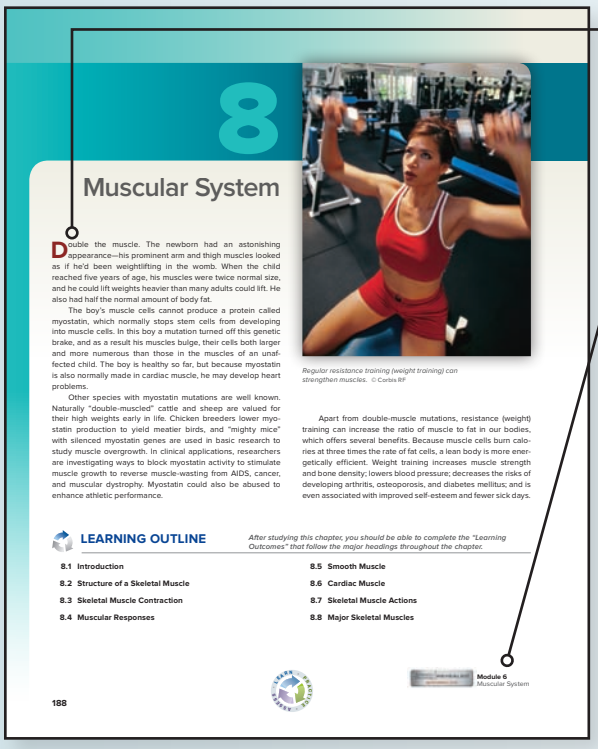
8.2 | Structure of a Skeletal Muscle

LEARN

2. Identify the structures that make up a skeletal muscle.
3. Identify the major parts of a skeletal muscle fiber, and the function of each.
4. Discuss nervous stimulation of a skeletal muscle.

Learning tools to help you succeed . . .

Check out the Chapter Preview, *Foundations for Success,* on page 1. The Chapter Preview was specifically designed to help you **LEARN** how to study. It provides helpful study tips.


8

Muscular System

Double the muscle. The newborn had an astonishing appearance—his prominent arm and thigh muscles looked as if he'd been weightlifting in the womb. When the child reached five years of age, his muscles were twice normal size, and he could lift weights heavier than many adults could lift. He also had half the normal amount of body fat.

The boy's muscle cells cannot produce a protein called myostatin, which normally stops stem cells from developing into muscle cells. In this boy a mutation turned off this genetic brake, and as a result his muscles bulge, their cells both larger and more numerous than those in the muscles of an unaffected child. The boy is healthy so far, but because myostatin is also normally made in cardiac muscle, he may develop heart problems.

Other species with myostatin mutations are well known. Naturally "double-muscled" cattle and sheep are valued for their high weights early in life. Chicken breeders lower myostatin production to yield meatier birds, and "mighty mice" with silenced myostatin genes are used in basic research to study muscle overgrowth. In clinical applications, researchers are investigating ways to block myostatin activity to stimulate muscle growth to reverse muscle-wasting from AIDS, cancer, and muscular dystrophy. Myostatin could also be abused to enhance athletic performance.

Regular resistance training (weight training) can strengthen muscles. © Corbis RF

Apart from double-muscle mutations, resistance (weight) training can increase the ratio of muscle to fat in our bodies, which offers several benefits. Because muscle cells burn calories at three times the rate of fat cells, a lean body is more energetically efficient. Weight training increases muscle strength and bone density; lowers blood pressure; decreases the risks of developing arthritis, osteoporosis, and diabetes mellitus; and is even associated with improved self-esteem and fewer sick days.

LEARNING OUTLINE

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

8.1 Introduction
8.2 Structure of a Skeletal Muscle
8.3 Skeletal Muscle Contraction
8.4 Muscular Responses
8.5 Smooth Muscle
8.6 Cardiac Muscle
8.7 Skeletal Muscle Actions
8.8 Major Skeletal Muscles

Module 6 Muscular System

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Vignettes lead into chapter content. They connect you to many areas of health care including technology, physiology, medical conditions, historical perspectives, and careers.

Anatomy & Physiology REVEALED® (APR) icon at the beginning of each chapter tells you which system in APR applies to this chapter.

Aids to Understanding Words examines root words, stems, prefixes, suffixes, and pronunciations to help you build a solid anatomy and physiology vocabulary.

Reference Plates offer vibrant detail of body structures.

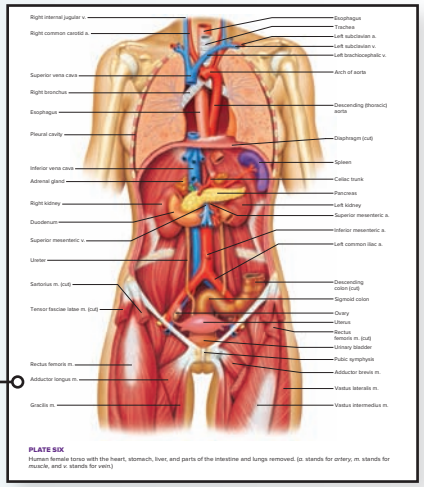

PLATE SIX

Human female torso with the heart, stomach, liver, and parts of the intestine and lungs removed. (a. stands for artery, m. stands for muscle, and v. stands for vein.)

Practice

Practice with a question or series of questions after major sections. They will test your understanding of the material.

Interesting applications help you practice and apply knowledge . . .

PRACTICE

13. Which organ occupies the cranial cavity? the vertebral canal?
14. What does *viscera* mean?
15. Name the cavities of the head.
16. Describe the membranes associated with the thoracic and abdominopelvic cavities.

Figure Questions allow an additional assessment. Found on key figures throughout the chapter.

Figure 8.5 A neuromuscular junction includes the end of a motor neuron and the motor end plate of a muscle fiber. APR

How does acetylcholine released into the synaptic cleft reach the muscle fiber membrane?

Answer can be found in Appendix F.

Boxed information expands on the concepts discussed in the text.

In *tendinitis,* a tendon (the attachment of a muscle to a bone) becomes painfully inflamed and swollen following injury or the repeated stress of athletic activity. If rest, physical therapy, and anti-inflammatory drugs do not alleviate tendinitis, then ultrasound can be applied to break up scar tissue. In *tenosynovitis,* the connective tissue sheath of the tendon (the tenosynovium) is inflamed. The tendons most commonly affected are those associated with the joint capsules of the shoulder, elbow, and hip and those that move the hand, thigh, and foot.

Facts of Life provides interesting bits of anatomy and physiology information, adding a touch of wonder to chapter topics.

FACTS OF LIFE The skeleton of an average 160-pound body weighs about 29 pounds.

Clinical Applications present disorders, physiological responses to environmental factors, and other topics of general interest and applies them to clinical situations.

CLINICAL APPLICATION 18.1

Water Balance Disorders

Dehydration, water intoxication, and edema are among the more common disorders that involve a water imbalance in body fluids.

Dehydration

In *dehydration,* water output exceeds water intake. Dehydration may develop following excessive sweating or as a result of prolonged water deprivation accompanied by continued water output. The extracellular fluid becomes more concentrated, and water leaves cells by osmosis (Figure 18A). Dehydration may also accompany prolonged vomiting or diarrhea that depletes body fluids.

also especially susceptible to developing water imbalances because the sensitivity of their thirst mechanism decreases with age, and physical disabilities may make it difficult for them to obtain adequate fluids.

The treatment for dehydration is to replace the lost water and electrolytes. If only water is replaced, the extracellular fluid will become more dilute than normal, causing cells to swell (Figure 18B). This may produce a condition called water intoxication.

Water Intoxication

Until recently, runners were advised to drink as much fluid as they could, particularly in long events. But

Genetics Connections explore the molecular underpinnings of familiar as well as not so familiar illnesses. Read about such topics as ion channel disorders, muscular dystrophy, and cystic fibrosis.

GENETICS CONNECTION 8.1

Inherited Diseases of Muscle

Several inherited conditions affect muscle tissue. These disorders differ in the nature of the genetic defect, the type of protein that is abnormal in form or function, and the muscles that are impaired.

The Muscular Dystrophies—Missing Proteins

A muscle cell is packed with filaments of actin and myosin. Much less abundant, but no less important, is a protein called *dystrophin.* It holds skeletal muscle cells together by linking actin in the cell to glycoproteins in the cell membrane, which helps attach the cell to the extracellular matrix. Missing or abnormal dystrophin or the glycoproteins cause muscular dystrophies.

These illnesses vary in severity and age of onset, but in all cases, muscles weaken and degenerate. Eventually fat and connective tissue replace muscle.

Duchenne muscular dystrophy (DMD) is the most severe type of the illness (fig. 8B). Symptoms begin by age five and affect only boys. By age thirteen, the person cannot walk, and by early adulthood he usually dies from failure of the respiratory muscles. In DMD, dystrophin is absent or shortened. In Becker muscular dystrophy, symptoms begin in early adulthood, are less severe, and result from underproduction of dystrophin. An experimental genetic therapy produces nearly full-length dystrophin by skipping over the part

Assess

Tools to help you make the connection and master anatomy & physiology!

Chapter Assessments check your understanding of the chapter's learning outcomes.

Integrative Assessments/Critical Thinking questions allow you to connect and apply information from previous chapters as well as information within the current chapter.

Chapter Summary Outlines help you review the chapter's main ideas.

CHAPTER ASSESSMENTS

8.1 Introduction

1. The three types of muscle tissue are _____, _____, and _____.

8.2 Structure of a Skeletal Muscle

2. Describe the difference between a tendon and an aponeurosis.
3. Describe how connective tissue associates with skeletal muscle.
4. List the major parts of a skeletal muscle fiber, and describe the function of each part.
5. Describe a neuromuscular junction.
6. A neurotransmitter _____.
   a. binds actin filaments, causing them to slide
   b. diffuses across a synapse from a neuron to a

8.4 Muscular Responses

13. Define *threshold stimulus.*
14. Sketch a myogram of a single muscular twitch, and identify the latent period, period of contraction, and period of relaxation.
15. Define *motor unit.*
16. Which of the following describes the addition of muscle fibers to take part in a contraction?
    a. summation
    b. recruitment
    c. tetany
    d. twitch
17. Explain how skeletal muscle stimulation produces a sustained contraction.

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

OUTCOMES 4.4, 8.3

1. As lactate and other substances accumulate in an active muscle, they stimulate pain receptors and the muscle may feel sore. How might the application of heat or substances that dilate blood vessels relieve such soreness?

