Third Edition

Essentials of Anatomy & Physiology

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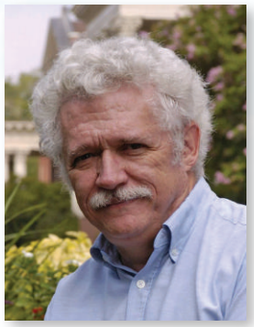
About the Authors



Tim Vacula

KENNETH S. SALADIN is Distinguished Professor of Biology, Emeritus, at Georgia College in Milledgeville, Georgia, where he taught from 1977 to 2017. Ken's courses included human anatomy and physiology, introductory medical physiology, histology, animal behavior, parasitology, and natural history of the Galápagos Islands. Ken is a member of the Human Anatomy and Physiology Society, American Physiological Society, American Association for Anatomy, Society for Integrative and Comparative Biology, and Textbook and Academic Authors Association. He is the author of the best-selling textbooks *Anatomy & Physiology: The Unity of Form and Function* and *Human Anatomy.* Ken's textbooks support several scholarships—as well as an endowed chair in biomedical science; an endowed annual lecture in science, medicine, and society; and ecosystem conservation in the Galápagos Islands.

©Robin McFarland

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Dedicated to the memory of my most important teacher and mentor, Donald R. Sly (1931–2019). *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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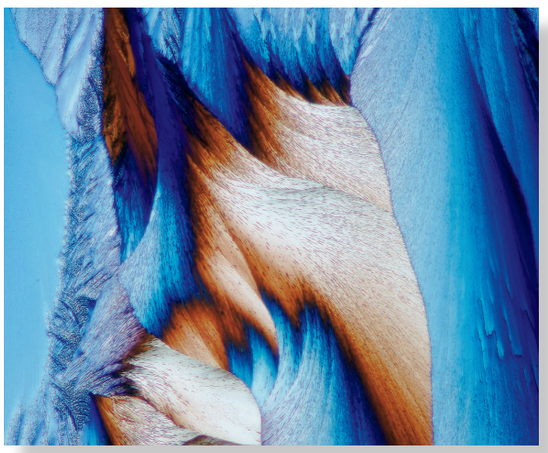

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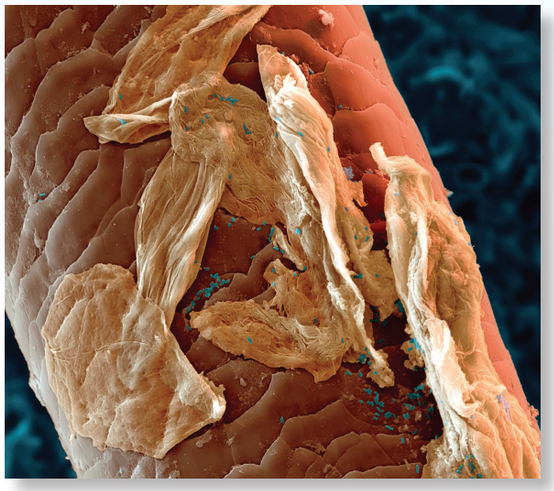

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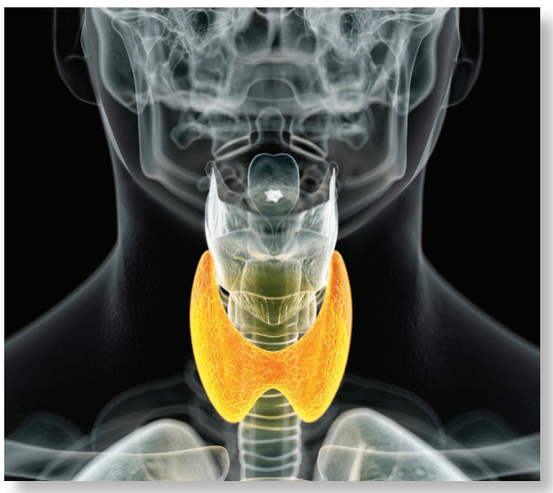

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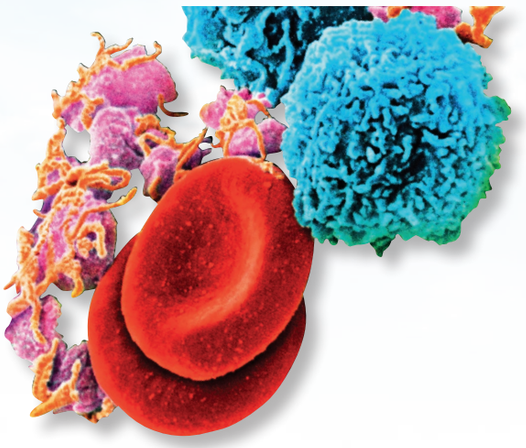

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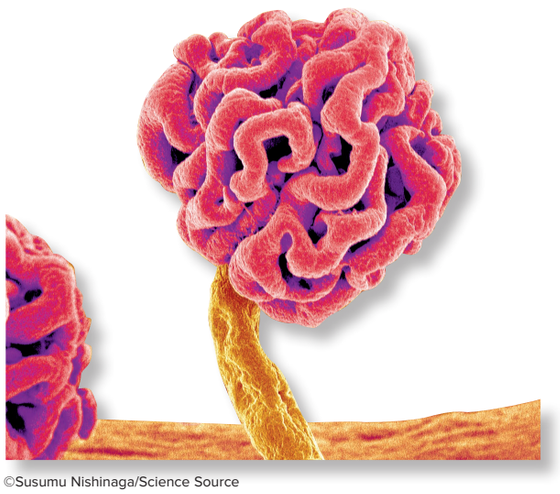

