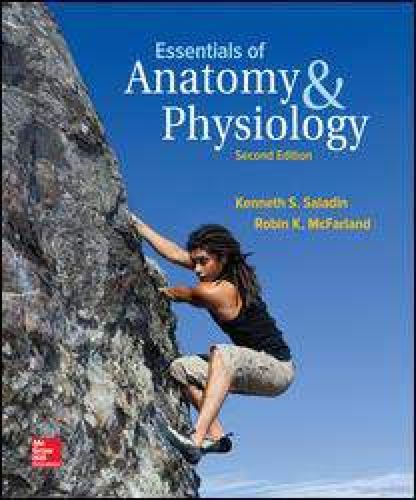
Essentials of Anatomy & Physiology

Second Edition

Kenneth S. Saladin
Robin K. McFarland



Second Edition

Essentials of Anatomy & Physiology

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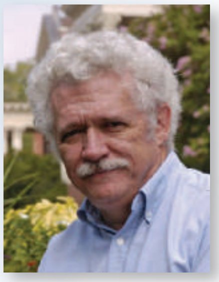
Brief Contents

About the Authors



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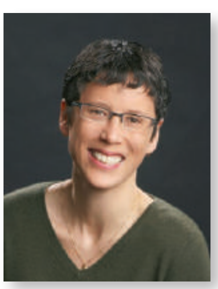
KENNETH S. SALADIN is a Professor of Biology at Georgia College in Milledgeville, Georgia, where he has taught since 1977. Ken teaches human anatomy and physiology, introductory medical physiology, histology, animal behavior, and natural history of the Galápagos Islands. He has also previously taught introductory biology, general zoology, sociobiology, parasitology, and biomedical etymology. Ken is a member of the Human Anatomy and Physiology Society, American Physiological Society, Society for Integrative and Comparative Biology, and American Association for the Advancement of Science. He is the author of the best-selling textbooks *Anatomy & Physiology: The Unity of Form and Function* and *Human Anatomy.* Ken and his wife Diane have two adult children.

Courtesy of Robin McFarland

ROBIN MCFARLAND has taught anatomy and physiology at Cabrillo College in Aptos, California, since 1998. She earned a Ph.D. in physical (biological) anthropology from the University of Washington, where she studied the relationship between body fat and reproduction in primates. Robin subsequently conducted research on comparative ape anatomy with colleagues at the University of California, Santa Cruz. Robin is a member of the Human Anatomy and Physiology Society, a member of the American Association of Anatomists, and a participant in the Physiology Education Community of Practice (PECOP) sponsored by the American Physiological Society. She was a contributing author to *Human Anatomy,* second edition, by Ken Saladin. She and her husband Jeff have two children, Reid and Madeleine. Robin enjoys hiking and climbing mountains.



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Dedicated to everyone who's ever danced in the rain .—K.S.S.
This book is dedicated to my students, who inspire and delight me.—R.K.M.

The authors would enjoy hearing from colleagues and students alike who use this book and may wish to offer suggestions for our next edition, or encouragement to continue doing certain things the way we have. Such feedback is invaluable for improving a textbook, and the authors will endeavor to answer all correspondence.

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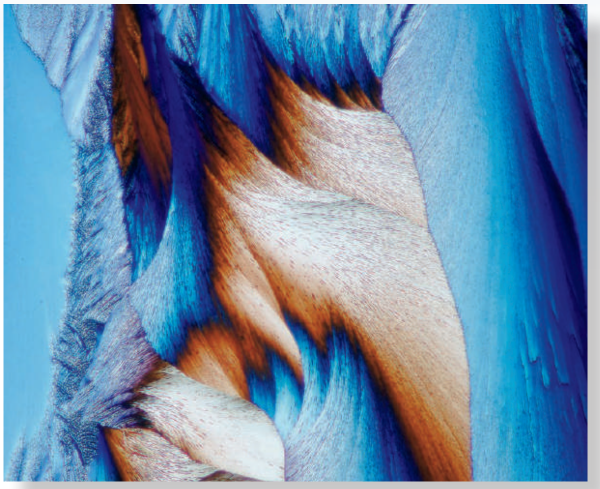

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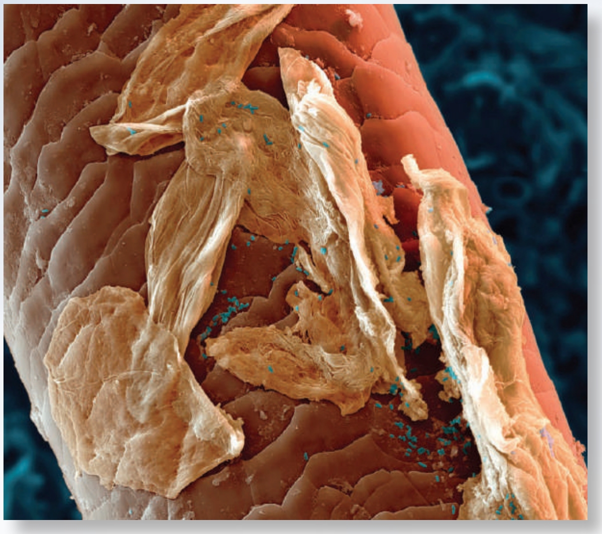

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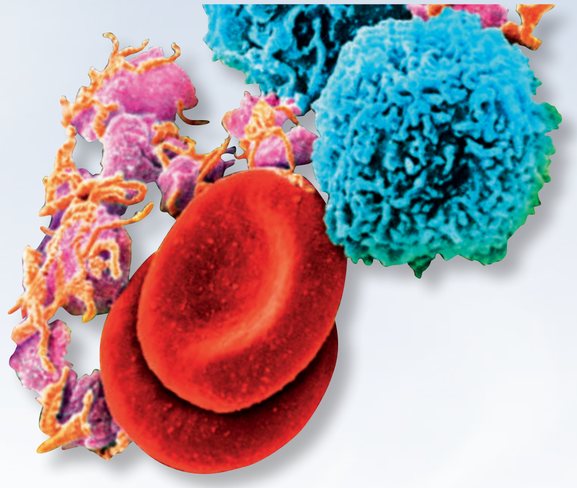

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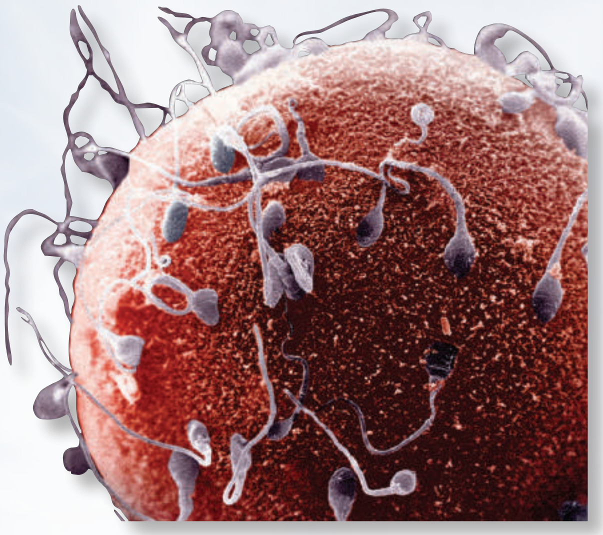

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Taking Anatomy & Physiology to New Heights

Audience

Essentials of Anatomy & Physiology, second edition, is intended for students in associate degree, certification, and career-training programs; students in high-school advanced placement classes; students who are seeking a general education science class; and those who may not have set foot in a college classroom for many years. The prose and vocabulary in *Essentials of Anatomy & Physiology* are appropriate to serve this broad spectrum of readers.

Keeping in mind that many students are interested in exploring medical professions, a "Career Spotlight" feature has been included in every chapter, and references to further career information are found in appendix B.

What's New in the Second Edition?

The new edition of *Essentials of Anatomy & Physiology* by Saladin and McFarland has been significantly updated. A hallmark of the first edition, according to both students and reviewers, is the exceptionally clear writing. In this new edition, the authors have analyzed explanations to ensure accessibility for readers who do not have an extensive scientific background. In addition, numerous scientific updates, new photographs and illustrations, and enhanced pedagogical features are included.

Updated Science

The second edition presents the following updated or new scientific information:

- New guidelines on trans fats (chapter 2)
- Expanded roles for vitamin D (chapter 5)
- Expanded role of astrocytes, including their vasomotor role (chapter 8)
- Spinal cord injuries and paralysis (chapter 8)
- Oxidative stress and Alzheimer disease (chapter 8)
- Water and oleogustus as primary taste sensations (chapter 10)
- Replacement of *nonspecific resistance* with *innate immunity* (chapter 14)
- Meanings of *immunity* and *immune system* (chapter 14)
- Expanded discussions of *cellular* and *humoral immunity* (chapter 14)
- Updates on polio and HIV (chapter 14)
- Updated view of female urinary sphincter (chapter 16)
- Hepcidin and iron metabolism (chapter 17)
- Gut microbiota (chapter 17)
- Updates on papillomavirus, genital warts, and cervical cancer (chapter 19)

Keeping pace with changing terminology, the new edition has updated terms to agree with the latest *Gray's Anatomy* and the *Terminologia Anatomica* and to delete little-used synonyms and obsolete eponyms.

Enhanced Content

This new edition updates and enhances anatomical and physiological concepts:

- Pseudopods as a cell surface feature (chapter 3)
- Proteasomes (chapter 3)
- Vitamin D synthesis and functions (chapter 5)
- Steps of muscle excitation, contraction, and relaxation (chapter 7)
- New terminology of muscle attachments (chapter 7)
- Action potential steps (chapter 8)
- Congestive heart failure (chapter 13)
- Benefits of exercise on the aging cardiovascular system (chapter 13)
- Cellular and humoral immunity (chapter 14)
- Pressure changes during inspiration and expiration (chapter 15)
- Structure and function of the male prepuce (chapter 19)

New Photographs

- Figure 1.1: new brain scans
- Figure 3.12: fluorescent micrograph of cytoskeleton
- Figure 4.12: squamous cells from the mucosa of the vagina
- Figure 6.3: bone marrow histology
- Figure 10.20: SEM of human rods and cones
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- Figure 12.3: TEM of erythrocytes in a capillary
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- Figure 13.5: polymer cast of coronary circulation
- Figure 14.8: cadaver abdomen showing position of spleen
- Figure 19.2: electron micrograph of seminiferous tubule
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New and Enhanced Art

- Figure 1.4: negative feedback in response to drop in blood pressure
- Figure 3.6: pseudopods
- Figure 3.9: mechanism of osmosis
- Figure 6.25: surface anatomy of the clavicle
- Figure 7.5: organization and size principle of motor units
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- Figure 13.4: cross-sectional shapes and relationships of heart ventricles
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- Figure 18.6: environmental temperatures versus core and shell body temperatures

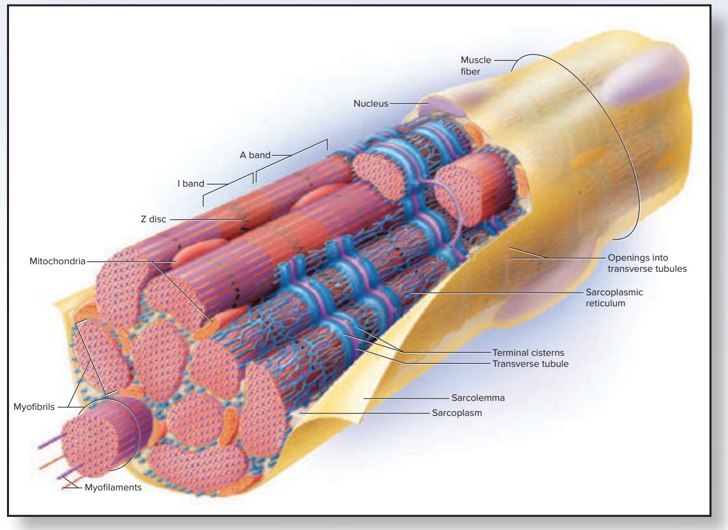
New Pegagogy

In each chapter "Study Guide," students are asked to analyze 10 false statements and to correct them, in contrast to the first edition, where they were prompted to distinguish between 5 true and 5 false statements.

