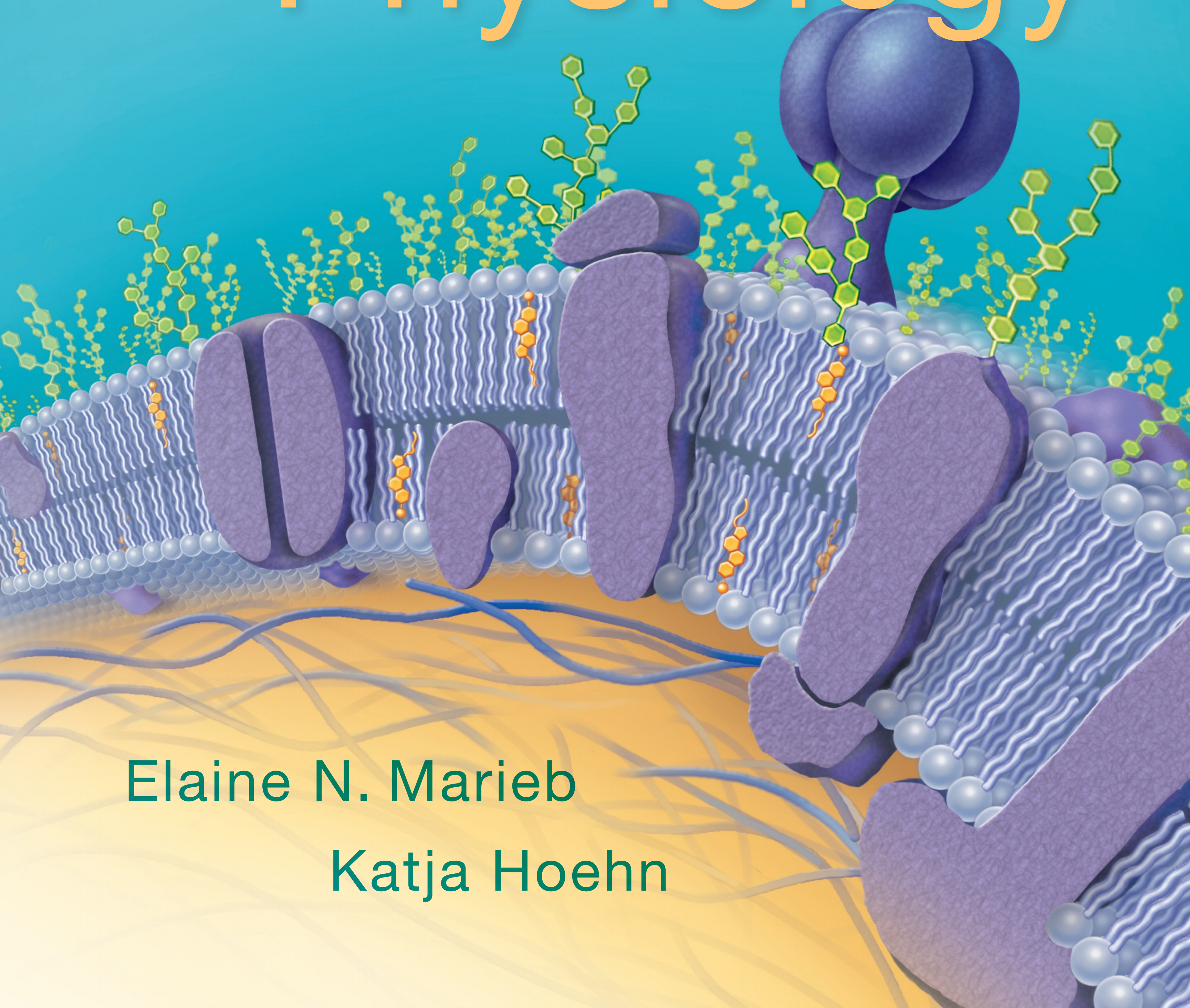
Sixth Edition

Anatomy & Physiology



Elaine N. Marieb

Katja Hoehn

Brief Contents

ELAINE MARIEB is the most trusted name in all of A&P. More than 3 million health care professionals started their careers with one of Elaine Marieb's Anatomy & Physiology texts.

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NEW! eText 2.0 brings your textbook to any web-enabled device.

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LEARN WHY THIS MATTERS

NEW! Chapter-opening Why This Matters videos describe how the material applies to your future career. **Scan the QR codes** to see brief videos of real health care professionals discussing how they use the chapter content every day in the field.

SEE WHERE YOU

NEW! Key concept organization presents the material in manageable chunks and helps you easily navigate the chapter. Each section header states the key concept of that section.

Overview of Key Concepts

Key Concept section header

5 The Integumentary System

WHY THIS MATTERS

KEY CONCEPTS

Would you be enticed by an ad for a coat that is waterproof, stretchable, washable, and air-conditioned, that automatically repairs small cuts, rips, and burns? How about one that's guaranteed to last a lifetime? Sounds too good to be true, but you already have such a coat—your skin.

The skin and its derivatives (sweat and oil glands, hairs, and nails) make up a complex set of organs that serves several functions, mostly protective. Together, these organs form the **integumentary system** (in-teg″u-men′tar-e).

5.1 The skin consists of two layers: the epidermis and dermis

→ Learning Objective

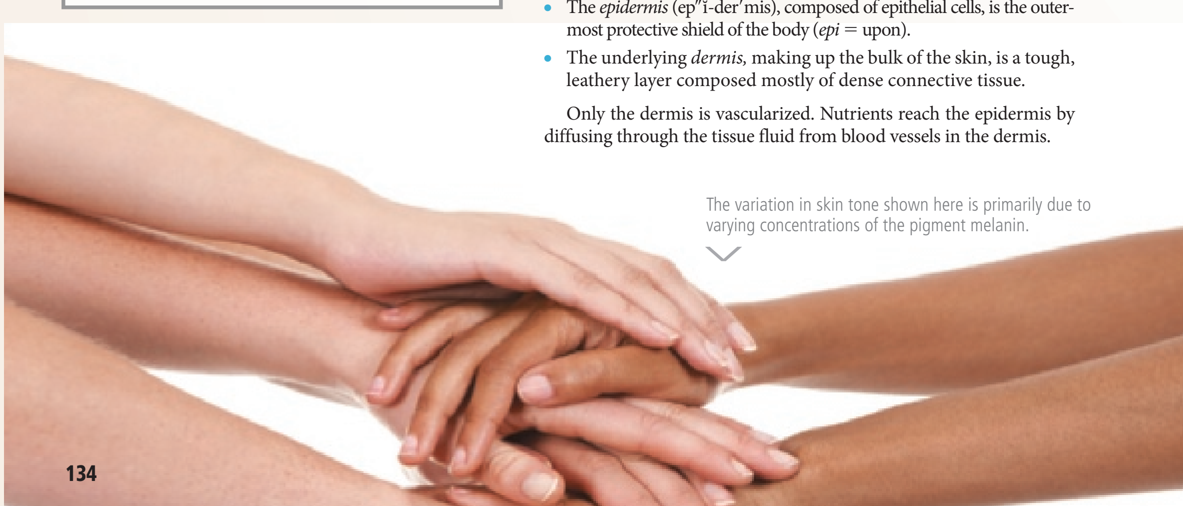
☐ **List the two layers of skin and briefly describe subcutaneous tissue.**

The skin receives little respect from its inhabitants, but architecturally it is a marvel. It covers the entire body, has a surface area of 1.2 to 2.2 square meters, weighs 4 to 5 kilograms (4–5 kg = 9–11 lb), and accounts for about 7% of total body weight in the average adult. Also called the integument ("covering"), the skin multitasks. Its functions go well beyond serving as a bag for body contents. Pliable yet tough, it takes constant punishment from external agents. Without our skin, we would quickly fall prey to bacteria and perish from water and heat loss.