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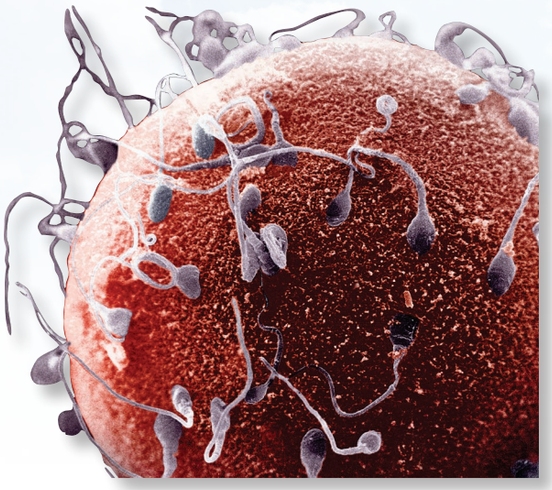

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Taking Anatomy & Physiology to New Heights

Audience

Essentials of Anatomy & Physiology, third 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.

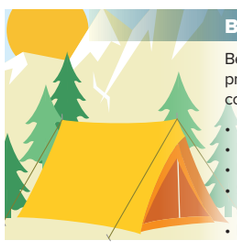
Theme

The goal of this book is to help students succeed. Like climbing a mountain, learning essentials of anatomy and physiology takes place one step at a time, and, similar to the feeling of exhilaration when one has arrived at a mountain peak, there is a powerful sense of achievement upon mastering the knowledge of anatomy and physiology. The mountain-climbing theme is echoed in visual and pedagogical features of the book. A base camp on the first page of each chapter lists key information students need to understand in preparation for navigating the chapter. Throughout the chapter, there are milestones that mark progress, such as the Before You Go On checkpoints with an image of a climber steadily moving upward. The study guide at the end of each chapter features a victorious climber on the summit, a celebration that mirrors the student's mastery of the chapter information.

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

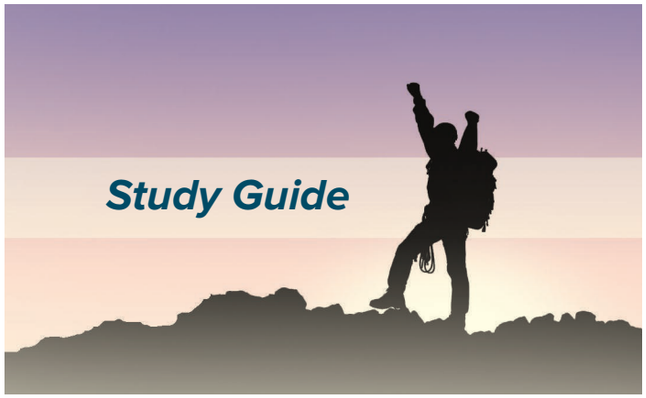
1. *Which term refers to all the cell contents between the plasma membrane and nucleus:* cytosol, cytoplasm, tissue fluid, *or* extracellular fluid?
2. *About how big would a cell have to be for you to see it without a microscope? Are any cells actually this big? If so, which ones?*
3. *Explain why cells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



BASE CAMP

Before ascending to the next level, be sure you're properly equipped with a knowledge of these concepts from earlier chapters.

- Thoracic cavity anatomy (see section 1.3e)
- Desmosomes and gap junctions (see section 3.2d)
- Muscle tissue (see section 4.4b)
- Skeletal muscle excitation and contraction (see section 7.2a)
- Resting membrane potentials and action potentials (see section 8.2a and b)



What's New in the Third Edition?

The new edition of *Essentials of Anatomy & Physiology* by Saladin and McFarland has been significantly updated. A hallmark of previous editions, according to both students and reviewers, is the exceptionally clear writing. In this new edition, we continue our commitment to students, with approachable language and relatable examples and analogies. We present current, solid scientific information. We have included numerous updates based on recent, peer-reviewed journal articles, as well as updated clinical examples and disease statistics. We have expanded discussions of health and disease to help students apply concepts of anatomy and physiology to their daily lives.

Updated Science and Enhanced Content

Some examples of updated or new scientific information, as well as enhanced anatomical and physiological concepts, follow:

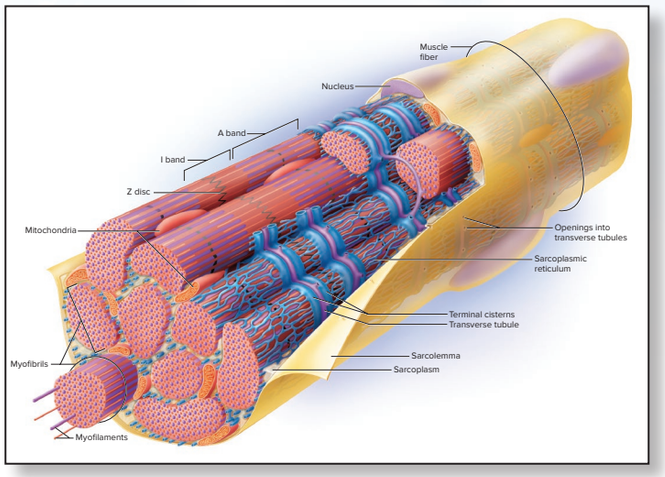
- Chapter 1—new information about use of PET scans to diagnose Alzheimer disease
- Chapter 3—updated discussion of genomic medicine; new summary table of features and functions of organelles
- Chapter 4—expanded discussion of epithelial functions; new research on brown and white fat and endocrine functions of adipose tissue; new Clinical Application and photo of diabetic foot ulcers; new information on regenerative medicine and stem cells
- Chapter 5—updates on pathology and immunotherapy of melanoma
- Chapter 6—updates on the endocrine function of bones and their widespread effects on the body; updates on functions of osteocytes; new Clinical Application on rickets
- Chapter 7—new information on causes of muscle fatigue; streamlined chapter by omitting minor muscles; expanded discussion of health benefits of exercise
- Chapter 8—expanded discussion of organization of the nervous system and added a figure; expanded discussion of functions of the nervous system; added table of functions of neuroglial cells; expanded explanation of myelin
- Chapter 9—new information on meningitis and traumatic brain injury; updates on the basal nuclei
- Chapter 10—added evolutionary perspectives on taste preference and present-day obesity and comparative, evolutionary perspectives on the sense of smell; new research on smell and Alzheimer disease and depression
- Chapter 11—new summary tables for pituitary gland hormones and hormones from other sources; updated discussion of oxytocin; added new information about leptin
- Chapter 12—new summary table of ABO blood group; updated discussion of research on gene therapy and sickle-cell disease
- Chapter 13—updates on the interaction between heart and brain; streamlined discussion of coronary circulation; updated blood pressure guidelines
- Chapter 14—expanded discussion of microbiome; new research about neutrophil extracellular traps
- Chapter 15—expanded discussion of surfactant and premature infants; new information about effects of e-cigarettes (vaping) and smoking marijuana on respiratory health; updated statistics regarding tobacco cigarette smoking
- Chapter 17—updates on enteric nervous system; updates on rotavirus vaccine and childhood mortality
- Chapter 18—updates on sugar consumption in the United States and obesity
- Chapter 19—new information about prostate cancer; new information on the role the fetus plays in initiating labor
- Chapter 20—added new information about the zica virus

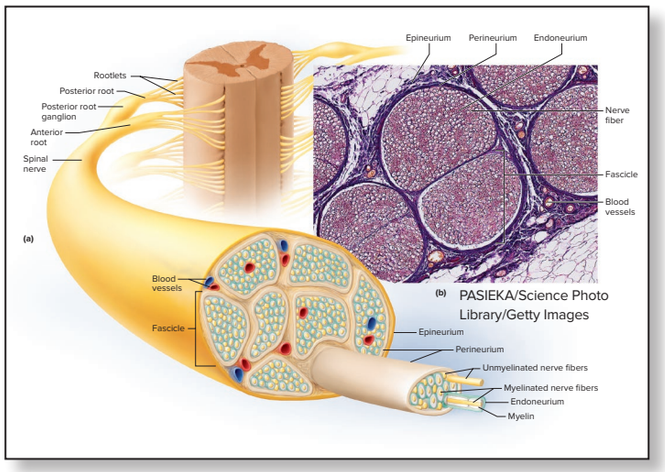
Making *Anatomy & Physiology* Intriguing and Inspiring

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.





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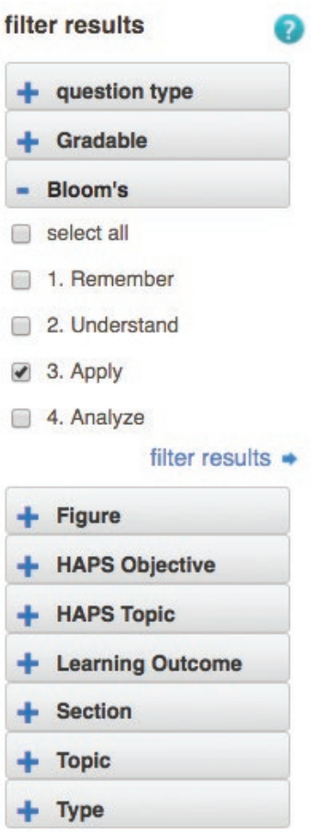
Cognitive Skill Building

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?
3. Name the action that would occur at each of the following joints in the indicated situation. (For example, the shoulder in picking up a suitcase. Answer: elevation.) (a) The arm when you raise it to rest your hand on the back of a sofa on which you're sitting. (b) Your neck when you look up at a plane in the sky. (c) Your tibia when you turn the toes of one foot to touch the heel of the other foot. (d) Your humerus when you reach up to scratch the back of your head. (e) A bowler's backswing. (f) A basketball player's foot as she makes a jump shot. (g) Your shoulder when you pull back on the oars of a rowboat. (h) Your elbow when lifting a barbell. (i) A soccer player's knee when kicking the ball. (j) Your index finger when dialing an old rotary telephone. (k) Your thumb when you pick up a tiny bead between your thumb and index finger.

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.

Assess Your Learning Outcomes

The parallel "Assess Your Learning Outcomes" at the end of each chapter provides a comprehensive overview of key points in the chapter. Study guide questions probe understanding of concepts and highlight for students what they need to review.

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.

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.

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

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

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. 8.11**). Action potentials do not travel; nerve signals do.