Many of the "Apply What You Know" questions have been revised to further elicit critical thinking.

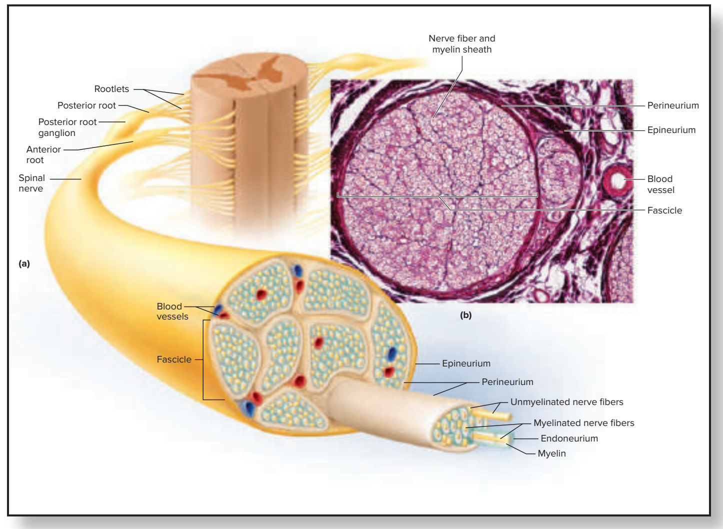
Making *Anatomy & Physiology* Intriguing and Inspiring

Essentials of Anatomy & Physiology crafts the facts of A&P into art and prose in a way that makes the book exciting and rewarding to read.



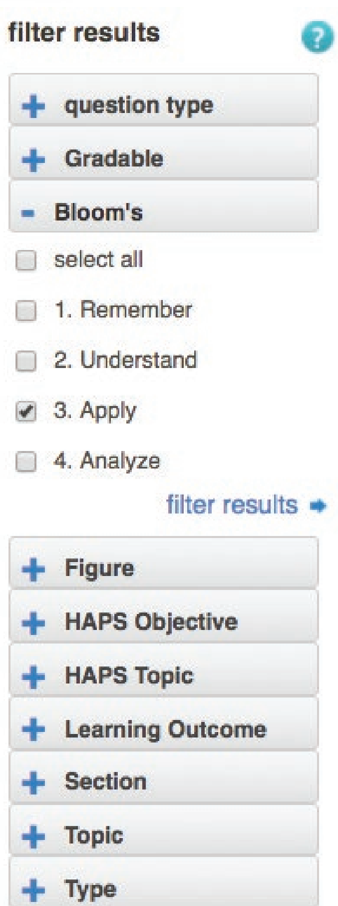
Captivating Art and Photography

A&P is a highly visual subject; beautiful illustrations pique the curiosity and desire to learn. *Essentials of Anatomy & Physiology*'s illustrations set a new standard in the A&P Essentials market, where many students regard themselves as visual learners.



Cognitive Skill Building

Essentials of Anatomy & Physiology asks questions that not only test memory, but also exercise and expand the student's thinking skills at multiple levels of Bloom's Taxonomy of Learning Outcomes. Within Connect™ there is also the opportunity to assess student understanding of the Learning Outcomes by leveraging question filters that allow the curation of custom assignments and efficient reporting for administrative assessment purposes.



Testing Your Comprehension

1. Most osteocytes of an osteon are far removed from blood vessels, but are still able to respond to hormones in the blood. Explain how it is possible for hormones to reach and stimulate these cells.
2. How does the regulation of blood calcium concentration exemplify negative feedback and homeostasis?

Expected Learning Outcomes

This book provides a ready-made course outline of course objectives and means of assessment with its “Expected Learning Outcomes” presented at the start of each chapter section.

3.4 The Life Cycle of Cells

Expected Learning Outcomes

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

a. describe the stages of a cell’s life cycle and list the events that define each stage; and
b. name the stages of mitosis and describe what occurs in each.

Assess Your Learning Outcomes

The parallel “Assess Your Learning Outcomes” at the end of each chapter imparts a comprehensive overview of the key points in the chapter, and requires the student to reexamine the text to get information, rather than simply handing it to them.

Before You Go On/ Apply What You Know

Intermediate aids such as “Before You Go On” and “Apply What You Know” provide an easy means for meeting the requirements of an outcome-driven curriculum and also work to encourage active learning over passive reading.

Before You Go On

Answer these questions from memory. Reread the preceding section if there are too many you don’t know.

1. *Which term refers to all the cell contents between the plasma membrane and nucleus:* cytosol, cytoplasm, tissue fluid, *or* extracellular fluid?
2. *About how big would a cell have to be for you to see it without a microscope? Are any cells actually this big? If so, which ones?*
3. *Explain why cells cannot grow to an indefinitely large size.*

Apply What You Know

Physical exercise obviously increases cardiac output. Do you think it achieves this through heart rate, contraction strength, or both? Explain.

Making *Anatomy & Physiology* Intriguing and Inspiring

Stimulating Prose

Far more than "just the facts," *Essentials of Anatomy & Physiology*'s narrative style weaves the facts into an engaging story of human form and function. Vivid analogies that captivate the imagination make complex concepts easy to understand.

We have seen how a nerve signal is initiated; now we examine how it travels to its final destination. The action potential is a voltage spike over a limited area of plasma membrane. However, it triggers another action potential in the membrane immediately ahead of it, and that action potential triggers another, and so forth. Thus, we get a chain reaction of one action potential after another along the length of a nerve fiber. This chain reaction constitutes the **nerve signal.** An illuminating analogy to this is standing up a long row of dominoes and pushing the first one over. When that domino falls, it pushes over the second, and so forth—and the chain reaction produces a wave of energy traveling to the end of the line. No one domino moves to the other end of the line; a falling domino is a local event. Similarly, an action potential is a local event, but it triggers the next one and, like the row of falling dominoes, we get a wave of energy traveling from one end of the axon to the other. That traveling wave is the nerve signal (fig. 8.10). Action potentials do not travel; nerve signals do.

Figure Legend Questions

Thought questions in many figure legends encourage students to think analytically about the art, not merely view it. These questions are also great for in-class discussion.

Figure 5.5 **Structure of a Hair and Its Follicle.** (a) Anatomy of the follicle and associated structures. (b) Light micrograph of the base of a hair follicle. APR

b: © Ed Reschke/Getty Images

- *In light of your knowledge of hair, discuss the validity of an advertising claim that a shampoo will "nourish your hair." Where and how does a hair get its sole nourishment?*

Building Vocabulary

The plethora of medical terms in A&P is one of a student's most daunting challenges. Chapter 1 teaches core principles of how to break words down into familiar roots, prefixes, and suffixes, making medical terminology less intimidating while teaching the importance of precision in spelling *(ilium/ileum, malleus/malleolus).*

- An end-of-book "Glossary" provides clear definitions of the most important or frequently used terms, and "Appendix D: Biomedical Word Roots, Prefixes, and Suffixes" defines nearly 400 Greek and Latin roots, which make up about 90% of today's medical terms.
- *Footnoted word origins* show how new terms are composed of familiar word roots.

[5]*oss* = bone; *icle* = little
[6]*malleus* = hammer, mallet
[7]*incus* = anvil
[8]*stapes* = stirrup
[9]Bartholomeo Eustachio (1520–74), Italian anatomist

- *Pronunciation guides* that appear throughout chapters make it easier to pronounce key terms, and make these words more likely to be remembered and understood.

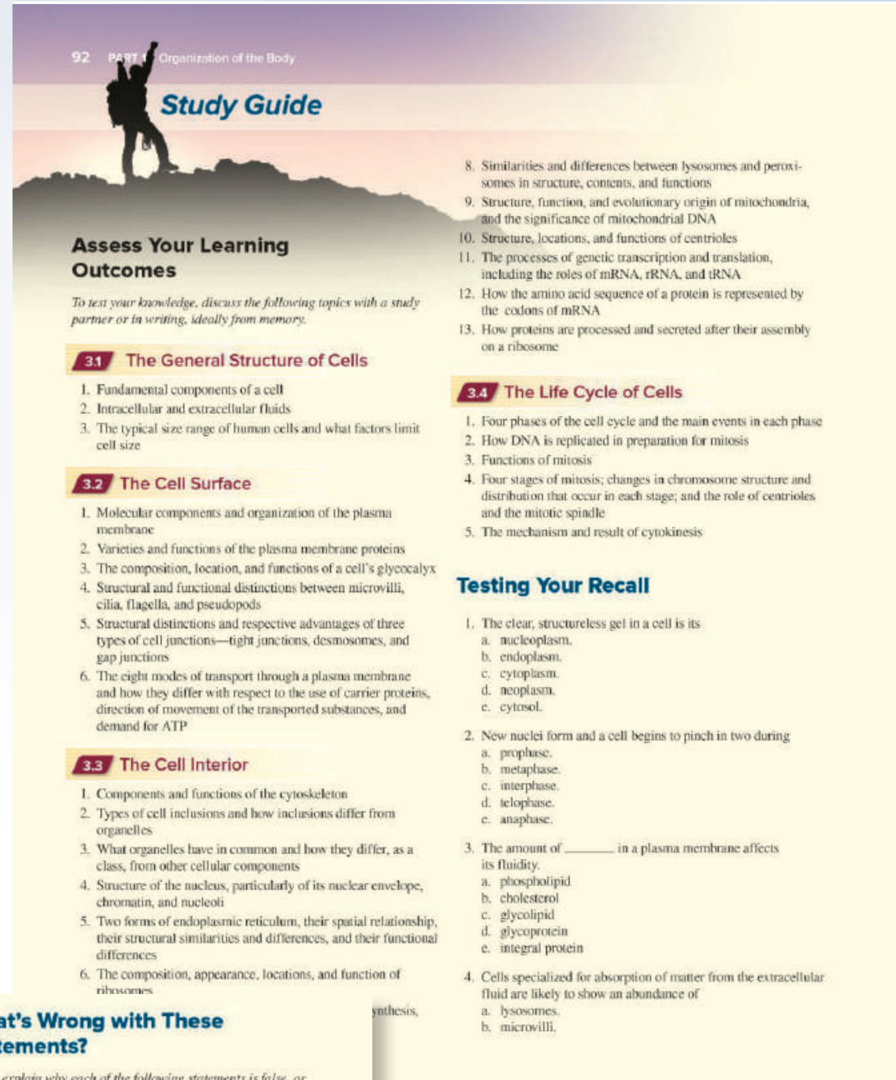
Analyzing Medical Terms

There is a simple trick to becoming more comfortable with the technical language of medicine. Those who, at first, find scientific terms confusing and difficult to pronounce, spell, and remember often feel more confident once they realize the logic of how such terms are composed. A term such as *hyponatremia* is less forbidding once we recognize that it is composed of three common word elements: *hypo-* (below normal), *natr-* (sodium), and *-emia* (blood condition). Thus, hyponatremia is a deficiency of sodium in the blood. Those three word elements appear over and over in many other medical terms: *hypothermia, natriuretic, anemia,* and so on. Once you learn the meanings of *hypo-, natri-,* and *-emia,* you already have the tools to at least partially understand hundreds of other biomedical terms.

cholecystokinin (CCK) (CO-leh-SIS-toe-KY-nin) A polypeptide employed as a hormone and neurotransmitter, secreted by some brain neurons and cells of the small intestine. In the digestive system, stimulates contraction of the gallbladder, release of bile, and secretion of pancreatic enzymes.