Varying in thickness from 1.5 to 4.0 millimeters (mm) or more in different parts of the body, the skin is composed of two distinct layers (**Figure 5.1**):

- The *epidermis* (ep″ĭ-der′mis), composed of epithelial cells, is the outermost protective shield of the body (*epi* = upon).
- The underlying *dermis,* making up the bulk of the skin, is a tough, leathery layer composed mostly of dense connective tissue.

Only the dermis is vascularized. Nutrients reach the epidermis by diffusing through the tissue fluid from blood vessels in the dermis.



The variation in skin tone shown here is primarily due to varying concentrations of the pigment melanin.

ARE HEADED

Check Your Understanding questions end each section and allow you to assess your understanding of the concept before moving on.

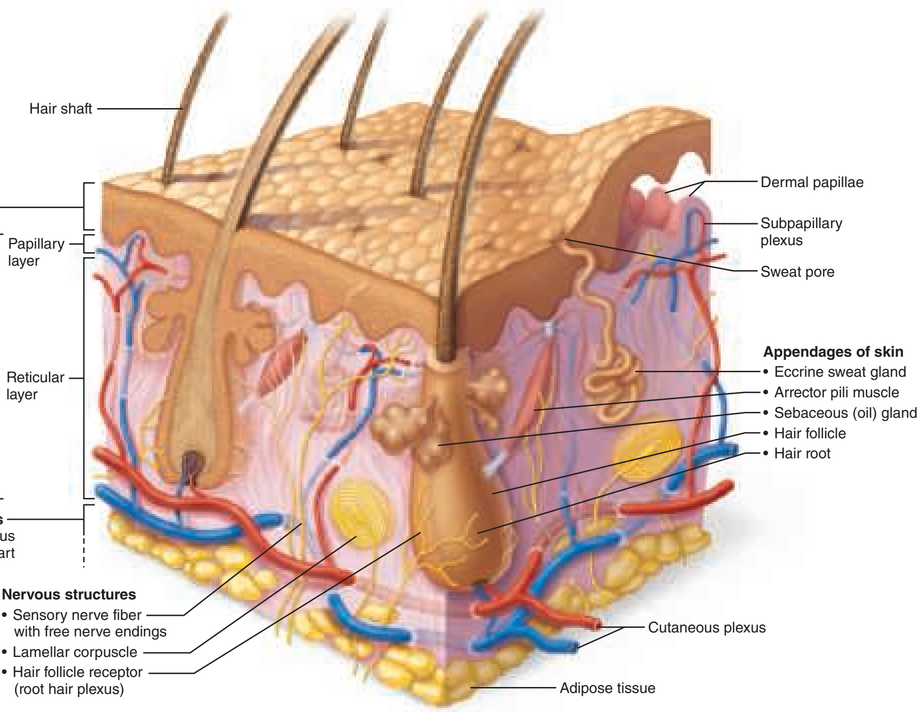


Figure 5.1 Skin structure. Three-dimensional view of the skin and underlying subcutaneous tissue. The epidermal and dermal layers have been pulled apart at the upper right corner to reveal the dermal papillae.

and accounts for about 7% of total body weight in the average adult. Also called the integument ("covering"), the skin multitasks. Its functions go well beyond serving as a bag for body contents. Pliable yet tough, it takes constant punishment from external agents. Without our skin, we would quickly fall prey to bacteria and perish from water and heat loss.

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Only the dermis is vascularized. Nutrients reach the epidermis by diffusing through the tissue fluid from blood vessels in the dermis.

The subcutaneous tissue just deep to the skin is known as the **hypodermis** (Figure 5.1). Strictly speaking, the hypodermis is not part of the skin, but it shares some of the skin's protective functions. The hypodermis, also called **superficial fascia** because it is superficial to the tough connective tissue wrapping (fascia) of the skeletal muscles, consists mostly of adipose tissue.

Besides storing fat, the hypodermis anchors the skin to the underlying structures (mostly to muscles), but loosely enough that the skin can slide relatively freely over those structures. Sliding skin protects us by ensuring that many blows just glance off our bodies. Because of its fatty composition, the hypodermis also acts as a shock absorber and an insulator that reduces heat loss.

☑ Check Your Understanding

1. Which layer of the skin—dermis or epidermis—is better nourished?

For answers, see Answers Appendix.

Check Your Understanding self-assessment

TOOLS TO HELP YOU

NEW! Find study tools online with references to MasteringA&P® in the book. Visit MasteringA&P for self-study modules, interactive animations, virtual lab tools, and more!

Practice art labeling
MasteringA&P®>Study Area>Chapter 10

Figure 10.26 Summary: Actions of muscles of the thigh and leg.

NEW! Easily find clinical examples to help you see how A&P concepts apply to your future career. The clinical content—including the Homeostatic Imbalance sections, clinical content modules, and the chapter-ending At the Clinic Case Study—has a unified new look and feel.

CLINICAL

12.9 Brain injuries and disorders have devastating consequences

Learning Objectives

- ☐ Describe the cause (if known) and major signs and symptoms of cerebrovascular accidents, Alzheimer's disease, Parkinson's disease, and Huntington's disease.
- ☐ List and explain several techniques used to diagnose brain disorders.

Brain dysfunctions are unbelievably varied and extensive. We have mentioned some of them already, but here we will focus on traumatic brain injuries, cerebrovascular accidents, and degenerative brain disorders.

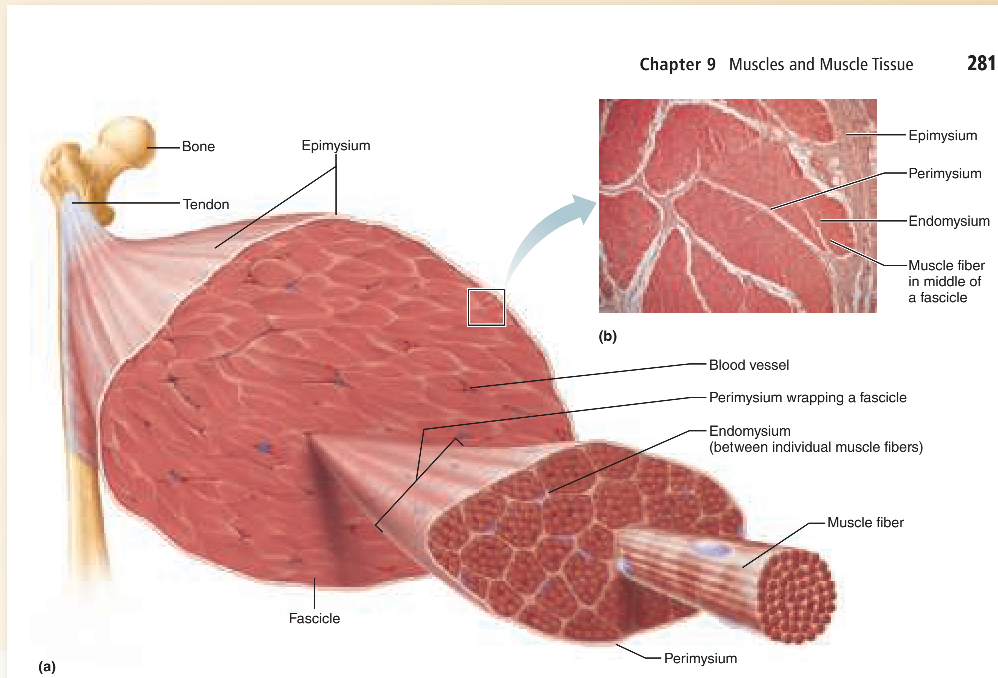
CLINICAL

HOMEOSTATIC IMBALANCE 22.3

Mumps, a common children's disease, is an inflammation of the parotid glands caused by the mumps virus (*myxovirus*), which spreads from person to person in saliva. If you check the location of the parotid glands in Figure 22.10a, you can understand why people with mumps complain that it hurts to open their mouth or chew. Other signs and symptoms include moderate fever and pain when swallowing acidic foods (pickles, grapefruit juice, etc.). Mumps in adult males carries a 25% risk of infecting the testes too, leading to sterility. ✚

ON YOUR JOURNEY

Stunning 3-D art with vibrant colors appears on every page to help you better visualize and understand key anatomical structures and their functions.