OUTCOMES 5.3, 8.2

2. Discuss how connective tissue is part of the muscular system.

OUTCOMES 8.3, 8.4

3. A woman takes her daughter to a sports medicine specialist and asks the specialist to determine the percentage of fast- and slow-twitch fibers in the girl's leg muscles. The parent wants to know if the healthy girl should try out for soccer or cross-country running. Do you think this is a valid reason to test muscle tissue? Why or why not?
4. Following an injury to a nerve, the muscle it supplies with motor nerve fibers may become paralyzed. How would you explain to a patient the importance of moving the disabled muscles passively or contracting them using electrical stimulation?

OUTCOMES 8.4, 8.8

5. What steps might be taken to minimize atrophy of the skeletal muscles in patients confined to bed for prolonged times?

Summary Outline

8.1 Introduction

The three types of muscle tissue are skeletal, smooth, and cardiac.

8.2 Structure of a Skeletal Muscle

Individual muscles are the organs of the muscular system. They include skeletal muscle tissue, nervous tissue, blood, and connective tissues.

1. Connective tissue coverings
   a. **Fascia** covers skeletal muscles.
   b. Other connective tissues attach muscles to bones or to other muscles.
   c. A network of connective tissue extends throughout the muscular system.
2. Skeletal muscle fibers
   a. Each skeletal muscle fiber is a single muscle cell.
   b. The cytoplasm contains mitochondria, sarcoplasmic reticulum, and **myofibrils** of actin and myosin.
   c. The organization of **actin** and **myosin** filaments produces striations.
   d. **Transverse tubules** extend inward from the cell membrane and associate with the **sarcoplasmic**

1. Role of myosin and actin
   a. Heads of myosin filaments form cross-bridge linkages with actin filaments.
   b. The reaction between actin and myosin filaments generates the force of contraction.
2. Stimulus for contraction
   a. **Acetylcholine** released from the distal end of a motor neuron axon stimulates a skeletal muscle fiber.
   b. Acetylcholine causes the muscle fiber to conduct an impulse over the surface of the fiber that reaches deep within the fiber through the transverse tubules.
   c. The impulse signals the sarcoplasmic reticulum to release calcium ions.
   d. Cross-bridge linkages form between actin and myosin, and the cross-bridges pull on actin filaments, shortening the fiber.
   e. The muscle fiber relaxes when myosin heads release from actin, breaking the cross-bridges (ATP is needed, but is not broken down) and when calcium ions are actively transported (requiring ATP breakdown) back into the sarcoplasmic reticulum.

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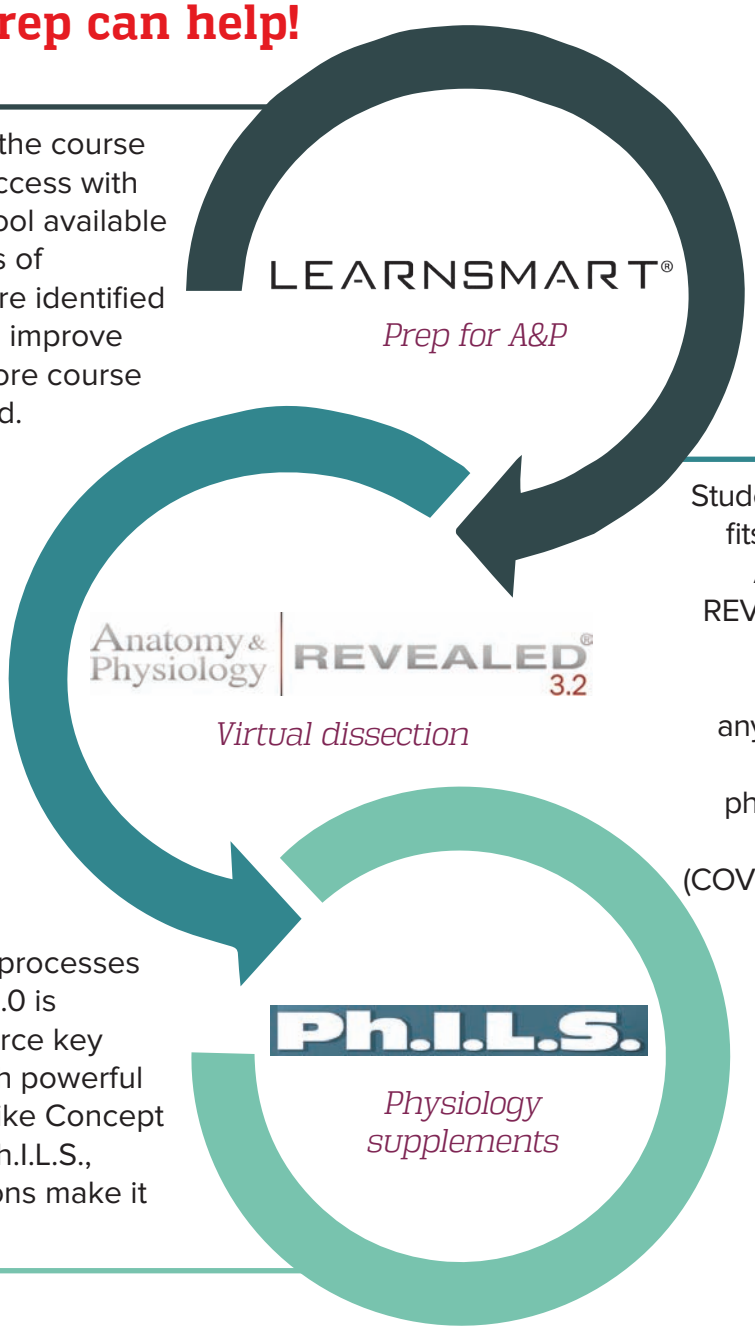

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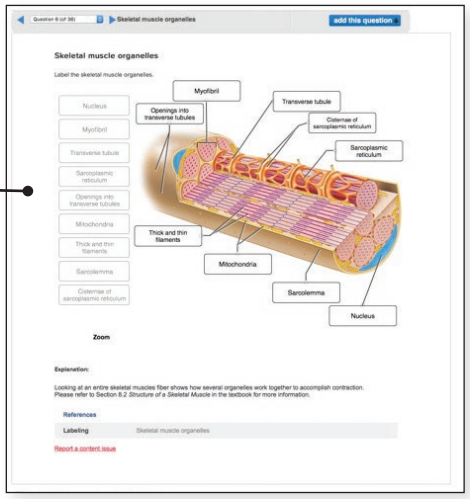
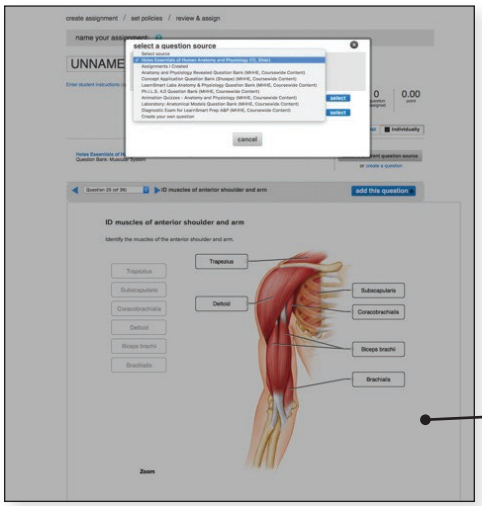
SEAMLESS DIGITAL & PRINT EXPERIENCE!

In this edition of *Hole's Essentials of Human Anatomy & Physiology,* the digital author team of Leslie Day and Julie Pilcher worked hand-in-hand with the print author team to deliver a seamless experience for instructors and students.

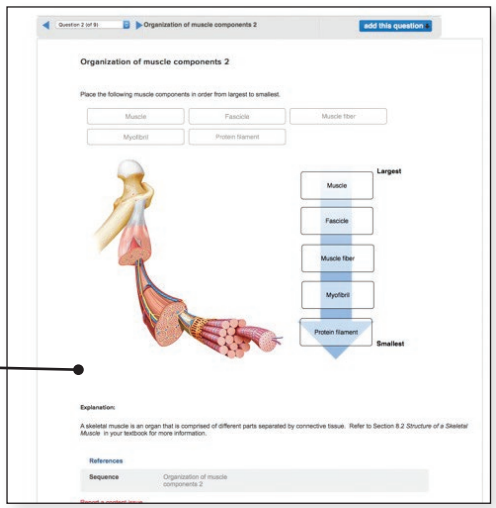
The digital authors make sure there is a variety of questions with different Bloom's Taxonomy levels. In this edition, we have increased the number of questions that are higher level Bloom's to 30 percent.



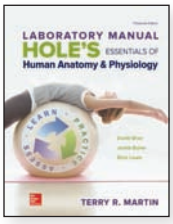


Leslie and Julie ensure that there is an appropriate number of questions for each learning outcome in the chapter. They tagged questions to textbook learning outcomes and to the Human Anatomy & Physiology Society (HAPS) learning outcomes. This makes it easy for instructors to find questions to assign in their course.

McGraw-Hill Connect® gives the instructor access to additional course-wide material for A&P. Instructors can access questions for Anatomy & Physiology REVEALED®, a variety of animations, diagnostic exam for LearnSmart Prep®, concept application questions, and supplemental laboratory questions.



For a detailed list of updates made to the digital resources, please contact your Learning Technology Representative.