Study Guide

The "Study Guide" at the end of each chapter provides an overview of key points, as well as a variety of self-testing question formats, for students who wish to have a study guide for their next exam. A student who masters these study guides should do well on an exam.



92 PART I Organization of the Body

Study Guide

Assess Your Learning Outcomes

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

3.1 The General Structure of Cells

1. Fundamental components of a cell
2. Intracellular and extracellular fluids
3. The typical size range of human cells and what factors limit cell size

3.2 The Cell Surface

1. Molecular components and organization of the plasma membrane
2. Varieties and functions of the plasma membrane proteins
3. The composition, location, and functions of a cell's glycocalyx
4. Structural and functional distinctions between microvilli, cilia, flagella, and pseudopods
5. Structural distinctions and respective advantages of three types of cell junctions—tight junctions, desmosomes, and gap junctions
6. The eight modes of transport through a plasma membrane and how they differ with respect to the use of carrier proteins, direction of movement of the transported substances, and demand for ATP

3.3 The Cell Interior

1. Components and functions of the cytoskeleton
2. Types of cell inclusions and how inclusions differ from organelles
3. What organelles have in common and how they differ, as a class, from other cellular components
4. Structure of the nucleus, particularly of its nuclear envelope, chromatin, and nucleoli
5. Two forms of endoplasmic reticulum, their spatial relationship, their structural similarities and differences, and their functional differences
6. The composition, appearance, locations, and function of ribosomes

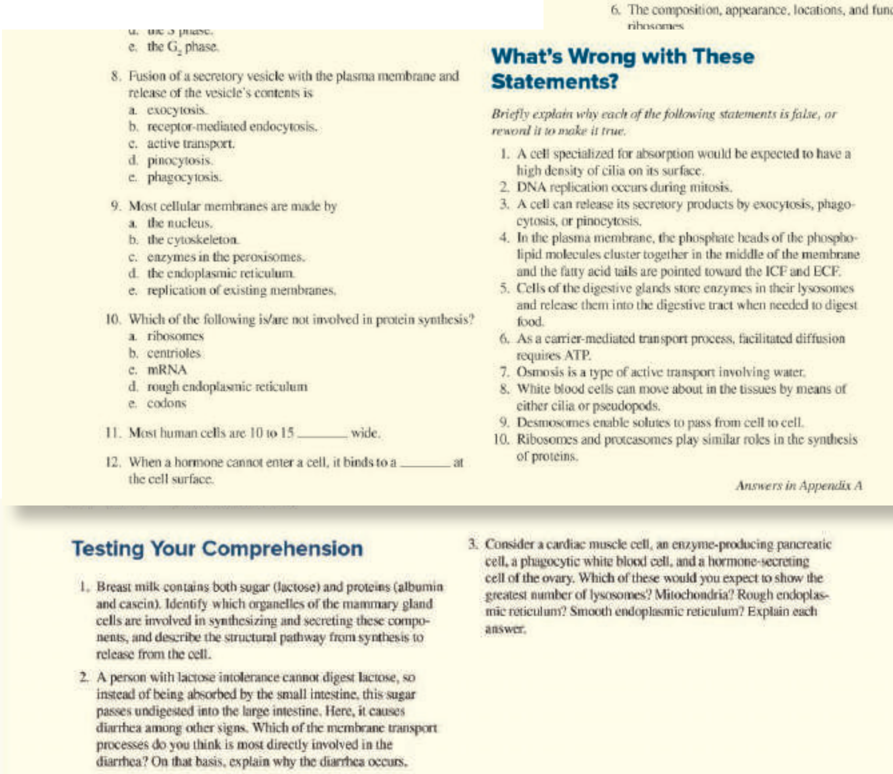
8. Similarities and differences between lysosomes and peroxisomes in structure, contents, and functions
9. Structure, function, and evolutionary origin of mitochondria, and the significance of mitochondrial DNA
10. Structure, locations, and functions of centrioles
11. The processes of genetic transcription and translation, including the roles of mRNA, rRNA, and tRNA
12. How the amino acid sequence of a protein is represented by the codons of mRNA
13. How proteins are processed and secreted after their assembly on a ribosome

3.4 The Life Cycle of Cells

1. Four phases of the cell cycle and the main events in each phase
2. How DNA is replicated in preparation for mitosis
3. Functions of mitosis
4. Four stages of mitosis; changes in chromosome structure and distribution that occur in each stage; and the role of centrioles and the mitotic spindle
5. The mechanism and result of cytokinesis

Testing Your Recall

1. The clear, structureless gel in a cell is its
   a. nucleoplasm.
   b. endoplasm.
   c. cytoplasm.
   d. neoplasm.
   e. cytosol.
2. New nuclei form and a cell begins to pinch in two during
   a. prophase.
   b. metaphase.
   c. interphase.
   d. telophase.
   e. anaphase.
3. The amount of ______ in a plasma membrane affects its fluidity.
   a. phospholipid
   b. cholesterol
   c. glycolipid
   d. glycoprotein
   e. integral protein
4. Cells specialized for absorption of matter from the extracellular fluid are likely to show an abundance of
   a. lysosomes.
   b. microvilli.



e. the G_2 phase.

8. Fusion of a secretory vesicle with the plasma membrane and release of the vesicle's contents is
   a. exocytosis.
   b. receptor-mediated endocytosis.
   c. active transport.
   d. pinocytosis.
   e. phagocytosis.
9. Most cellular membranes are made by
   a. the nucleus.
   b. the cytoskeleton.
   c. enzymes in the peroxisomes.
   d. the endoplasmic reticulum.
   e. replication of existing membranes.
10. Which of the following is/are not involved in protein synthesis?
    a. ribosomes
    b. centrioles
    c. mRNA
    d. rough endoplasmic reticulum
    e. codons
11. Most human cells are 10 to 15 ______ wide.
12. When a hormone cannot enter a cell, it binds to a ______ at the cell surface.

What's Wrong with These Statements?

Briefly explain why each of the following statements is false, or reword it to make it true.

1. A cell specialized for absorption would be expected to have a high density of cilia on its surface.
2. DNA replication occurs during mitosis.
3. A cell can release its secretory products by exocytosis, phagocytosis, or pinocytosis.
4. In the plasma membrane, the phosphate heads of the phospholipid molecules cluster together in the middle of the membrane and the fatty acid tails are pointed toward the ICF and ECF.
5. Cells of the digestive glands store enzymes in their lysosomes and release them into the digestive tract when needed to digest food.
6. As a carrier-mediated transport process, facilitated diffusion requires ATP.
7. Osmosis is a type of active transport involving water.
8. White blood cells can move about in the tissues by means of either cilia or pseudopods.
9. Desmosomes enable solutes to pass from cell to cell.
10. Ribosomes and proteasomes play similar roles in the synthesis of proteins.

Answers in Appendix A

Testing Your Comprehension

1. Breast milk contains both sugar (lactose) and proteins (albumin and casein). Identify which organelles of the mammary gland cells are involved in synthesizing and secreting these components, and describe the structural pathway from synthesis to release from the cell.
2. A person with lactose intolerance cannot digest lactose, so instead of being absorbed by the small intestine, this sugar passes undigested into the large intestine. Here, it causes diarrhea among other signs. Which of the membrane transport processes do you think is most directly involved in the diarrhea? On that basis, explain why the diarrhea occurs.
3. Consider a cardiac muscle cell, an enzyme-producing pancreatic cell, a phagocytic white blood cell, and a hormone-secreting cell of the ovary. Which of these would you expect to show the greatest number of lysosomes? Mitochondria? Rough endoplasmic reticulum? Smooth endoplasmic reticulum? Explain each answer.

Multiple Question Types

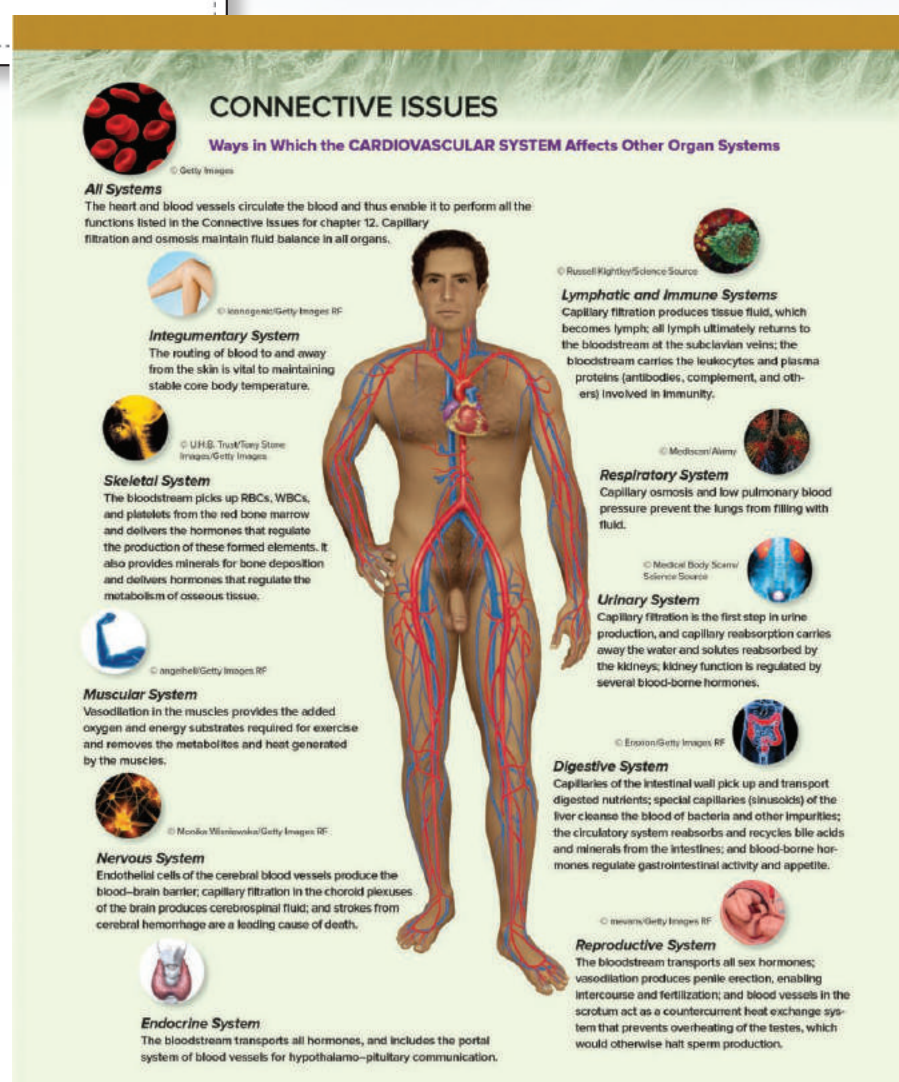
- "Testing Your Recall" questions check for simple memory of terms and facts.
- The false assertions in "What's Wrong with These Statements?" require students to analyze the validity of ideas and to explain or rephrase each false statement.
- "Testing Your Comprehension" questions necessitate insight and application to clinical and other scenarios.