NEW! Making Connections questions in each chapter ask you to apply what you've learned across different body systems and chapters so that you build a cohesive understanding of the body.

☑ Check Your Understanding

21. What chemicals produced in the skin help provide barriers to bacteria? List at least three and explain how the chemicals are protective.

22. Which epidermal cells play a role in body immunity?

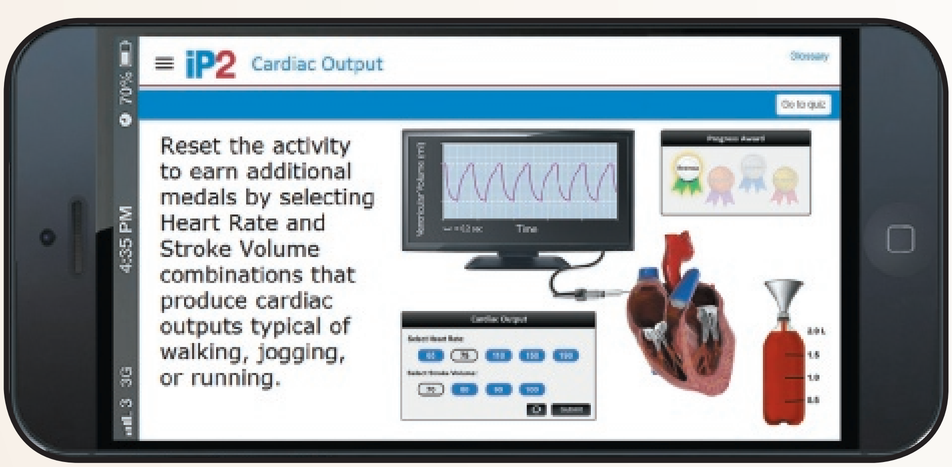
23. How is sunlight important to bone health?

24. MAKING connections When blood vessels in the dermis constrict or dilate to help maintain body temperature, which type of muscle tissue that you learned about (in Chapter 4) acts as the effector that causes blood vessel dilation or constriction?

For answers, see Answers Appendix.

PRACTICE MAKES PERFECT

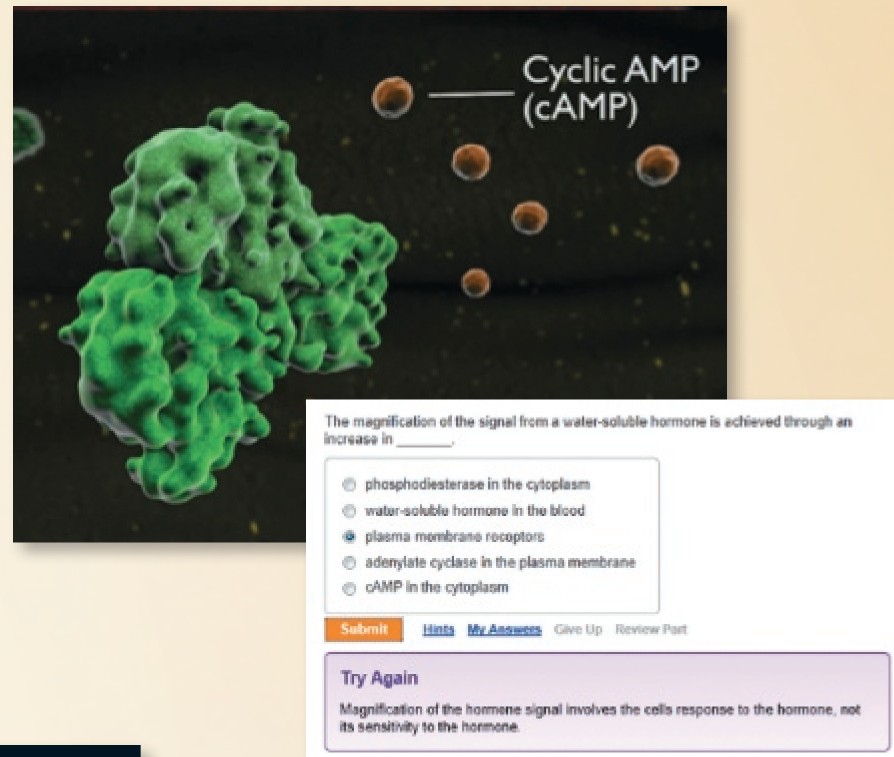
NEW! Concept Maps are fun and challenging activities that help you solidify your understanding of a key course concept. These fully mobile activities allow you to combine key terms with linking phrases into a free-form map for topics such as protein synthesis, events in an action potential, and excitation-contraction coupling.



NEW! Interactive Physiology® 1.0 and 2.0 help 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. IP 2.0 includes topics that have been updated for today's technology, such as **Resting Membrane Potential, Cardiac Output, Electrical Activity of the Heart, Factors Affecting Blood Pressure,** and **Cardiac Cycle**.

WITH MasteringA&P

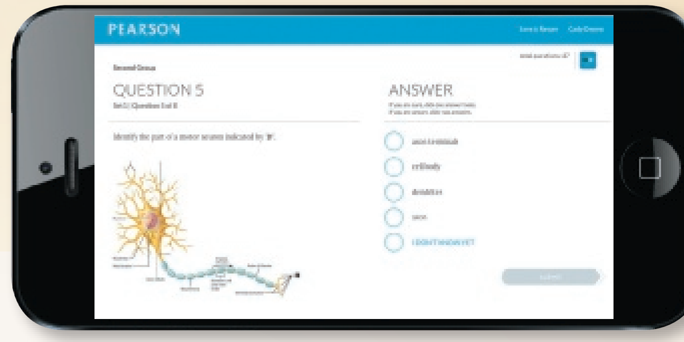
A&P Flix™ are 3-D movie-quality animations with self-paced tutorials and gradable quizzes that help you master the toughest topics in A&P.



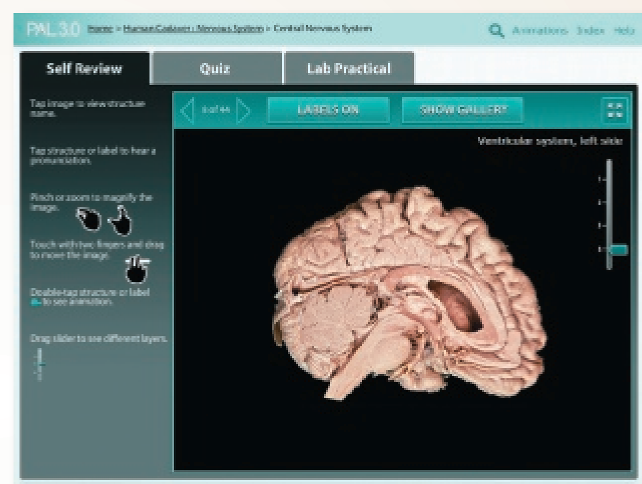
Practice Anatomy Lab™ **(PAL**™**) 3.0** is a virtual anatomy study and practice tool that gives you 24/7 access to the most widely used lab specimens, including the human cadaver, anatomical models, histology, cat, and fetal pig. PAL 3.0 is easy to use and includes built-in audio pronunciations, rotatable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

STUDY ON THE GO WITH THESE MOBILE TOOLS

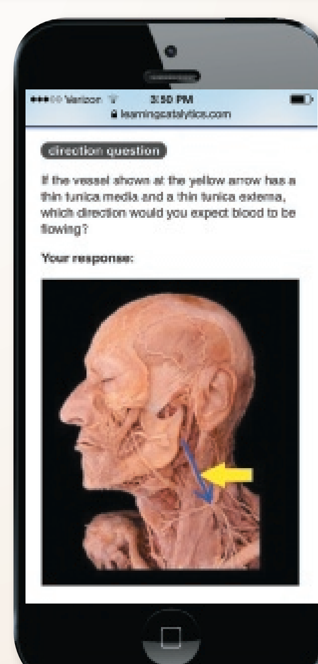
NEW! Dynamic Study Modules offer a mobile-friendly, personalized reading experience of the chapter content. As you answer questions to master the chapter content, you receive detailed feedback with text and art from the book itself. The Dynamic Study Modules help you acquire, retain, and recall information faster and more efficiently than ever before.



