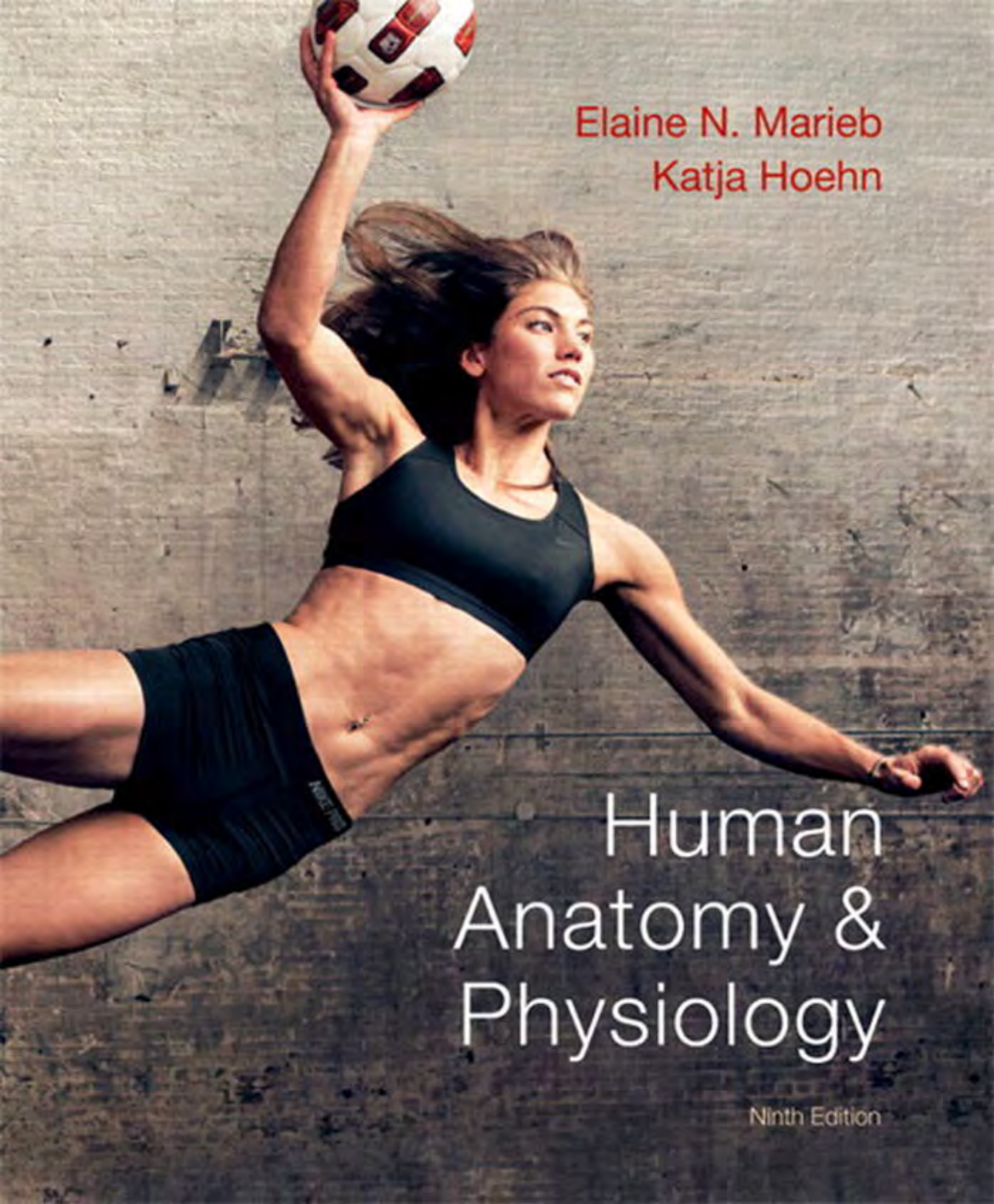
Elaine N. Marieb
Katja Hoehn
Human Anatomy & Physiology
Ninth Edition

Human Anatomy & Physiology

Ninth Edition

Elaine N. Marieb, R.N., Ph.D.
Holyoke Community College

Katja Hoehn, M.D., Ph.D.
Mount Royal University

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About the Authors

We dedicate this work to our students both present and past, who always inspire us to "push the envelope."

Elaine N. Marieb

For Elaine N. Marieb, taking the student's perspective into account has always been an integral part of her teaching style. Dr. Marieb began her teaching career at Springfield College, where she taught anatomy and physiology to physical education majors. She then joined the faculty of the Biological Science Division of Holyoke Community College in 1969 after receiving her Ph.D. in zoology from the University of Massachusetts at Amherst. While teaching at Holyoke Community College, where many of her students were pursuing nursing degrees, she developed a desire to better understand the relationship between the scientific study of the human body and the clinical aspects of the nursing practice. To that end, while continuing to teach full time, Dr. Marieb pursued her nursing education, which culminated in a Master of Science degree with a clinical specialization in gerontology from the University of Massachusetts. It is this experience that has informed the development of the unique perspective and accessibility for which her publications are known.

Dr. Marieb has partnered with Benjamin Cummings for over 30 years. Her first work was *Human Anatomy & Physiology Laboratory Manual* (*Cat Version*), which came out in 1981. In the years since, several other lab manual versions and study guides, as well as the softcover *Essentials of Human Anatomy & Physiology* textbook, have hit the campus bookstores. This textbook, now in its 9th edition, made its appearance in 1989 and is the latest expression of her commitment to the needs of students studying human anatomy and physiology.

Dr. Marieb has given generously to provide opportunities for students to further their education. She contributes to the New Directions, New Careers Program at Holyoke Community College by funding a staffed drop-in center and by providing several full-tuition scholarships each year for women who are returning to college after a hiatus or attending college for the first time and who would be unable to continue their studies without financial support. She funds the E. N. Marieb Science Research Awards at Mount Holyoke College, which promotes research by undergraduate science majors, and has underwritten renovation and updating of one of the biology labs in Clapp Laboratory at that college. Dr. Marieb also contributes to the University of Massachusetts at Amherst where she generously provided funding for reconstruction and instrumentation of a cutting-edge cytology research laboratory. Recognizing the severe national shortage of nursing faculty, she underwrites the Nursing Scholars of the Future Grant Program at the university.

In 1994, Dr. Marieb received the Benefactor Award from the National Council for Resource Development, American Association of Community Colleges, which recognizes her ongoing sponsorship of student scholarships, faculty teaching awards, and other academic contributions to Holyoke Community College. In May 2000, the science building at Holyoke Community College was named in her honor.

Dr. Marieb is an active member of the Human Anatomy and Physiology Society (HAPS) and the American Association for the Advancement of Science (AAAS). Additionally, while actively engaged as an author, Dr. Marieb serves as a consultant for the Benjamin Cummings *Interactive Physiology*® CD-ROM series.

When not involved in academic pursuits, Dr. Marieb is a world traveler and has vowed to visit every country on this planet. Shorter term, she serves on the scholarship committee of the Women's Resources Center and on the board of directors of several charitable institutions in Sarasota County. She is an enthusiastic supporter of the local arts and enjoys a competitive match of doubles tennis.

Katja Hoehn

Dr. Katja Hoehn is an associate professor in the Department of Chemical and Biological Sciences at Mount Royal University in Calgary, Canada. Dr. Hoehn's first love is teaching. Her teaching excellence has been recognized by several awards during her 17 years at Mount Royal University. These include a PanCanadian Educational Technology Faculty Award (1999), a Teaching Excellence Award from the Students' Association of Mount Royal (2001), and the Mount Royal Distinguished Faculty Teaching Award (2004).

Dr. Hoehn received her M.D. (with Distinction) from the University of Saskatchewan, and her Ph.D. in Pharmacology from Dalhousie University. In 1991, the Dalhousie Medical Research Foundation presented her with the Max Forman (Jr.) Prize for excellence in medical research. During her Ph.D. and postdoctoral studies, she also pursued her passion for teaching by presenting guest lectures to first- and second-year medical students at Dalhousie University and at the University of Calgary.

Dr. Hoehn has been a contributor to several books and has written numerous research papers in Neuroscience and Pharmacology. She oversaw a recent revision of the Benjamin Cummings *Interactive Physiology*® CD-ROM series modules, and coauthored the newest module, *The Immune System*.

Following Dr. Marieb's example, Dr. Hoehn provides financial support for students in the form of a scholarship that she established in 2006 for nursing students at Mount Royal University.

Dr. Hoehn is also actively involved in the Human Anatomy and Physiology Society (HAPS) and is a member of the American Association of Anatomists. When not teaching, she likes to spend time outdoors with her husband and two sons, compete in triathlons, and play Irish flute.

Introduce yourself to the chapter

Improved readability and navigability makes the text more accessible and easier to study.

Chapter Outlines

Chapter outlines provide a preview of the chapter and help you locate information easily.

Learning Objectives

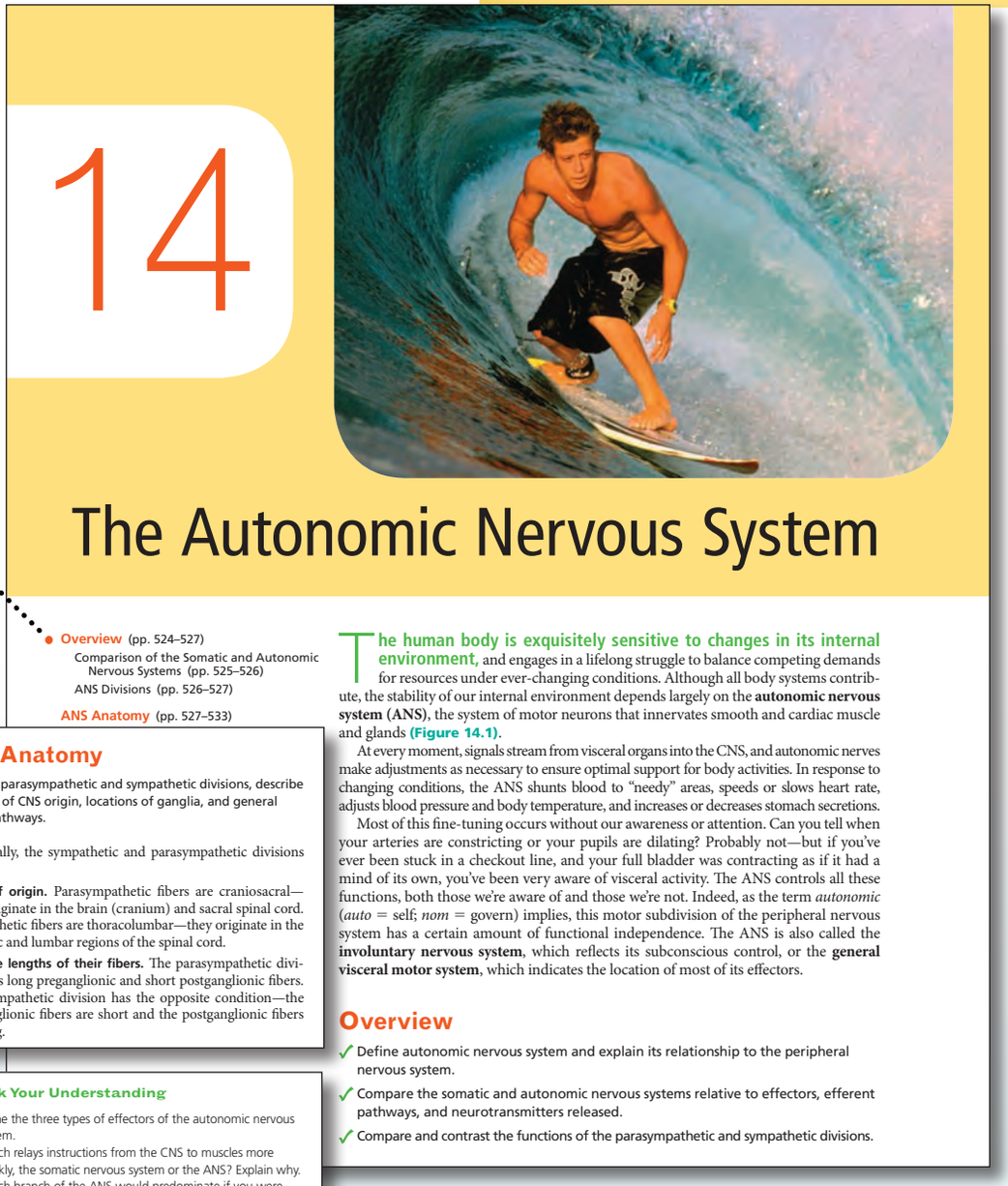
Learning objectives are integrated into the chapter and give you a preview of what content is to come and what you are expected to learn.

Bulleted Narrative

The narrative has been bulleted wherever possible to make the text easier to read and navigate.

Check Your Understanding

Concept check questions are tied to the sections' Learning Objectives and ask you to stop, think, and check your understanding before moving on.



14

The Autonomic Nervous System

The human body is exquisitely sensitive to changes in its internal environment, and engages in a lifelong struggle to balance competing demands for resources under ever-changing conditions. Although all body systems contribute, the stability of our internal environment depends largely on the **autonomic nervous system (ANS)**, the system of motor neurons that innervates smooth and cardiac muscle and glands **(Figure 14.1)**.

At every moment, signals stream from visceral organs into the CNS, and autonomic nerves make adjustments as necessary to ensure optimal support for body activities. In response to changing conditions, the ANS shunts blood to "needy" areas, speeds or slows heart rate, adjusts blood pressure and body temperature, and increases or decreases stomach secretions.

Most of this fine-tuning occurs without our awareness or attention. Can you tell when your arteries are constricting or your pupils are dilating? Probably not—but if you've ever been stuck in a checkout line, and your full bladder was contracting as if it had a mind of its own, you've been very aware of visceral activity. The ANS controls all these functions, both those we're aware of and those we're not. Indeed, as the term *autonomic* (*auto* = self; *nom* = govern) implies, this motor subdivision of the peripheral nervous system has a certain amount of functional independence. The ANS is also called the **involuntary nervous system**, which reflects its subconscious control, or the **general visceral motor system**, which indicates the location of most of its effectors.

Overview

- ✓ Define autonomic nervous system and explain its relationship to the peripheral nervous system.
- ✓ Compare the somatic and autonomic nervous systems relative to effectors, efferent pathways, and neurotransmitters released.
- ✓ Compare and contrast the functions of the parasympathetic and sympathetic divisions.

ANS Anatomy

✓ For the parasympathetic and sympathetic divisions, describe the site of CNS origin, locations of ganglia, and general fiber pathways.

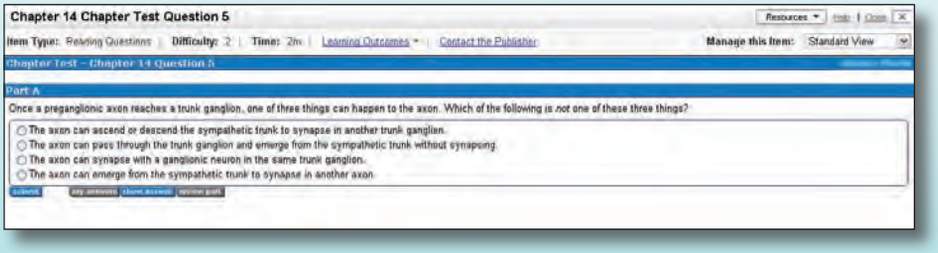
Anatomically, the sympathetic and parasympathetic divisions differ in

- **Sites of origin.** Parasympathetic fibers are craniosacral—they originate in the brain (cranium) and sacral spinal cord. Sympathetic fibers are thoracolumbar—they originate in the thoracic and lumbar regions of the spinal cord.
- **Relative lengths of their fibers.** The parasympathetic division has long preganglionic and short postganglionic fibers. The sympathetic division has the opposite condition—the preganglionic fibers are short and the postganglionic fibers are long.