Making *Anatomy & Physiology* Intriguing and Inspiring

Tying It All Together

Base Camp

- "Base Camp" lists key concepts from earlier chapters that a student should know before embarking on the new one, and effectively ties all chapters together into an integrated whole.



Connective Issues

- No organ system functions in isolation. The "Connective Issues" tool shows how every organ system affects all other body systems, and generates a more holistic understanding of human function.

Career Spotlight

- "Career Spotlight" features provide a relevant career idea in every chapter with basic information on educational requirements and entry into a career, and expand student awareness of opportunities in allied health professions. "Appendix B" refers students to online sources of further information about 20 career fields and a list of 83 more health-care career ideas.

CAREER SPOTLIGHT

Electrocardiographic Technician

© MCT/Getty Images

An *electrocardiographic (ECG or EKG) technician* prepares electrocardiograms (ECGs) for diagnostic, exercise testing, and other purposes. The ECG technician prepares the patient for the test by attaching electrodes to specific sites on the chest and limbs and monitors the equipment while results are recorded. One can become a certified ECG technician through programs at community colleges or vocational colleges. A typical course of training entails 4 months beyond high school and includes anatomy and physiology, medical terminology, interpretation of cardiac rhythms, patient-care techniques, cardiovascular medication, and medical ethics. Many people, however, become ECG technicians through on-the-job training rather than formal programs. Most employers prefer to train people who are already in a health-care profession, such as nurses' aides. With more advanced training, one may become a cardiovascular technologist and assist physicians in diagnosis, cardiac catheterization, echocardiography, and other more specialized skills and for correspondingly better salaries. For further information on a career as an ECG technician or cardiovascular technologist, see appendix B.

Clinical Application

- "Clinical Application" essays apply basic science to interesting issues of health and disease.

Clinical Application 3.2

CALCIUM CHANNEL BLOCKERS

Membrane channels may seem only an abstract concept until we see how they relate to disease and drug design. For example, drugs called *calcium channel blockers* are often used to treat high blood pressure (hypertension). How do they work? The walls of the arteries contain smooth muscle that constricts to narrow the vessels and raise blood pressure, or relaxes to let them widen and reduce blood pressure. Excessive, widespread vasoconstriction (vessel narrowing) can cause hypertension, so one approach to the treatment of hypertension is to inhibit vasoconstriction. In order to constrict, smooth muscle cells open calcium channels in the plasma membrane. The inflow of calcium activates the proteins of muscle contraction. Calcium channel blockers act, as their name says, by preventing calcium channels from opening and thereby preventing constriction.

Perspectives on Health

- "Perspectives on Health" essays make basic science relevant to the student's interest in health and disease.

PERSPECTIVES ON HEALTH

Methods of Contraception

Contraception means any procedure or device intended to prevent pregnancy (the presence of an implanted conceptus in the uterus). This essay summarizes the most popular methods and some issues involved in choosing among them.

Behavioral Methods

Abstinence (refraining from intercourse) is, obviously, a completely reliable method if used consistently. The *fertility awareness-based method* relies on avoiding intercourse near the time of expected ovulation. Among typical users, it has a 25% failure rate, partly due to lack of restraint and partly because it is difficult to predict the exact date of ovulation. Intercourse must be avoided for at least 7 days before ovulation so there will be no surviving sperm in the reproductive tract when the egg is ovulated, and for at least 2 days after ovulation so there will be no fertile egg present when sperm are introduced.

Withdrawal (coitus interruptus) requires the male to withdraw the penis before ejaculation. This often fails because of lack of willpower, because some sperm are present in the preejaculatory fluid, and because sperm ejaculated *anywhere* in the vulva can potentially get into the reproductive tract.

Barrier and Spermicidal Methods

Barrier methods are designed to prevent sperm from getting into or beyond the vagina. They are most effective when used with chemical spermicides, available as nonprescription foams, creams, and jellies. Second only to birth-control pills in popularity is the male *condom*, a sheath usually made of latex, worn over the penis. Female condoms that cover the vulva and line the vagina are also available. Condoms are the only contraceptive methods that also protect against disease transmission. Condoms have the advantages of being inexpensive and requiring no medical examination or prescription.

The *diaphragm* is a latex dome worn over the cervix to block sperm migration. It requires a physical examination and prescription to ensure proper fit, but is otherwise comparable to the condom in convenience and reliability, provided it is used with a spermicide. Without a spermicide, it is not very effective. Unlike the male and female condoms, the diaphragm and other methods that follow offer no protection from sexually transmitted diseases.

The *sponge* is a concave foam disc inserted before intercourse to cover the cervix. It is coated with spermicide and acts by absorbing semen and killing the sperm. It requires no prescription or fitting. The sponge provides protection for up to 12 hours, and must be left in place for 6 hours after intercourse.

Hormonal Methods

Most hormonal methods of contraception are aimed at preventing ovulation. They mimic the negative feedback effect of ovarian hormones on the pituitary gland, inhibiting FSH and LH secretion so follicles do not mature. For most women, they are highly effective and present minimal complications.

The oldest and still the most widely used hormonal method in the United States is the *combined oral contraceptive (birth-control pill)*. It is composed of estrogen and progestin, a synthetic progesterone. It must be taken daily, at the same time of day, for 21 days each cycle. The 7-day withdrawal allows for menstruation. Side effects include an elevated risk of heart attack or stroke in smokers and in women with a history of diabetes, hypertension, or clotting disorders.

Other hormonal methods avoid the need to remember a daily pill. One option is a skin patch that releases estrogen and progestin transdermally. It is changed at 7-day intervals (three patches per month and 1 week without). The NuvaRing is a soft flexible vaginal ring that releases estrogen and progestin for absorption through the vaginal mucosa. It must be worn continually for 3 weeks and removed for the fourth week of each cycle. Medroxyprogesterone (trade name Depo-Provera) is a progestin administered by injection every 3 months. It provides highly reliable, long-term contraception, although in some women it causes headaches, nausea, or weight gain.

Some drugs can be taken orally after intercourse to prevent implantation of a conceptus. These are called emergency contraceptive pills (ECPs), or "morning-after pills." An ECP is a high dose of estrogen and progestin or a progestin alone. It can be taken within 72 hours after intercourse and induces menstruation within 2 weeks. ECPs inhibit ovulation, inhibit sperm or egg transport in the uterine tube, and prevent implantation. They do not work if a blastocyst is already implanted.

Intrauterine Devices

Intrauterine devices (IUDs) are sprin
inserted through the cervical canal
act by releasing a synthetic proge
copper wire wrapping or copper sl
ine lining and interfere with blasto
per IUDs also inhibit sperm motility.
for 5 to 12 years.

Aging of Body Systems

- "Aging of [Body Systems]" is a section within each systems chapter that describes how each organ system changes over time, especially in old age. This discussion expands anatomical and physiological understanding beyond the prime of life, and is highly relevant to patient treatment, since older patients constitute most of the health-care market.

Aging of the Muscular System

One of the most common changes in old age is the replacement of lean body mass (muscle) with fat, accompanied by loss of muscular strength. Muscular strength and mass peak in the 20s, and by the age of 80, most people have only half as much strength and endurance. Many people over age 75 cannot lift a 4.5 kg (10 lb) weight, making such simple tasks as carrying a bag of groceries very difficult. Tasks such as buttoning the clothes also take more time and effort. The loss of strength is a major contributor to falls, fractures, and dependence on others for living assistance. Fast-twitch muscle fibers show the earliest and greatest atrophy, thus increasing reaction time, slowing the reflexes, and reducing coordination.

There are multiple reasons for the loss of strength. Aged muscle has fewer myofibrils; more disorganized sarcomeres; smaller mitochondria; and reduced amounts of ATP, myoglobin, glycogen, and creatine phosphate. Increased adipose and fibrous tissue in the muscles limits their movement and blood circulation. In addition, there are fewer motor neurons in the spinal cord, so some muscle atrophy may result from reduced innervation. Even the neurons that do remain produce less acetylcholine and stimulate the muscles less effectively.

Even though people typically lose muscle mass and function as they age, these effects are noticeably less in people who continue to exercise throughout life. For example, studies show that even moderate exercise can help elderly people maintain muscle mass and improve balance. Recent research suggests that it also increases mental agility and decreases the risk of dementia.

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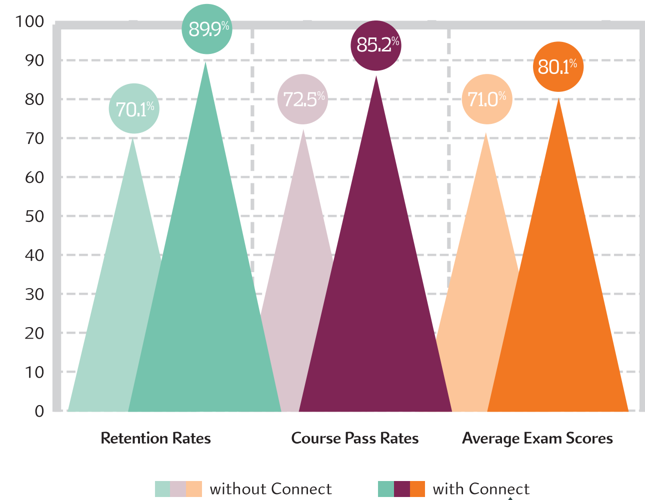

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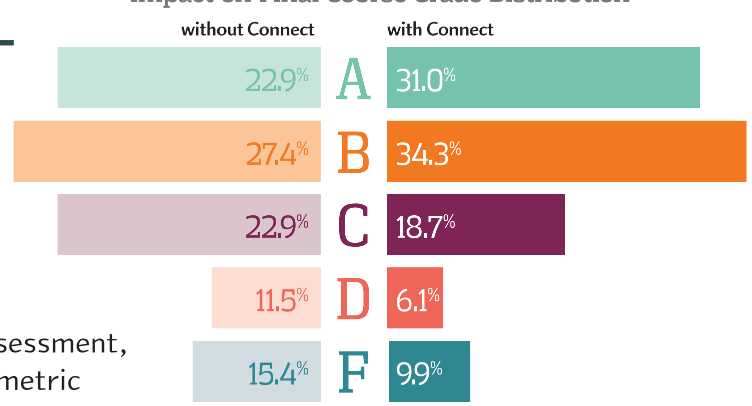

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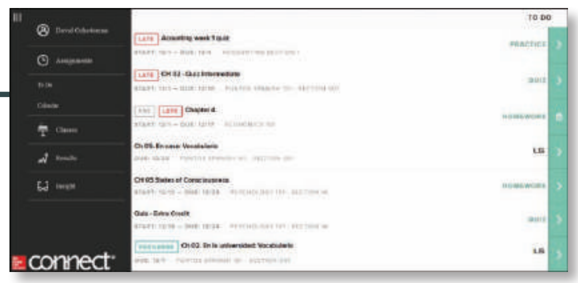