The PAL 3.0 App lets you access PAL 3.0 on your iPad or Android tablet. Enlarge images, watch animations, and study for your lab practicals with multiple-choice and fill-in-the-blank quizzes—all while on the go!



Learning Catalytics is a "bring your own device" (laptop, smartphone, or tablet) engagement, assessment, and classroom intelligence system. Use your device to respond to open-ended questions, and then discuss your answers in groups based on responses.



Anatomy & Physiology

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Library of Congress Cataloging-in-Publication Data

Marieb, Elaine Nicpon / Hoehn, Katja.
Anatomy & physiology / Elaine N. Marieb, R.N., Ph.D. Holyoke Community College, Katja Hoehn, M.D., Ph.D., Mount Royal University.
Anatomy and physiology
Sixth edition. / San Francisco : Pearson Education, Inc., [2017]
Includes index.
LCCN 2015035194 / ISBN 9780134156415
LCSH: Human physiology. / Human anatomy.
LCC QP34.5 .M454 2017 / DDC
612—dc23
LC record available at http://lccn.loc.gov/ 2015035194

PEARSON www.pearsonhighered.com

ISBN 10: 0-13-415641-2; ISBN 13: 978-0-13-415641-5 (Student Edition)
ISBN 10: 0-13-421336-X; ISBN 13: 978-0-13-421336-1 (Instructor's Review Copy)
1 2 3 4 5 6 7 8 9 10—V357-19 18 17 16 15

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 10th 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 colleges both near and far 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 a professor in the Department of Biology 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 21 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.

Preface

As educators we continually make judgments about the enormous amount of information that besets us daily, so we can choose which morsels to pass on to our students. Yet even this refined information avalanche challenges the learning student's mind. What can we do to help students apply the concepts they are faced with in our classrooms? We believe that this new edition of our textbook addresses that question by building on the strengths of previous editions while using new, innovative ways to help students visualize connections between various concepts.

Unifying Themes

Three unifying themes that have helped to organize and set the tone of this textbook continue to be valid and are retained in this edition. These themes are:

Interrelationships of body organ systems. This theme emphasizes the fact that nearly all regulatory mechanisms have interactions with several organ systems. The respiratory system, for example, cannot carry out its role of gas exchange in the body if there are problems with the cardiovascular system that prevent the normal delivery of blood throughout the body.

Homeostasis. Homeostasis is the normal and most desirable condition of the body. Its loss is always associated with past or present pathology. This theme is not included to emphasize pathological conditions but rather to illustrate what happens in the body when homeostasis is lost.

Whenever students see a red balance beam symbol accompanied by an associated clinical topic, their understanding of how the body works to stay in balance is reinforced.

Complementarity of structure and function. This theme encourages students to understand the structure of some bodily part (cell, bone, lung, etc.) in order to understand the function of that structure. For example, muscle cells can produce movement because they are contractile cells.

Changes Past and Present

Many of the changes made to the 5th edition have been retained and are reinforced in this 6th edition.

- There are more step-by-step blue texts accompanying certain pieces of art (blue text refers to the instructor's voice).
- The many clinical features of the book have been clearly identified to help students understand why this material is important.
- The "Check Your Understanding" questions at the end of each module reinforce understanding throughout the chapter.
- We have improved a number of our Focus Figures. (Focus Figures are illustrations that use a "big picture" layout and dramatic art to walk the student through difficult processes in a step-by-step way.)
- MasteringA&P continues to provide text-integrated media of many types to aid learning. These include *Interactive Physiology* (IP) tutorials that help students to grasp difficult concepts, *A&PFlix* animations that help students visualize tough A&P topics, and the PAL (Practice Anatomy Lab) collection of virtual anatomy study and practice tools focusing on the most widely used lab specimens. These are by no means all of the helpful tools to which students have access. It's just a smattering.

New to the Sixth Edition

So, besides these tools, what is really new to this textbook this time around? Each chapter's first page has a "Why This Matters" icon and QR code that links to a video of a health-care professional telling us why the chapter's content is important for his or her work.

Other new features include (1) declarative headers at the beginning of each chapter module so that the student can quickly grasp the "big idea" for that module, (2) more modularization (chunking) of the text so that students can tackle manageable pieces of information as they read through the material, (3) increased readability of the text as a result of more bulleted lists and shorter paragraphs, (4) more summary tables to help students connect information, (5) improvements to many of the figures so that they teach even more effectively, and (6) "Making Connections" questions in each chapter that ask students to incorporate related information from earlier chapters or earlier modules in the same chapter, helping students to see the forest, not just the trees, as they study.

Chapter-by-Chapter Changes

Chapter 1 The Human Body: An Orientation

- Updated Figure 1.8 for better teaching effectiveness.

Chapter 2 Chemistry Comes Alive

- Updated Figure 2.18 for better teaching effectiveness.

Chapter 3 Cells: The Living Units

- Updated statistics on Tay-Sachs disease.
- Updated information about riboswitches and added information about small interfering RNAs (siRNAs).
- Added summary text to Figure 3.3 for better pedagogy.
- Updated Focus Figure 3.4.

Chapter 4 Tissue: The Living Fabric

- New photos of simple columnar epithelium, pseudostratified ciliated columnar epithelium, cardiac muscle tissue, and smooth muscle tissue (Figures 4.3c, d and 4.9b, c).

Chapter 5 The Integumentary System

- Added information about the role of tight junctions in skin.
- New photo of stretch marks (Figure 5.5).
- New photo of cradle cap (seborrhea) in a newborn (Figure 5.9).
- New photo of malignant melanoma (Figure 5.10).

Chapter 6 Bones and Skeletal Tissues

- Revised Figure 6.9 for improved teaching effectiveness.
- New X rays showing Paget's disease and normal bone (Figure 6.16).

Chapter 7 The Skeleton

- Illustrated the skull bone table to facilitate student learning (Table 7.1).
- Added three new Check Your Understanding figure questions asking students to make anatomical identifications.
- New photos of humerus, radius, and ulna (Figures 7.28 and 7.29).

Chapter 8 Joints

- Updated statistics for osteoarthritis.
- Updated figure showing movements allowed by synovial joints (Figure 8.5).
- New photos of special body movements (Figure 8.6).

Chapter 9 Muscles and Muscle Tissue

- Updated Table 9.2 information on sizes of skeletal muscle fiber types in humans.

Chapter 10 The Muscular System

- New photos showing surface anatomy of muscles used in seven facial expressions (Figure 10.7).

Chapter 11 Fundamentals of the Nervous System and Nervous Tissue

- Added overview figure of nervous system (Figure 11.2).
- Improved Focus Figure 11.2 (*Action Potential*) for better student understanding.
- New image of a motor neuron based on a computerized 3-D reconstruction of serial sections.
- Converted Figure 11.17 to tabular head style to teach better.

Chapter 12 The Central Nervous System

- Updated mechanisms of Alzheimer's disease to include propagation of misfolded proteins.
- Updated information about gender differences in the brain.
- Streamlined discussion of sleep, memory, and stroke.
- New figure to show distribution of gray and white matter (Figure 12.3).
- Functional neuroimaging of the cerebral cortex (Figure 12.6).
- Improved reticular formation figure with "author's voice" blue text (Figure 12.18).
- New figure showing decreased brain activity in Alzheimer's (Figure 12.26).

Chapter 13 The Peripheral Nervous System and Reflex Activity

- Updated description of cytostructure of human cochlear hair cells (they have no kinocilia).
- New data on the number of different odors that humans can detect.
- Reorganized discussion of sound transmission to the inner ear. New numbered text improves text-art correlation.
- New figure teaches the function of the basilar membrane (Figure 13.26).
- New figure on how the hairs on the cochlear hair cells transduce sound (Figure 13.27).
- New figure shows the structure and function of the macula (Figure 13.28).
- Updated and expanded description of axon regeneration (in Figure 13.31).