☑ Check Your Understanding

1. Name the three types of effectors of the autonomic nervous system.
2. Which relays instructions from the CNS to muscles more quickly, the somatic nervous system or the ANS? Explain why.
3. Which branch of the ANS would predominate if you were lying on the beach enjoying the sun and the sound of the waves? Which branch would predominate if you were on a surfboard and a shark appeared within a few feet of you?

For answers, see Appendix H.



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Reading Questions keep you on track.

Follow complex processes step by step

Focus Figures help you grasp tough topics in A&P by walking you through carefully developed step-by-step illustrations that use a big-picture layout and dramatic art to provide a context for understanding the process.

Overview

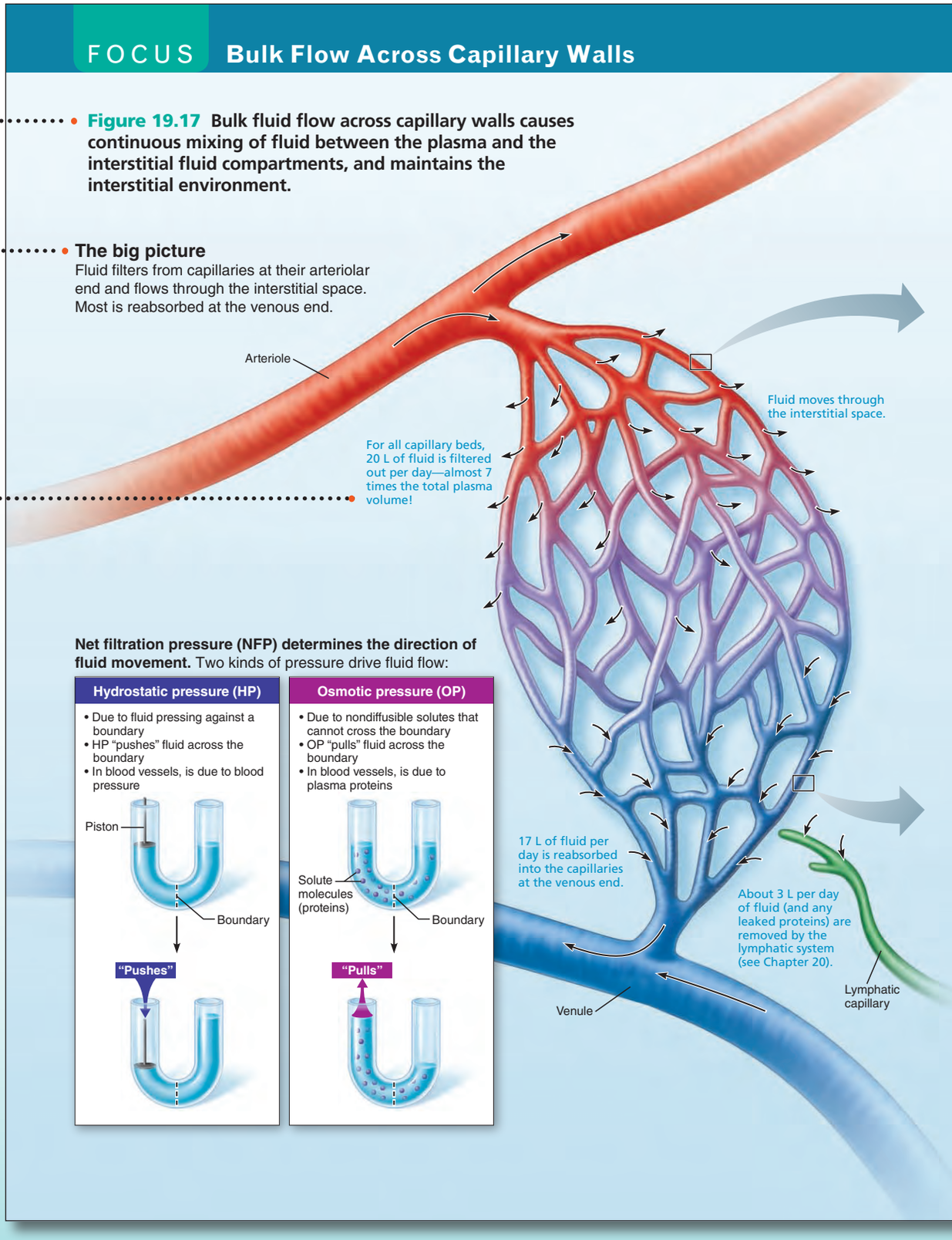
Each Overview quicky summarizes the key idea of the figure.

Big Picture Orientation

The big picture provides you with a concrete starting point for the process.

Blue Text

This text acts as the instructor's voice and explains difficult concepts. In some figures the text is broken into numbered steps to help you more easily understand difficult processes.



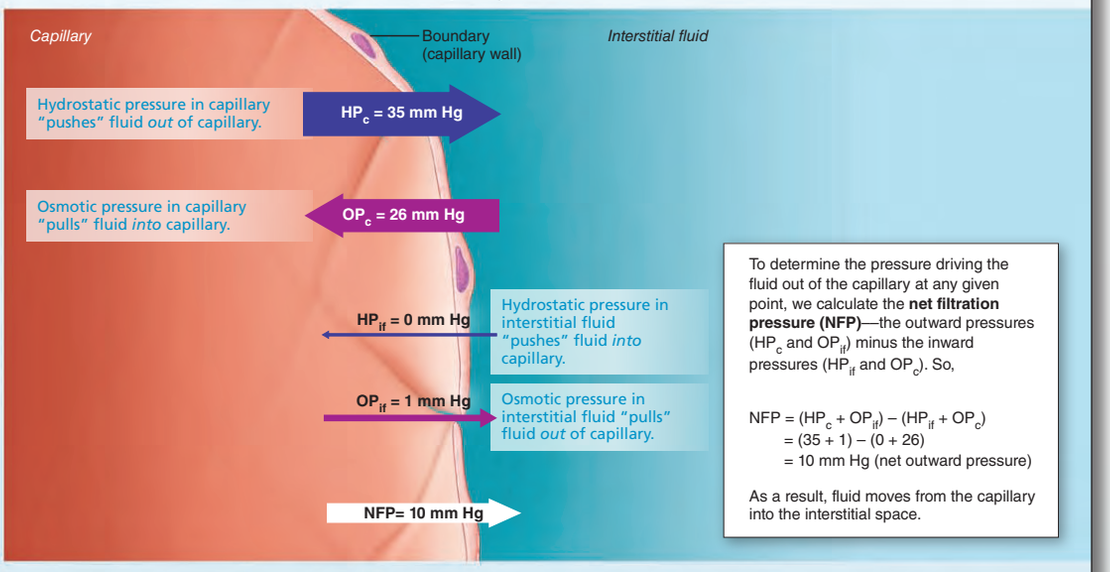
MasteringA&P®

Focus Figure Tutorials

All Focus Figures have related tutorials in MasteringA&P that your instructor can assign and that will guide you through the figures step by step.

How do the pressures drive fluid flow across a capillary?

Net filtration occurs at the arteriolar end of a capillary.

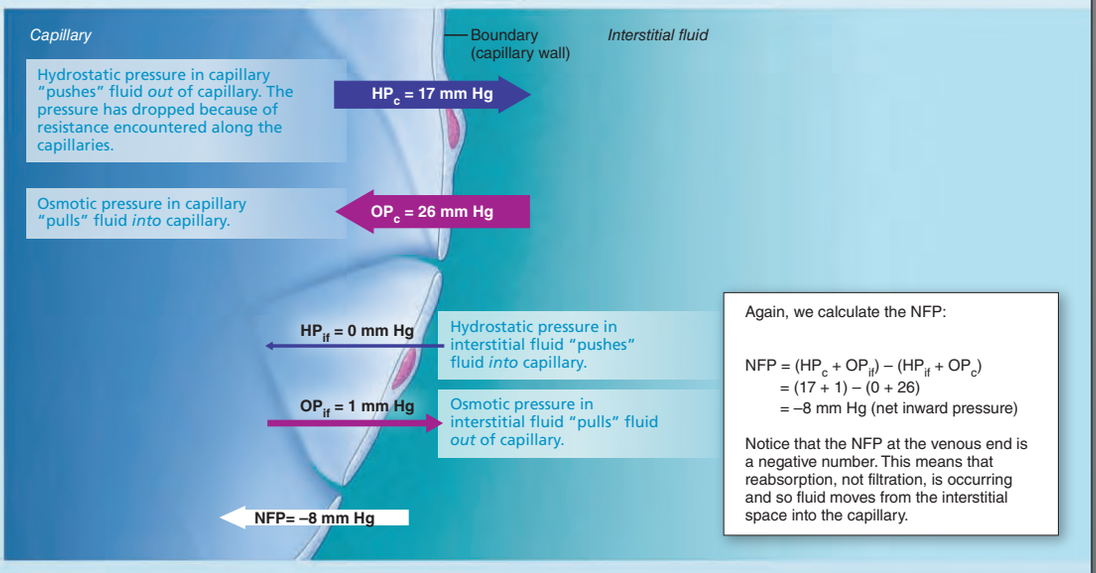


To determine the pressure driving the fluid out of the capillary at any given point, we calculate the **net filtration pressure (NFP)**—the outward pressures (HP_c and OP_{if}) minus the inward pressures (HP_{if} and OP_c). So,

$NFP = (HP_c + OP_{if}) - (HP_{if} + OP_c)$
$= (35 + 1) - (0 + 26)$
$= 10$ mm Hg (net outward pressure)

As a result, fluid moves from the capillary into the interstitial space.

Net reabsorption occurs at the venous end of a capillary.



Again, we calculate the NFP:

$NFP = (HP_c + OP_{if}) - (HP_{if} + OP_c)$
$= (17 + 1) - (0 + 26)$
$= -8$ mm Hg (net inward pressure)

Notice that the NFP at the venous end is a negative number. This means that reabsorption, not filtration, is occurring and so fluid moves from the interstitial space into the capillary.

Study figures as you read the text

Select pieces of art provide more visual content and often have step-by-step text that helps you better understand structure, functions, and processes.

▼ 3-D anatomy art

Stunning 3-D anatomy art is rendered in a dramatically more dynamic, realistic style that uses vibrant, saturated colors to help you visualize key anatomical structures.

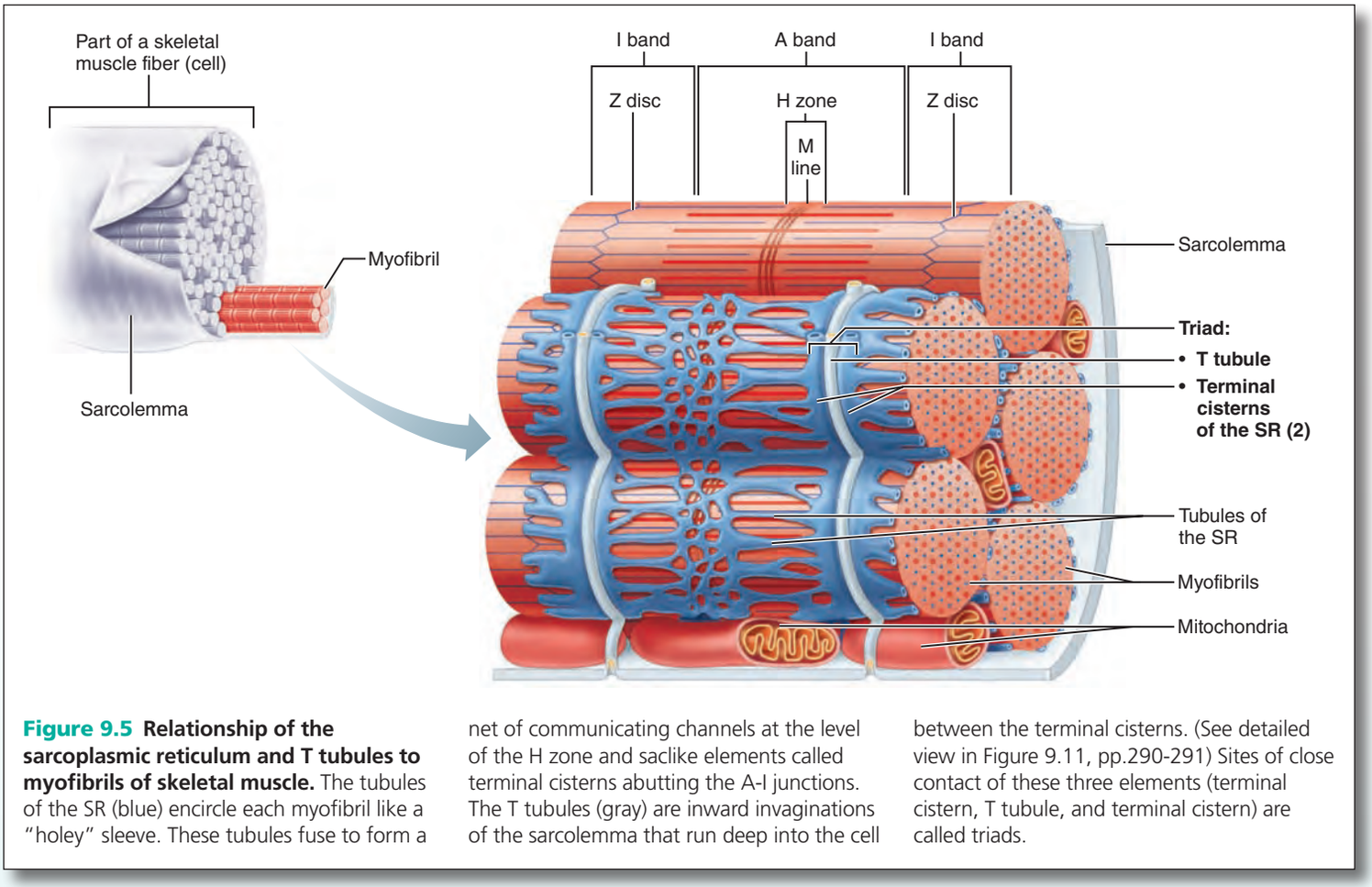


Figure 9.5 Relationship of the sarcoplasmic reticulum and T tubules to myofibrils of skeletal muscle. The tubules of the SR (blue) encircle each myofibril like a "holey" sleeve. These tubules fuse to form a net of communicating channels at the level of the H zone and saclike elements called terminal cisterns abutting the A-I junctions. The T tubules (gray) are inward invaginations of the sarcolemma that run deep into the cell between the terminal cisterns. (See detailed view in Figure 9.11, pp.290-291) Sites of close contact of these three elements (terminal cistern, T tubule, and terminal cistern) are called triads.