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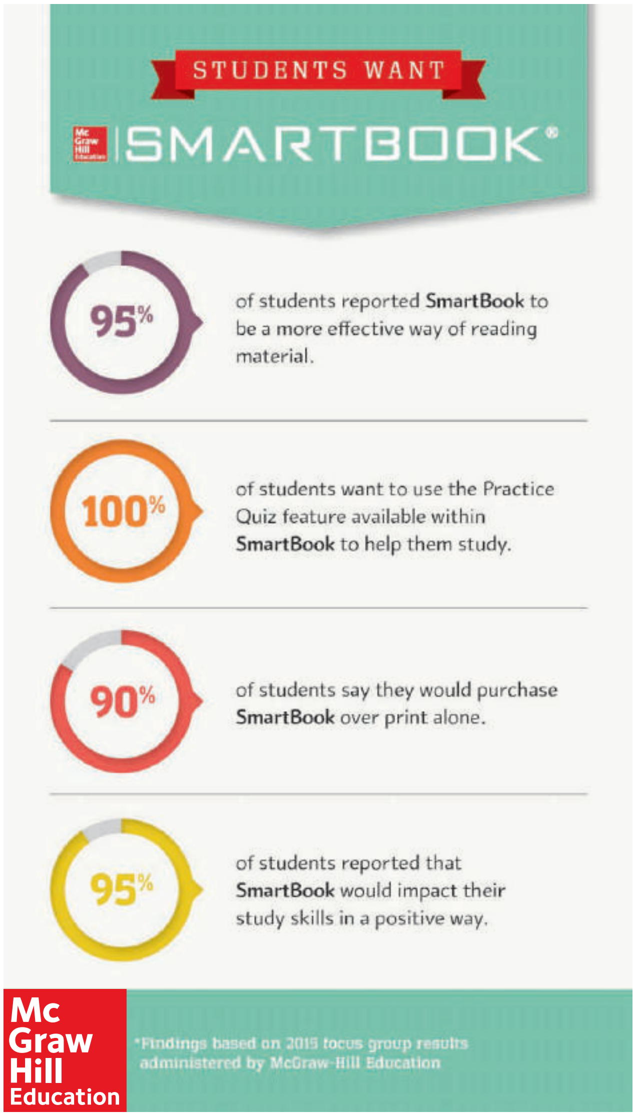

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Acknowledgments

I gratefully acknowledge the team at McGraw-Hill who have provided excellent ideas and unfailing encouragement t.hroughout this project. I am immensely grateful to my coauthor Ken Saladin for a rewarding collaboration and firm friendship. I appreciate my colleagues in the biology department at Cabrillo College who inspire me every day with their dedication to student success. Finally, I wish to thank my husband Jeff and my children Reid and Madeleine for their support and patience.

Robin McFarland

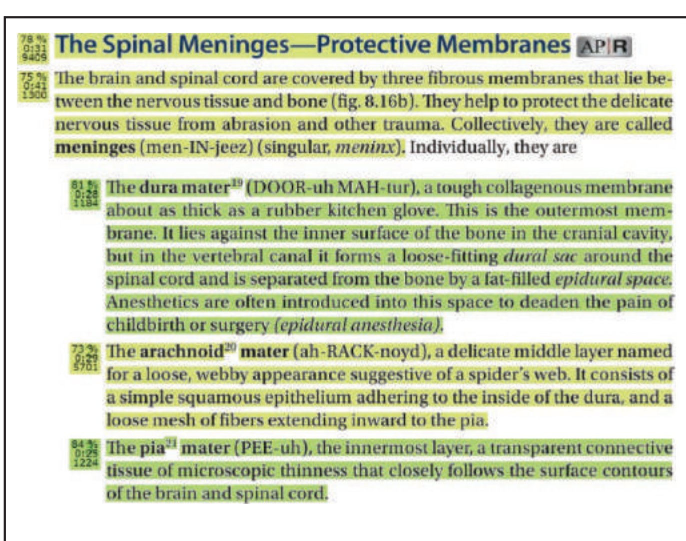
My heartfelt appreciation goes to our team at McGraw-Hill who have provided such friendship, collegiality, and support over my 20-year history in textbooks; to Robin for adding this new dimension and stimulating collaboration to my writing career; to my colleagues at Georgia College for an atmosphere that supports and rewards such work; and to Diane for her steadfast love and encouragement.

Ken Saladin

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

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly, we substantively revised or reorganized the content to be as clear and illustrative as possible.
- In some sections, the data showed that a smaller percentage of the students had difficulty learning the material. In those cases, we revised the text to provide a clearer presentation by rewriting the section, providing additional examples to strengthen student problem-solving skills, designing new text art or figures to assist visual learners, and so on.
- In other cases, one or more of the LearnSmart probes for a section was not as clear as it might be or did not appropriately reflect the content. In these cases, the *probe*— rather than the text—was edited.

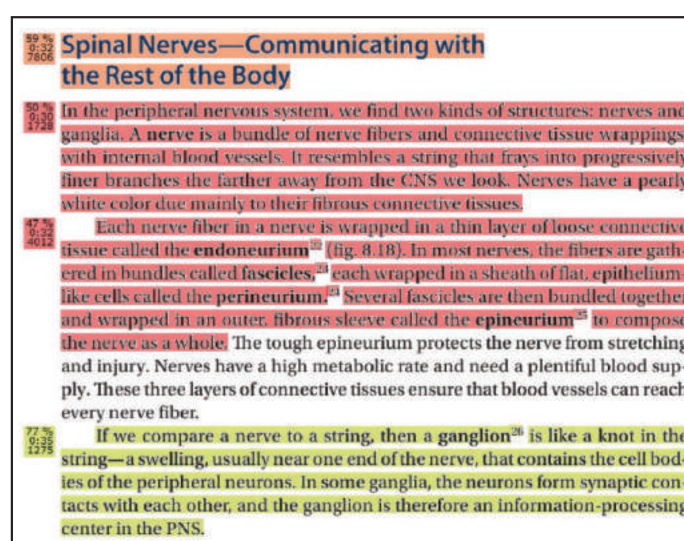
Following is an example of one of the heat maps from chapter 8 that was particularly useful in guiding our revisions. The highlighted sections indicate the various levels of difficulty students experienced in learning the material. This evidence informed all of the revisions described in the "What's New in the Second Edition?" section of this preface.



The Spinal Meninges—Protective Membranes APR

The brain and spinal cord are covered by three fibrous membranes that lie between the nervous tissue and bone (fig. 8.16b). They help to protect the delicate nervous tissue from abrasion and other trauma. Collectively, they are called **meninges** (men-IN-jeez) (singular, *meninx*). Individually, they are

- The **dura mater**[19] (DOOR-uh MAH-tur), a tough collagenous membrane about as thick as a rubber kitchen glove. This is the outermost membrane. It lies against the inner surface of the bone in the cranial cavity, but in the vertebral canal it forms a loose-fitting *dural sac* around the spinal cord and is separated from the bone by a fat-filled *epidural space*. Anesthetics are often introduced into this space to deaden the pain of childbirth or surgery *(epidural anesthesia)*.
- The **arachnoid**[20] **mater** (ah-RACK-noyd), a delicate middle layer named for a loose, webby appearance suggestive of a spider's web. It consists of a simple squamous epithelium adhering to the inside of the dura, and a loose mesh of fibers extending inward to the pia.
- The **pia**[21] **mater** (PEE-uh), the innermost layer, a transparent connective tissue of microscopic thinness that closely follows the surface contours of the brain and spinal cord.



Spinal Nerves—Communicating with the Rest of the Body

In the peripheral nervous system, we find two kinds of structures: nerves and ganglia. A **nerve** is a bundle of nerve fibers and connective tissue wrappings, with internal blood vessels. It resembles a string that frays into progressively finer branches the farther away from the CNS we look. Nerves have a pearly white color due mainly to their fibrous connective tissues.

Each nerve fiber in a nerve is wrapped in a thin layer of loose connective tissue called the **endoneurium**[22] (fig. 8.18). In most nerves, the fibers are gathered in bundles called **fascicles**,[23] each wrapped in a sheath of flat, epithelium-like cells called the **perineurium**.[24] Several fascicles are then bundled together and wrapped in an outer, fibrous sleeve called the **epineurium**[25] to compose the nerve as a whole. The tough epineurium protects the nerve from stretching and injury. Nerves have a high metabolic rate and need a plentiful blood supply. These three layers of connective tissues ensure that blood vessels can reach every nerve fiber.

If we compare a nerve to a string, then a **ganglion**[26] is like a knot in the string—a swelling, usually near one end of the nerve, that contains the cell bodies of the peripheral neurons. In some ganglia, the neurons form synaptic contacts with each other, and the ganglion is therefore an information-processing center in the PNS.

Our grateful thanks are extended to these reviewers, who read early drafts of these chapters and provided instructive comments to help shape the content within these pages.

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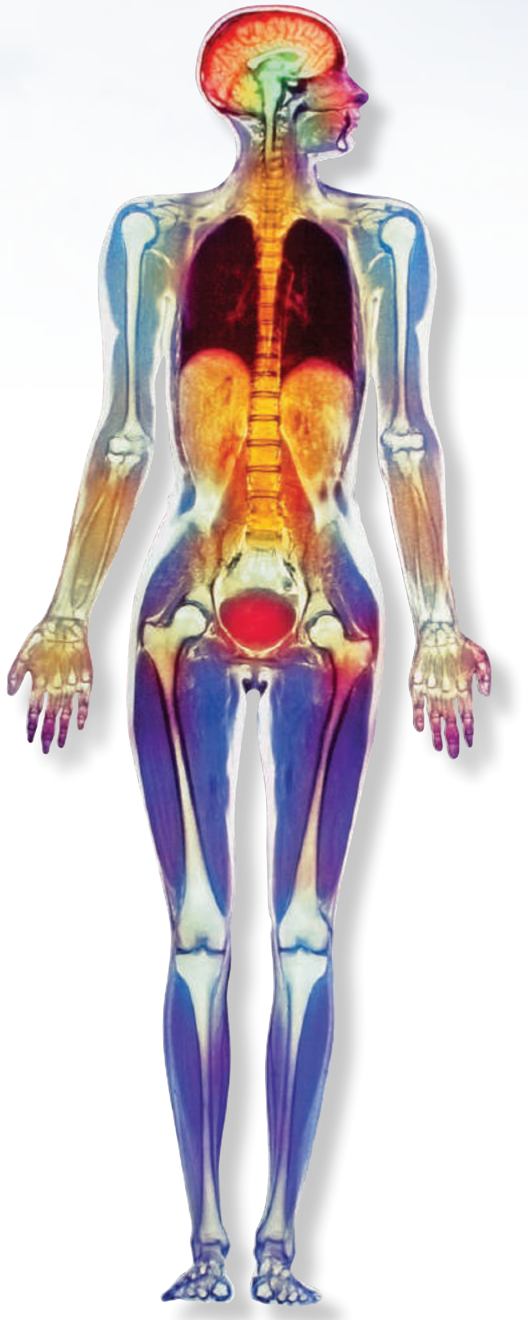
Chapter

1

The Study of Anatomy and Physiology



A full-body image made by magnetic resonance imaging (MRI). MRI is one of several ways of viewing the interior of the body without surgery.
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Chapter Outline

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Module 1: Body Orientation

No branch of science hits as close to home as the science of our own bodies. We're grateful for the dependability of our hearts, we're awed by the capabilities of joints and muscles displayed by Olympic athletes, and we ponder with philosophers the ancient mysteries of mind and emotion. We want to know how our body works, and when it malfunctions, we want to know what's happening and what we can do about it. In recent decades, scientists have revealed a wealth of information about our bodies, but fascination with the science of the body is nothing new. Ancient texts and medical illustrations attest to humanity's timeless drive to know and heal the body and mind.