Laboratory Manual for Hole's Essentials of Human Anatomy & Physiology, Thirteenth Edition, by Terry R. Martin, Kishwaukee College, is designed to accompany the thirteenth edition of *Hole's Essentials of Human Anatomy & Physiology.*

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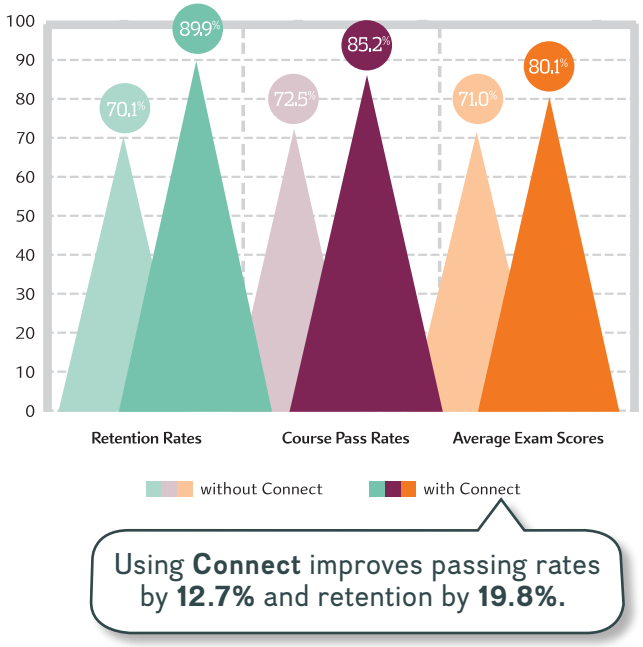

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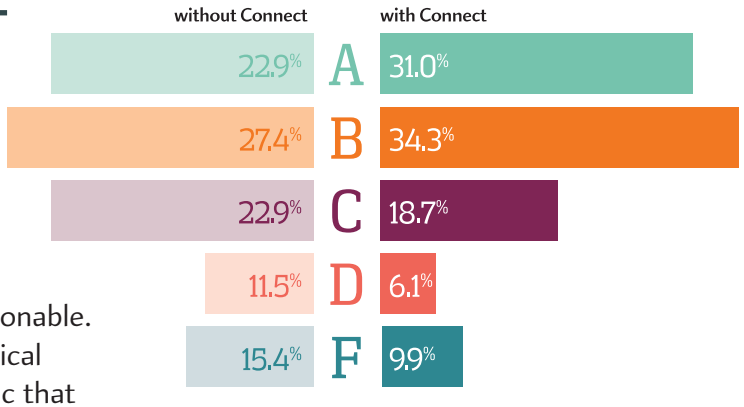

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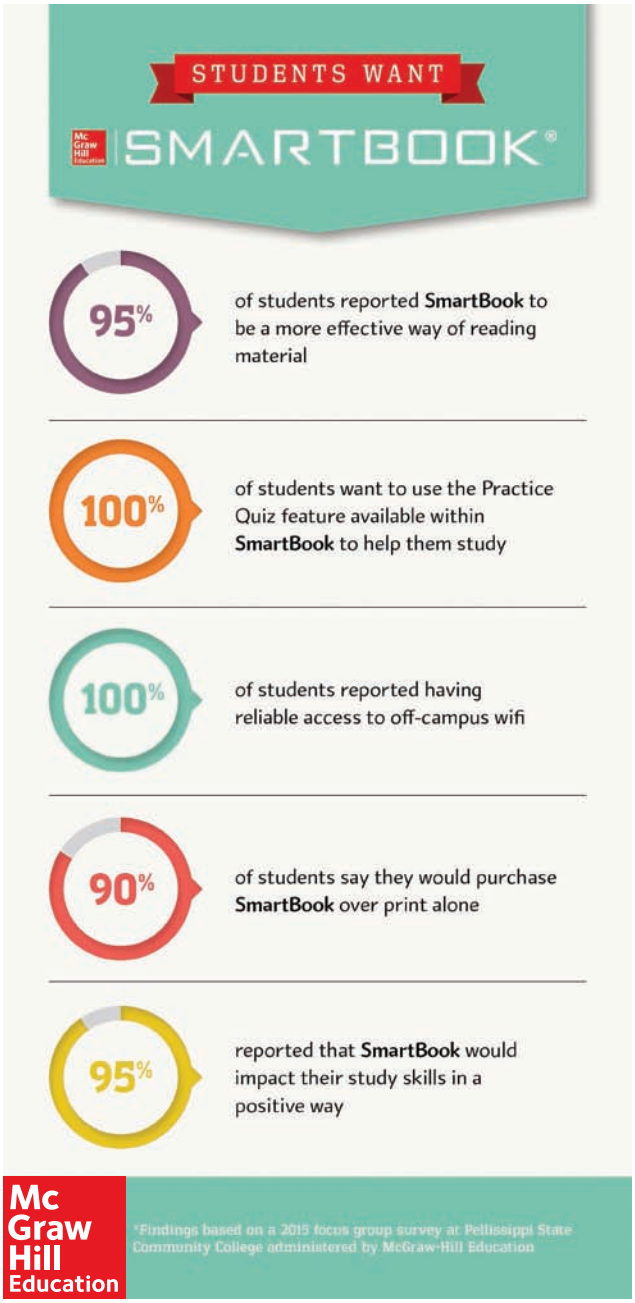

ACKNOWLEDGMENTS

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Any textbook is the result of hard work by a large team. Although we directed the revision, many "behind-the-scenes" people at McGraw-Hill were indispensable to the project. We would like to thank our editorial team of Amy Reed, Chloe Bouxsein, and Fran Simon; Jim Connely and Kelly Brown, marketing managers; our production team, which included Jayne Klein, Sandy Ludovissy, Tara McDermott, Lori Hancock, and Christina Nelson. We would also like to thank copyeditor Wendy Nelson, and most of all, John Hole, for giving us the opportunity and freedom to continue his classic work. We also thank our wonderfully patient families for their support.

David Shier
Jackie Butler
Ricki Lewis

A NOTE FROM THE AUTHORS

To the Student

Welcome! As you read this (with your eyes) and understand it (with your brain), perhaps turning to the next page (with muscle actions of your fingers, hand, forearm, and arm), you are using the human body to do so. Indeed, some of you may be using your fingers, hand, forearm, and arm to read through the eBook on your computer, tablet, or smartphone. Whether you use traditional or new technology, the thirteenth edition of *Hole's Essentials of Human Anatomy & Physiology* offers an interesting and readable introduction to how the human body accomplishes these tasks. The functioning of the body is not simple, and at times understanding may not seem easy, but learning how the body works is always fascinating and can be both useful and fun!

Many of you are on a path toward a career in health care, athletics, science, or education. Be sure to check out the Career Corner in every chapter. They present interesting options for future careers. Balancing family, work, and academics is challenging, but try to look at this course not as a hurdle along your way but as a stepping stone. We have written this book to help you succeed in your coursework and to help prepare you to make that journey to a successful and rewarding career.

To the Teacher

With this edition of *Hole's Essentials of Human Anatomy & Physiology,* Leslie Day and Julie Pilcher are continuing to develop LearnSmart and Connect and fully integrating them with the Hole's content. We are extremely excited that Hole's is keeping pace with the ever-changing array of technologies available to support teaching and learning.

The Learn, Practice, Assess approach continues with this thirteenth edition. Each chapter opens with Learning Outcomes, contains many opportunities to Practice throughout, and closes with Assessments that are closely tied to the Learning Outcomes. Students can use this feature not only to focus their study efforts, but also to take an active role in monitoring their own progress toward mastering the material. All of these resources are described in more detail in the Chapter Preview/ Foundations for Success beginning on page 1.

David Shier, Jackie Butler, Ricki Lewis, Leslie Day, and Julie Pilcher

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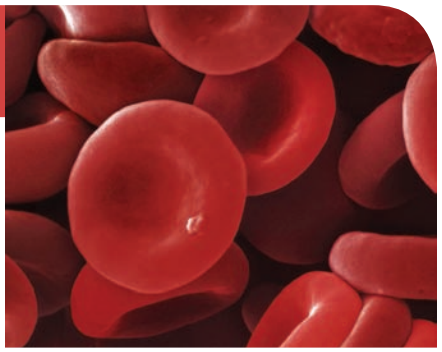
UNIT 1
LEVELS OF ORGANIZATION



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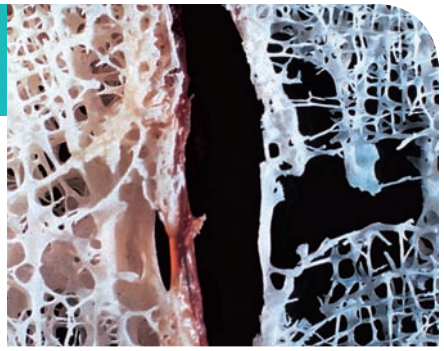
UNIT 2
SUPPORT AND MOVEMENT



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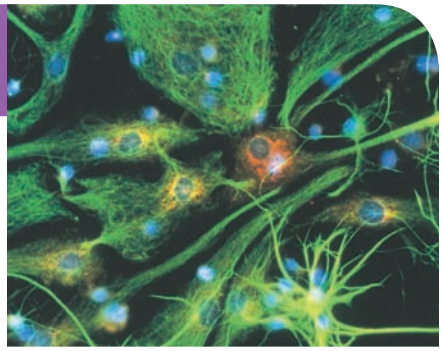
UNIT 3
INTEGRATION AND COORDINATION



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UNIT 4
TRANSPORT

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UNIT 5
ABSORPTION AND EXCRETION

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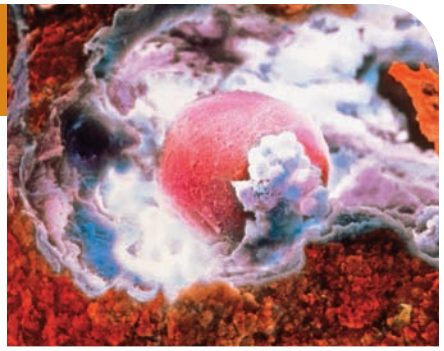
UNIT 6
THE HUMAN LIFE CYCLE



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A photo on the opening page for each chapter generates interest.

CHAPTER PREVIEW

Foundations for Success

The Chapter Preview not only provides great study tips to offer a foundation for success, but it also offers tips on how to utilize this particular text. Those tips will be found in boxes just like this.

AN OPENING VIGNETTE discusses current events or research news relating to the subject matter in the chapter. These vignettes apply the concepts learned in the study of anatomy and physiology.

Pay attention. It is a beautiful day. You can't help but stare wistfully out the window, the scent of spring blooms and sound of birds making it impossible to concentrate on what the instructor is saying. Gradually the lecture fades as you become aware of your own breathing, the beating of your heart, and the sweat that breaks out on your forehead in response to the radiant heat from the glorious day. Suddenly your reverie is cut short—a classmate has dropped a human anatomy and physiology textbook on the floor. You jump. Your heart hammers and a flash of fear grips your chest, but you soon realize what has happened and recover.

The message is clear: pay attention. So you do, tuning out the great outdoors and focusing on the class. In this course, you will learn all about the events that you have just experienced, including your response to the sudden stimulation. This is a good reason to stay focused.

LEARNING OUTLINE

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

Each chapter has a learning outline introducing what will be discussed in the chapter.

This digital tool, as indicated below and with the APR icons within the chapters, allows you to explore the human body in depth through simulated dissection of cadavers and histology preparations. It also offers animations on chapter concepts.

The section below introduces building blocks of words that your instructor may assign. Learning them is a good investment of your time, because they can be used over and over and apply to many of the terms you will use in your career. Appendix A has a comprehensive list of these prefixes, suffixes, and root words.