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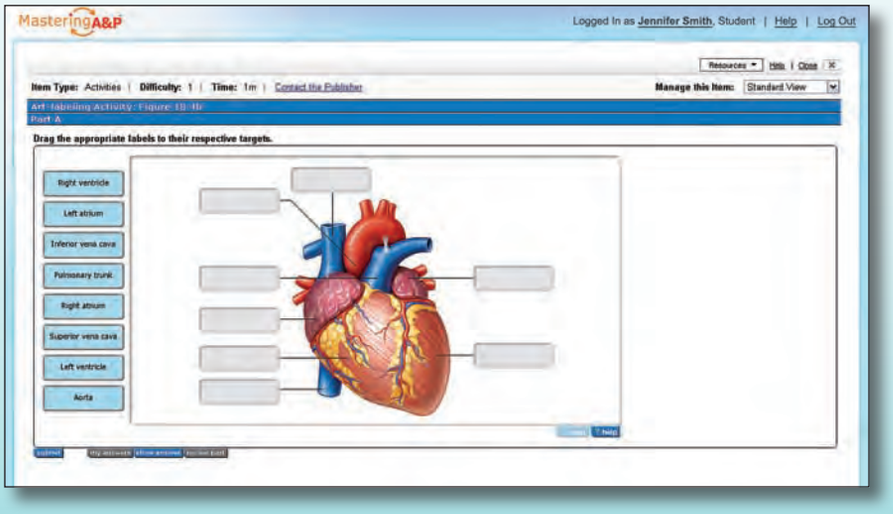
NEW! **Art Labeling** and **Ranking/Sorting Questions** are drag and drop activities that allow you to assess your knowledge of terms and structures as well as the order of steps and elements involved in physiological processes.



Prepare for your future career

Clinical coverage and case studies have been expanded throughout.

Homeostatic Imbalance 6.1

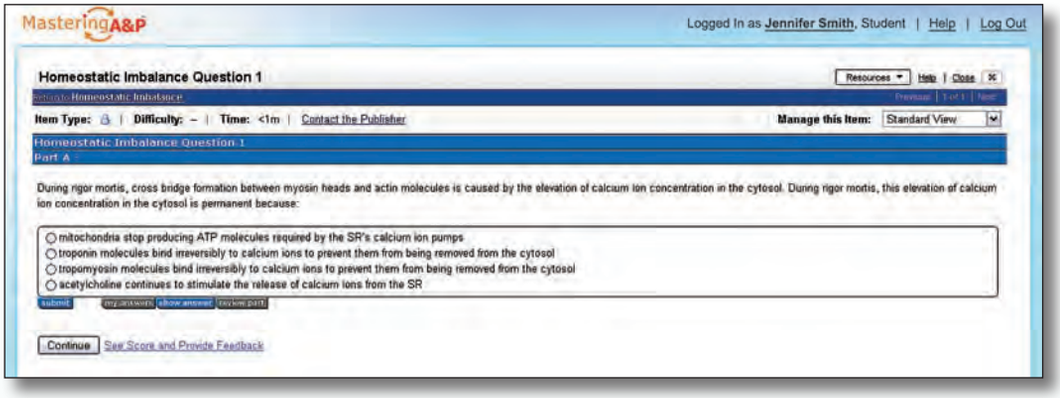
Minute changes from the homeostatic range for blood calcium can lead to severe neuromuscular problems ranging from hyperexcitability (when blood Ca^{2+} levels are too low) to nonresponsiveness and inability to function (with high blood Ca^{2+} levels). In addition, sustained high blood levels of Ca^{2+}, a condition known as *hypercalcemia* (hi″per-kal-se′me-ah), can lead to undesirable deposits of calcium salts in the blood vessels, kidneys, and other soft organs, which may hamper their function. ✚

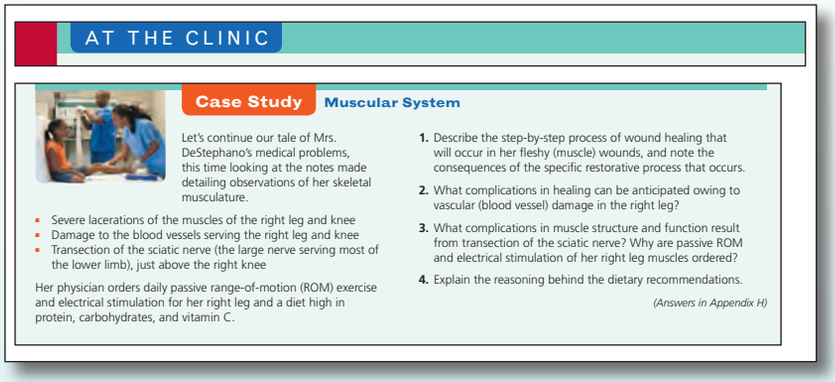
◂ Homeostatic Imbalance

Homeostatic Imbalance sections are integrated within the text and alert you to the consequences of body systems not functioning optimally. These pathological conditions are integrated with the text to clarify and illuminate normal functioning.

MasteringA&P®

NEW! Homeostatic Imbalance Clinical Questions can be assigned to you by your instructor on MasteringA&P. They help strengthen your understanding of how the body works to stay in balance and what happens when it falls out of balance.



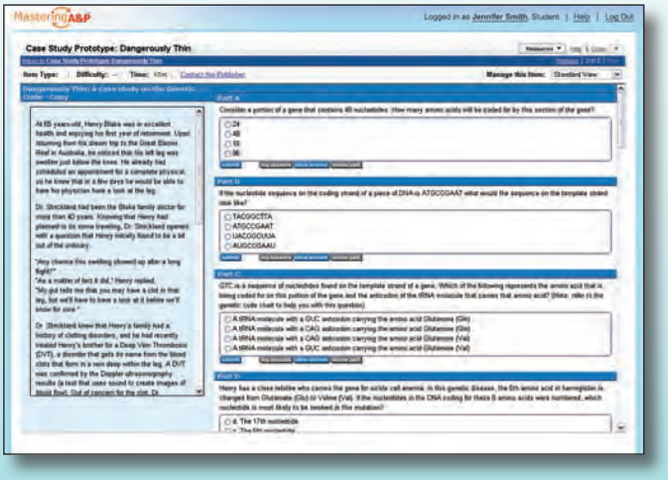


▲ NEW! At the Clinic

End-of-chapter sections now contain an At the Clinic feature, which help you apply what you've learned. By learning related clinical terms and reading short Case Studies and answering questions, you will begin to prepare for your future career.

MasteringA&P®

NEW! Case Study Coaching Activities increase your problem-solving skills and prepare you for your future career.



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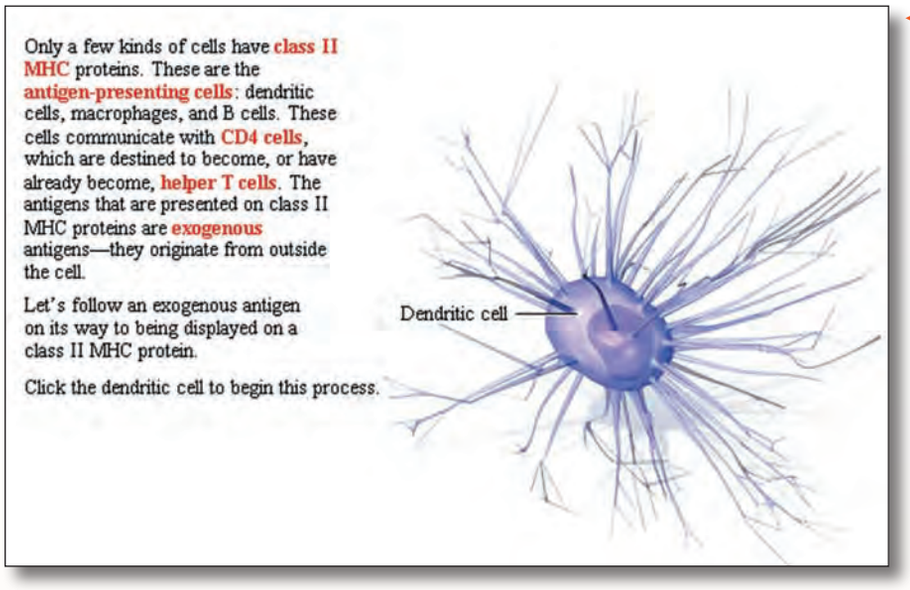
MasteringA&P includes a Study Area that has many tools to help you succeed, including:

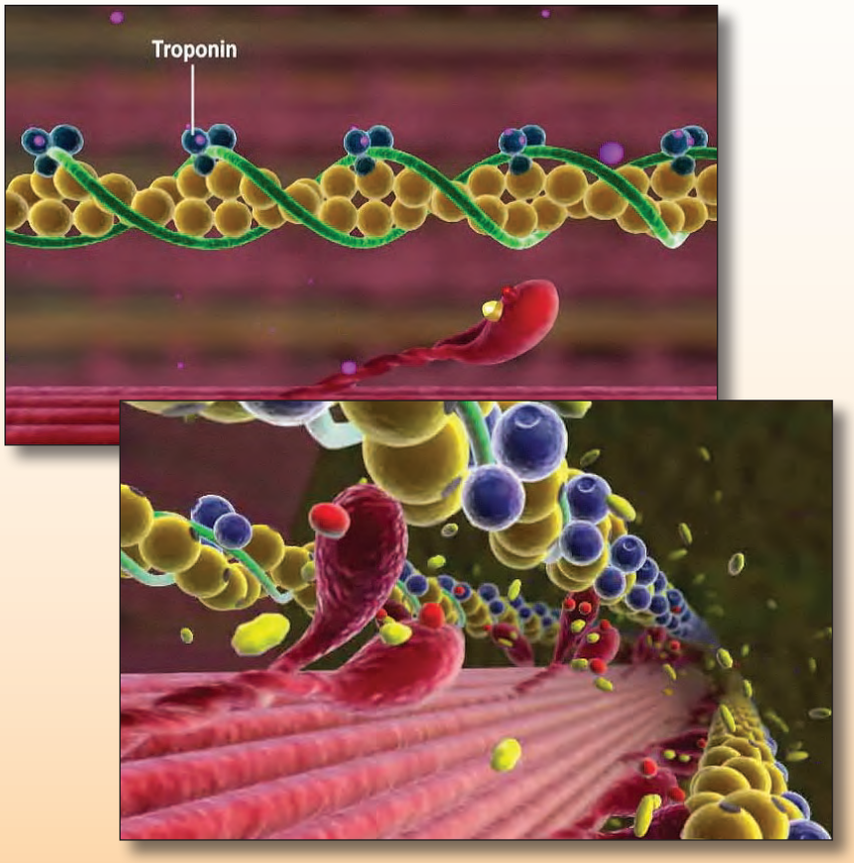


Interactive Physiology® iP 10-System Suite

IP helps you understand the hardest part of A&P: physiology. Fun, interactive tutorials, games, and quizzes give you additional explanations to help you grasp difficult concepts.

Modules:

- Muscular System
- Nervous System I
- Nervous System II
- Cardiovascular System
- Respiratory System
- Urinary System
- Fluids & Electrolytes
- Endocrine System
- Digestive System
- Immune System



A&P Flix

A&P Flix™ are 3-D movie-quality animations with self-paced tutorials and gradable quizzes that help you master the toughest topics in A&P:

Cell Physiology

- Membrane Transport
- DNA Replication
- Mitosis
- Protein Synthesis

Muscle Physiology

- Events at the Neuromuscular Junction
- Excitation-Contraction Coupling
- Cross-Bridge Cycle

Neurophysiology

- Resting Membrane Potential
- Generation of an Action Potential
- Propagation of an Action Potential

Origins, Insertions, Actions, Innervations

- 63 animations on this topic

Group Muscle Actions & Joints

- 54 animations on this topic

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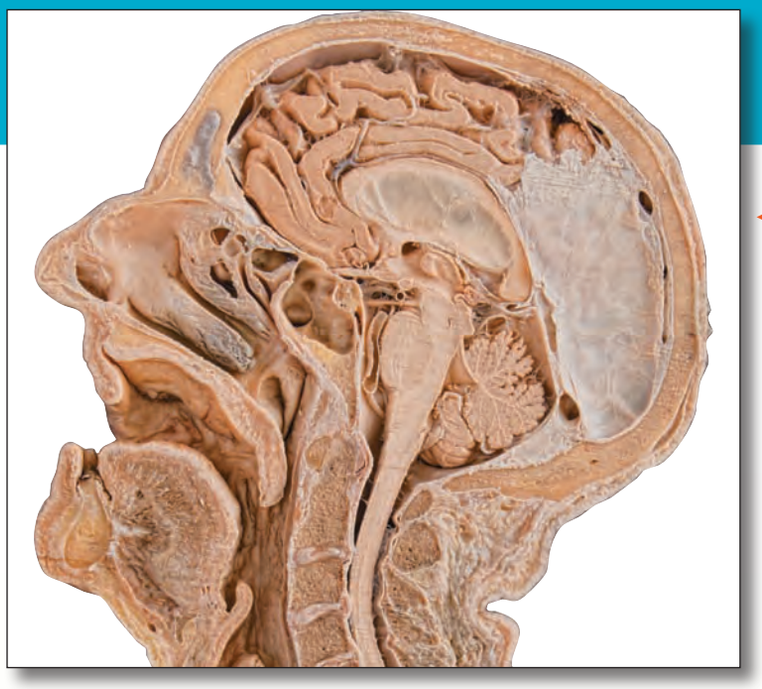

PAL practice anatomy lab™

Practice Anatomy Lab™ (PAL™) 3.0 is a virtual anatomy study and practice tool that gives you 24/7 access to the most widely used lab specimens, including the human cadaver, anatomical models, histology, cat, and fetal pig. PAL 3.0 retains all of the key advantages of version 2.0, including ease of use, built-in audio pronunciations, rotatable bones, and simulated fill-in-the-blank lab practical exams.

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Annotation Function
Allows you to take notes.

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search function.

Highlight Function
Lets you highlight what you want to remember.

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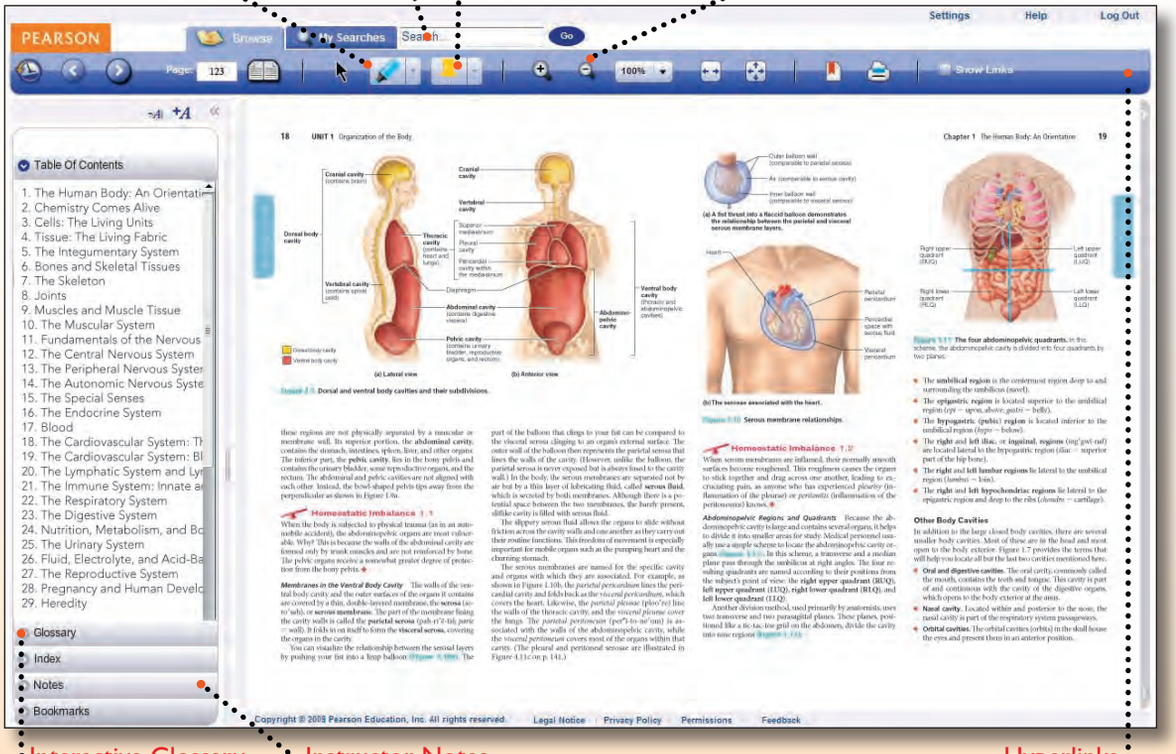
Lets you zoom in and out for better viewing.