This book introduces the essentials of human structure and function. It will give you a deeper understanding of the healthy body, as well as accurate, up-to-date insights into disease processes. The disciplines of anatomy and physiology are fundamental to health-care professionals, as well as to those who study human performance, fitness, and nutrition. Beyond that, however, the study of anatomy and physiology provides a deeply satisfying sense of self-understanding.

In this chapter, we introduce the disciplines of anatomy and physiology. We discuss criteria that define life and consider a core concept called *homeostasis,* a vital process necessary for maintaining life. We look at the body's general structural plan and levels of organization. Finally, because one of the greatest challenges to beginning students is to master vocabulary associated with anatomy and physiology, we end the chapter with tools to help you effectively learn and use the language of the body.

1.1 Anatomy—The Structural Basis of Human Function

Expected Learning Outcomes

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

a. define *anatomy* and *physiology;*
b. describe some of the subfields of human anatomy;
c. explain the importance of dissection;
d. describe some methods of examining a living patient;
e. discuss the principles and applications of some medical imaging methods; and
f. discuss the significance of variations in human anatomy.

Anatomy is the study of the structure of the body, with an emphasis on how it relates to function. *Physiology* is the study of dynamic processes in the living body. The two disciplines are very much intertwined, and both are necessary to understand the totality of the body.

The Anatomical Sciences

There are many approaches to the study of human anatomy, both in research for the purposes of discovery and understanding, and in clinical settings for diagnosis and treatment. **Gross anatomy** is structure visible to the naked eye, either by surface observation or dissection. Ultimately, though, body functions result from individual cells. To see those, we usually take tissue samples, thinly slice and stain them, and observe them under the microscope. This approach is called **histology.**[1] **Histopathology** is the microscopic examination of tissues for signs of disease.

Surface anatomy is the external structure of the body, and is especially important in conducting a physical examination of a patient. **Systemic anatomy** is the study of one organ system at a time; this is the approach taken by introductory textbooks such as this one. **Regional anatomy** is the study of multiple organ systems at the same time in a given region of the body, such as the head or chest. Medical schools and anatomical atlases typically teach anatomy from this perspective, because it is more logical to dissect all structures of the head and neck, the chest, or a limb, than to try to dissect the entire digestive system, then the cardiovascular system, and so forth. Dissecting one system almost inevitably destroys organs of other systems that stand in the way.

Apply What You Know

Do you think that a surgeon thinks more in terms of systemic anatomy or regional anatomy? Explain your answer.

You can study human anatomy from an atlas; yet, as fascinating and valuable as anatomy atlases are, they teach almost nothing but the locations, appearances, and names of structures. This book is much different; it deals with what biologists call **functional morphology**[2]—not simply describing structures but also analyzing how they function.

Functional morphology draws heavily on comparative anatomy, the study of more than one species. Such comparisons reveal similarities and differences, highlight evolutionary trends, and clarify structure–function relationships. Often, human structure makes sense only when we compare it to the structure of other animals. The human pelvis, for example, has a unique bowl-shaped configuration that can be best understood by comparison with animals such as a chimpanzee, whose pelvis is adapted to walking on four legs rather than two.

Examination of the Body

The simplest method of examining the body is **inspection** of surface structure, such as physicians perform during a physical examination. A deeper understanding depends on **dissection**[3]—the careful cutting and separation of tissues to reveal their relationships. The word *anatomy*[4] literally means "cutting apart," and dissection was called "anatomizing" until the nineteenth century. The dissection of a dead human body, or **cadaver,**[5] was crucial historically for accurately mapping the human body, and remains an essential part of the training of many health-science students.

---

[1]*histo* = tissue; *logy* = study of

[2]*morpho* = form; *logy* = study of

[3]*dis* = apart; *sect* = cut

[4]*ana* = apart; *tom* = cut

[5]*cadere* = to fall or die

Dissection, of course, is not the method of choice when examining a living patient! Some additional methods of clinical examination include the following.

- **Palpation**[6] is feeling structures with the fingertips, such as palpating a swollen lymph node or taking a pulse.
- **Auscultation**[7] (AWS-cul-TAY-shun) is listening to the natural sounds made by the body, such as heart and lung sounds.
- **Percussion** is tapping on the body and listening to the sound for signs of abnormalities such as pockets of fluid or air.
- **Medical imaging** includes methods of viewing the inside of the body without surgery. Anatomy learned in this way is called **radiologic anatomy,** and those who use radiologic methods for clinical purposes include **radiologists** and **radiologic technologists** (see Career Spotlight at end of chapter).

Techniques of Medical Imaging

It was once common to diagnose disorders through *exploratory surgery*—opening the body and taking a look inside to see what was wrong and what could be done about it. Any breach of the body cavities is risky, however, and most exploratory surgery has been replaced by imaging techniques that allow physicians to see inside the body without cutting. These methods are called *noninvasive* if they involve no penetration of the skin or body orifices. *Invasive* techniques may entail inserting ultrasound probes into the esophagus, vagina, or rectum to get closer to the organ to be imaged, or injecting substances into the bloodstream or body passages to enhance image clarity.

Anatomy students today must be acquainted with the basic methods of imaging and their advantages and limitations. Many images in this book have been produced by the following techniques. Most of these methods produce black and white images; those in the book are colorized to enhance detail or for esthetic appeal.

Radiography (fig. 1.1a, b) is the process of photographing internal structures with X-rays, a form of high-energy radiation. The term *X-ray* also applies to a photograph *(radiograph)* made by this method. X-rays are absorbed by dense structures

[6] *palp* = touch, feel
[7] *auscult* = listen

(a) X-ray (radiograph)

(b) Cerebral angiogram

Figure 1.1 Radiologic Images of the Head. (a) An X-ray (radiograph) of the head. (b) A colorized cerebral angiogram, made by injecting a substance opaque to X-rays into the circulation and then taking an X-ray of the head to visualize the blood vessels. (c) A CT scan of the head at the level of the eyes. (d) An MRI scan of the head at the level of the eyes. The optic nerves appear in red and the muscles that move the eyes in green. (e) A PET scan of the brain of an unmedicated schizophrenic patient. Red areas indicate regions of high metabolic rate. In this patient, the visual center of the brain (at bottom of photo) was especially active.

a: © U.H.B. Trust/Tony Stone Images/Getty Images **b:** © Zephyr/Science Source **c:** © Miriam Maslo/Science Source **d:** © UHB Trust/Getty Images **e:** © ISM/Phototake

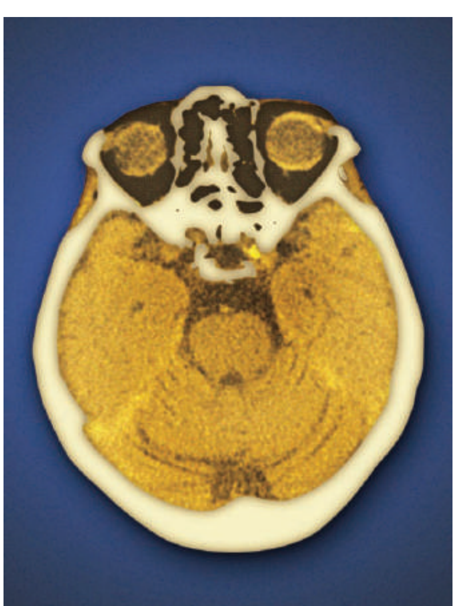
- *Why is a PET scan considered invasive whereas MRI is noninvasive?*

such as bone, teeth, and tumors, which produce a lighter image than soft tissues. Radiography is commonly used in dentistry; mammography; diagnosis of fractures; and examination of the digestive, respiratory, and urinary tracts. Some disadvantages of radiography are that images of overlapping organs can be confusing; slight differences in tissue density are not detected well; and, although the risk of harm is very low, X-rays can potentially cause mutations and cancer.

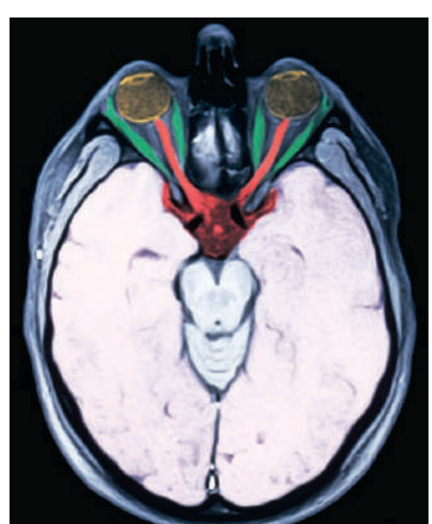
Computed tomography[8] (the **CT scan**) (fig. 1.1c) is a more sophisticated application of X-rays. The patient is moved through a ring-shaped machine that emits low-intensity X-rays on one side and receives them with a detector on the opposite side. A computer analyzes signals from the detector and produces an image of a "slice" of the body about as thin as a coin. CT scanning has the advantage of imaging thin sections of the body, so there is little organ overlap and the image is much sharper than a conventional X-ray. CT scanning is useful for identifying tumors, aneurysms, cerebral hemorrhages, kidney stones, and other abnormalities.

Magnetic resonance imaging (MRI) (fig. 1.1d) is even better than CT for visualizing soft tissues. The patient lies in either a tube or an open-sided scanner with a powerful electromagnet. Hydrogen atoms in the patient's tissues alternately align themselves with this magnetic field and with a radio-frequency field turned on and off by the technologist. These changes in hydrogen alignment generate signals that are analyzed by computer to produce an anatomical image. MRI can "see" clearly through the skull and spine to produce images of the nervous tissue within, and it is better than CT for distinguishing between soft tissues such as the white and gray matter of the brain. It has some disadvantages, however, such as the claustrophobic feeling some patients experience in the scanner, and long exposure times that prevent sharp images being made of the constantly moving stomach and intestines. *Functional MRI (fMRI)* is a form of MRI that visualizes moment-to-moment changes in tissue physiology; fMRI scans of the brain, for example, show shifting patterns of activity as the brain applies itself to a specific task. This method has been very useful in clarifying which parts of the brain are involved in emotions, thought, language, sensation, and movement.

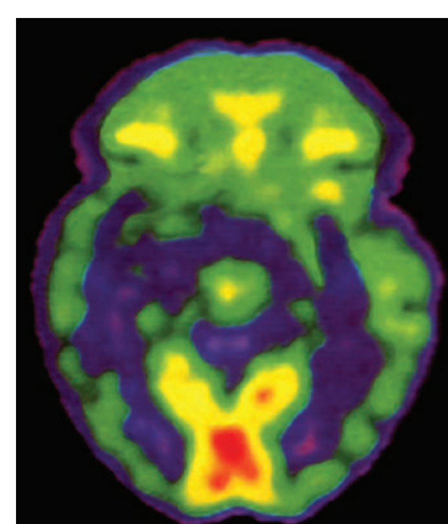
[8]*tomo* = section, cut, slice; *graphy* = recording process



(c) Computed tomographic (CT) scan



(d) Magnetic resonance image (MRI)



(e) Positron emission tomographic (PET) scan

Positron emission tomography (the **PET scan**) (fig. 1.1e) is used to assess the metabolic state of a tissue and to distinguish which areas are most active. It uses an injection of radioactively labeled glucose to highlight which tissues are most actively consuming energy at the moment of the scan. In cardiology, for example, PET scans can show the extent of tissue death from a heart attack. Since damaged tissue consumes little or no glucose, it appears dark. PET scans are widely used to diagnose cancer and evaluate tumor status. The PET scan is an example of **nuclear medicine**—the use of radioisotopes to treat disease or to form diagnostic images of the body.