AIDS TO UNDERSTANDING WORDS *(Appendix A has a complete list of Aids to Understanding Words.)*

ana- [up] *ana*tomy: the study of breaking up the body into its parts.

multi- [many] *multi*tasking: performing several tasks simultaneously.

physio- [relationship to nature] *physi*ology: the study of how body parts function.

Major divisions within a chapter are called "A-heads." They are numbered sequentially and entitled with very large, blue type to designate major content areas.

P.1 | Introduction

After each A-Head is a list of learning outcomes indicating the knowledge you should gain as you work through the section. (Note the blue learn arrow preceding the "LEARN" heading.) These outcomes are intended to help you master the similar outcomes set by your instructor. The outcomes are tied directly to assessments of knowledge gained.

LEARN

1. Explain the importance of an individualized approach to learning.

Studying the human body can be overwhelming at times. The new terminology, used to describe body parts and how they work, can make it seem as if you are studying a foreign language. Learning all the parts of the body, along with the composition of each part, and how each part fits with the other parts to make the whole requires memorization. Understanding the way each body part works individually, as well as body parts working together, requires a higher level of knowledge, comprehension, and application. Identifying underlying structural similarities, from the macroscopic to the microscopic levels of body organization, taps more subtle critical thinking skills. This chapter will catalyze success in this active process of learning. (Remember that although the skills and tips discussed in this chapter relate to learning anatomy and physiology, they can be applied to other subjects.)

Learning occurs in different ways or modes. Most students use several modes (multimodal), but are more comfortable and use more effectively one or two, often referred to as learning styles. Some students prefer to read the written word to remember it and the concept it describes or to actually write the words; others learn best by looking at visual representations, such as photographs and drawings. Still others learn most effectively by hearing the information or explaining it to someone else. For some learners, true understanding remains elusive until a principle is revealed in a laboratory or clinical setting that provides a memorable context and engages all of the senses. This text accommodates the range of learning styles. Read-write learners will appreciate the lists, definitions (glossary), and tables. Visual learners will discover many diagrams, flow charts, and figures, all with consistent and purposeful use of color. For example, a particular bone is always the same color in figures where bones are color coded. Auditory learners will find pronunciations for new scientific terms to help sound them out, and kinesthetic learners can relate real-life examples and applications to their own activities.

After each major section, a question or series of questions tests your understanding of the material and enables you to practice using the new information. (Note the green practice arrow preceding the "PRACTICE" heading.) If you cannot answer the question(s), you should reread that section, being on the lookout for the answer(s).

PRACTICE

1. List some difficulties a student may experience when studying the human body.
2. Describe the ways people learn.

P.2 | Strategies for Your Success

LEARN

2. Summarize what you should do before attending class.
3. Identify student activities that enhance classroom experience.
4. List and describe several study techniques that can facilitate learning new material.

Many strategies for academic success are common sense, but it might help to review them. You may encounter new and helpful methods of learning.

The major divisions are subdivided into "B-heads," which are identified by large, black type. These will help you organize the concepts upon which the major divisions are built.

As you read, you may feel the need for a "study break" or to "chill out." At other times you may just need to shift gears. Try the following: Look for the shaded boxes throughout the book that present sidelights to the main focus of the text. Some of these may cover topics that your instructor chooses to highlight. Read them! They are interesting, informative, and a change of pace.

FACTS OF LIFE The skeleton of an average 160-pound person contributes about 29 pounds total body weight.

Before Class

Before attending class, prepare by reading and outlining or taking notes on the assigned pages of the text. If outlining, leave adequate space between entries to allow room for note-taking during lectures. Or fold each page of notes taken before class in half so that class notes can be written on the blank side of the paper across from the reading notes on the same topic. This strategy introduces the topics of the next class discussion, as well as new terms. Some students team a vocabulary list with each chapter's notes. Take the notes from the reading to class and expand them. At a minimum, the student should at least skim the text, reading the A-heads and B-heads and the summary outline to become acquainted with the topics and vocabulary before class.

CLINICAL APPLICATION 9.1

Factors Affecting Synaptic Transmission

Many chemicals affect synaptic transmission. A drug called Dilantin (diphenylhydantoin) treats seizure disorders by blocking gated sodium channels, thereby limiting the frequency of action potentials reaching the axon terminal. Caffeine in coffee, tea, cola, and energy drinks stimulates nervous system activity by lowering the thresholds at synapses. As a result, postsynaptic neurons are more easily excited. Antidepressants called "selective serotonin reuptake inhibitors" keep the neurotransmitter serotonin in synapses longer, compensating for a still little-understood decreased serotonin release that presumably causes depression.

Health-care workers repeatedly monitor patients' *vital signs*—observable body functions that reflect essential metabolic activities. Vital signs indicate that a person is alive. Assessment of vital signs includes measuring body temperature and blood pressure and monitoring heart rate and breathing movements. Absence of vital signs may signify death. A person who has died displays no spontaneous muscular movements, including those of the breathing muscles and beating heart. A dead person does not respond to stimuli and has no reflexes, such as the knee-jerk reflex and the pupillary reflexes of the eye. Brain waves cease with death, as demonstrated by a flat electroencephalogram (EEG), which signifies a lack of electrical activity in the brain.

Many students who use this book and take various other courses in the health sciences are preparing for careers in health care. Some students may be undecided as to a specific area or specialty. The Career Corner feature presents a description of a particular career choice with each chapter. If it doesn't describe a career that you seek, perhaps it will give you a better sense of what some of your coworkers and colleagues do!

CAREER CORNER

Massage Therapist

The woman feels something give way in her left knee as she lands from a jump in her dance class. She limps away between her classmates, in great pain. At home, she uses "RICE"—rest, ice, compression, elevation—then has a friend take her to an urgent care clinic, where a physician diagnoses patellar tendinitis, or "jumper's knee." Frequent jumping followed by lateral movements caused the injury.

Three days later, at her weekly appointment with a massage therapist for stress relief, the woman mentions the injury. Over the next few weeks, the massage therapist applies light pressure to the injured area to stimulate circulation, and applies friction in a transverse pattern to break up scar tissue and relax the muscles. She also massages the muscles to improve flexibility.

A massage therapist manipulates soft tissues, using combinations of stroking, kneading, compressing, and vibrating, to relieve pain and reduce stress. Training includes 300 to 1,000 hours of class time, hands-on practice, and continuing education. Specialties include pediatrics, sports injuries, and even applying massage techniques to racehorses.

GENETICS CONNECTION 16.1
Cystic Fibrosis

Many young children with this disease who cannot pronounce its name call it "65 Roses." Cystic fibrosis (CF) is an inherited defect in the ion channels that control chloride movement out of cells in certain organs. In the lungs, thick, sticky mucus accumulates and creates an environment hospitable to certain bacteria that are not common in healthy lungs. A mucus-clogged pancreas prevents digestive secretions from reaching the intestines, impairing nutrient digestion and absorption. A child with CF has trouble breathing and maintaining weight.

CF is inherited from two carrier parents, and affects about 30,000 people in the United States and about 70,000 worldwide. Many others may have milder cases, with recurrent respiratory infections. More than 2,000 mutations have been recognized in the cystic fibrosis transmembrane regulator (*CFTR*) gene, which encodes the chloride channel protein. Today fetuses and newborns with CF are diagnosed using genetic tests, but years ago the first signs were typically "failure to thrive," salty sweat, and foul-smelling stools.

When CF was recognized in 1938, life expectancy was only five years, but today median survival is about age fifty, with many patients living longer, thanks to drug treatments. Inhaled antibiotics control the respiratory infections, and daily "bronchial drainage" exercises shake stifling mucus from the lungs. A vibrating vest worn for half-hour periods two to four times a day also loosens mucus. Digestive enzymes mixed into soft foods enhance nutrient absorption, although some patients require feeding tubes.

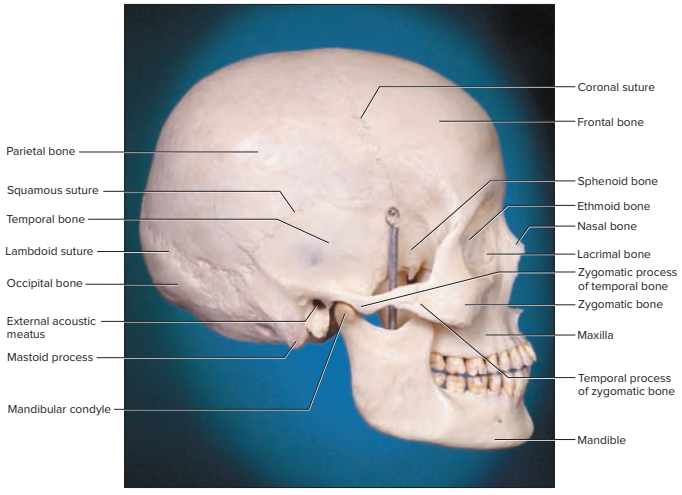
Discovery of the most common *CFTR* mutation in 1989 enabled development of more-targeted treatments. Thirty drugs are now in development. The new drugs work in various ways: correcting misfolded *CFTR* protein, restoring liquid on airway surfaces, breaking up mucus, improving nutrition, and fighting inflammation and infection.

Life with severe CF is challenging. In summertime, a child must avoid water from hoses, which harbor lung-loving *Pseudomonas* bacteria. Cookouts spew lung-irritating particulates. Too much chlorine in pools irritates lungs, whereas too little invites bacterial infection. New infections arise, too. In the past few years, multidrug-resistant *Mycobacterium abscessus*, related to the pathogen that causes tuberculosis, has affected 3% to 10% of CF patients in the United States and Europe.

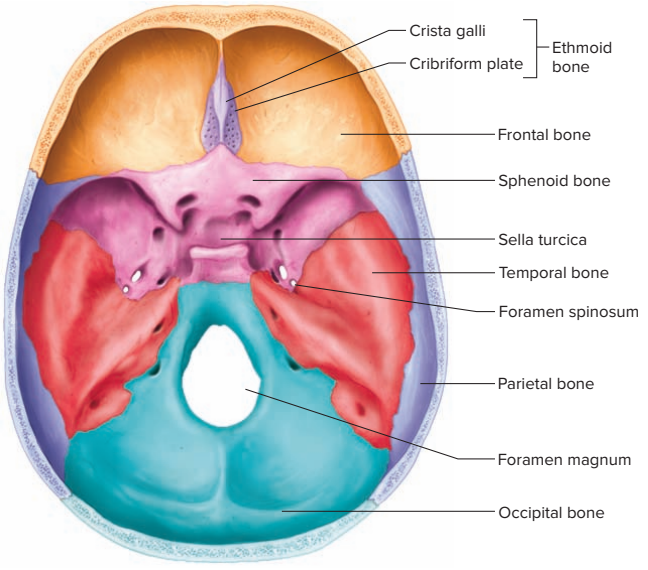
Remember when you were very young and were presented with a substantial book for the first time? You were likely intimidated by its length but were reassured that it contained "a lot of pictures." This book has many "pictures" (figures) too, all designed to help you master the material. Some of the figure legends are followed by a question pertaining to that figure, intended to reinforce a concept or usage of terminology.