Interactive Glossary
Provides pop-up definitions and terms.

Instructor Notes
Your instructor might also share his or her notes and highlights with the class.

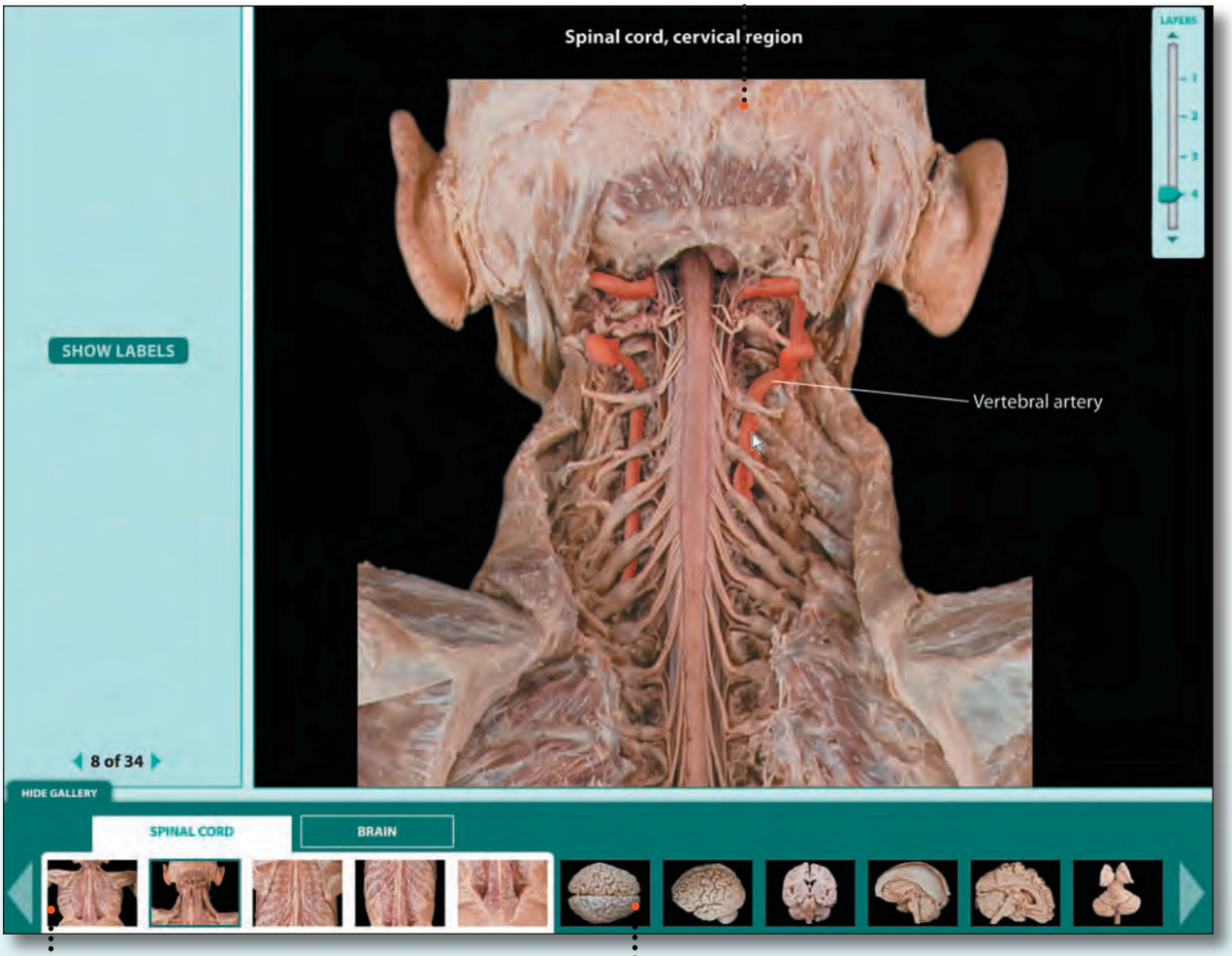
Hyperlinks
Links to quizzes, tests, activities, and animations.

Get 24/7 lab practice

NEW! PAL practice anatomy lab™

PAL 3.0 is an indispensable virtual anatomy study and practice tool that gives you 24/7 access to the most widely used lab specimens, including the human cadaver, anatomical models, histology, cat, and fetal pig. PAL 3.0 retains all of the key advantages of version 2.0, including ease of use, built-in audio pronunciations, rotatable bones, and simulated fill-in-the-blank lab practical exams.

NEW! **Carefully prepared dissections** show nerves, blood vessels, and arteries across body systems.



NEW! **Layering slider** allows you to peel back layers of the human cadaver and view and explore hundreds of brand-new dissections especially commissioned for 3.0.

NEW! **Photo gallery** allows you to quickly see thumbnails of images for a particular region or sub region.

PAL 3.0 is available in the **Study Area of MasteringA&P** (www.masteringaandp.com). The PAL 3.0 DVD can be packaged with the book for no extra charge.

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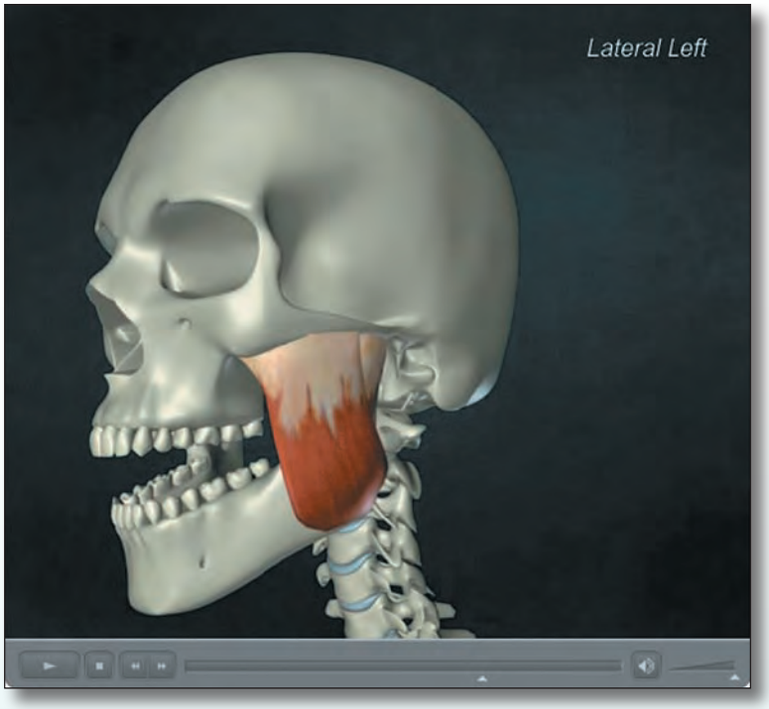
NEW! Interactive Histology

Interactive Histology module allows you to view the same tissue slide at varying magnifications, thereby helping you identify structures and their characteristics.



3-D Anatomy Animations

3-D Anatomy Animations of origins, insertions, actions, and innervations of over 65 muscles are now viewable in both Cadaver and Anatomical Models and modules. A new closed-captioning option provides textual presentation of narration to help you retain information and supports ADA compliance.

PAL practice anatomy lab™

PAL 3.0 also includes:

- NEW! **Question randomization** feature gives you more opportunities for practice and self-assessment. Each time you retake a quiz or lab practical, a new set of questions is generated.
- NEW! **Hundreds of new images and views** are included, especially of the human cadaver, anatomical models, and histology.
- NEW! **Turn-off highlight feature** in quizzes and lab practicals gives you the option to see a structure without the highlight overlay.

physioEX™ VERSION 9

NEW! PhysioEx 9.0

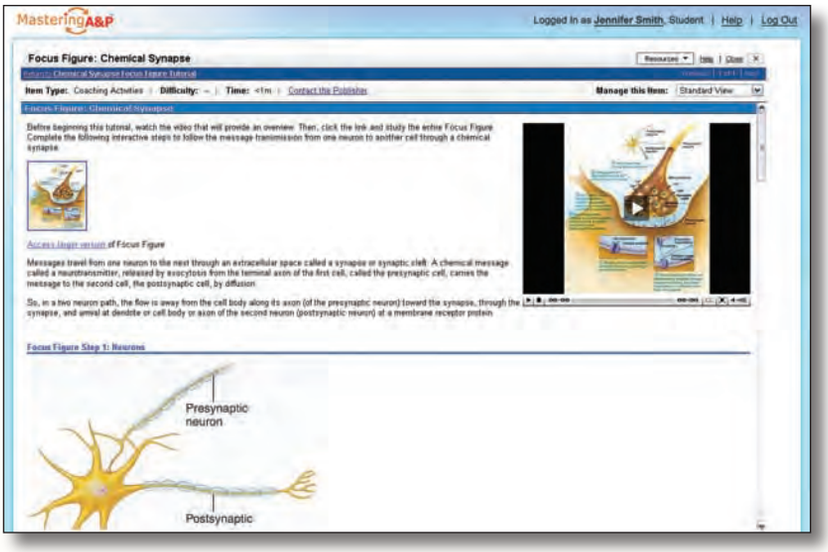
PhysioEx 9.0: Laboratory Simulations in Physiology is easy-to-use laboratory simulation software with an accompanying lab manual that consists of 12 exercises containing 63 physiology lab activities. It can be used to supplement or substitute for wet labs. PhysioEx allows you to repeat labs as often as you like, perform experiments without harming live animals, and conduct experiments that are difficult to perform in a wet lab environment because of time, cost, or safety concerns.

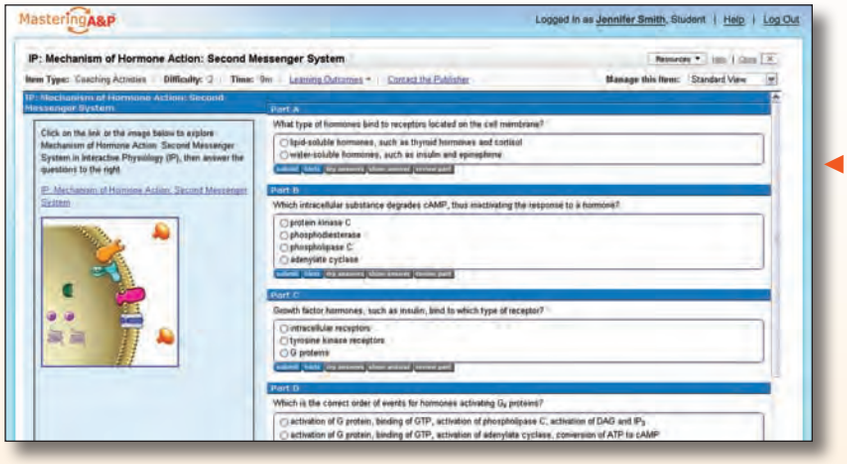
To the Instructor: Everything from the Book is now Integrated with MasteringA&P®

All text features of *Human Anatomy & Physiology* are now assignable in MasteringA&P, providing students with unlimited opportunities to study.

NEW! Focus Figure Tutorials

Focus Figure Tutorials guide students through key parts of each Focus Figure, assessing their understanding of the major concepts through a variety of assessment tools—multiple choice questions with hints and specific wrong-answer feedback, interactive ranking and sorting exercises, and labeling activities.



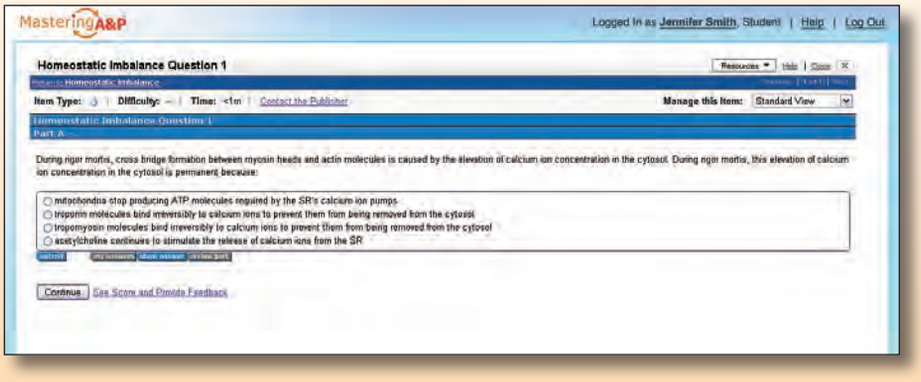


Interactive Physiology® Coaching Activities

20 new *Interactive Physiology* Coaching Activities have been added to the Item Library.

NEW! Homeostatic Imbalance Clinical Questions

Homeostatic Imbalance Clinical Questions are higher-order thinking questions that assess students on their comprehension of the Homeostatic Imbalance content in each chapter, making one of the text's hallmark features now assignable.



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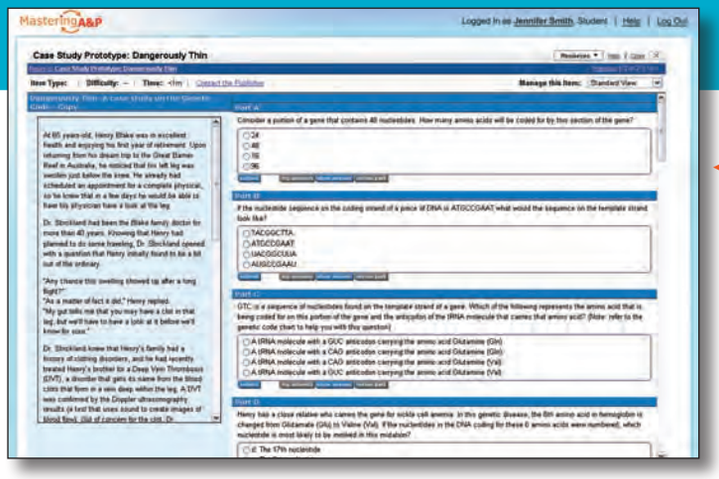
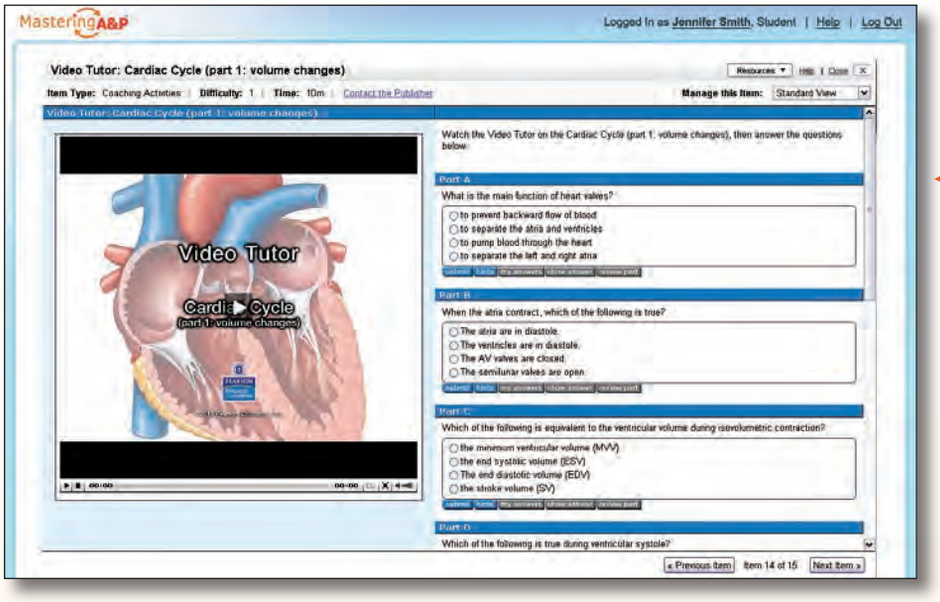


NEW! Case Study Coaching Activities

Case Study Coaching Activities increase problem-solving skills and prepare students for future careers in allied health. Corresponding Teaching Notes give instructors valuable tips on when and how to use case studies in the classroom.