Sonography[9] (fig. 1.2) uses a handheld device placed firmly against the skin; it emits high-frequency ultrasound and receives signals reflected back from internal organs. Sonography avoids the harmful effects of X-rays, and the equipment is relatively inexpensive and portable. It also is very useful for imaging motion, such as operation of the heart valves, ejection of blood from the heart, and fetal movements. It is the method of choice in obstetrics, where the image *(sonogram)* can be used to locate the placenta and evaluate fetal age, position, and development. *Echocardiography* is the sonographic examination of the beating heart. The primary disadvantages of sonography are that it does not produce a very sharp image and it cannot penetrate bone.

Anatomical Variation

A quick look around any classroom is enough to show that no two humans look exactly alike; on close inspection, even identical twins exhibit differences. Anatomy atlases and textbooks can easily give you the impression that everyone's internal anatomy is the same, but this simply is not true. Someone who thinks that all human bodies are the same internally would be a very confused medical student or an incompetent surgeon. Books such as this one teach only the most common structural patterns—the anatomy seen in approximately 70% or more of people.

Some people completely lack certain organs. For example, most of us have a *palmaris longus muscle* in the forearm and a *plantaris muscle* in the leg, but not everyone does. Most of us have one spleen, but some people have two. Most have two kidneys, but some have only one. Most kidneys are supplied by a single *renal artery* and drained by one *ureter,* but in some people a single kidney has two renal arteries or ureters. Figure 1.3 shows some common variations in human anatomy, and Perspectives on Health (in section 1.2) describes a particularly dramatic variation.

(b)

(a)

[9]*sono* = sound; *graphy* = recording process

Figure 1.2 Sonography. (a) Producing a sonogram for an expectant family. (b) Three-dimensional sonogram of a fetus at 32 weeks of gestation.

a: © Alexander Tsiaras/Science Source **b:** © Ken Saladin

- *Why is this procedure safer than radiography for fetal assessment?*

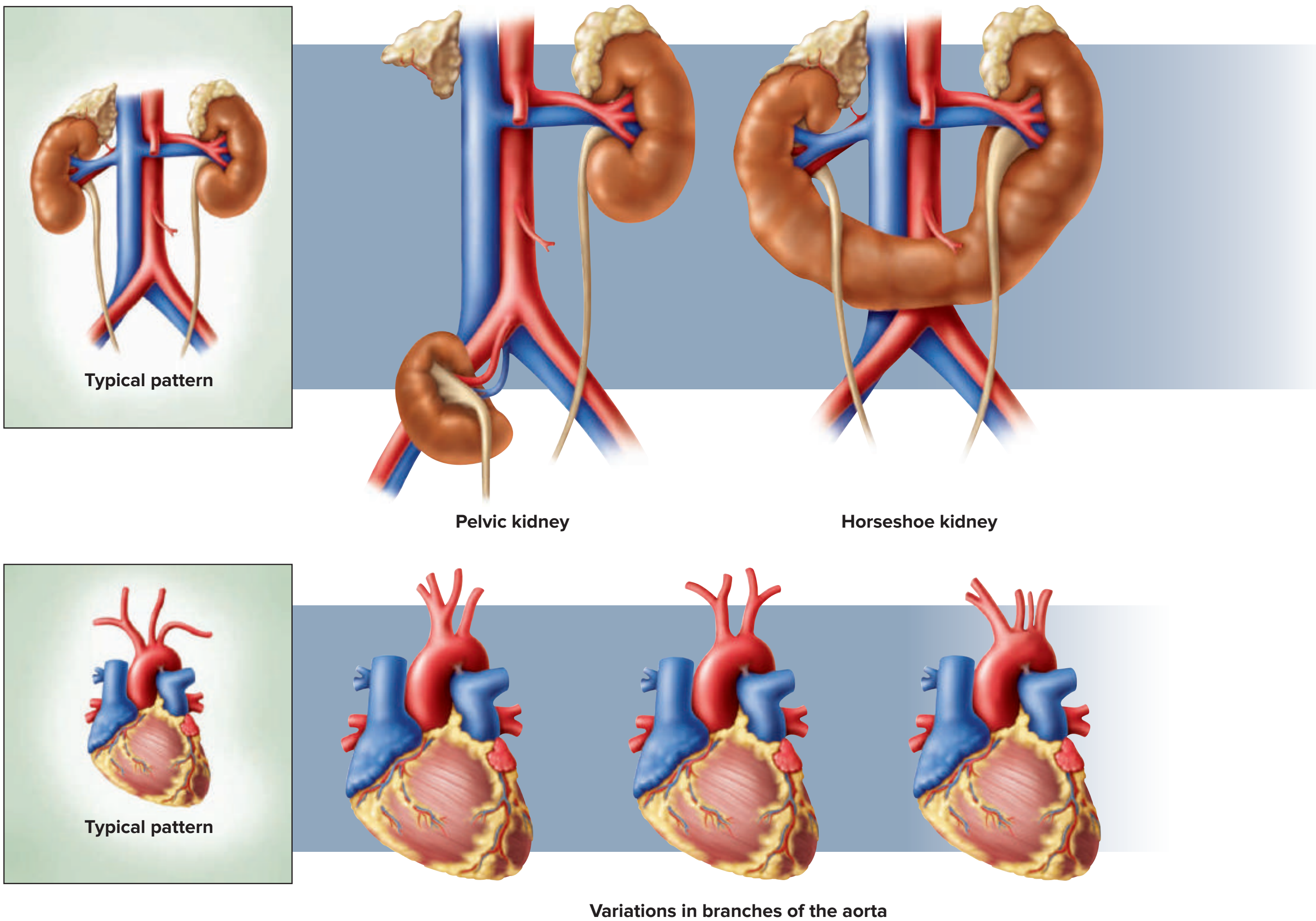


Figure 1.3 Variations in Human Anatomy. Not all humans have the usual "textbook structure."

Before You Go On

Answer these questions from memory. Reread the preceding section if there are too many you don't know.

1. *What is the difference between gross anatomy and histology?*
2. *In a routine physical examination, a physician may inspect you by palpation and auscultation. What is the difference between these procedures?*
3. *What are the advantages of CT over sonography? Conversely, what are the advantages of sonography over CT?*

1.2 Physiology—Dynamic Processes in the Living Body

Expected Learning Outcomes

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

a. identify some subdisciplines of physiology;
b. describe the characteristics that define an organism as alive;
c. define *homeostasis,* explain its significance, and discuss how it is maintained by negative feedback;
d. discuss positive feedback and its effects on the body; and
e. discuss the significance of variation in human physiology.

Physiology[10] is the study of the body's life processes. The term comes from Aristotle, who believed in both supernatural and natural causes of human disease. He called the supernatural causes *theologi* and natural causes *physiologi.* For centuries, physicians were called "doctors of physick."

The Physiological Sciences

Physiology uses the methods of experimental science to determine how the body functions. It has many subdisciplines such as *neurophysiology* (physiology of the nervous system), *endocrinology* (physiology of hormones), and *pathophysiology* (mechanisms of disease). Partly because of limitations on experimentation with humans, much of what we know about bodily function has been gained through **comparative physiology,** the study of how different species have solved problems of life such as water balance, respiration, and reproduction. Comparative physiology is also the basis for the development of most new medications and procedures. For example, a new drug is tested for safety in laboratory mammals such as rats before it proceeds to trials with human subjects.

Essential Life Functions

Whereas anatomy views the body as a set of interconnected structures, physiology views it as a set of interconnected processes. Collectively, we call these processes *life*. But what exactly is life? Why do we consider a growing child to be alive, but not a growing crystal? Is abortion the taking of a human life? If so, what about a contraceptive foam that kills only sperm? As a patient is dying, at what point does it become ethical to disconnect life-support equipment and remove organs for donation? (See Perspectives on Health that follows.) If these organs are alive, as they must be to be useful to someone else, then why isn't the donor considered alive? Such questions have no easy answers, but they demand a concept of what life is—a concept that may differ with one's biological, medical, religious, or legal perspective.

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[10]*physio* = nature; *logy* = study of

PERSPECTIVES ON HEALTH

Situs Inversus and Other Unusual Anatomy

Two particularly striking examples of anatomical variation are situs (SITE-us) perversus and situs inversus. In *situs perversus,* an organ occupies an atypical locality; for example, a kidney may be located low in the pelvic cavity instead of high in the abdominal cavity (see fig. 1.3), or a parathyroid gland may be found in the root of the tongue instead of on the posterior surface of the thyroid gland.

In most people, the heart tilts toward the left, the spleen and sigmoid colon are on the left, and the gallbladder and appendix are on the right. But in *situs inversus,* occurring in about 1 out of 8,000 people, the organs of the thoracic and abdominal cavities are reversed between right and left. Selective right–left reversal of the heart is called *dextrocardia.* Conditions such as dextrocardia can cause serious medical problems. Complete situs inversus, however, usually causes no functional problems because all of the viscera, though reversed, maintain their normal relationships to each other.

Defining the End of Life

Earlier in this chapter we saw that *life* is a difficult property to define. That being the case, so is defining the end of life—and yet we're often forced to make decisions on that issue. How do we decide when to "let go" of a terminally ill loved one, perhaps to disconnect life-support equipment?

There is no easily defined instant of biological death. Some organs function for an hour or longer after the heart stops beating. During this time, even if a person is declared legally dead, living organs may be removed for transplantation. For legal purposes, death was once defined as the loss of a spontaneous heartbeat and respiration. Now that cardiopulmonary functions can be restarted and artificially maintained for years, this criterion is less useful. Clinical death is now widely defined in terms of *brain death*—a lack of any detectable electrical activity in the brain, including the brainstem, accompanied by coma, lack of unassisted respiration, and lack of brainstem reflexes (such as pupillary, blinking, or coughing reflexes). A judgment of death is generally accepted only upon finding a complete lack of brain activity for a period ranging from 2 to 24 hours, depending on state laws. The permanent lack of cerebral activity is called a *persistent vegetative state.* Controversy has lingered, however, over the question of whether death of the entire brain (including the brainstem) should be required as a criterion of clinical death, or whether death may be declared upon lack of activity in only the cerebrum (the upper level of the brain that houses consciousness, sensation, and thought).

Medical educators, ethicists, philosophers, and theologians struggle continually with the difficulty of defining life and the moment of its cessation. The demand for organs for transplant pressures physicians to make delicate decisions as to when the life of the whole person is irretrievable, yet individual organs are still in sufficiently healthy condition to be useful to a recipient. Theologians, on the other hand, may wish for moral certainty that death has overtaken the whole person, and may see the "culture of organ donation" as incompatible with religious values.

From a biological viewpoint, life is not a single property. It is a collection of qualities that help to distinguish living from nonliving things:

- **Organization.** Living things exhibit a far higher level of organization than the nonliving world around them. They expend a great deal of energy to maintain order, and disease and death result from a breakdown in this order.
- **Cells.** Living matter is always compartmentalized into one or more cells.
- **Metabolism.**[11] Living things take in molecules from the environment and chemically change them into molecules that form their own structures, control their physiology, or provide energy. Metabolism is the sum of all this internal chemical change. There is a constant turnover of molecules in the

[11]*metabol* = change; *ism* = process

body; although you sense a continuity of personality and experience from your childhood to the present, nearly every molecule of your body has been replaced within the past year.