Chapter 14 The Autonomic Nervous System

- Improved teaching effectiveness of Figure 14.3 (differences in the parasympathetic and sympathetic nervous systems).
- New summary table for autonomic ganglia (Table 14.2).

Chapter 15 The Endocrine System

- New information on actions of vitamin D and location of its receptors.
- New summary table showing differences between water-soluble and lipid-soluble hormones (Table 15.1).

- New summary flowchart shows the signs and symptoms of diabetes mellitus (Figure 15.19).

Chapter 16 Blood

- Improved teaching effectiveness of Figure 16.14 (intrinsic and extrinsic clotting factors).

Chapter 17 The Cardiovascular System: The Heart

- Rearranged topics in this chapter for better flow.
- New section and summary table (Table 17.1) teach key differences between skeletal muscle and cardiac muscle.
- New Making Connections figure question (students compare three action potentials).
- Rearranged material so that all electrical events are presented in one module.
- Added tabular headers, a photo, and bullets to more effectively teach ECG abnormalities (Figure 17.18).
- Streamlined figure showing effects of norepinephrine on heart contractility (Figure 17.22).

Chapter 18 The Cardiovascular System: Blood Vessels

- New information about pericytes (now known to be stem cells and generators of scar tissue in the CNS).
- New information that the fenestrations in fenestrated capillaries are dynamic structures.
- Rearranged topics in the physiology section of this chapter for better flow.
- New micrograph of artery and vein (Figure 18.2).
- Revised Figure 18.3 (the structure of different types of capillaries), putting all of the information in one place.
- New figure summarizes the major factors determining mean arterial pressure to give a "big picture" view (Figure 18.9).
- New figure illustrating active hyperemia (Figure 18.15).
- Updated Focus Figure 18.1 (*Bulk Flow across Capillary Walls*).
- New Homeostatic Imbalance feature on edema relates it directly to the preceding Focus Figure 18.1) and incorporates information previously found in Chapter 25.
- New photos of pitting edema (Figure 18.18).

Chapter 19 The Lymphatic System and Lymphoid Organs and Tissues

- Updated statistics on survival of non-Hodgkin's lymphoma patients.
- Updated figure to improve teaching of primary and secondary lymphoid organs (Figure 19.4).

Chapter 20 The Immune System: Innate and Adaptive Body Defenses

- Updated information on aging and the immune system, particularly with respect to chronic inflammation.
- Added a new term, pattern recognition receptors, to help describe how our innate defenses recognize pathogens.
- Provided new research results updating the number of genes in the human genome to about 20,000.

Chapter 21 The Respiratory System

- New Check Your Understanding question with graphs reinforces concepts learned in Focus Figure 21.1 (*The Oxygen-Hemoglobin Dissociation Curve*).
- New figure illustrating pneumothorax (Figure 21.14).

Chapter 22 The Digestive System

- Updated information about the treatment of peptic ulcers.
- Updated information about the types and locations of epithelial cells of the small intestine.
- New information about roles of our intestinal flora.
- Updated hepatitis C treatment to include the new FDA-approved drug sofosbuvir.
- Added discussion of non-alcoholic fatty liver disease.
- New information about fecal transplants to treat antibiotic-associated diarrhea.
- Updated figure that compares and contrasts peristalsis and segmentation (Figure 22.3) for improved teaching effectiveness.
- Updated Figure 22.4 explaining the relationship between the peritoneum and the abdominal organs to improve teaching effectiveness.
- Enteric nervous system section rewritten and rearranged with new figure (Figure 22.6).
- Improved teaching effectiveness of Figure 22.14 (the steps of deglutition).
- Streamlined Figure 22.19 to enhance teaching of regulation of gastric secretion.
- Updated Figure 22.20 (the mechanism of HCl secretion by parietal cells) for improved teaching effectiveness.
- Improved the text flow by moving discussion of the liver, gallbladder, and pancreas before the small intestine.
- Improved teaching effectiveness of Figure 22.28 (mechanism promoting secretion and release of bile and pancreatic juice).
- Updated and revised sections about motility of the small and large intestines.
- Rearranged text to discuss digestion and absorption together for each nutrient. The figures for digestion and absorption of carbohydrates (Figure 22.35) and proteins (Figure 22.36) now parallel each other and appear together for easy comparison.
- Rearranged and rewrote lipid digestion and absorption text and updated Figure 22.37.

Chapter 23 Nutrition, Metabolism, and Energy Balance

- Chapter title changed from Nutrition, Metabolism, and Body Temperature Regulation in order to emphasize the concept of energy balance.
- Updated shape and mechanism of action of ATP synthase to reflect new research findings.
- Updated hypothalamic control of food intake per new research findings.
- Revised Figure 23.4 to enhance the ability of students to compare and contrast the mechanisms of phosphorylation that convert ADP to ATP.
- Revised figure describing ATP synthase structure and function (Figure 23.10).
- Revised Figure 23.13 to help students compare and contrast glycogenesis and glycogenolysis (Figure 23.12).
- Three new figures help students grasp the terms for key pathways in carbohydrate, protein, and fat metabolism (Figures 23.12, 23.14, and 23.18).

Chapter 24 The Urinary System

- New cadaver photo of urinary tract organs (Figure 24.2).
- New Check Your Understanding question for nephron labeling.
- Improved Focus Figure 24.1 (*Medullary Osmotic Gradient*) for better teaching effectiveness.
- Added new illustrations to improve teaching effectiveness of Figure 24.19 (the effects of ADH on the nephron).

Chapter 25 Fluid, Electrolyte, and Acid-Base Balance

- New Check Your Understanding figure question requires students to integrate information.

Chapter 26 The Reproductive System

- Updated screening recommendations for prostate cancer, as well as updated information on detection and treatment.
- Updated screening guidelines for cervical cancer.
- Updated breast cancer statistics.
- New Check Your Understanding figure labeling question.
- New figure teaches independent assortment (Figure 26.8).
- New photo of female pelvic organs (Figure 26.15c).
- New photos of mammograms showing normal and cancerous breast tissues (Figure 26.19).
- Revised Figure 26.23 to reflect recent research about follicular development in humans.
- Revised section describing the stages of follicle development to facilitate student learning and to incorporate recent research.

Appendices

- Added a table of the genetic code (Appendix B).

Acknowledgments

Each time we put this textbook to bed, we promise ourselves that the next time will be easier and will require less of our time. Now hear this! This is its 6th edition (and 30 years more or less) and fulfillment of this promise has yet to materialize. How could there be so much going on in physiology research and so many new medical findings? Winnowing through these findings to decide on the updates to include in this edition has demanded much of our attention. Many people at Pearson have labored with us to produce another fine text. Let's see if we can properly thank them.

As Katja and I worked on the first draft of the manuscript, Tanya Martin (our text Development Editor) worked tirelessly to improve the readability of the text, all the while trying to determine which topics could be shortened or even deleted in the 6th edition. After we had perused and acted on some of Tanya's suggestions, we forwarded the manuscript to Michele Mangelli who oversees everything having to do with getting a clean manuscript to production. Michele reviewed the entire revised manuscript. Nothing escaped her attention as she worked to catch every problem.

At the same time the text was in revision, the art program was going through a similar process. Laura Southworth, our superb Art Development Editor (aided briefly by Elisheva Marcus), worked tirelessly to make our Focus Figures and other art even better. Needing a handshake and a heartfelt "thank you" in the process are Kristin Piljay (Photo Researcher) and Jean Lake, who handled the administrative aspects of the art program. This team ensured that the artists at Imagineering had all the information they needed to produce beautiful final art products.

As the manuscript made the transition from Editorial to Production, Michele Mangelli, the Production and Design Manager, made her appearance known. The head honcho and skilled handler of all aspects of production, everyone answered to her from this point on. In all previous editions, the manuscript would simply go directly into production once the writing and editing phases were over, but our new modular design required extra steps to make the art-text correlation a reality—the electronic page layout. Working closely with Katja and her husband Larry Haynes, Michele's small but powerful team "yanked" the new design to attention, fashioning two-page spreads, each covering one or more topics with its supporting art or table. This was our Holy Grail for this edition and the ideal student coaching device. They made it look easy (which it was not). Thank you Katja, Larry, and Michele—you are the ideal electronic page layout team. This was one time I felt fortunate to be the elder author.