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Preface

As educators, clinically trained individuals, and perennial students, we are continually challenged by the learning mind. What works best to help students apply new information to the world they personally understand? Our clinical backgrounds have served our teaching and writing purposes well. Perhaps even more important, our clinical experience has allowed us to see our presentations through our students' eyes and from the vantage points of their career interests.

For this edition, as for those preceding it, feedback from student and instructor reviews indicated areas of the text that needed to be revised for clarity, timeliness, and just plain reduction of verbal meatiness. Overall, feedback was positive, verifying that our approach is effective: Explaining fundamental principles and unifying themes first creates a strong base for what comes later. Backing these explanations up with comfortable analogies and familiar examples enhances students' understanding of the workings of the human body.

Unifying Themes

Three integrating themes that organized, unified, and set the tone of the first edition of this text continue to be valid and are retained in this edition. These themes are:

Interrelationships of body organ systems. The fact that nearly all regulatory mechanisms require interaction of several organ systems is continually emphasized. For example, Chapter 25, which deals with the structure and function of the urinary system, discusses the vital importance of the kidneys not only in maintaining adequate blood volume to ensure normal blood circulation, but also in continually adjusting the chemical composition of blood so that all body cells remain healthy. The unique *System Connections* feature is the culmination of this approach and should help students think of the body as a dynamic community of interdependent parts rather than as a number of isolated structural units.

Homeostasis. The normal and most desirable condition of body functioning is homeostasis. Its loss or destruction always leads to some type of pathology—temporary or permanent. Pathological conditions are integrated with the text to clarify and illuminate normal functioning, not as an end in and of themselves. For example, Chapter 19, which deals with the structure and function of blood vessels, explains how the ability of healthy arteries to expand and recoil ensures continuous blood flow and proper circulation. The chapter goes on to discuss the effects on homeostasis when arteries lose their elasticity: high blood pressure and all of its attendant problems. These homeostatic imbalances are indicated visually by a pink symbol with a fulcrum:

Whenever students see the imbalance symbol in text, the concept of disease as a loss of homeostasis is reinforced. Every Homeostatic Imbalance section has a new, related clinical question that is assignable in MasteringA&P. These new clinical questions help strengthen students' understanding of how the body works to stay in balance.

Complementarity of structure and function. Students are encouraged to understand the structure of an organ, a tissue, or a cell as a prerequisite to comprehending its function. Concepts of physiology are explained and related to structural characteristics that promote or allow the various functions to occur. For example, the lungs can act as a gas exchange site because the walls of their air sacs present an incredibly thin barrier between blood and air.

NEW TO THE NINTH EDITION

With every edition, our goal is powerful but simple—to make anatomy and physiology as engaging, accurate, and relevant as possible for both instructors and students. The Ninth Edition represents a monumental revision, with changes to the text and art presentation that build upon the hallmark strengths of the previous eight editions. The changes to the Ninth Edition are all driven by the needs of today's students, as we seek to make the learning of key concepts in A&P as easy as possible for them. Key concepts are important because of the overwhelming amount of material in this course. Mastering this material gives

students structure for organizing this wealth of information. Below are the ways in which we've revised the Ninth Edition to make this book the one where learning happens most effectively, followed by a detailed list of specific chapter-by-chapter content changes.

An expanded art program. The drive for this revision began as a simple list. We sat down together and created a chapter-by-chapter list of the key concepts in A&P where students struggle the most. This list became the basis for our art revision plans for both the Eighth and Ninth editions. We first boiled it down to some of the toughest topics to get our list of Focus figures. These Focus figures are illustrations that use a "big picture" layout and dramatic art to walk the student through difficult physiological processes in a step-by-step way. These have been wildly popular with both instructors and students. In response to repeated requests for more, we are pleased to present 12 new Focus figures. We hope you'll be as pleased with the results of the added Focus figures in the Ninth Edition as you were in the Eighth.

All of the art in the Eighth Edition was carefully examined and reviewed by both instructors and students. Many of their suggested changes have been incorporated into this edition. As always, we have updated many figures to reflect the latest scientific findings and to improve their ability to teach important concepts. Finally, many new photos—histology, cadaver, and others—were painstakingly chosen for this edition to enhance the learning process.

Flipping through the Ninth Edition, you can see that we have built upon the dynamic, three-dimensional, and realistic art style, utilizing dramatic views and perspectives and vibrant, saturated colors.

Improved text presentation. New text features initiated in the Eighth Edition that focus students on key concepts have been retained and expanded in the Ninth Edition. In the current edition, student objectives still appear by topic throughout the chapter and some new *Check Your Understanding* questions have been added at the end of sections. These changes along with a brand-new design make the book easier than ever to study from and navigate. Our hallmark analogies and accessible, friendly style while using simpler, more concise language and shorter paragraphs make the information easier for students to manage.

Factual updates and accuracy. As authors we pride ourselves on keeping our book as up-to-date and as accurate as possible in all areas—a monumental task that requires painstaking selectivity. Although information changes even as a textbook goes to press, be assured that our intent and responsibility to update has been carried out to the best of our ability. We have incorporated current research in the field as much as possible; many of these updates are included in the chapter-by-chapter changes. A more complete list is available from your Pearson sales representative and in the *Instructor Guide to Text and Media.*

Terminology changes. For this edition we've substantially updated the terminology to be in accordance with *Terminologia Anatomica* and *Terminologia Histologica*. Professors can find a complete list of terminology changes detailed in the *Instructor Guide to Text and Media.*

Chapter-by-Chapter Changes

Chapter 1 The Human Body: An Orientation

- Updated information on diagnostic uses of MRI scans (*A Closer Look*).
- New MRI photo of frontal section through the torso (Figure 1.8a).
- Enhanced art showing layers of the pericardium (Figure 1.10).

Chapter 2 Chemistry Comes Alive

- Updated information on stress and aging.
- Improved art showing structure of an atom (Figure 2.1).
- New photos of blood (Figure 2.4).
- New photo of a water strider (Figure 2.10).
- Updated art for levels of protein structure (Figure 2.19).

Chapter 3 Cells: The Living Units

- New information on RNA in translation, rRNA, and tRNA.
- Revised Focus Figure 3.10: Primary Active Transport: The Na^+-K^+ Pump.
- Revised art for three types of endocytosis (Figure 3.13).
- Improved Focus Figure 3.16: G Proteins.
- New photo of smooth and rough endoplasmic reticulum (Figure 3.18).
- New TEM of lysosomes (Figure 3.21).
- Revised art and new TEM for centrioles (Figure 3.25).
- Revised Focus Figure 3.33: Mitosis.
- New Focus Figure 3.37: Translation.

Chapter 4 Tissue: The Living Fabric

- New photomicrographs of epithelium (Figure 4.3).
- New photomicrographs of connective tissues (Figure 4.8).
- New photomicrographs of muscle (Figure 4.10).
- Simplified explanation of polarity.
- Improved rendering of goblet cell (Figure 4.4), with more realistic details.
- Improved teaching effectiveness of Figure 4.11 (classes of membranes).
- Improved layout of Figure 4.12 (tissue repair).
- Added explanation to art for embryonic germ layers (Figure 4.13).

Chapter 5 The Integumentary System

- Updated information on the skin's epithelial cells and stratum corneum.
- New information on tinea versicolor ("sunspots") and friction ridges.
- Updated information on importance of the stratum corneum as a physical barrier.
- Added new term scleroderma, an autoimmune disorder characterized by hardened skin, in *At the Clinic: Related Clinical Terms.*
- New research on the role of friction ridges in the sense of touch.

Chapter 6 Bones and Skeletal Tissues
- Updated information on bone resorption and remodeling.
- New bone-related information on serotonin, glucose intolerance, and diabetes mellitus.
- Updated information on osteogenic cells and microscopic anatomy of bone cells.
- New information on osteoporosis in prostate cancer patients who receive androgen-suppressing therapy.
- New information on osteocalcin, a hormone which helps regulate bone formation and also protects against obesity, glucose intolerance, and diabetes mellitus.
- New information on the monoclonal antibody drug denosumab as a treatment for osteoporosis.

Chapter 7 The Skeleton
- New Clinical Case Study.
- New photos of the skull, temporal bone, sphenoid and ethmoid bones, mandible, and orbits (Figures 7.5–7.12).
- New photos of defects in spinal curvature (Figure 7.17).
- New photos of proximal tibia (Figure 7.33).

Chapter 8 Joints
- New Clinical Case Study.
- New Focus Figure 8.7: Types of Synovial Joints.
- Added information on meniscal transplant surgery.
- Updated information on treatment of sprains.
- Updated statistics on arthritis; updated treatment of rheumatoid arthritis.
- Updated description of sinovitis.
- Updated statistics on joint replacements in the U.S.
- Updated research aimed at future treatments of joint problems.

Chapter 9 Muscles and Muscle Tissue
- New discussion of EPOC (excess postexercise oxygen consumption).
- New photomicrograph of skeletal muscle (Figure 9.1).
- New Figure 9.9 (skeletal muscle action potentials).
- Added information of myosin head orientation in smooth muscle.
- Updated information on treatments for Duchenne muscular dystrophy.
- Streamlined discussion of muscle fatigue.
- Added skeletal muscle fibers to Figure 9.17 for better teaching effectiveness.

Chapter 10 The Muscular System
- New Focus Figure 10.1: Muscle Action.
- New Clinical Case Study.
- New photo of hip and thigh muscles (Figure 10.21).

Chapter 11 Fundamentals of the Nervous System and Nervous Tissue
- Update on multiple sclerosis risk factors and treatment.
- New information on addiction treatment and prescription drug abuse (*A Closer Look*).
- New Clinical Case Study.
- Updated discussion on neuronal transport.
- New information on gasotransmitters.
- Update on shingles and vaccination available for its prevention.
- Discuss direct and indirect neurotransmitter receptor mechanisms in two figures (Figures 11.20 and 11.21). Added relay-runner motif to G-protein linked receptor figure (Figure 11.21) to tie it to previous G-protein figure in Chapter 3.

Chapter 12 The Central Nervous System
- New Clinical Case Study.
- Updated information on premotor cortex and the role of the basal nuclei.
- New information on Alzheimer's disease and Parkinson's disease.
- Update on amyotrophic lateral sclerosis.
- Updated information on genetic causes of autism.
- New photos of brain sections (Figures 12.9, 12.10, and 12.12).
- New photo of spinal cord (Figure 12.26).

Chapter 13 The Peripheral Nervous System and Reflex Activity
- New information on vanilloid receptors, pain tolerance, and Bell's palsy.
- New SEM of nerve cross-section (Figure 13.4).
- New photos of brachial and sacral plexuses (Figures 13.10 and 13.12).
- New Clinical Case Study.

Chapter 14 The Autonomic Nervous System
- Updated information on aging and blood pressure receptors.
- Streamlined discussion of sympathetic trunks and pathways.
- More explicit statement about the "background" firing rate of neurons along sympathetic and parasympathetic axons in ANS.

Chapter 15 The Special Senses
- New Clinical Case Study.
- New information on link between vitamin C and cataract formation.
- New photos of retina (Figure 15.7), cataract (Figure 15.9), and refraction (Figure 15.11).
- New summary Table 15.1—differences between rods and cones.
- Updated discussion of olfactory processing.
- New summary Table 15.2—structures of internal ear and their functions.

Chapter 16 The Endocrine System
- New research on ghrelin and growth hormone release.
- New photo showing effects of growth hormone excess and deficiency (Figure 16.7).
- Updated information on type 1 diabetes.
- New Focus Figure 16.5: Hypothalamus and Pituitary Interactions.
- New photomicrographs of thyroid (Figure 16.8), parathyroid (Figure 16.12), adrenal gland (Figure 16.14), and pancreas (Figure 16.18).
- New flowchart of parathyroid hormone effects (Figure 16.13).

Chapter 17 Blood
- New Clinical Case Study.
- New SEMs of normal and sickled RBCs (Figure 17.8).

- New photomicrographs of leukocytes (Figure 17.10).
- Updated Figure 17.11 (leukocyte formation).
- Updated statistics on sickle cell anemia and malaria.
- Improved teaching effectiveness of Figure 17.14 (pathways of coagulation).

Chapter 18 The Cardiovascular System: The Heart

- New Clinical Case Study.
- New Focus Figure 18.9: Blood Flow Through the Heart.
- Updated information on ischemic cell death in myocardial infarction.
- New photos of the heart (Figures 18.4 and 18.6).
- Expanded overview of systemic and pulmonary circuits (in response to focus group feedback).
- Reorganized presentation of heart anatomy.
- Updated the effects of hyperkalemia and hypercalcemia on the heart.

Chapter 19 The Cardiovascular System: Blood Vessels

- Update on obesity-linked hypertension.
- New Focus Figure 19.17: Bulk Flow Across Capillary Walls.
- New photomicrograph of artery and vein (Figure 19.1).
- Added information on C-reactive protein as a marker of systemic inflammation and a predictor of future heart attacks and strokes.
- Reorganized Figure 19.15 for better teaching effectiveness.
- Reorganized section on venous return.
- Reorganized discussion of baroreceptor reflex.
- Consolidated discussion of renal regulation of blood pressure by adding material previously in Chapter 25. Moved details of renin-angiotensin-aldosterone mechanism from Figure 25.10 to Figure 19.10.
- Reorganized presentation on homeostatic imbalances of blood pressure.

Chapter 20 The Lymphatic System and Lymphoid Organs and Tissues

- New information on the spleen as a monocyte reservoir.
- New photomicrographs of thymus (Figure 20.7) and tonsil (Figure 20.8).
- Improved discussion of lymphoid cells and lymphoid tissues.
- Reorganized section on mucosa-associated lymphoid tissue (MALT).
- Updated statistics for non-Hodgkin's lymphoma.

Chapter 21 The Immune System: Innate and Adaptive Body Defenses

- Major revision of chapter to streamline presentation.
- New Clinical Case Study.
- Added coverage of lectin pathway (Figure 21.6).
- New SEM of macrophage engaged in phagocytosis (Figure 21.2).
- Two new summary tables (Tables 21.3 and 21.5).

Chapter 22 The Respiratory System

- Update on early detection of lung cancer.
- Updated discussion of cystic fibrosis.
- New Focus Figure 22.20: Oxygen-Hemoglobin Dissociation Curve.
- New photomicrograph of lung tissue (Figure 22.8).
- New SEM of pulmonary capillary casts (Figure 22.9).

Chapter 23 The Digestive System

- New photomicrograph of esophagus-stomach junction (Figure 23.12).
- New photograph of gastric ulcer (Figure 23.16).
- New photomicrograph of pancreas (Figure 23.26).
- New art on the absorption of monosaccharides (Figure 23.35).

Chapter 24 Nutrition, Metabolism, and Body Temperature Regulation

- Coverage of the USDA's new MyPlate logo (Figure 24.1) and dietary recommendations.
- New Focus Figure 24.8: Oxidative Phosphorylation.
- New Clinical Case Study.
- Updated information on obesity (*A Closer Look*).