- **Growth.** Some nonliving things grow, but not in the way your body does. When a saturated sugar solution evaporates, crystals grow from it, but not through a change in the composition of the sugar. They merely add more sugar molecules from the solution to the crystal surface. The growth of the body, by contrast, occurs through metabolic change; for the most part, the body is not composed of the molecules one eats, but of molecules made by chemically altering the food.
- **Development.** Development is any change in form or function over the lifetime of the organism. It includes not only growth but also *differentiation*—the transformation of cells and tissues with no specialized function to ones that are committed to a particular task. For example, a single embryonic, unspecialized tissue called *mesoderm* differentiates into muscle, bone, cartilage, and blood.
- **Excitability.** The ability to sense and react to *stimuli* (changes in their environment) is called *excitability* or *irritability*. It occurs at all levels from the cell to the entire body, and it characterizes all living things from bacteria to humans. Excitability is especially obvious in animals because of nerve and muscle cells that exhibit high sensitivity to stimuli, rapid transmission of information, and quick reactions.
- **Homeostasis.**[12] Although the environment around an organism changes, the organism maintains relatively stable internal conditions—for example, a stable temperature, blood pressure, and body weight. This internal stability, called *homeostasis,* is discussed in greater depth in the next section.
- **Reproduction.** Living organisms produce copies of themselves, thus passing their genes on to new, younger "containers"—their offspring.
- **Evolution.** All living species exhibit genetic change from generation to generation, and therefore evolve. This occurs because new variations are inevitably introduced by *mutations* (changes in the genes), and environmental conditions favor some variations over others, thus perpetuating some genes and eliminating others. Evolution simply means genetic change in the population over time. Unlike the other characteristics of life, evolution is a characteristic seen only in the population as a whole. No single individual evolves over the course of its life. Evolution, however, holds the explanation for why human structure and function are as they are. *Evolutionary medicine* is a science that interprets human disease and dysfunction in the context of the biological history of the species.

Homeostasis and Feedback

Of the foregoing properties of life, the one most frequently addressed in this book is homeostasis (ho-me-oh-STAY-sis)—the ability to maintain internal stability. Homeostatic mechanisms stabilize such variables as body temperature, blood pressure, body weight, electrolyte balance, and pH.

[12]*homeo* = the same; *stasis* = stability

Homeostasis has been one of the most enlightening concepts in physiology. The term was introduced by American physiologist Walter Cannon in his book *The Wisdom of the Body* (1932), but the concept that the body maintains internal stability was around long before that. Physiology centers around mechanisms that maintain this stability, and the loss of homeostatic control usually leads to illness or death. Pathophysiology is essentially the study of unstable conditions that result when our homeostatic controls go awry.

Negative Feedback and Stability

The fundamental mechanism that maintains homeostasis is **negative feedback**—a process in which the body senses a change and activates mechanisms that negate (reverse) it. Negative feedback does not produce absolute constancy in the body, but maintains physiological values within a narrow range of a certain **set point**—an average value such as 37°C (98.6°F) for body temperature. Conditions fluctuate slightly around the set point. Thus, negative feedback is said to maintain a *dynamic equilibrium*—not a total lack of change, but a state of ever-changing balance within limits. Variables regulated by negative feedback mechanisms include blood pressure, blood glucose (sugar), and many others. By maintaining physiological equilibrium, negative feedback is the key mechanism for maintaining health.

Let's consider blood pressure regulation as an example of negative feedback. When you first rise from bed in the morning, gravity causes some of your blood to drain away from your head and upper torso, resulting in falling blood pressure in this region (fig. 1.4). The resulting imbalance in homeostasis is detected by sensory nerve endings called *baroreceptors* in large arteries near the heart. The baroreceptors transmit nerve signals to the brain, where we have a cardiac center that regulates the heart rate. The cardiac center responds by sending nerve signals to the heart, which speed it up. The faster heart rate raises the blood pressure and restores normal homeostasis. In elderly people, this feedback loop is sometimes insufficiently responsive, and they may feel dizzy as they rise from a reclining position. The drop in blood pressure may result in decreased blood to the brain and this sometimes causes fainting.

This correction of blood pressure illustrates three common, although not universal, components of a feedback loop: a receptor, an integrating center, and an effector. The **receptor** is a structure that senses a change in the body, such as the baroreceptors that monitor blood pressure. The **integrating (control) center,** such as the cardiac center of the brain, processes this information, relates it to other available information (for example, comparing what the blood pressure is with what it should be), and "makes a decision" about what the appropriate response should be. The **effector** is the cell or organ that carries out the final corrective action. In the blood pressure example, it is the heart. The **response,** such as the restoration of normal blood pressure, is then sensed by the receptor, and the feedback loop is complete.

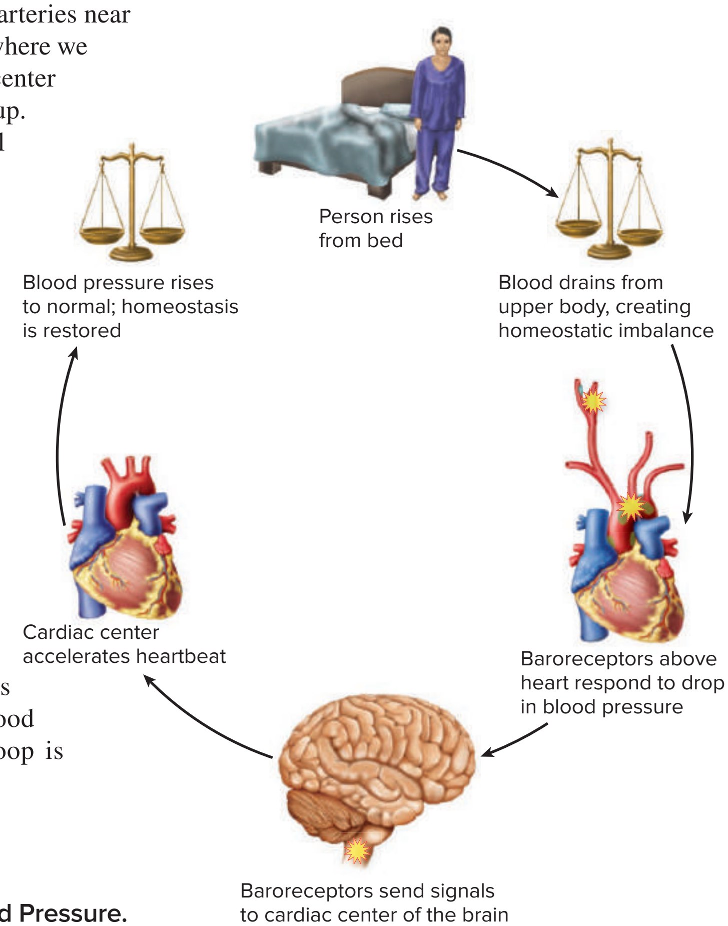

Figure 1.4 Negative Feedback in Response to Drop in Blood Pressure.

Clinical Application 1.1

MEN IN THE OVEN

English physician Charles Blagden (1748–1820) staged a rather theatrical demonstration of homeostasis long before Cannon coined the word. In 1775, Blagden spent 45 minutes in a chamber heated to 127°C (260°F)—along with a steak, a dog, and some research associates. Being dead and unable to maintain homeostasis, the steak was cooked. But being alive and capable of evaporative cooling, the dog panted, the men sweated, and all of them survived. History does not record whether the men ate the steak in celebration or shared it with the dog.

Positive Feedback and Rapid Change

Positive feedback is a self-amplifying cycle in which a physiological change leads to even greater change in the same direction, rather than producing the self-corrective effects of negative feedback. Positive feedback is sometimes a normal way of producing rapid change. During childbirth, for example, the head of the fetus pushes against a woman's cervix (the neck of the uterus) and stimulates its nerve endings (fig. 1.5). Nerve signals travel to the brain, which in turn stimulates the pituitary gland to secrete the hormone *oxytocin.* Oxytocin travels in the blood and stimulates the uterus to contract. This pushes the fetus downward, stimulating the cervix still more and causing the positive feedback loop to be repeated. Labor contractions therefore become more and more intense until the fetus is expelled. Other cases of beneficial positive feedback occur in blood clotting, protein digestion, and the generation of nerve signals.

More often, however, positive feedback is a harmful or even life-threatening process. This is because its self-amplifying nature can quickly change the internal state of the body to something far from its homeostatic set point. Consider a high fever, for example. A fever triggered by infection is beneficial up to a point, but if the body temperature rises much above 42°C (108°F), it may create a dangerous positive feedback loop: The high temperature raises the metabolic rate, which makes the body produce heat faster than it can get rid of it. Thus, temperature rises still further, increasing the metabolic rate and heat production still more. This "vicious circle" becomes fatal at approximately 45°C (113°F). Positive feedback loops often create dangerously out-of-control situations that require emergency medical treatment.

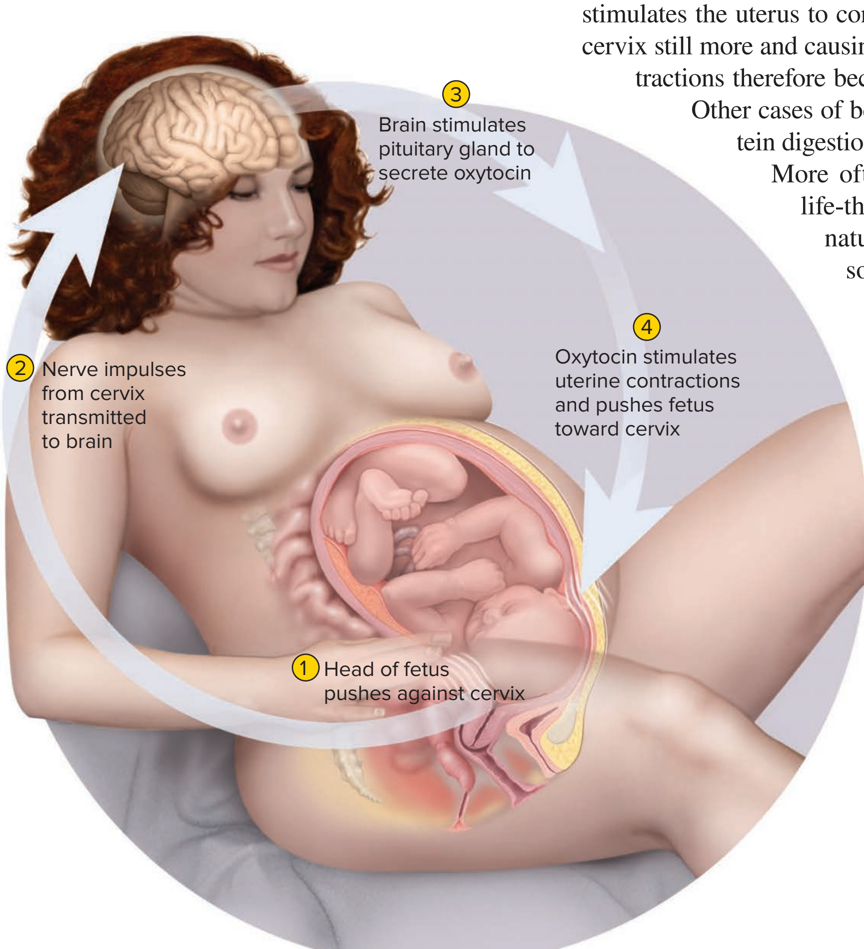

Figure 1.5 Positive Feedback in Childbirth. Repetition of this cycle of events has a self-amplifying effect, intensifying labor contractions until the infant is born. This is one case in which positive feedback has a beneficial outcome.

- *Could childbirth as a whole be considered a negative feedback event? Discuss.*