The remaining people who helped with Production include David Novak (our conscientious Production Supervisor), Martha Ghent (Proofreader), Betsy Dietrich (Art Proofreader), Sallie Steele (Indexer), Cynthia Mutheardy (Project Manager at Imagineering), and Tim Frelick (Compositor). Copyeditor Anita Hueftle (formerly Anita Wagner) is the unofficial third author of our book. We are absolutely convinced that she memorizes the entire text. She verified the spelling of new terms, checked the generic and popular names of drugs, confirmed our grammar, and is the person most responsible for the book's consistency and lack of typographical errors. We are grateful to Izak Paul for meticulously reading each chapter to find any remaining errors, and to Yvo Riezebos for his stunning design work on the cover, chapter opening pages, and the text.

Finally—what can we say about Brooke Suchomel, our Acquisitions Editor? She loved playing with the modular design and the chapter road maps and advising on Focus Figures, but most of her time was spent out in the field talking to professors, demonstrating the book's changes and benefits. She spent weeks on the road, smiling all the time—no easy task. Finally, we are fortunate to have the ongoing support and friendship of Serina Beauparlant, our Editor-in-Chief.

Other members of our team with whom we have less contact but who are nonetheless vital are: Barbara Yien (Director of Development), Michael Early (Program Manager Team Lead), Nancy Tabor (Project Manager Team Lead), Stacey Weinberger (our Senior Manufacturing Buyer), Allison Rona (our top-notch Executive Marketing Manager), and Derek Perrigo (Senior Anatomy & Physiology Specialist). We appreciate the hard work of our media production team headed by Laura Tomassi, Aimee Pavy, and Lauren Hill and also wish to thank Eric Leaver.

Kudos to our entire team. We feel we have once again prepared a superb textbook. We hope you agree.

There are many people who reviewed parts of this text—both professors and students, either individually or in focus groups, and we would like to thank them. Input from the following reviewers has contributed to the continued excellence and accuracy of this text:

Matthew Abbott, *Des Moines Area Community College*
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George A. Steer, *Jefferson College of Health Sciences*
Shirley A. Whitescarver, *Bluegrass Community and Technical College*

Harvey Howell, my beloved husband and helpmate, died in August of 2013. He is sorely missed.

Katja would also like to acknowledge the support of her colleagues at Mount Royal University (Trevor Day, Sarah Hewitt, Tracy O'Connor, Izak Paul, Michael Pollock, Lorraine Royal, Karen Sheedy, Kartika Tjandra, and Margot Williams) and of Ruth Pickett-Seltner (Chair), Tom MacAlister (Associate Dean), and Jeffrey Goldberg (Dean). Thanks also to Katja's husband, Dr. Lawrence Haynes, who as a fellow physiologist has provided invaluable assistance to her during the course of the revision. She also thanks her sons, Eric and Stefan Haynes, who are an inspiration and a joy.

We would really appreciate hearing from you concerning your opinion—suggestions and constructive criticisms—of this text. It is this type of feedback that will help us in the next revision, and underlies the continued improvement of this text.

Elaine N. Marieb

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Contents

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1 The Human Body: An Orientation

WHY THIS MATTERS

KEY CONCEPTS

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 helps 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. And finally you'll learn the language of anatomy—terminology that anatomists use to describe the body and its parts.

1.1 Form (anatomy) determines function (physiology)

Learning Objectives

- ☐ **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.

For simplicity, when we refer to body structures and 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*).

Knowledge of anatomy and physiology is crucial to this physiotherapist working on a patient.

Although we use the reference values and common directional and regional terms to refer to all human bodies, you know from observing the faces and body shapes of people around you that we humans differ in our external anatomy. The same kind of variability holds for internal organs as well. In one person, for example, a nerve or blood vessel may be somewhat out of place, or a small muscle may be missing. Nonetheless, well over 90% of all structures present in any human body match the textbook descriptions. We seldom see extreme anatomical variations because they are incompatible with life.

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* (from Greek, 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 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.

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.

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 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 Answers Appendix.

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

1.2 The body's organization ranges from atoms to the entire organism

Learning Objectives

- ☐ 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.

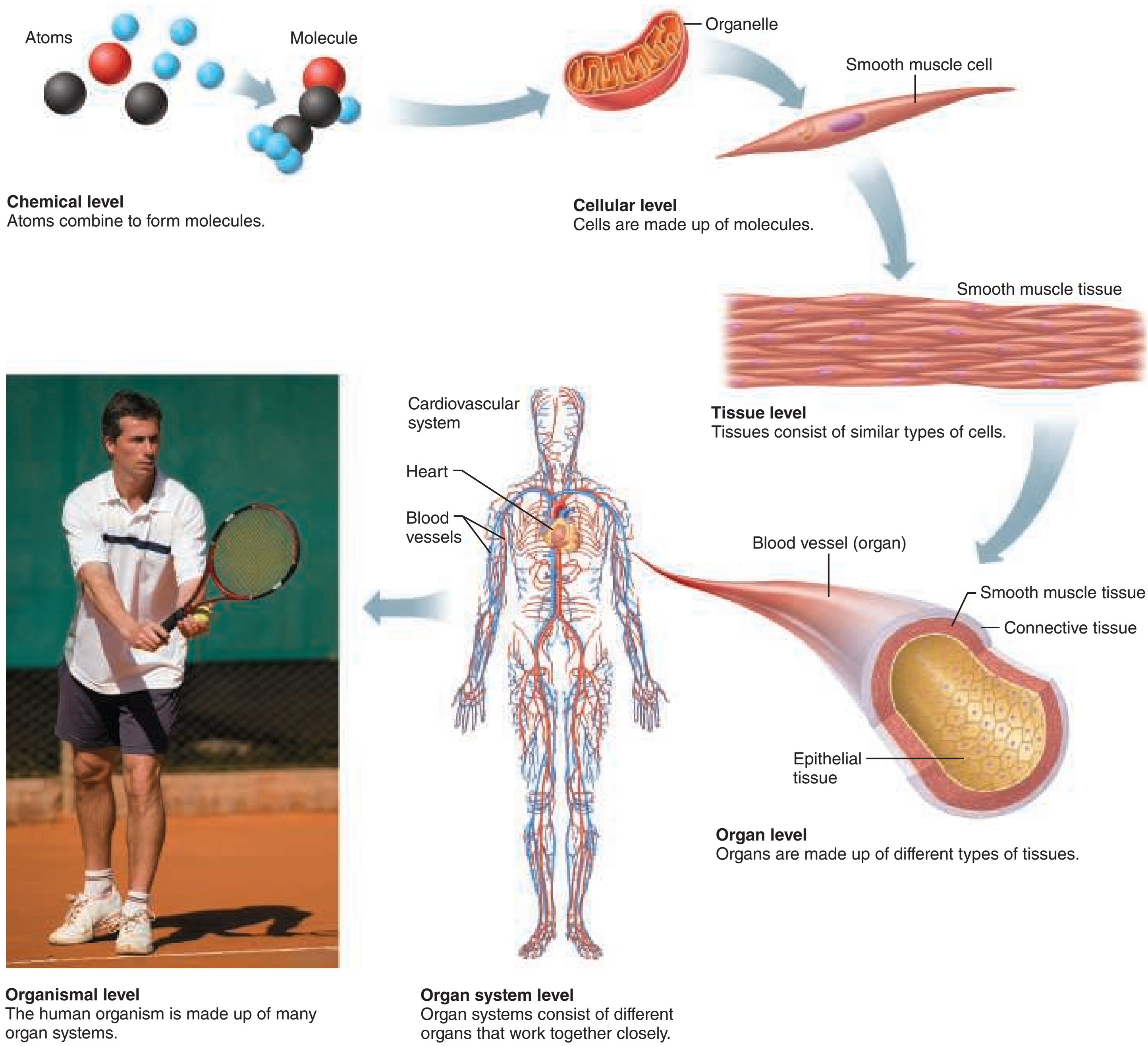


Figure 1.1 Levels of structural organization. Components of the cardiovascular system are used to illustrate the levels of structural organization in a human being.