Stimulating Prose

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

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?

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.

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

1.4a Analyzing Medical Terms

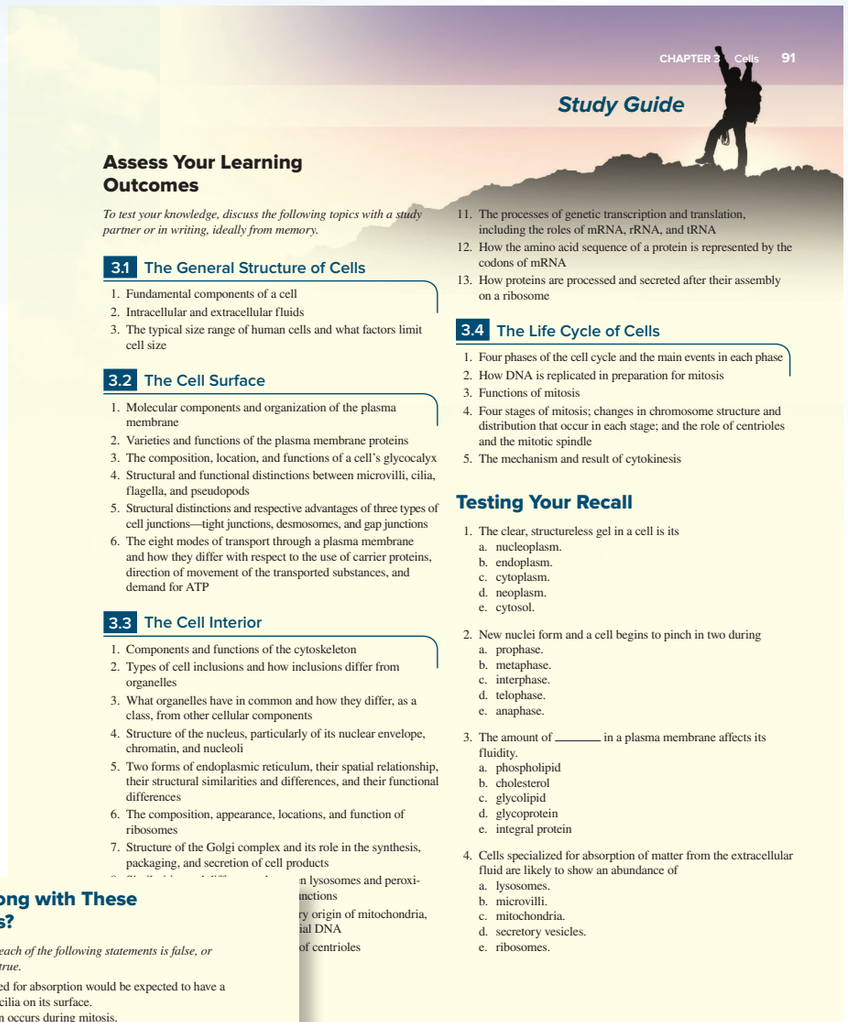
There is a simple trick to becoming more comfortable with the technical language of medicine. Those who, at first, find scientific terms confusing and difficult to pronounce, spell, and remember often feel more confident once they realize the logic of how such terms are composed. A term such as *hyponatremia* is less forbidding once we recognize 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-,* [illegible] at least partially understand hundreds

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.

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

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 to effectively reinforce the material. A student who masters these study guides should do well on an exam.



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
7. Structure of the Golgi complex and its role in the synthesis, packaging, and secretion of cell products

n lysosomes and peroxi-
inctions
ry origin of mitochondria,
ial DNA
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.
   c. mitochondria.
   d. secretory vesicles.
   e. ribosomes.

6. The word root *phago-* means
   a. eating.
   b. drinking.
   c. emitting fluid.
   d. intracellular.
   e. extracellular.
7. The amount of DNA in a cell doubles during
   a. prophase.
   b. metaphase.
   c. anaphase.
   d. the S phase.
   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.
13. _____ are channels in the plasma membrane that open or close in response to various stimuli.
14. Cells are somewhat protected from mechanical trauma by a carbohydrate surface coat called the _____.
15. The separation of chromatids from each other marks the _____ stage of mitosis.
16. The majority of molecules that compose the plasma membrane are _____.
17. Two human organelles that are surrounded by a double membrane are the _____ and _____.

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 the Golgi complex play similar roles in the synthesis of proteins.

Answers in Appendix A

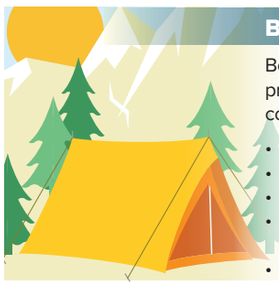
Testing Your Comprehension

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



BASE CAMP

Before ascending to the next level, be sure you're properly equipped with a knowledge of these concepts from earlier chapters.