Chapter 25 The Urinary System

- Major revision of chapter to streamline presentation.
- New Focus Figure 25.16: Medullary Osmotic Gradient.
- New information on symptoms and manifestations of renal failure.
- New Clinical Case Study.
- New SEM of nephron blood vessel casts (Figure 25.7).
- New illustration of net filtration forces (Figure 25.11).
- New illustration on tubular reabsorption and secretion (Figure 25.15).
- New photo of kidney (Figure 25.3).

Chapter 26 Fluid, Electrolyte, and Acid-Base Balance

- Updated discussion of regulation of sodium and water balance, and dehydration.
- New text and summary table (Table 26.2) contrasting extracellular fluid sodium concentration and body sodium content.

Chapter 27 The Reproductive System

- New photo of testis (Figure 27.3).
- New illustration of male perineum (Figure 27.4).
- New SEM of seminiferous tubules (Figure 27.8).
- New graph of plasma testosterone versus age (Figure 27.11).
- New photomicrograph of ovary (Figure 27.13).
- Update on circumcision and statistics on reduction in risk of HIV and other infections.

Chapter 28 Pregnancy and Human Development

- New Focus Figure 28.2: Sperm Penetration and the Cortical Reaction.
- Updated contraception methods (*A Closer Look*).
- New Clinical Case Study.
- Updated information on role of hCG.
- Updated information on assisted reproductive technologies.
- Simplified Figure 28.10 to improve teaching effectiveness.
- New photo of nursing mother (Figure 28.19).

Chapter 29 Heredity

- New Clinical Case Study.
- New photos of karyotyping (Figure 29.1).

Acknowledgments

Each new edition of this textbook holds out a promise to its authors. "You're done—the book is perfect!" Not! Although it would appear that this would be so after all the work bestowed upon it over eight editions, it still takes the better part of two years, demands our participation in many focus groups, mobilizes our library research skills, and tests our creativity once again before we finally put the last page of the new edition to rest. It never really gets easier as we grind away—the grist finer with each edition.

In all fairness, we don't work alone. Many people shared the work of this edition and deserve their proper due. Once the first draft of each chapter was complete in our estimations, it was sent off to Alice Fugate, the text developmental editor, who wielded her pen to ensure readability and consistency—factors very important to student success. Backing up Alice's work was the director of development Barbara Yien, well known for her ability to see the whole picture. After we perused and processed Alice's suggestions, the manuscript went to Shannon Cutt. Shannon, our cheery associate project editor, checked every aspect of the newly modified text before sending it on to production. Nobody escapes Shannon's ministrations—especially her amazing ability to chase down things that threaten to fall through the cracks. If we failed to meet her deadlines, a barrage of emails rained down, all asking us in the sweetest way to get the missing item in. After Shannon had assured herself that all was well, the manuscript went to Anita Wagner, our skilled copyeditor for the last several editions. Anita knows our text as well or better than we do. She checks grammar, spelling of new drugs or procedures, and verifies statistics; much of the superb accuracy of this text is to her credit as a copyeditor par excellence.

Whew! But that's not all, folks. Once the writing and editing part of the revision is complete, the manuscript goes to the production department, where the text and art come together. This business-like domain is headed by Michele Mangelli, our production manager once again. Always knowledgeable, Michele guides the production process with great skill and works seamlessly with the members of her excellent staff. She makes sure the artists are on schedule producing art with the appropriate look and accuracy, directs the industrious photo researcher Kristin Piljay, and oversees the work of David Novak (the conscientious production supervisor) and that hard-working art coordinator Jean Lake.

The last edition of this text touched every figure—making each piece of art more timely, more colorful, more accurate, or better pedagogically. The really big success in the art arena was the fabulous one- to two-page Focus figures introduced in the Eighth Edition. These new figures selected physiological concepts that students have the most difficulty with and "unpacked them." They say you never really have too much of a good thing, so this edition has 12 new Focus Figures. We hope you will like these as much as you did the last offerings. Helping to ensure that you will is Laura Southworth, the art developmental manager who worked tirelessly on these figures. She is not only the art manager but also a skilled professional artist who can illustrate just about any concept we ask for. This capability ensures that the art manuscript delivered to the talented artists of Imagineering and Electronic Publishing Services, who drew the final art, had all the information they needed to produce a quality product. Laura is truly amazing. Important in a different art arena was Lisa Lee, who supplied several of our histology photos and served as a consultant on images from other sources. Tom Fink (East Carolina University), William Karkow (Dubuque University), and Olga Malakhova and Charles Poulton (both from University of Florida College of Medicine, Gainesville) provided histology and cadaver images on an incredibly tight schedule. Thanks so much!

We also thank two people who contributed significantly to this edition: James Hewlett and William Karkow. Working on a tight schedule, James Hewlett contributed 13 new case studies, which were expertly reviewed for clinical accuracy by thoracic surgeon William Karkow.

Thanks also to Yvo Riezebos, cover designer, and tani hasegawa, text designer. Their creativity helped to produce a truly beautiful book. We are very happy that our cover photo, taken by renowned photographer Annie Leibovitz, is of the best known female goalkeeper in the world — Hope Solo. Hope won an Olympic gold medal in 2008, was named Women's Professional Soccer's Goalkeeper of the Year in 2009, and was awarded the Golden Glove at the 2011 World Cup. Sustaining the effort to produce a beautiful book all the way to press were our excellent proofreader, Martha Ghent, and S4Carlisle Publishing Services, the proficient compositor who assembled the final pages with their customary expertise.

The sponsoring editor for the last edition, Serina Beauparlant, has a jazzy new title, "Editor-in-Chief." Even with a slew of new duties, she is resolute about producing the best educational product possible—both in textbook and media. Her replacement for this edition, who took over a large number of Serina's duties, is Gretchen Puttkamer, a real go-getter. We haven't seen too much of Gretchen because she spends most of her time in the field talking to professors, students, and anyone else that will listen to her. Also contributing were several others that we rarely get to talk to, including: editorial assistants Lisa Damerel and John Maas, managing editor Debbie Cogan, Stacey Weinberger, who has been our expert manufacturing buyer for years, and our crackerjack marketing manager, Derek Perrigo, who goes the extra mile to make sure professors are enlightened about special features of the text. Kudos also to our media staff—Lauren Fogel, director of media development, Aimee Pavy, media producer, and the entire media team for PAL 3.0 and PhysioEx 9.0.

Benjamin Cummings spares no effort in its drive to publish an accurate and instructive book. Over 400 reviews were commissioned, enlisting comments and suggestions from both generalist academicians and specialists in various niches of anatomy and physiology. These reviewers' contributions have been of inestimable value in the continuing development of this text. We also want to thank the many students and colleagues who were generous with their time and comments. They did not always tell us what we wanted to hear, but assured of the sincerity of their criticism, we always listened. Input from the following reviewers resulted in the continued excellence and accuracy of this text.

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Marcia Anglin, *Miami Dade College*
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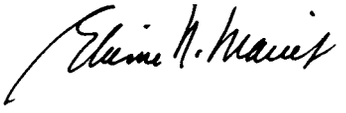
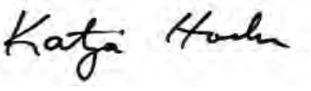
Well, our tenure on this edition is over, but there will be another edition three years hence. We would really appreciate hearing from you concerning your opinion—suggestions and constructive criticisms—of this text. It is this type of feedback that provides the basis of each revision, and underwrites its improvement.



Elaine N. Marieb



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Brief Contents

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Contents

UNIT 5 Continuity

1

The Human Body: An Orientation

Welcome to the study of one of the most fascinating subjects possible—your own body. Such a study is not only highly personal, but timely as well. We get news of some medical advance almost daily. To appreciate emerging discoveries in genetic engineering, to understand new techniques for detecting and treating disease, and to make use of published facts on how to stay healthy, you'll find it helpful to learn about the workings of your body. If you are preparing for a career in the health sciences, the study of anatomy and physiology has added rewards because it provides the foundation needed to support your clinical experiences.

In this chapter we define and contrast anatomy and physiology and discuss how the human body is organized. Then we review needs and functional processes common to all living organisms. Three essential concepts—*the complementarity of structure and function,*

the hierarchy of structural organization, and *homeostasis*—will unify and form the bedrock for your study of the human body. The final section of the chapter deals with the language of anatomy—terminology that anatomists use to describe the body or its parts.

An Overview of Anatomy and Physiology

1

- ✓ Define anatomy and physiology and describe their subdivisions.
- ✓ Explain the principle of complementarity.

Two complementary branches of science—anatomy and physiology—provide the concepts that help us to understand the human body. **Anatomy** studies the *structure* of body parts and their relationships to one another. Anatomy has a certain appeal because it is concrete. Body structures can be seen, felt, and examined closely. You don't need to imagine what they look like.

Physiology concerns the *function* of the body, in other words, how the body parts work and carry out their life-sustaining activities. When all is said and done, physiology is explainable only in terms of the underlying anatomy.

To simplify the study of the body, when we refer to body structures and/or physiological values (body temperature, heart rate, and the like), we will assume that we are talking about a healthy young (22-year-old) male weighing about 155 lb (the *reference man*) or a healthy young female weighing about 125 lb (the *reference woman*).

Topics of Anatomy

Anatomy is a broad field with many subdivisions, each providing enough information to be a course in itself. **Gross**, or **macroscopic**, **anatomy** is the study of large body structures visible to the naked eye, such as the heart, lungs, and kidneys. Indeed, the term *anatomy* (derived from the Greek words meaning "to cut apart") relates most closely to gross anatomy because in such studies preserved animals or their organs are dissected (cut up) to be examined.

Gross anatomy can be approached in different ways. In **regional anatomy**, all the structures (muscles, bones, blood vessels, nerves, etc.) in a particular region of the body, such as the abdomen or leg, are examined at the same time.

In **systemic anatomy** (sis-tem′ik),* body structure is studied system by system. For example, when studying the cardiovascular system, you would examine the heart and the blood vessels of the entire body.

Another subdivision of gross anatomy is **surface anatomy**, the study of internal structures as they relate to the overlying skin surface. You use surface anatomy when you identify the bulging muscles beneath a bodybuilder's skin, and clinicians use it to locate appropriate blood vessels in which to feel pulses and draw blood.

Microscopic anatomy deals with structures too small to be seen with the naked eye. For most such studies, exceedingly thin slices of body tissues are stained and mounted on glass slides to be examined under the microscope. Subdivisions of microscopic anatomy include **cytology** (si-tol′o-je), which considers the cells of the body, and **histology** (his-tol′o-je), the study of tissues.

Developmental anatomy traces structural changes that occur in the body throughout the life span. **Embryology** (em″bre-ol′o-je), a subdivision of developmental anatomy, concerns developmental changes that occur before birth.

Some highly specialized branches of anatomy are used primarily for medical diagnosis and scientific research. For example, *pathological anatomy* studies structural changes caused by disease. *Radiographic anatomy* studies internal structures as visualized by X-ray images or specialized scanning procedures.

Subjects of interest to anatomists range from easily seen structures down to the smallest molecule. In *molecular biology*, for example, the structure of biological molecules (chemical substances) is investigated. Molecular biology is actually a separate branch of biology, but it falls under the anatomy umbrella when we push anatomical studies to the subcellular level.

One essential tool for studying anatomy is a mastery of anatomical terminology. Others are observation, manipulation, and, in a living person, *palpation* (feeling organs with your hands) and *auscultation* (listening to organ sounds with a stethoscope). A simple example illustrates how some of these tools work together in an anatomical study.

Let's assume that your topic is freely movable joints of the body. In the laboratory, you will be able to *observe* an animal joint, noting how its parts fit together. You can work the joint (*manipulate* it) to determine its range of motion. Using *anatomical terminology*, you can name its parts and describe how they are related so that other students (and your instructor) will have no trouble understanding you. The list of word roots (at the back of the book) and the glossary will help you with this special vocabulary.

Although you will make most of your observations with the naked eye or with the help of a microscope, medical technology has developed a number of sophisticated tools that can peer into the body without disrupting it. Read about these exciting medical imaging techniques in *A Closer Look* on pp. 16–17.

Topics of Physiology

Like anatomy, physiology has many subdivisions. Most of them consider the operation of specific organ systems. For example, **renal physiology** concerns kidney function and urine production. **Neurophysiology** explains the workings of the nervous system. **Cardiovascular physiology** examines the operation of the heart and blood vessels. While

*For the pronunciation guide rules, see the first page of the glossary in the back of the book.

anatomy provides us with a static image of the body's architecture, physiology reveals the body's dynamic and animated workings.

Physiology often focuses on events at the cellular or molecular level. This is because the body's abilities depend on those of its individual cells, and cells' abilities ultimately depend on the chemical reactions that go on within them. Physiology also rests on principles of physics, which help to explain electrical currents, blood pressure, and the way muscles use bones to cause body movements, among other things. We present basic chemical and physical principles in Chapter 2 and throughout the book as needed to explain physiological topics.

Complementarity of Structure and Function

Although it is possible to study anatomy and physiology individually, they are really inseparable because function always reflects structure. That is, what a structure can do depends on its specific form. This key concept is called the **principle of complementarity of structure and function**.

For example, bones can support and protect body organs because they contain hard mineral deposits. Blood flows in one direction through the heart because the heart has valves that prevent backflow. Throughout this book, we accompany a description of a structure's anatomy with an explanation of its function, and we emphasize structural characteristics contributing to that function.

Check Your Understanding

1. In what way does physiology depend on anatomy?
2. Would you be studying anatomy or physiology if you investigated how muscles shorten? If you explored the location of the lungs in the body?

For answers, see Appendix H.

Levels of Structural Organization

- Name the different levels of structural organization that make up the human body, and explain their relationships.
- List the 11 organ systems of the body, identify their components, and briefly explain the major function(s) of each system.

The human body has many levels of structural organization **(Figure 1.1)**. The simplest level of the structural hierarchy is the **chemical level**, which we study in Chapter 2. At this level, *atoms*, tiny building blocks of matter, combine to form *molecules* such as water and proteins. Molecules, in turn, associate in specific ways to form *organelles*, basic components of the microscopic cells. *Cells* are the smallest units of living things. We examine the **cellular level** in Chapter 3. All cells have some common functions, but individual cells vary widely in size and shape, reflecting their unique functions in the body.

The simplest living creatures are single cells, but in complex organisms such as human beings, the hierarchy continues on to the **tissue level**. *Tissues* are groups of similar cells that have a common function. The four basic tissue types in the human body are epithelium, muscle, connective tissue, and nervous tissue.

Each tissue type has a characteristic role in the body, which we explore in Chapter 4. Briefly, epithelium covers the body surface and lines its cavities. Muscle provides movement. Connective tissue supports and protects body organs. Nervous tissue provides a means of rapid internal communication by transmitting electrical impulses.

An *organ* is a discrete structure composed of at least two tissue types (four is more common) that performs a specific function for the body. The liver, the brain, and a blood vessel are very different from the stomach, but each is an organ. You can think of each organ of the body as a specialized functional center responsible for a necessary activity that no other organ can perform.

At the **organ level**, extremely complex functions become possible. Let's take the stomach for an example. Its lining is an epithelium that produces digestive juices. The bulk of its wall is muscle, which churns and mixes stomach contents (food). Its connective tissue reinforces the soft muscular walls. Its nerve fibers increase digestive activity by stimulating the muscle to contract more vigorously and the glands to secrete more digestive juices.

The next level of organization is the **organ system level**. Organs that work together to accomplish a common purpose make up an *organ system*. For example, the heart and blood vessels of the cardiovascular system circulate blood continuously to carry oxygen and nutrients to all body cells. Besides the cardiovascular system, the other organ systems of the body are the integumentary, skeletal, muscular, nervous, endocrine, lymphatic, respiratory, digestive, urinary, and reproductive systems. (Note that the immune system is closely associated with the lymphatic system.) Look ahead to Figure 1.3 on pp. 6 and 7 for an overview of the 11 organ systems, which we discuss in the next section and study in more detail in Units 2–5.