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. 6–7 for an overview of the 11 organ systems.

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 Answers Appendix.

1.3 What are the requirements for life?

Learning Objectives

- [ ] **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. **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** on pp. 6–7 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

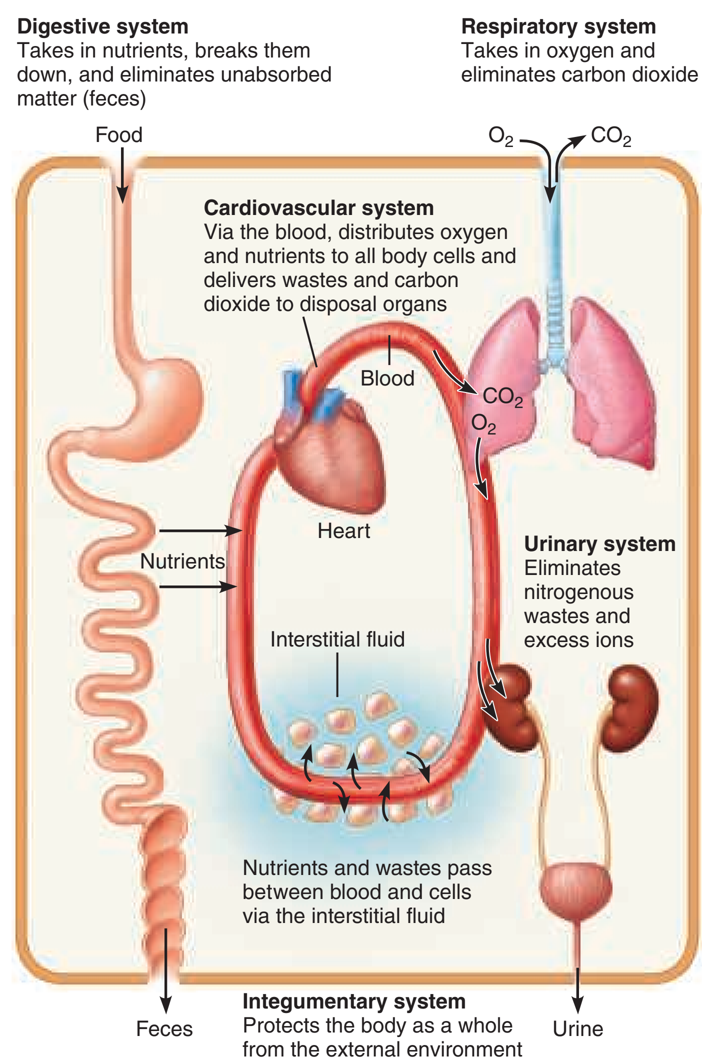


Figure 1.2 Examples of interrelationships among body organ systems.

external environment (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 body cells 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 (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).

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 simpler building blocks (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).

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 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.

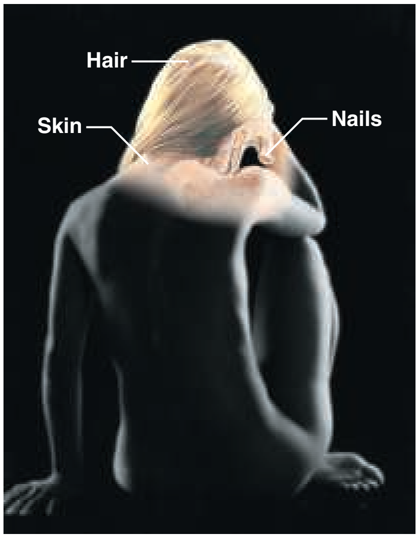
Survival Needs

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.

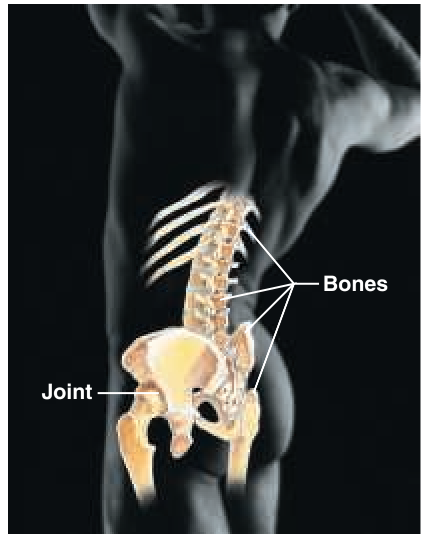
Nutrients

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.

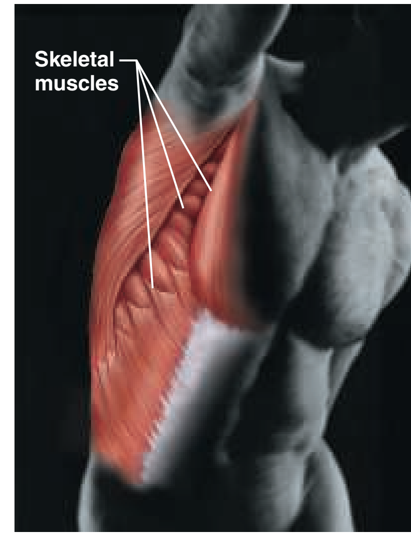
(Text continues on p. 8.)



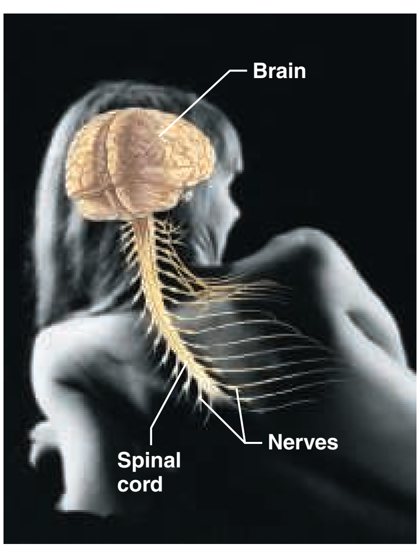
(a) Integumentary System
Forms the external body covering, and protects deeper tissues from injury. Synthesizes vitamin D, and houses cutaneous (pain, pressure, etc.) receptors and sweat and oil glands.



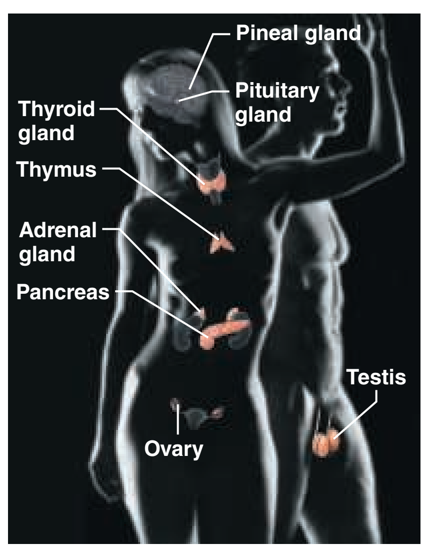
(b) Skeletal System
Protects and supports body organs, and provides a framework the muscles use to cause movement. Blood cells are formed within bones. Bones store minerals.



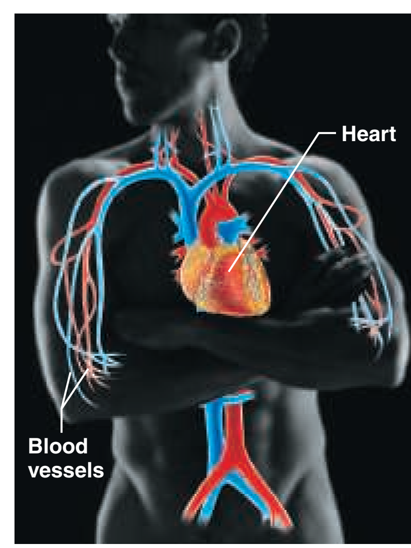
(c) Muscular System
Allows manipulation of the environment, locomotion, and facial expression. Maintains posture, and produces heat.