Photographs and Line Art

Photographs provide a realistic view of anatomy.

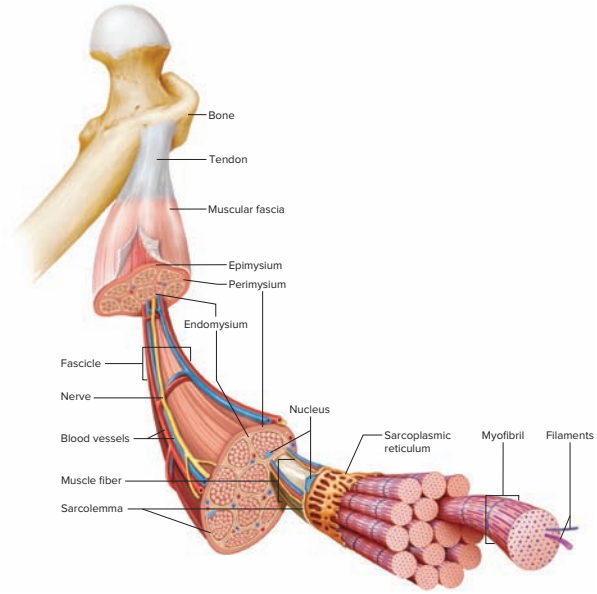


Line art can present different positions, layers, or perspectives.



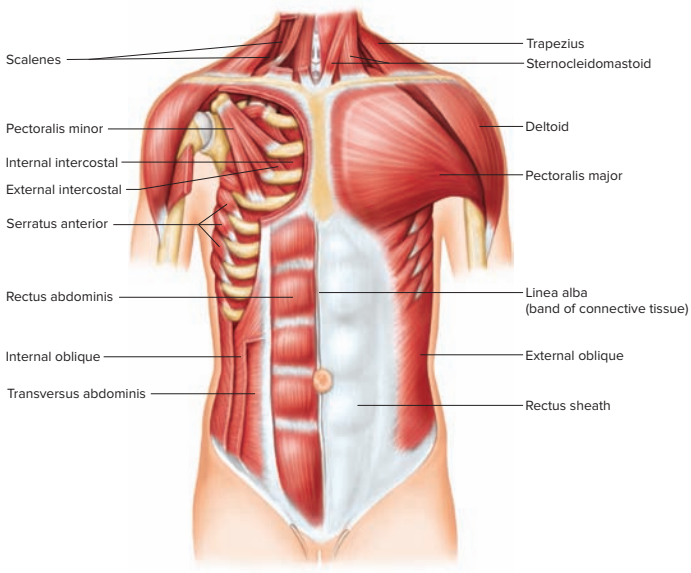
Macroscopic to Microscopic

Many figures show anatomical structures in a manner that is macroscopic to microscopic (or vice versa).



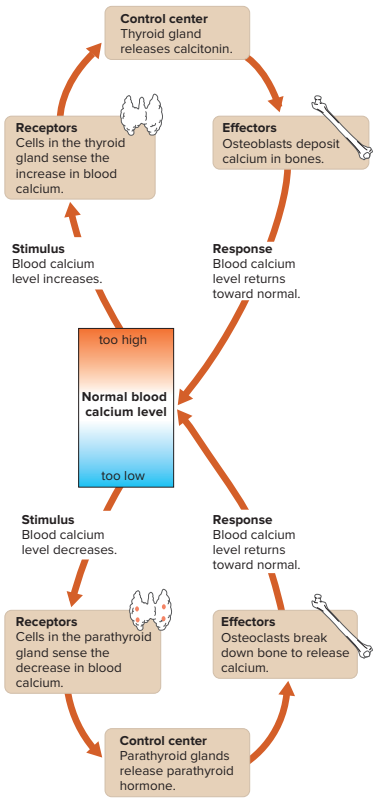
Anatomical Structures

Some figures illustrate the locations of anatomical structures.

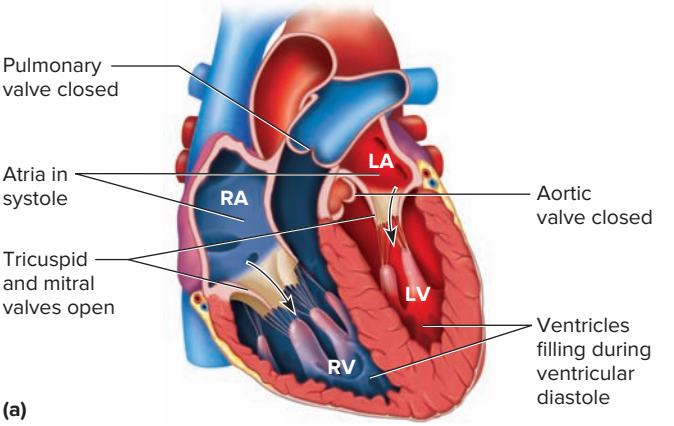


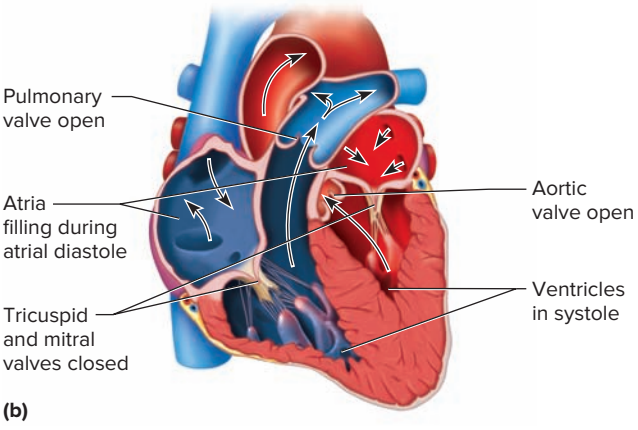
Flow Charts

Flow charts depict sequences of related events, steps of pathways, and complex concepts, easing comprehension. Other figures may show physiological processes.



Other figures illustrate the functional relationships of anatomical structures.





Organizational Tables

Organizational tables can help "put it all together," but are not a substitute for reading the text or having good notes.

TABLE 5.6 Muscle and Nervous Tissues

Type	Function	Location
Skeletal muscle tissue (striated)	Voluntary movements of skeletal parts	Muscles usually attached to bones
Smooth muscle tissue (lacks striations)	Involuntary movements of internal organs	Walls of hollow internal organs
Cardiac muscle tissue (striated)	Heart movements	Heart muscle
Nervous tissue	Sensory reception and conduction of electrical impulses	Brain, spinal cord, and peripheral nerves

It is critical that you attend class regularly, and be on time—even if the instructor's notes are posted online and the information is in the textbook. For many learners, hearing and writing new information is a better way to retain facts than just scanning notes on a computer screen. Attending lectures and discussion sections also provides more detailed and applied analysis of the subject matter, as well as a chance to ask questions.

During Class

Be alert and attentive in class. Take notes by adding to your outline or the notes you took while reading. Auditory learners benefit from recording the lectures and listening to them while doing chores. This is called **multitasking**—doing more than one activity at a time.

Participate in class discussions, asking questions of the instructor and answering questions he or she poses. All of the students are in the class to learn, and many will be glad someone asked a question others would not be comfortable asking. Such student response can alert the instructor to topics that are misunderstood or not understood at all. However, respect class policy. Due to time constraints and class size, asking questions may be more appropriate after class, for a large lecture class, or during tutorial (small group) sessions.

After Class

In learning complex material, expediency is critical. Organize, edit, and review notes as soon after class as possible, fleshing out sections where the lecturer got ahead of you. Highlighting or underlining (in color, for visual learners) the key terms, lists, important points, and major topics make them stand out, which is helpful for daily reviews and studying for exams.

Lists

Organizing information into lists or categories can minimize information overload, breaking it into manageable chunks. For example, when you study the muscles of the thigh, you will find it easier to learn the insertion, origin, action, and nerve supply of the four muscles making up the quadriceps femoris if you study them as a group, because they all have the same insertion, action at the knee, and nerve supply—they differ only in their origins.

Mnemonic Devices

Another method for remembering information is the **mnemonic device.** One type of mnemonic device is a list of words, forming a phrase, in which the first letter of each word corresponds to the first letter of each word that must be remembered. For example, ***Frequent parades often test soldiers' endurance*** stands for the skull bones **f**rontal, **p**arietal, **o**ccipital, **t**emporal, **s**phenoid, and **e**thmoid. Another type of mnemonic device is a word formed by the first letters of the items to be remembered. For example, ***ipmat*** represents the stages in the cell cycle: **i**nterphase, **p**rophase, **m**etaphase, **a**naphase, and **t**elophase. Be inventive! Develop mnemonic devices that you find helpful!

Study Groups

Forming small study groups helps some students. Together the students review course material and compare notes. Working as a team and alternating leaders allows students to verbalize the information. Individual students can study and master one part of the assigned material, and then explain it to the others in the group, which incorporates the information into the memory of the speaker. Hearing the material spoken aloud also helps the auditory learner. Be sure to use anatomical and physiological terms, in explanations and everyday conversation, until they become part of your working vocabulary, rather than intimidating jargon. Most important of all—the group must stay on task, and not become a vehicle for social interaction. Your instructor may have suggestions or guidelines for setting up study groups.

Flash Cards

Flash cards may seem archaic in this computer age, but they are still a great way to organize and master complex and abundant information. The act of writing or drawing on a note card helps the tactile learner. Master a few new cards each day and review cards from previous days, then use them all again at the end of the semester to prepare for the comprehensive final exam. They may even come in handy later, such as in studying for exams for admission to medical school or graduate school. Divide your deck in half and flip half of the cards so that the answer rather than the question is showing. Mix and shuffle them. Get used to identifying a structure or process from a description as well as giving

a description when provided with the name of a process or structure. This is more like what will be expected of you in the real world of the health-care professional.