The highest level of organization is the *organism*, the living human being. The **organismal level** represents the sum total of all structural levels working together to keep us alive.

Check Your Understanding

3. What level of structural organization is typical of a cytologist's field of study?
4. What is the correct structural order for the following terms: tissue, organism, organ, cell?
5. Which organ system includes the bones and cartilages? Which includes the nasal cavity, lungs, and trachea?

For answers, see Appendix H.

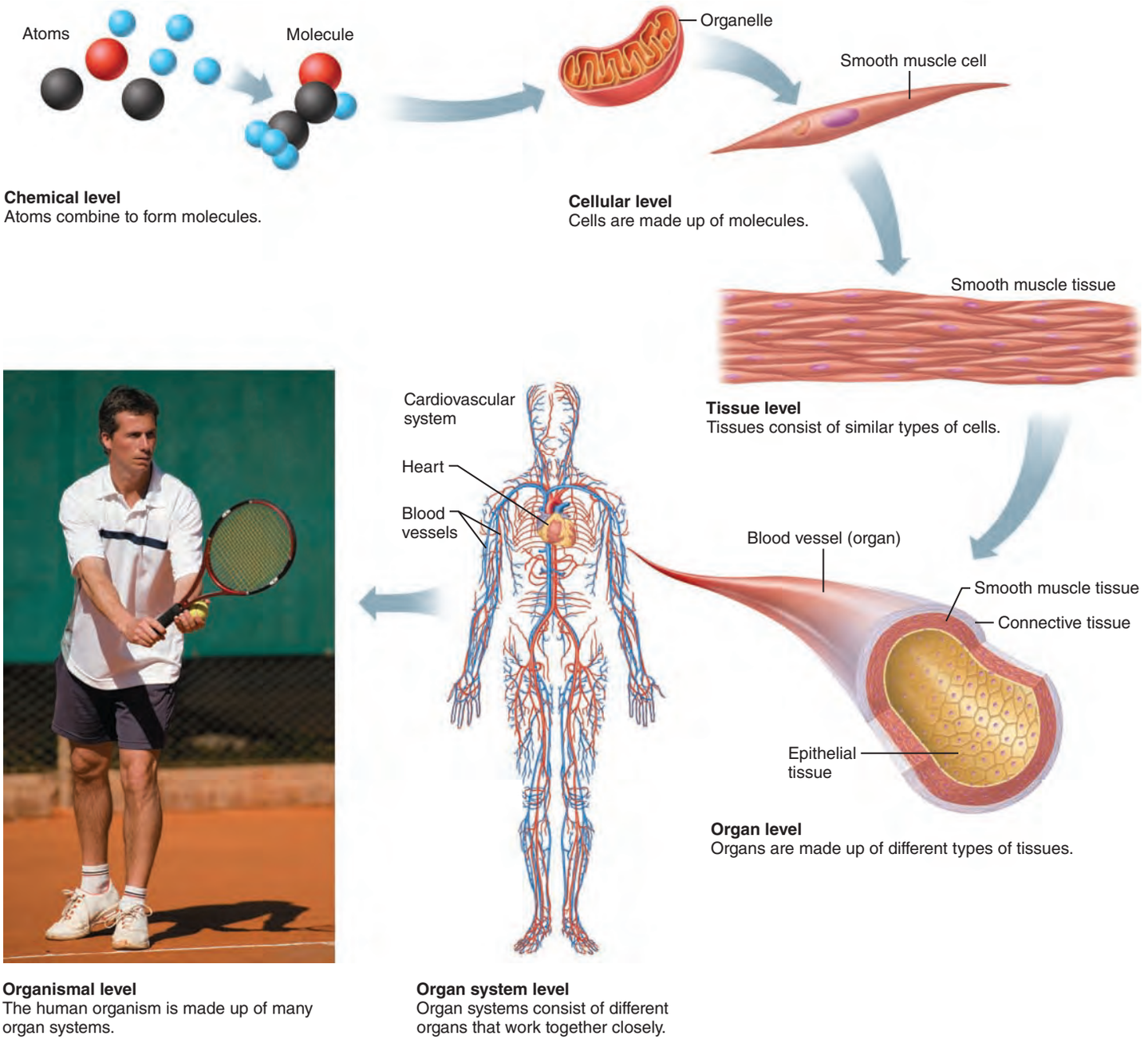


Figure 1.1 Levels of structural organization. Components of the cardiovascular system are used to illustrate the levels of structural organization in a human being.

Maintaining Life

- ✓ List the functional characteristics necessary to maintain life in humans.
- ✓ List the survival needs of the body.

Necessary Life Functions

Now that you know the structural levels of the human body, the question that naturally follows is: What does this highly organized human body do?

Like all complex animals, humans maintain their boundaries, move, respond to environmental changes, take in and digest nutrients, carry out metabolism, dispose of wastes, reproduce themselves, and grow. We will introduce these necessary life functions here and discuss them in more detail in later chapters.

We cannot emphasize too strongly that all body cells are interdependent. This interdependence is due to the fact that humans are multicellular organisms and our vital body functions are parceled out among different organ systems. Organ systems, in turn, work cooperatively to promote the well-being

of the entire body. This theme is repeated throughout the book. **Figure 1.2** identifies some of the organ systems making major contributions to necessary life functions. Also, as you read this section, check **Figure 1.3** for more detailed descriptions of the body's organ systems.

Maintaining Boundaries

Every living organism must **maintain its boundaries** so that its internal environment (its inside) remains distinct from the external environment surrounding it (its outside). In single-celled organisms, the external boundary is a limiting membrane that encloses its contents and lets in needed substances while restricting entry of potentially damaging or unnecessary substances. Similarly, all the cells of our body are surrounded by a selectively permeable membrane.

Additionally, the body as a whole is enclosed and protected by the integumentary system, or skin (Figure 1.3a). This system protects our internal organs from drying out (a fatal change), bacteria, and the damaging effects of heat, sunlight, and an unbelievable number of chemicals in the external environment.

Movement

Movement includes the activities promoted by the muscular system, such as propelling ourselves from one place to another by running or swimming, and manipulating the external environment with our nimble fingers (Figure 1.3c). The skeletal system provides the bony framework that the muscles pull on as they work (Figure 1.3b). Movement also occurs when substances such as blood, foodstuffs, and urine are propelled through internal organs of the cardiovascular, digestive, and urinary systems, respectively. On the cellular level, the muscle cell's ability to move by shortening is more precisely called **contractility**.

Responsiveness

Responsiveness, or **excitability**, is the ability to sense changes (which serve as stimuli) in the environment and then respond to them. For example, if you cut your hand on broken glass, a withdrawal reflex occurs—you involuntarily pull your hand away from the painful stimulus (the broken glass). You don't have to think about it—it just happens! Likewise, when carbon dioxide in your blood rises to dangerously high levels, chemical sensors respond by sending messages to brain centers controlling respiration, and you breathe more rapidly.

Because nerve cells are highly excitable and communicate rapidly with each other via electrical impulses, the nervous system is most involved with responsiveness (Figure 1.3d). However, all body cells are excitable to some extent.

Digestion

Digestion is the breaking down of ingested foodstuffs to simple molecules that can be absorbed into the blood. The nutrient-rich blood is then distributed to all body cells by the cardiovascular system. In a simple, one-celled organism such as an amoeba, the cell itself is the "digestion factory," but in the multicellular human body, the digestive system performs this function for the entire body (Figure 1.3i).

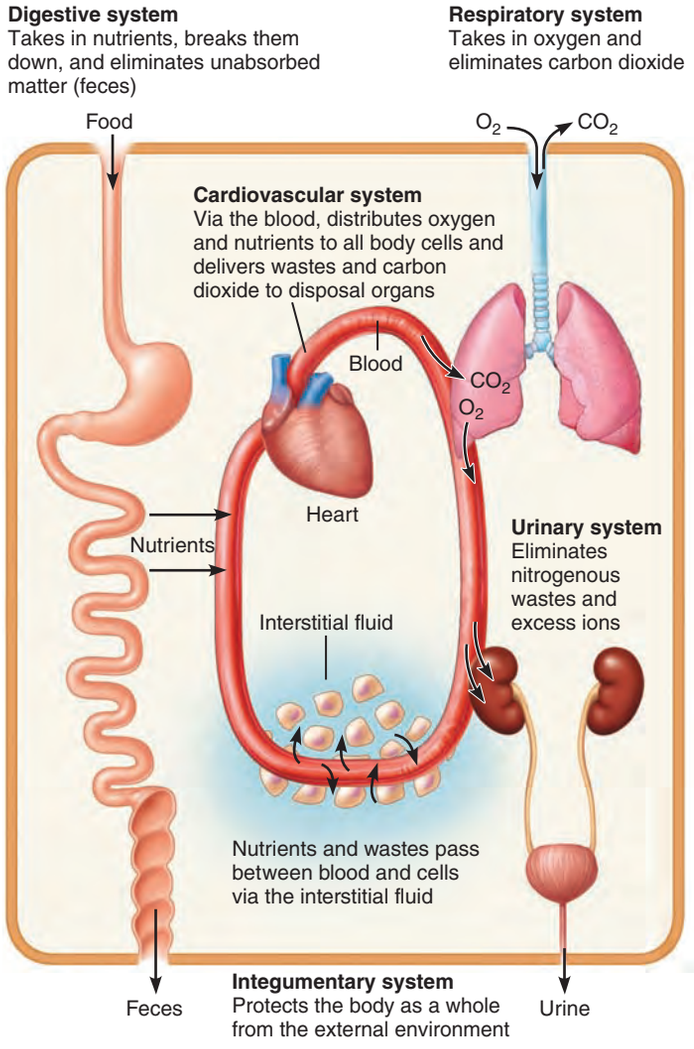
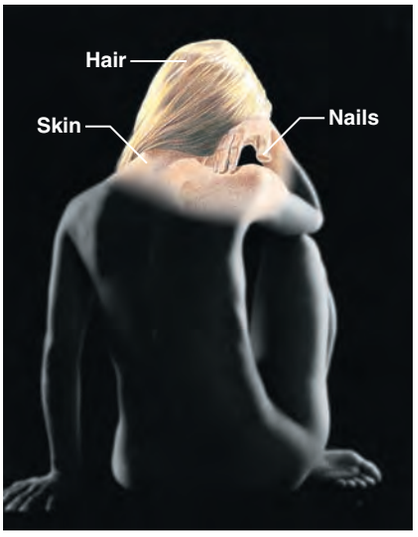


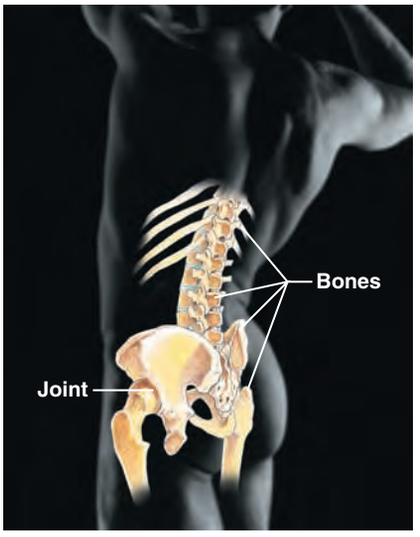
Figure 1.2 Examples of interrelationships among body organ systems.

Metabolism

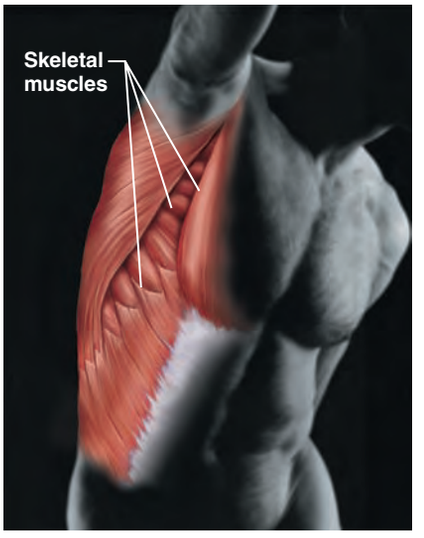
Metabolism (mĕ-tab′o-lizm; "a state of change") is a broad term that includes all chemical reactions that occur within body cells. It includes breaking down substances into their simpler building blocks (more specifically, the process of *catabolism*), synthesizing more complex cellular structures from simpler substances (*anabolism*), and using nutrients and oxygen to produce (via *cellular respiration*) ATP, the energy-rich molecules that power cellular activities. Metabolism depends on the digestive and respiratory systems to make nutrients and oxygen available to the blood and on the cardiovascular system to distribute them throughout the body (Figure 1.3i, h, and f, respectively). Metabolism is regulated largely by hormones secreted by endocrine system glands (Figure 1.3e).



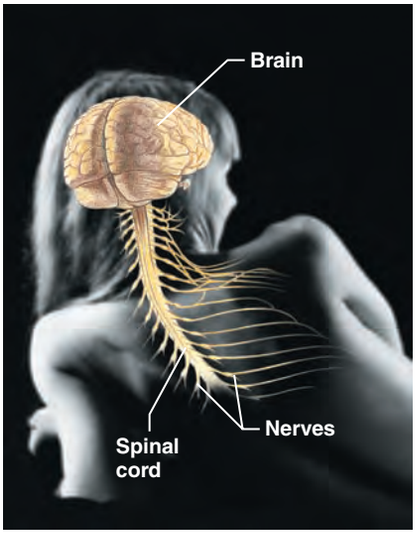
(a) Integumentary System
Forms the external body covering, and protects deeper tissues from injury. Synthesizes vitamin D, and houses cutaneous (pain, pressure, etc.) receptors and sweat and oil glands.



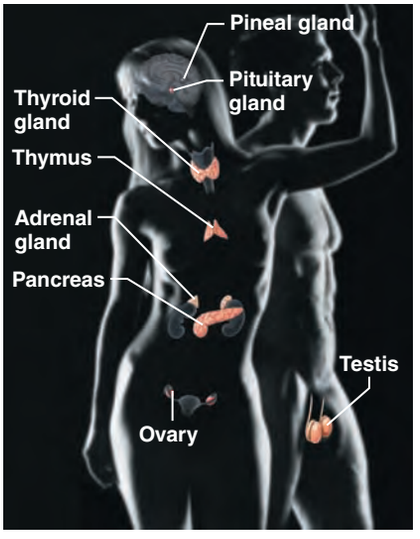
(b) Skeletal System
Protects and supports body organs, and provides a framework the muscles use to cause movement. Blood cells are formed within bones. Bones store minerals.



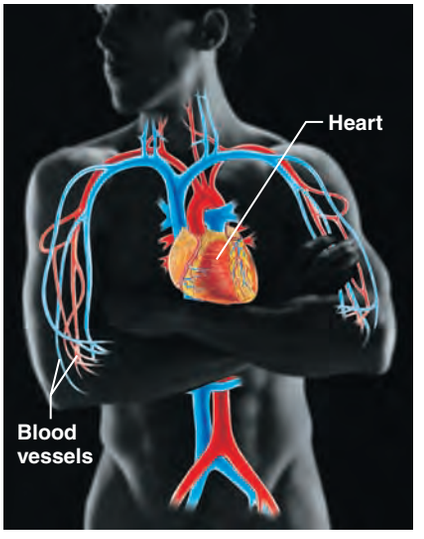
(c) Muscular System
Allows manipulation of the environment, locomotion, and facial expression. Maintains posture, and produces heat.



(d) Nervous System
As the fast-acting control system of the body, it responds to internal and external changes by activating appropriate muscles and glands.