(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.

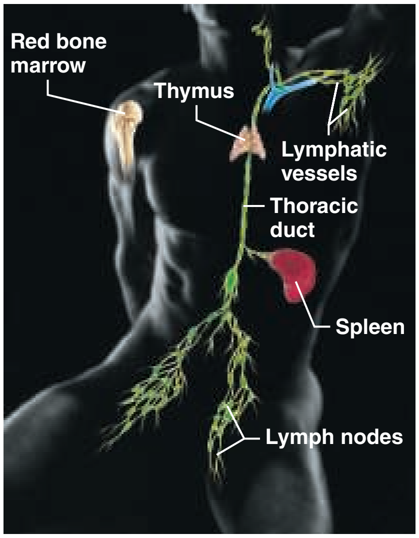


(e) Endocrine System
Glands secrete hormones that regulate processes such as growth, reproduction, and nutrient use (metabolism) by body cells.

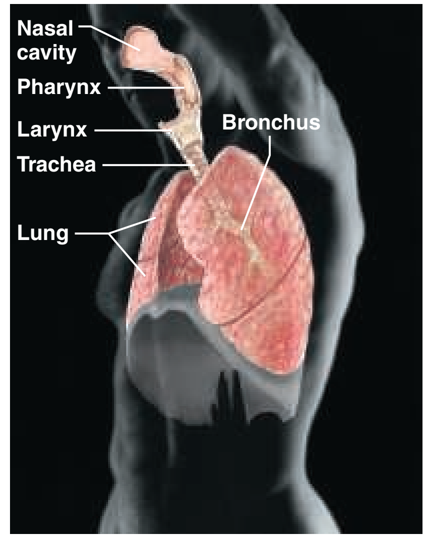


(f) Cardiovascular System
Blood vessels transport blood, which carries oxygen, carbon dioxide, nutrients, wastes, etc. The heart pumps blood.

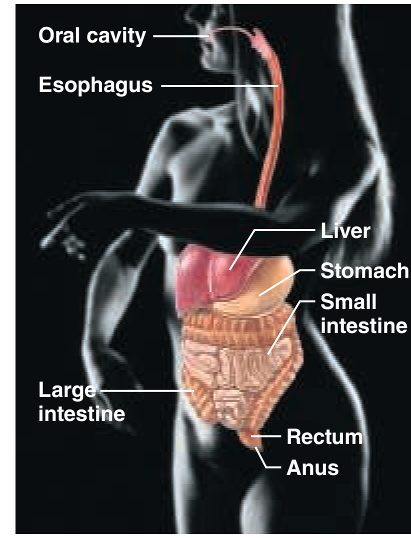
Figure 1.3 The body's organ systems and their major functions.



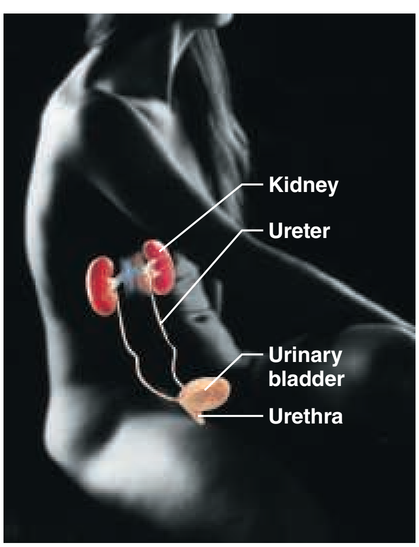
(g) Lymphatic System/Immunity
Picks up fluid leaked from blood vessels and returns it to blood. Disposes of debris in the lymphatic stream. Houses white blood cells (lymphocytes) involved in immunity. The immune response mounts the attack against foreign substances within the body.



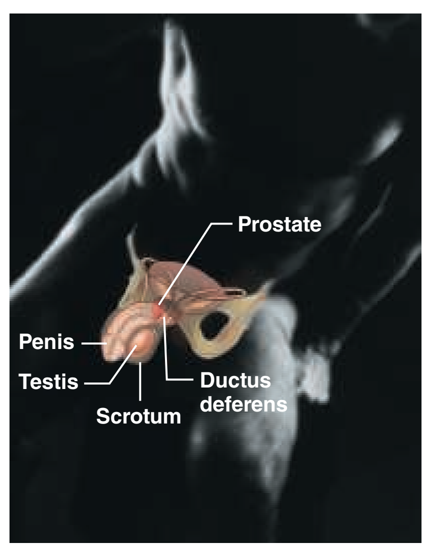
(h) Respiratory System
Keeps blood constantly supplied with oxygen and removes carbon dioxide. The gaseous exchanges occur through the walls of the air sacs of the lungs.

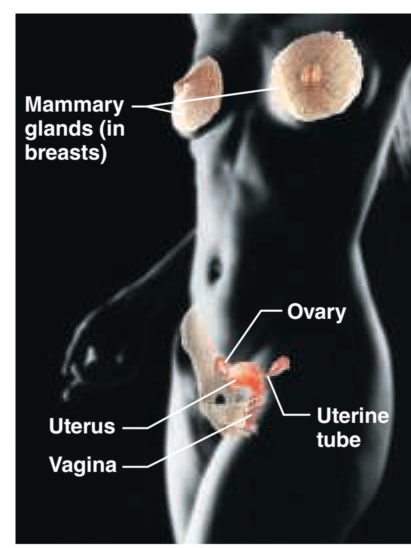


(i) Digestive System
Breaks down food into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.



(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.

Figure 1.3 *(continued)*

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

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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 50–60% 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 the proper 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 here 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 Answers Appendix.

1.4 Homeostasis is maintained by negative feedback

Learning Objectives

- ☐ **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 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 *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. 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," 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 so that the whole control process is shut off, or enhancing it 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.

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 the furnace between "ON" and "OFF" so that the temperature in the house stays very near the desired temperature.

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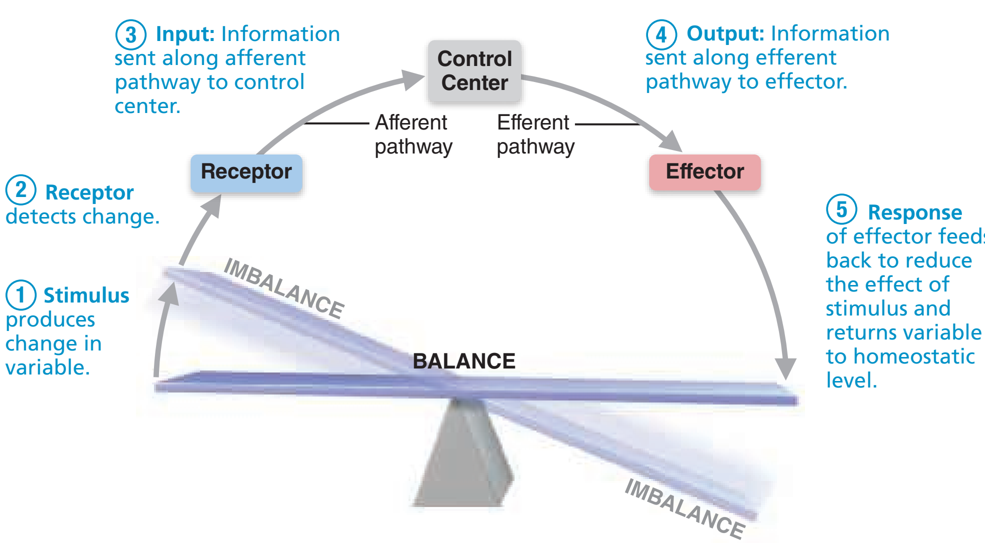

Figure 1.4 **Interactions among the elements of a homeostatic control system maintain stable internal conditions.**

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