Manage Your Time

For each hour in the classroom, most students will spend at least three hours outside of class studying. Many of you have important obligations outside of class, such as jobs and family responsibilities. As important as these are, you still need to master this material on your path to becoming a health-care professional. Good time-management skills are therefore essential in your study of human anatomy and physiology. In addition to class, lab, and study time, multitask. When you are waiting for a ride or sitting in a doctor's waiting room, use your time by reviewing notes or reading the text.

Daily repetition is helpful, so you should schedule several short study periods each day instead of an end-of-semester crunch to cram for an exam. This does not take the place of time spent to prepare for the next class. If you follow these suggestions for learning now, you can maximize your study time throughout the semester and will give yourself your best prospects for academic success. A working knowledge of the structure and function of the human body provides the foundation for all careers in the health sciences.

PRACTICE

3. Why is it important to prepare before attending class?
4. Name two ways to participate in class discussions.
5. List several aids for remembering information.

Summary Outline

A summary of the chapter provides an outline to review major ideas and is a tool for organizing thoughts.

P.1 Introduction

Try a variety of methods to study the human body.

P.2 Strategies for Your Success

Although strategies for academic success seem to be common sense, you might benefit from reminders of study methods.

1. Before class
   Read the assigned text material prior to the corresponding class meeting.
   a. Photographs give a realistic view, and line art shows different perspectives.
   b. Figures depicting macroscopic to microscopic show increase in detail.
   c. Flow charts depict sequences and steps.
   d. Figures of anatomical structures show locations.
   e. Organizational charts/tables summarize text.
2. During class
   Take notes and participate in class discussions.
3. After class
   a. Organize, edit, and review class notes.
   b. Mnemonic devices aid learning.
      (1) The first letters of the words you want to remember begin words of an easily recalled phrase.
      (2) The first letters of the items to be remembered form a word.
   c. Small study groups reviewing and vocalizing material can divide and conquer the learning task.
   d. Making flash cards helps the tactile learner.
   e. Time management skills encourage scheduled studying, including daily repetition instead of cramming for exams.

CHAPTER ASSESSMENTS

Chapter assessments that are tied directly to the learning outcomes allow you to assess your mastery of the material. (Note the purple assess arrow.)

P.1 Introduction

1. Explain why the study of the human body can be overwhelming.

P.2 Strategies for Your Success

2. Methods to prepare for class include _____.
   a. reading the chapter
   b. outlining the chapter
   c. making a vocabulary list
   d. all of the above

3. Describe how you can participate in class discussions.
4. Forming the phrase "I passed my anatomy test" to remember the cell cycle (interphase, prophase, metaphase, anaphase, telophase) is a _____ device.
5. Name a benefit and a drawback of small study groups.
6. Give an example of effective time management used in preparation for success in the classroom.

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

A textbook is inherently linear. This text begins with Chapter 1 and ends with Chapter 20. Understanding physiology and the significance of anatomy, however, requires you to be able to recall previous concepts. Critical thinking is all about linking previous concepts with current concepts under novel circumstances, in new ways. Toward this end, we have included in the Integrative Assessments/Critical Thinking exercises referencing sections from earlier chapters. Making connections is what it is all about!

OUTCOMES P.1, P.2

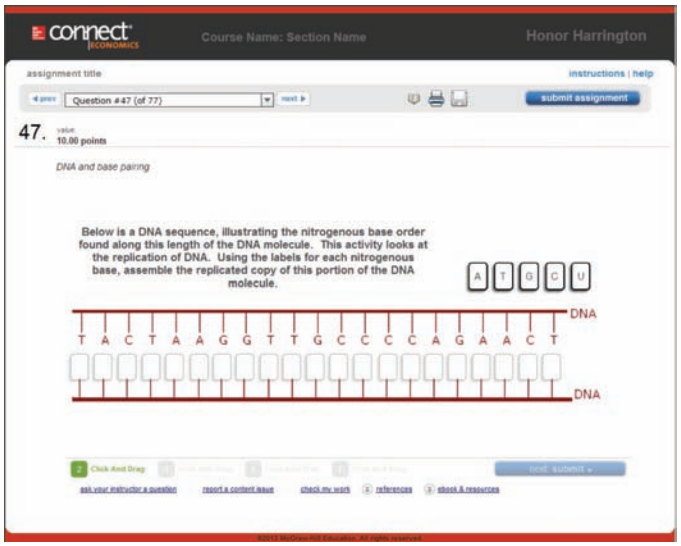
1. Which study methods are most successful for you?

OUTCOME P.2

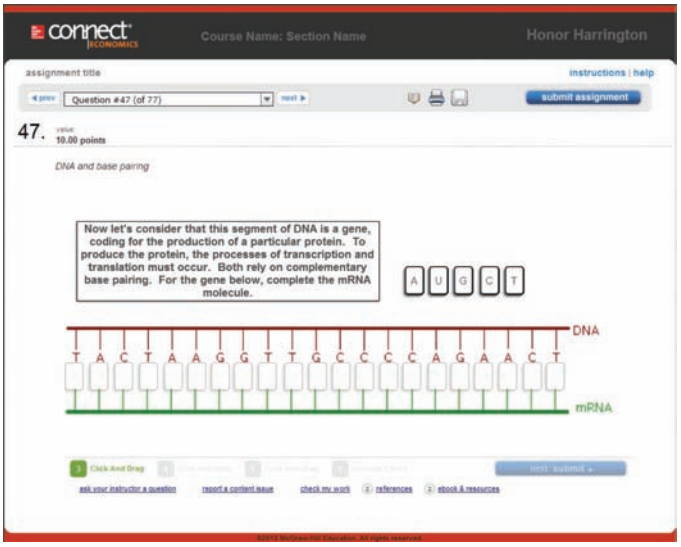
2. Design a personalized study schedule.

Check out McGraw-Hill online resources that can help you practice and assess your learning.

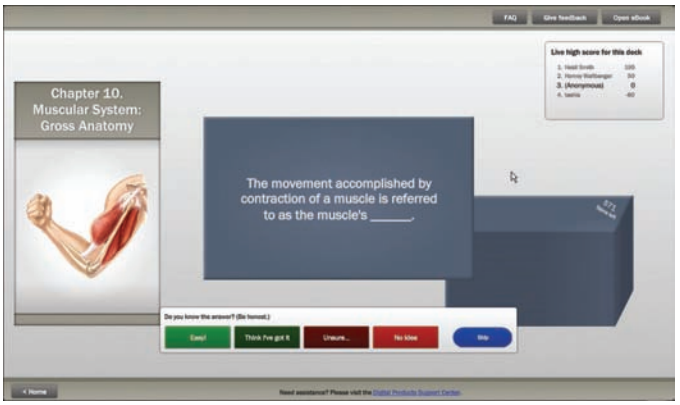
Connect Interactive Questions Reinforce your knowledge using assigned interactive questions.



Connect Integrated Activity Practice your understanding.



Learn Smart Discover which concepts you have mastered and which require more attention with this personalized, adaptive learning tool.



Anatomy & Physiology Revealed Go more in depth using virtual dissection of a cadaver.

A wooden toe on an ancient Egyptian mummy reveals sophisticated knowledge of human anatomy and physiology from long ago.

1

Introduction to Human Anatomy and Physiology

The mummy's toe. She lived between 1069 and 664 B.C. in Thebes, a city in ancient Egypt. Only pieces of her skeleton remain, held in place with plaster, glue, and linen. Yet the telltale bones reveal a little of what her life was like.

The shape of the pelvic bones indicates that the person was female. She was 50 to 60 years old when she died, according to the way the bony plates of her skull fit together and the lines of mineral deposition in a well-preserved tooth. Among the preserved bones from the skull, pelvis, upper limbs, and right lower limb, the right big toe stands out, because it ends in a prosthesis, a manufactured replacement for a skeletal part. Was it purely cosmetic, or did it work?

The mummy's toe tip is wooden and painted a dark brown, perhaps to blend in with her skin color. A long part and two smaller parts anchor the structure to the stump. Seven leather strings once attached it to the foot, and it even bears a fake nail. Connective tissue and skin grew over the prosthesis, revealing that her body had accepted the replacement part. The shape of the prosthesis was remarkably like that of a real toe. Signs of wear indicate that it was indeed used. Modern-day scientists made replicas of the toe and volunteers who were missing the same toe tried them out, demonstrating that the mummy's toe must have been crucial for balance and locomotion.

The replacement toe is evidence of sophisticated medical technology. Modern-day medical sleuths obtained computerized tomography (CT) scans of the remnants of the mummy. They detected poor mineral content in the toe, plus calcium deposits in the largest blood vessel, the aorta, suggesting impaired circulation to the feet. Perhaps the mummy in life suffered from diabetes mellitus, which can impede circulation to the toes. If gangrene had set in, healers might have amputated the affected portion of the toe, replacing it with a very reasonable facsimile.

The ancient Egyptians made other replacement parts, including ears, noses, feet, and lower limbs. Today prosthetic toes are made of silicones, which are plastic-like materials. People use prosthetic toes to replace digits lost to injury, cancer, or, perhaps like the ancient Egyptian woman, diabetes.

LEARNING OUTLINE

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

APR Module 1
Body Orientation

AIDS TO UNDERSTANDING WORDS *(Appendix A has a complete list of Aids to Understanding Words.)*

append- [to hang something] *append*icular: pertaining to the limbs.

cardi- [heart] peri*cardi*um: membrane that surrounds the heart.

cran- [helmet] *cran*ial: pertaining to the portion of the skull that surrounds the brain.

dors- [back] *dors*al: position toward the back.

homeo- [same] *homeo*stasis: maintenance of a stable internal environment.

-logy [study of] physio*logy*: study of body functions.

meta- [change] *meta*bolism: chemical changes in the body.

pariet- [wall] *pariet*al membrane: membrane that lines the wall of a cavity.

pelv- [basin] *pelv*ic cavity: basin-shaped cavity enclosed by the pelvic bones.

peri- [around] *peri*cardial membrane: membrane that surrounds the heart.

pleur- [rib] *pleur*al membrane: membrane that encloses the lungs and lines the thoracic cavity.

-stasis [standing still] homeo*stasis*: maintenance of a stable internal environment.

-tomy [cutting] ana*tomy*: study of structure, which often involves cutting or removing body parts.