- Thoracic cavity anatomy (see section 1.3e)
- Desmosomes and gap junctions (see section 3.2d)
- Muscle tissue (see section 4.4b)
- Skeletal muscle excitation and contraction (see section 7.2a)
- Resting membrane potentials and action potentials (see section 8.2a and b)

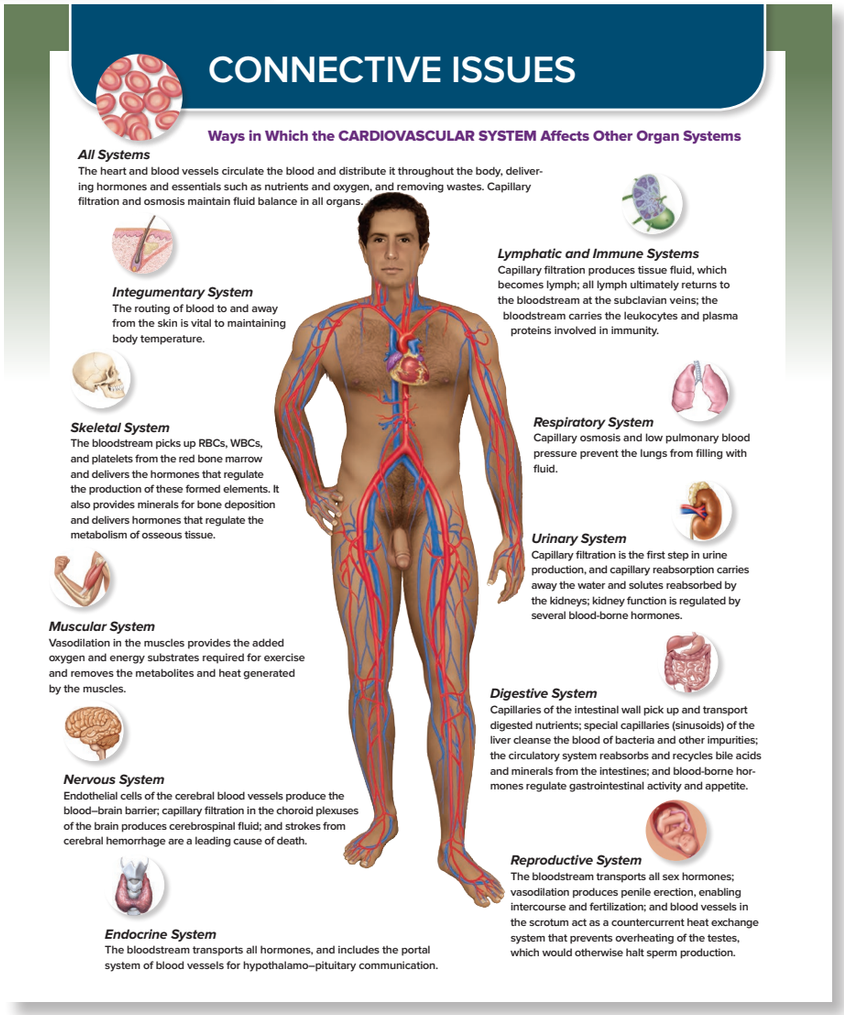
Tying It All Together

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.

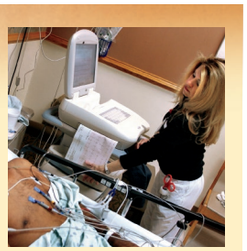


Career Spotlight

- "Career Spotlight" features provide a relevant career example in every chapter with basic information on educational requirements, 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



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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* (sometimes called the *rhythm 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 springy, often
inserted through the cervical canal into the
act by releasing a synthetic progesterone,
copper wire wrapping or copper sleeve. IU
ine lining and interfere with blastocyst impl
per IUDs also inhibit sperm motility. An IUD
for 5 to 12 years.

Aging of Body Systems

- "Aging of [Body Systems]" is a section within systems chapters 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

A common effect of aging is loss of muscle mass, and while the degree varies among individuals, everyone experiences some muscle atrophy and loss of strength with age. 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. Loss of muscle mass not only reduces mobility and ability to carry out normal daily tasks, but also increases the risk of obesity, cardiovascular disease, and type 2 diabetes. Fast-twitch muscle fibers show the earliest and greatest atrophy, resulting in increased reaction time, slower reflexes, and reduced coordination, meaning that tasks such as buttoning the clothes take more time and effort.

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 nerve supply. 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. Statistics indicate that less than a quarter of adults in the U.S. get the recommended amount of aerobic and strength-training exercise. The rising proportion of inactive adults and the associated high rates of obesity contribute to increased risk for several chronic, deadly diseases, including Alzheimer disease. Regular exercise, even if one starts late in life, counteracts these age-related diseases and improves overall quality of life.

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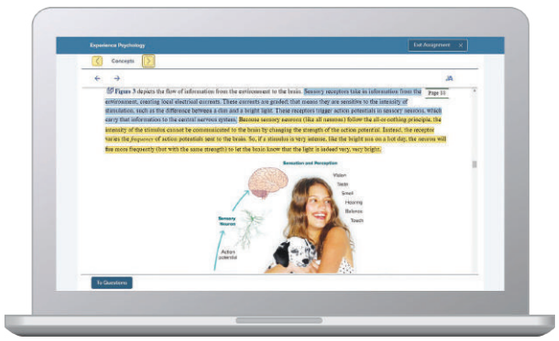

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Chapter 1

The Study of Anatomy and Physiology

Chapter Outline

1.1 Anatomy—The Structural Basis of Human Function
- 1.1a The Study of Anatomy
- 1.1b Examination of the Body
- 1.1c Techniques of Medical Imaging
- 1.1d Anatomical Variation