(e) Endocrine System
Glands secrete hormones that regulate processes such as growth, reproduction, and nutrient use (metabolism) by body cells.



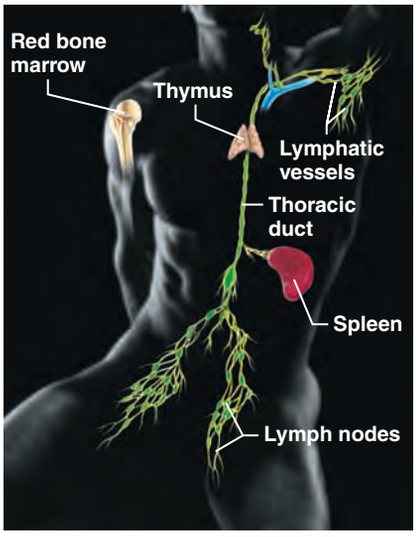
(f) Cardiovascular System
Blood vessels transport blood, which carries oxygen, carbon dioxide, nutrients, wastes, etc. The heart pumps blood.

Figure 1.3 The body's organ systems and their major functions.

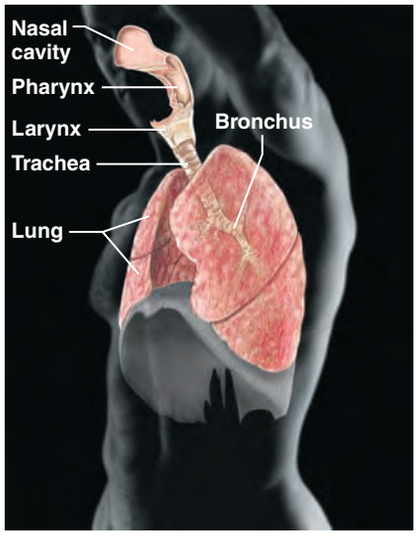
Excretion

Excretion is the process of removing wastes, or *excreta* (ek-skre′tah), from the body. If the body is to operate as we expect it to, it must get rid of nonuseful substances produced during digestion and metabolism.

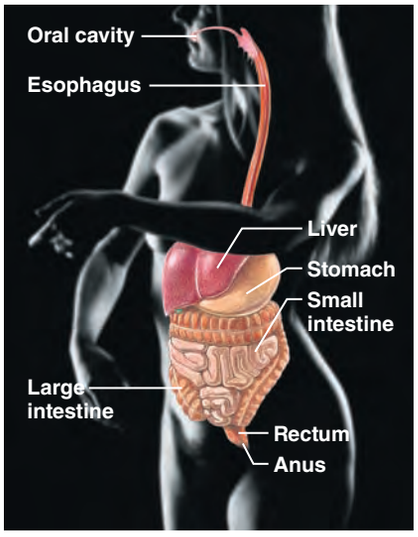
Several organ systems participate in excretion. For example, the digestive system rids the body of indigestible food residues in feces, and the urinary system disposes of nitrogen-containing metabolic wastes, such as urea, in urine (Figure 1.3i and j). Carbon dioxide, a by-product of cellular respiration, is carried in



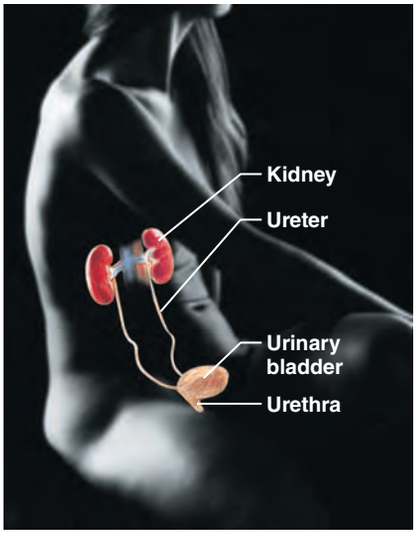
(g) Lymphatic System/Immunity
Picks up fluid leaked from blood vessels and returns it to blood. Disposes of debris in the lymphatic stream. Houses white blood cells (lymphocytes) involved in immunity. The immune response mounts the attack against foreign substances within the body.



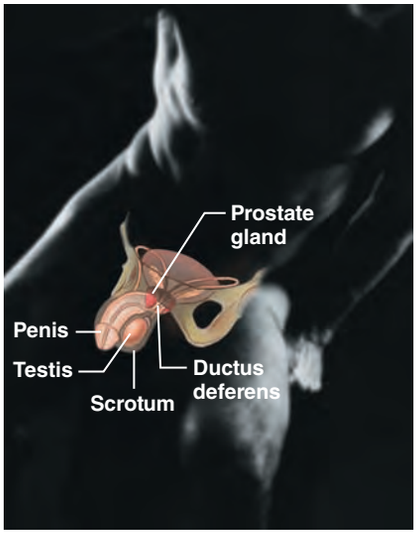
(h) Respiratory System
Keeps blood constantly supplied with oxygen and removes carbon dioxide. The gaseous exchanges occur through the walls of the air sacs of the lungs.



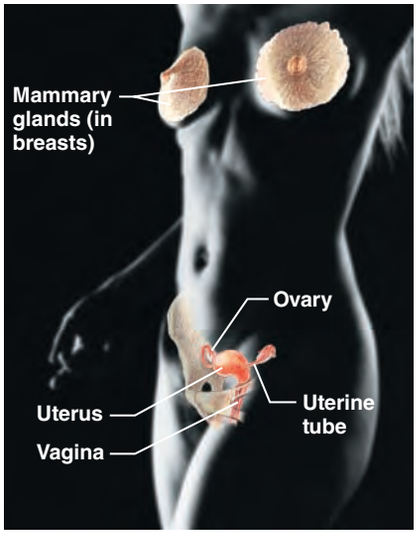
(i) Digestive System
Breaks down food into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.



(j) Urinary System
Eliminates nitrogenous wastes from the body. Regulates water, electrolyte and acid-base balance of the blood.



(k) Male Reproductive System



(l) Female Reproductive System

Overall function is production of offspring. Testes produce sperm and male sex hormone, and male ducts and glands aid in delivery of sperm to the female reproductive tract. Ovaries produce eggs and female sex hormones. The remaining female structures serve as sites for fertilization and development of the fetus. Mammary glands of female breasts produce milk to nourish the newborn.

the blood to the lungs, where it leaves the body in exhaled air (Figure 1.3h).

Reproduction

Reproduction occurs at the cellular and the organismal level. In cellular reproduction, the original cell divides, producing two identical daughter cells that may then be used for body growth or repair. Reproduction of the human organism, or making a whole new person, is the major task of the reproductive system. When a sperm unites with an egg, a fertilized egg forms and develops into a baby within the mother's body. The reproductive system is directly responsible for producing offspring, but its function is exquisitely regulated by hormones of the endocrine system (Figure 1.3e).

Because males produce sperm and females produce eggs (ova), there is a division of labor in reproduction, and the reproductive organs of males and females are different (Figure 1.3k, l). Additionally, the female's reproductive structures provide the site for fertilization of eggs by sperm, and then protect and nurture the developing fetus until birth.

Growth

Growth is an increase in size of a body part or the organism as a whole. It is usually accomplished by increasing the number of cells. However, individual cells also increase in size when not dividing. For true growth to occur, constructive activities must occur at a faster rate than destructive ones.

Survival Needs

The ultimate goal of all body systems is to maintain life. However, life is extraordinarily fragile and requires several factors. These factors, which we will call *survival needs*, include nutrients (food), oxygen, water, and appropriate temperature and atmospheric pressure.

Nutrients

Nutrients, taken in via the diet, contain the chemical substances used for energy and cell building. Most plant-derived foods are rich in carbohydrates, vitamins, and minerals, whereas most animal foods are richer in proteins and fats.

Carbohydrates are the major energy fuel for body cells. Proteins, and to a lesser extent fats, are essential for building cell structures. Fats also provide a reserve of energy-rich fuel. Selected minerals and vitamins are required for the chemical reactions that go on in cells and for oxygen transport in the blood. The mineral calcium helps to make bones hard and is required for blood clotting.

Oxygen

All the nutrients in the world are useless unless **oxygen** is also available. Because the chemical reactions that release energy from foods are *oxidative* reactions that require oxygen, human cells can survive for only a few minutes without oxygen. Approximately 20% of the air we breathe is oxygen. The cooperative efforts of the respiratory and cardiovascular systems make oxygen available to the blood and body cells.

Water

Water accounts for 60–80% of our body weight and is the single most abundant chemical substance in the body. It provides the watery environment necessary for chemical reactions and the fluid base for body secretions and excretions. We obtain water chiefly from ingested foods or liquids. We lose it from the body by evaporation from the lungs and skin and in body excretions.

Normal Body Temperature

If chemical reactions are to continue at life-sustaining rates, **normal body temperature** must be maintained. As body temperature drops below 37°C (98.6°F), metabolic reactions become slower and slower, and finally stop. When body temperature is too high, chemical reactions occur at a frantic pace and body proteins lose their characteristic shape and stop functioning. At either extreme, death occurs. The activity of the muscular system generates most body heat.

Appropriate Atmospheric Pressure

Atmospheric pressure is the force that air exerts on the surface of the body. Breathing and gas exchange in the lungs depend on *appropriate* atmospheric pressure. At high altitudes, where atmospheric pressure is lower and the air is thin, gas exchange may be inadequate to support cellular metabolism.

■ ■ ■

The mere presence of these survival factors is not sufficient to sustain life. They must be present in *appropriate* amounts. Too much and too little may be equally harmful. For example, oxygen is essential, but excessive amounts are toxic to body cells. Similarly, the food we eat must be of high quality and in proper amounts. Otherwise, nutritional disease, obesity, or starvation is likely. Also, while the needs listed above are the most crucial, they do not even begin to encompass all of the body's needs. For example, we can live without gravity if we must, but the quality of life suffers.

Check Your Understanding

6. What separates living beings from nonliving objects?
7. What name is given to all chemical reactions that occur within body cells?
8. Why is it necessary to be in a pressurized cabin when flying at 30,000 feet?

For answers, see Appendix H.

Homeostasis

- ✓ Define homeostasis and explain its significance.
- ✓ Describe how negative and positive feedback maintain body homeostasis.
- ✓ Describe the relationship between homeostatic imbalance and disease.

When you think about the fact that your body contains trillions of cells in nearly constant activity, and that remarkably little usually goes wrong with it, you begin to appreciate what a marvelous machine your body is. Walter Cannon, an American physiologist of the early twentieth century, spoke of the "wisdom of the body," and he coined the word **homeostasis** (ho″me-o-sta′sis) to describe its ability to maintain relatively stable internal conditions even though the outside world changes continuously.

Although the literal translation of homeostasis is "unchanging," the term does not really mean a static, or unchanging, state. Rather, it indicates a *dynamic* state of equilibrium, or a balance, in which internal conditions vary, but always within relatively

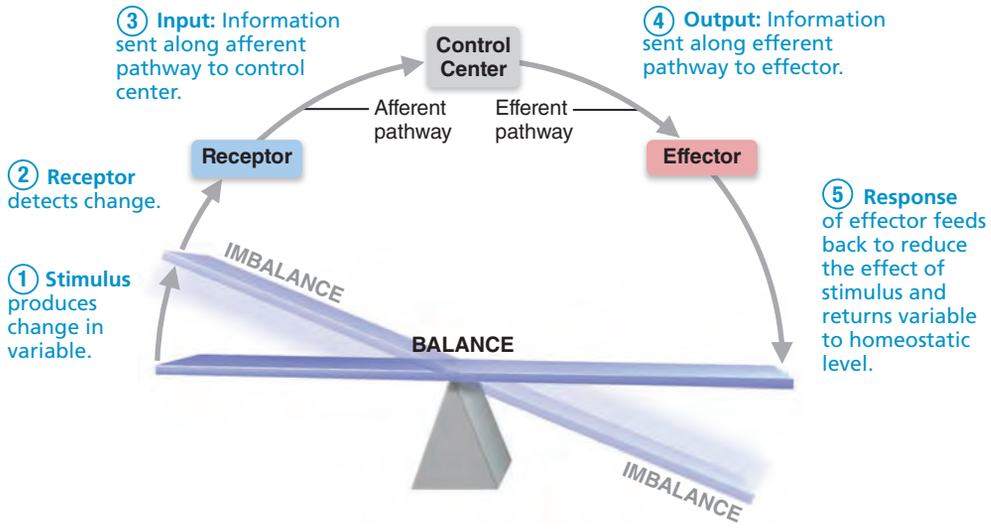


Figure 1.4 Interactions among the elements of a homeostatic control system maintain stable internal conditions.

narrow limits. In general, the body is in homeostasis when its needs are adequately met and it is functioning smoothly.

Maintaining homeostasis is more complicated than it appears at first glance. Virtually every organ system plays a role in maintaining the constancy of the internal environment. Adequate blood levels of vital nutrients must be continuously present, and heart activity and blood pressure must be constantly monitored and adjusted so that the blood is propelled to all body tissues. Also, wastes must not be allowed to accumulate, and body temperature must be precisely controlled. A wide variety of chemical, thermal, and neural factors act and interact in complex ways—sometimes helping and sometimes hindering the body as it works to maintain its "steady rudder."

Homeostatic Control

Communication within the body is essential for homeostasis. Communication is accomplished chiefly by the nervous and endocrine systems, which use neural electrical impulses or bloodborne hormones, respectively, as information carriers. We cover the details of how these two great regulating systems operate in later chapters, but here we explain the basic characteristics of control systems that promote homeostasis.

Regardless of the factor or event being regulated—the **variable**—all homeostatic control mechanisms are processes involving at least three components that work together **(Figure 1.4)**. The first component, the **receptor**, is some type of sensor that monitors the environment and responds to changes, called *stimuli*, by sending information (input) to the second component, the *control center*. Input flows from the receptor to the control center along the so-called *afferent pathway*.

The **control center** determines the *set point*, which is the level or range at which a variable is to be maintained. It also analyzes the input it receives and determines the appropriate response or course of action. Information (output) then flows from the control center to the third component, the *effector*, along the *efferent pathway*. (To help you remember the difference between "afferent" and "efferent," you might note that information traveling along the afferent pathway *approaches* the control center and efferent information *exits* from the control center.)

The **effector** provides the means for the control center's response (output) to the stimulus. The results of the response then *feed back* to influence the effect of the stimulus, either reducing it (in negative feedback) so that the whole control process is shut off, or enhancing it (in positive feedback) so that the whole process continues at an even faster rate.

Negative Feedback Mechanisms

Most homeostatic control mechanisms are **negative feedback mechanisms**. In these systems, the output shuts off the original effect of the stimulus or reduces its intensity. These mechanisms cause the variable to change in a direction *opposite* to that of the initial change, returning it to its "ideal" value; thus the name "negative" feedback mechanisms.

Let's start with an example of a nonbiological negative feedback system: a home heating system connected to a temperature-sensing thermostat. The thermostat houses both the receptor (thermometer) and the control center. If the thermostat is set at 20°C (68°F), the heating system (effector) is triggered ON when the house temperature drops below that setting. As the furnace produces heat and warms the air, the temperature rises, and when it reaches 20°C or slightly higher, the thermostat triggers the furnace OFF. This process results in a cycling of "furnace-ON" and "furnace-OFF" so that the temperature in the house stays very near the desired temperature of 20°C. Your body "thermostat," located in a part of your brain called the hypothalamus, operates in a similar fashion **(Figure 1.5)**.

Regulation of body temperature is only one of the many ways the nervous system maintains the constancy of the internal environment. Another type of neural control mechanism is seen in the *withdrawal reflex* mentioned earlier, in which the hand is jerked away from a painful stimulus such as broken glass.