1.1 | Introduction

LEARN

1. Identify some of the early discoveries that led to our understanding of the body.

Modern medicine began with long-ago observations on the function, and malfunction, of the human body. The study of the human body likely began when our early ancestors became curious about how their bodies worked, as we are today. At first they probably thought mostly about injuries and illnesses, because healthy bodies demand little attention from their owners. Early healers relied heavily on superstitions and notions about magic. However, as healers tried to help the sick, they began to discover useful ways of examining and treating the human body. They observed the effects of injuries, noticed how wounds healed, and examined cadavers to determine causes of death. They also found that certain herbs and potions could relieve coughs, headaches, fevers, and other common indications of illness.

Over time, people began to believe that humans could understand forces that caused natural events. They began observing the world around them more closely, asking questions and seeking answers. This curiosity set the stage for the development of modern medical science.

As techniques for making accurate observations and performing careful experiments evolved, knowledge of the human body expanded rapidly (fig. 1.1). At the same time, early medical providers coined many new terms to name body parts, describe the locations of the parts, and explain their functions and interactions. These terms, most of which originated from Greek and Latin words, formed the basis for the language of anatomy and physiology that persists today. (The names of some modern medical and applied sciences are listed in section 1.7, Anatomical Terminology.)

Much of what we know about the human body is based on *scientific method*, an approach to investigating the natural world. It is part of a general process called scientific inquiry. Scientific method consists of testing a hypothesis and then rejecting or accepting it, based on the results of experiments or observations. This method is described in greater detail in Appendix B, Scientific Method, but it is likely that aspects of its application are already familiar to you. Imagine buying a used car. The dealer insists that the car is in fine shape, but you discover that the engine doesn't start. That's an experiment! It tests the hypothesis: If this car is in good shape, then it will start. When the car doesn't start, the wary consumer rejects the hypothesis and doesn't buy the car.

Figure 1.1 The study of the human body has a long history, as evidenced by this illustration from the second book of *De Humani Corporis Fabrica* by Andreas Vesalius, issued in 1543. (Note the similarity to the anatomical position, described later in this chapter.) © Classic Image/Alamy

Rather than giving us all the answers, science eliminates wrong explanations. Our knowledge of the workings of the human body reflects centuries of asking questions, and testing, rejecting, and sometimes accepting hypotheses. New technologies provide new views of anatomy and physiology, so that knowledge is always growing. One day you may be the one to discover something previously unknown about the human body!

PRACTICE

1. What factors probably stimulated an early interest in the human body?
2. What kinds of activities helped promote the development of modern medical science?

1.2 | Anatomy and Physiology

LEARN

2. Explain how anatomy and physiology are related.

Anatomy (ah-nat′o-me) deals with the structure (morphology) of body parts—their forms and how they are organized. **Physiology** (fiz″e-ol′o-je) concerns the functions of body parts—what they do and how they do it.

The topics of anatomy and physiology are difficult to separate because the structures of body parts are so closely associated with their functions. Body parts form a well-organized unit—the human organism—and each part functions in the unit's operation. A particular body part's function depends on the way the part is constructed—that is, how its subparts are organized. For example, the organization of the parts in the human hand with its long, jointed fingers makes it easy to grasp objects; the hollow chambers of the heart are adapted to pump blood through tubular blood vessels; the shape of the mouth enables it to receive food; and teeth are shaped to break solid foods into small pieces (fig. 1.2).

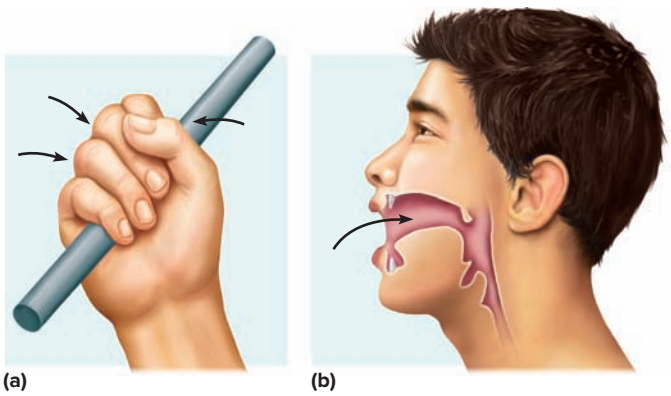


Figure 1.2 The structures of body parts make possible their functions: **(a)** The hand is adapted for grasping, **(b)** the mouth for receiving food. (Arrows indicate movements associated with these functions.)

As ancient as the fields of anatomy and physiology are, we are always learning more. For example, researchers recently used imaging technology to identify a previously unrecognized part of the brain, the planum temporale, which enables people to locate sounds in space. Many discoveries today begin with investigations at the microscopic level—molecules and cells. In this way, researchers discovered that certain cells in the small intestine bear the same types of taste receptor proteins as found on the tongue. At both locations, the receptors detect molecules of sugar. The cells in the tongue provide taste sensations, whereas the cells in the intestines help regulate the digestion of sugar. The discovery of the planum temporale is anatomical; the discovery of sugar receptors in the intestine is physiological.

By discovering which of our 20,500 or so genes are active in particular diseases, researchers are finding commonalities among illnesses that are not apparent on the whole-body level. These findings suggest new targets for drugs—both new ones and "repurposed" drugs that are already available.

CAREER CORNER

Emergency Medical Technician

The driver turns a corner and suddenly swerves as a cat dashes into the road. She slams on the brakes but hits a parked car, banging her head against the steering wheel. Onlookers call 911, and within minutes an ambulance arrives.

The driver of the ambulance and another emergency medical technician (EMT) leap out and run over to the accident scene. They open the driver-side door and quickly assess the woman's condition by evaluating her breathing and taking her blood pressure and pulse. She is bleeding from a laceration on her forehead, and is conscious but confused.

The EMTs carefully place a restraint at the back of the woman's neck and move her onto a board, then slide her into the ambulance. While one EMT drives, the other rides in the back with the patient and applies pressure to the cut. At the hospital, the EMTs document the care provided and clean and restock the ambulance.

EMTs care for ill or injured people in emergency situations and transport patients, such as from a hospital to a nursing home. The work is outdoors and indoors and requires quick thinking as well as strength. Requirements vary by state, but all EMTs must be licensed. Basic EMTs take 120–150 hours of training; paramedic EMTs take 1200–1800 hours of training. Paramedics may give injections, set up intravenous lines, and give more medications than can basic EMTs.

PRACTICE

3. Why is it difficult to separate the topics of anatomy and physiology?
4. List examples that illustrate how the structure of a body part makes possible its function.

1.3 | Levels of Organization

LEARN

3. List the levels of organization in the human body and the characteristics of each.

Until the invention of magnifying lenses and microscopes about 400 years ago, anatomists were limited in their studies to what they could see with the unaided eye—large parts. But with these new tools, investigators discovered that larger body structures are made up of smaller parts, which in turn are composed of even smaller ones.

Figure 1.3 shows the levels of organization that modern-day scientists recognize. All materials, including those that make up the human body, are composed of chemicals. Chemicals consist of microscopic particles called **atoms,** which join to form **molecules.** Small molecules can combine in complex ways to form larger **macromolecules.**

In the human and other organisms, the basic unit of structure and function is a **cell,** which is microscopic. Although cells vary in size, shape, and specialized functions, all share certain characteristics. For instance, all cells of humans and other complex organisms contain structures called **organelles** (or′gah-nelz′) that carry out specific activities. Organelles are composed of aggregates of macromolecules, such as proteins, carbohydrates, lipids, and nucleic acids.

Cells may be organized into layers or other structures that have common functions. Such a group of cells forms a **tissue.** Groups of different tissues that interact form **organs**—complex structures with specialized functions—and groups of organs that function closely together compose **organ systems.** Organ systems make up an **organism** (or′gah-nizm), which is a living thing.

Body parts can be described in terms of different levels of organization, such as the *atomic level,* the *molecular level,* or the *cellular level.* Furthermore, body parts differ in complexity from one level to the next. That is, atoms are less complex than molecules, molecules are less complex than organelles, tissues are less complex than organs, and so forth.

Chapters 2–6 discuss these levels of organization in more detail. Chapter 2 describes the atomic and molecular levels. Chapter 3 deals with organelles and cellular structures and functions, and chapter 4 explores cellular metabolism.