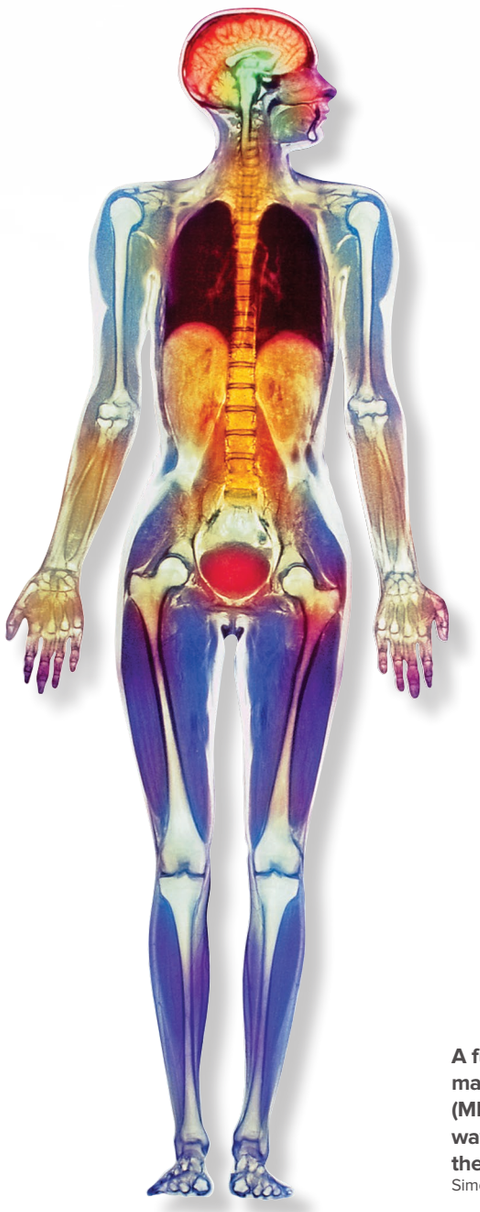
1.2 Physiology—Dynamic Processes in the Living Body
- 1.2a The Physiological Sciences
- 1.2b Essential Life Functions
- 1.2c Homeostasis and Feedback
- 1.2d Physiological Variation

1.3 The Human Body Plan
- 1.3a Levels of Human Structure
- 1.3b Anatomical Position
- 1.3c Anatomical Planes
- 1.3d Major Body Regions
- 1.3e Body Cavities and Membranes
- 1.3f Organ Systems

1.4 The Language of Medicine
- 1.4a Analyzing Medical Terms
- 1.4b Singular and Plural Forms
- 1.4c Directional Terminology

Clinical Applications/Perspectives on Health
- Clinical Application 1.1: Men in the Oven
- Clinical Application 1.2: Peritonitis
- Perspectives on Health

End of Chapter
- Career Spotlight: Radiologic Technologist
- Study Guide



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.
Simon Fraser/Science Source

Anatomy & Physiology Revealed 4.0 | **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 athletes, and we are curious about the 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 art are testaments to humanity's timeless quest 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.

1.1a The Study of Anatomy

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.

1.1b Examination of the Body

There are many ways to examine the body, the simplest of which is **inspection**—simply looking at the surface as physicians do during a physical examination. A deeper understanding depends on **dissection**[3]—carefully cutting and separating tissues to reveal relationships between structures. The word *anatomy*[4] literally means "cutting apart." Historically, the study of anatomy relied on dissections of dead human bodies, or **cadavers**,[5] to accurately map the human body. Cadaver dissection remains an essential part of the training of many health-science students.

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[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 the end of the chapter).

1.1c 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. Most exploratory surgery has been replaced by imaging techniques that allow physicians to see inside the body without cutting, posing much less risk to the patient. Medical imaging 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.

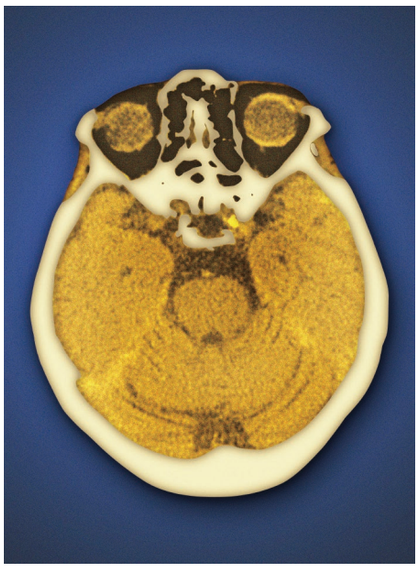
? *Why is a PET scan considered invasive, whereas MRI is noninvasive?*

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.

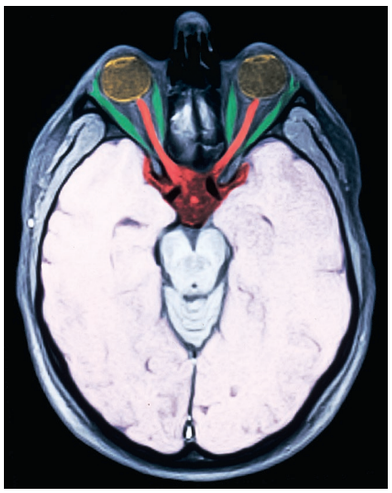
Computed tomography[8] (the **CT scan**) (fig. 1.1c) is a more sophisticated application of X-rays. The patient is moved through a ring-shaped machine that emits low-intensity X-rays on one side and receives them with a detector on the opposite side. A computer analyzes signals from the detector and 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 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 function. 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.