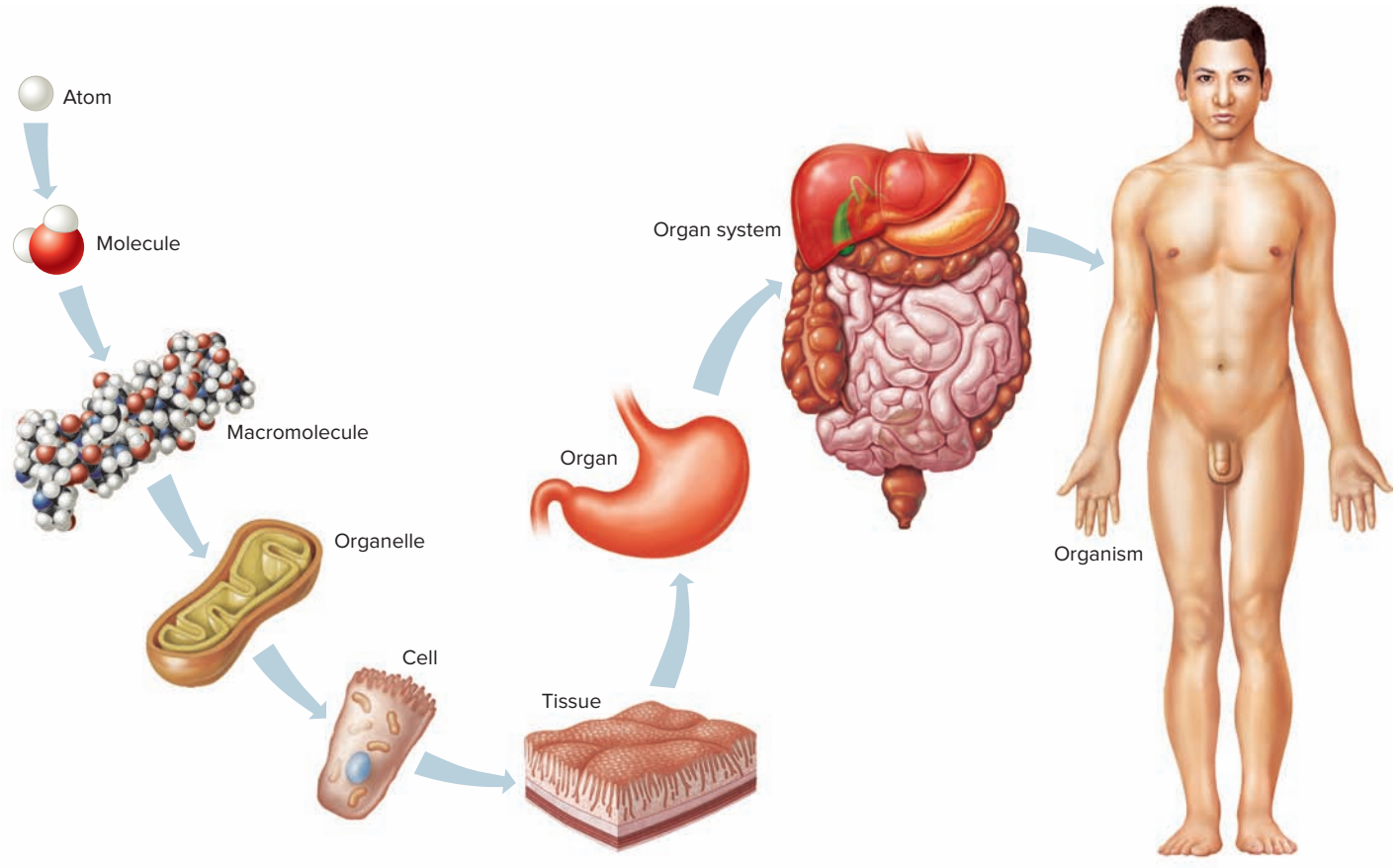


Figure 1.3 A human body is composed of parts made up of other parts, with increasing complexity.

Chapter 5 describes tissues and presents membranes (linings) as examples of organs, and chapter 6 considers the skin and its accessory organs as an example of an organ system. The remaining chapters describe the structures and functions of each of the other organ systems in detail.

PRACTICE

5. How does the human body illustrate levels of organization?
6. What is an organism?
7. How do body parts at different levels of organization vary in complexity?

1.4 | Characteristics of Life

LEARN

4. List and describe the major characteristics of life.
5. Give examples of metabolism.

As living organisms, we can respond to our surroundings. Our bodies grow, eventually becoming able to reproduce. We gain energy by ingesting (taking in), digesting (breaking down), absorbing, and assimilating the nutrients in food. The absorbed substances circulate throughout the internal environment of our bodies. We can then, by the process of respiration, use the energy in these nutrients for such vital functions as movement, growth, and repair of tissues. Finally, we excrete wastes. Taken together, these physical and chemical events that obtain, release, and use energy are a major part of **metabolism** (mĕ-tab′o-liz-m), which refers to all of the chemical reactions in cells. Table 1.1 summarizes the characteristics of life.

PRACTICE

8. What are the characteristics of life?
9. How are the characteristics of life dependent on metabolism?

1.5 | Maintenance of Life

LEARN

6. List and describe the major requirements of organisms.
7. Explain the importance of homeostasis to survival.
8. Describe the parts of a homeostatic mechanism and explain how they function together.

The structures and functions of almost all body parts help maintain life. Even an organism's reproductive structures, whose primary function is to ensure that the organism's species will continue into the future, may contribute to survival. For example, sex hormones help to strengthen bones.

Requirements of Organisms

Being alive requires certain environmental factors, including the following:

1. **Water** is the most abundant chemical in the body. It is required for many metabolic processes and provides the environment in which most of them take place. Water also carries substances within the organism and is important in regulating body temperature. Water inside the cells, along with substances dissolved in it, constitutes the *intracellular fluid*. Similarly, outside of the cells, including the tissue fluid and the liquid portion of the blood (plasma), is the *extracellular fluid* (fig. 1.4).
2. **Foods** are substances that provide the body with necessary chemicals (nutrients) in addition to water. Some

TABLE 1.1 Characteristics of Life

Process	Examples
Movement	Change in position of the body or of a body part; motion of an internal organ
Responsiveness	Reaction to a change inside or outside the body
Growth	Increase in body size without change in shape
Reproduction	Production of new organisms and new cells
Respiration	Obtaining oxygen, removing carbon dioxide, and releasing energy from foods (Some forms of life do not use oxygen in respiration.)
Digestion	Breakdown of food substances into simpler forms that can be absorbed and used
Absorption	Passage of substances through membranes and into body fluids
Circulation	Movement of substances in body fluids
Assimilation	Changing absorbed substances into chemically different forms
Excretion	Removal of wastes produced by metabolic reactions

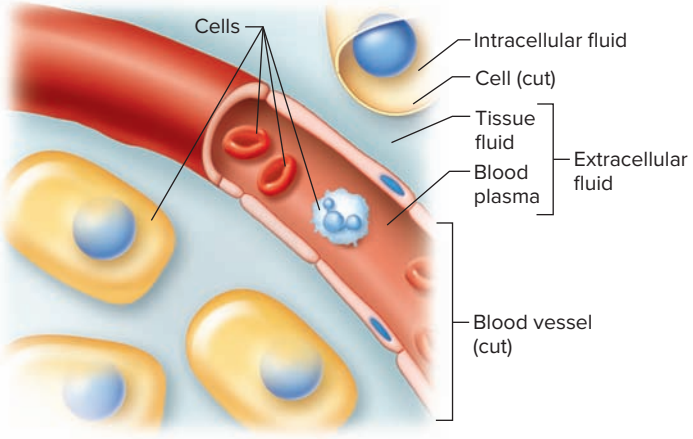


Figure 1.4 Intracellular and extracellular fluids. The extracellular fluid constitutes the internal environment of the body.

of these chemicals are used as energy sources, others supply raw materials for building new living matter, and still others help regulate vital chemical reactions.

3. **Oxygen** is a gas that makes up about one-fifth of ordinary air. It is used to release energy from food substances. This energy, in turn, drives metabolic processes.
4. **Heat** is a form of energy. It is a product of metabolic reactions, and the degree of heat present partly determines the rate at which these reactions occur. Generally, the more heat, the more rapidly chemical reactions take place. (*Temperature* is a measure of the degree of heat.)
5. **Pressure** is an application of force to something. For example, the force on the outside of the body due to the weight of air above it is called **atmospheric pressure.** In humans, this pressure is important in breathing. Similarly, organisms living underwater are subjected to **hydrostatic pressure**—a pressure a liquid exerts—due to the weight of water above them. In humans, heart action produces blood pressure (another form of hydrostatic pressure), which forces blood to flow through blood vessels.

Health-care workers repeatedly monitor patients' *vital signs*—observable body functions that reflect essential metabolic activities. Vital signs indicate that a person is alive. Assessment of vital signs includes measuring body temperature and blood pressure and monitoring rates and types of pulse and breathing movements. Absence of vital signs signifies death. A person who has died displays no spontaneous muscular movements, including those of the breathing muscles and beating heart. A dead person does not respond to stimuli and has no reflexes, such as the knee-jerk reflex and the pupillary reflexes of the eye. Brain waves cease with death, as demonstrated by a flat electroencephalogram (EEG), which signifies a lack of electrical activity in the brain.

Organisms require water, food, oxygen, heat, and pressure, but these alone are not enough to ensure survival. Both the quantities and the qualities of such factors are also important. For example, the volume of water entering and leaving an organism must be regulated, as must the concentration of oxygen in body fluids. Similarly, survival depends on the quality as well as the quantity of food available—that is, food must supply the correct nutrients in adequate amounts.

Homeostasis

Factors in the outside world, the external environment, may change. If an organism is to survive, however, conditions within the fluid surrounding its body cells, which compose its **internal environment,** must remain relatively stable. In other words, body parts function only when the concentrations of water, nutrients, and oxygen and the conditions of heat and pressure remain within certain narrow limits. This condition of a stable internal environment is called **homeostasis** (ho″me-ō-sta′sis).

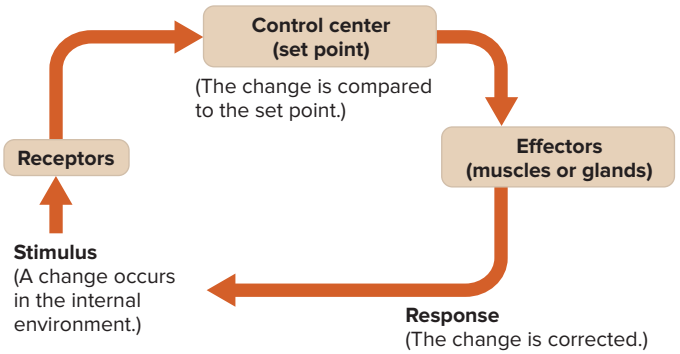


Figure 1.5 A homeostatic mechanism monitors a particular aspect of the internal environment and corrects any changes back to the value indicated by the set point.

The body maintains homeostasis through a number of self-regulating control systems, called **homeostatic mechanisms,** that share the following three components (fig. 1.5):

- **Receptors** provide information about specific conditions (stimuli) in the internal environment.
- A **set point** tells what a particular value should be, such as body temperature at 37°C (Celsius) or 98.6°F (Fahrenheit). More about metric equivalents can be found in Appendix C; metric units are used throughout this text.
- **Effectors** bring about responses that alter conditions in the internal environment.

A homeostatic mechanism generally works as follows. If the receptors measure deviations from the set point, effectors are activated that can return conditions toward normal. As conditions return toward normal, the deviation from the set point progressively lessens and the effectors are gradually shut down. Such a response is called a **negative feedback** (neg′ah-tiv fēd′bak) mechanism, both because the deviation from the set point is corrected (moves in the opposite or negative direction) and because the correction reduces the action of the effectors. This latter aspect is important because it prevents a correction from going too far.

To better understand the idea of negative feedback, imagine a room equipped with a furnace and an air conditioner (fig. 1.6). If the room temperature is to remain near 20°C (68°F), the thermostat is adjusted to an operating level, or set point, of 20°C. A thermostat, which senses temperature changes, signals the furnace to start and the air conditioner to stop whenever the room temperature drops below the set point. If the temperature rises above the set point, the thermostat stops the furnace and starts the air conditioner. As a result, the room maintains a relatively constant temperature.

Body temperature is regulated by a homeostatic mechanism that is similar to control of room temperature. Temperature receptors are scattered throughout the body. The "thermostat" is a temperature-sensitive region in a temperature control center of the brain. In healthy people, the set point of the brain's thermostat is at or near 37°C (98.6°F).

If a person is exposed to cold and body temperature begins to drop, the temperature receptors sense this change and the temperature control center triggers heat-generating