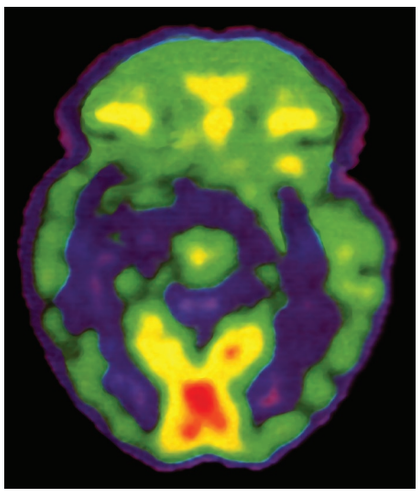
[8]*tomo* = section, cut, slice; *graphy* = recording process



(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. Because damaged tissue consumes little or no glucose, it appears dark. PET scans are widely used to diagnose cancer and evaluate tumor status. It is now possible to diagnose Alzheimer disease using PET scans. Until recently, a definitive diagnosis required analysis of brain tissue after death. Diagnosing living people with PET scans makes earlier diagnosis possible, potentially leading to more effective management of the disease. The PET scan is an example of **nuclear medicine**—the use of radioisotopes to treat disease or to form diagnostic images of the body.

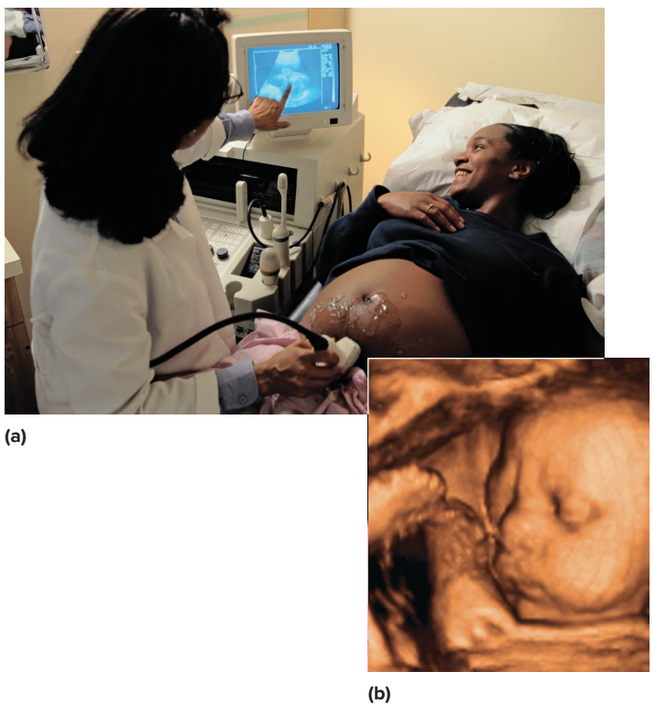
Sonography[9] (**fig. 1.2**) uses a handheld device placed firmly against the skin; it emits high-frequency ultrasound and receives signals reflected back from internal organs. Sonography avoids the harmful effects of X-rays, and the equipment is relatively inexpensive and portable. It also is very useful 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.

1.1d 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, but not everyone does. Most of us have one spleen, but some people have two. Most have two kidneys, but some have only one. **Figure 1.3** shows some common variations in human anatomy, and Perspectives on Health (in section 1.2) describes a particularly dramatic variation.

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



(a)

(b)

Figure 1.2 Sonography. (a) Producing a sonogram. (b) Three-dimensional sonogram of a fetus at 32 weeks of gestation.
a: Kevin Brofsky/Getty Images; **b:** ©Ken Saladin

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

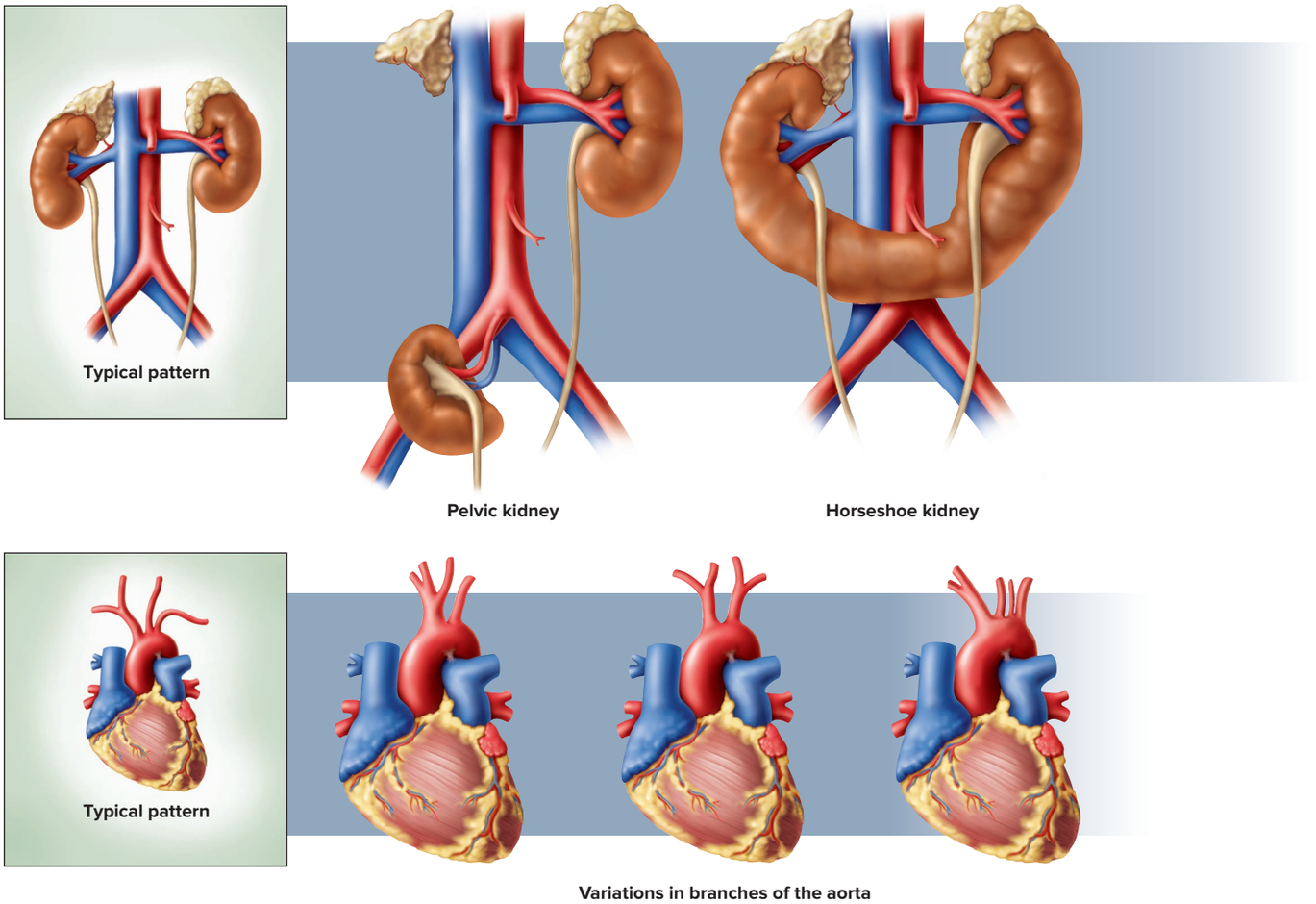


Figure 1.3 **Variations in Human Anatomy.** Not all humans have the usual "textbook structure."

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

1. *What is the difference between gross anatomy and histology?*
2. *In a routine physical examination, a physician might 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."

1.2a 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), and *pathophysiology* (mechanisms of disease). Partly because of limitations on experimentation with humans, much of what we know about how the body functions is from studies of **comparative physiology** that explore 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, new drugs are tested for safety in laboratory mammals such as rats before proceeding to trials with human subjects.

1.2b 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.

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.

[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 might be located low in the pelvic cavity instead of high in the abdominal cavity (see fig. 1.3), or a parathyroid gland might 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.

- **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 body. Although you sense a continuity of personality and experience from

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

your childhood to the present, nearly every molecule of your body has been replaced within the past year.

- **Development.** Development is any change in form or function over the lifetime of the organism. It involves two major processes: (1) **differentiation,** the transformation of cells with no specialized function to ones that are committed to a particular task; and (2) **growth,** an increase in size. Some nonliving things grow, but not in the way your body does. If you let a sugar solution evaporate, crystals will grow from it, but not through a change in the composition of the sugar. Sugar molecules are simply added 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.
- **Excitability.** The ability to sense and react to *stimuli* (changes in the 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 section 1.2c.
- **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.

1.2c Homeostasis and Feedback

The quality of life 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.

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

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

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 fail.

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 might 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, the effector 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.

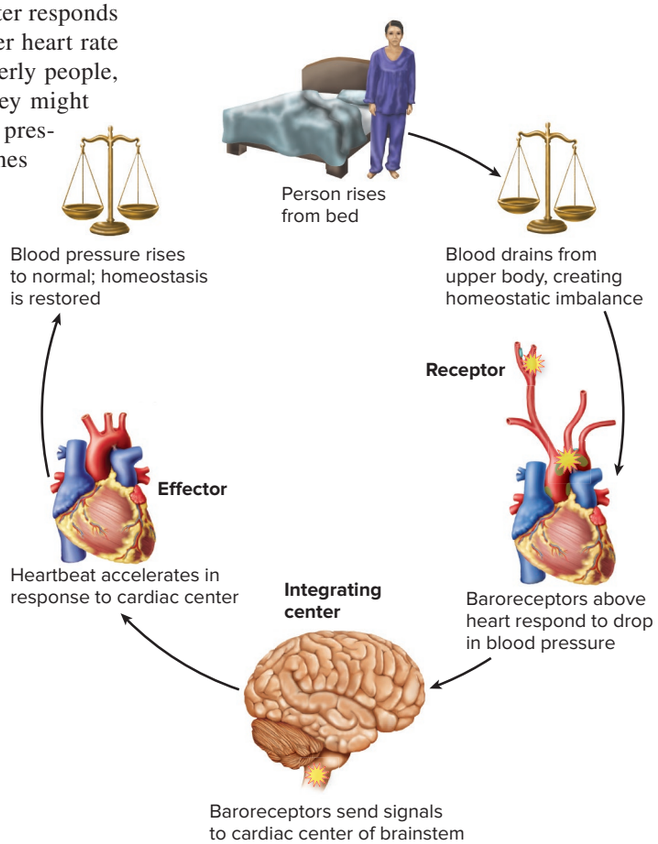


Figure 1.4 Negative Feedback in Response to Drop in Blood Pressure.

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 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 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 40°C (104°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.

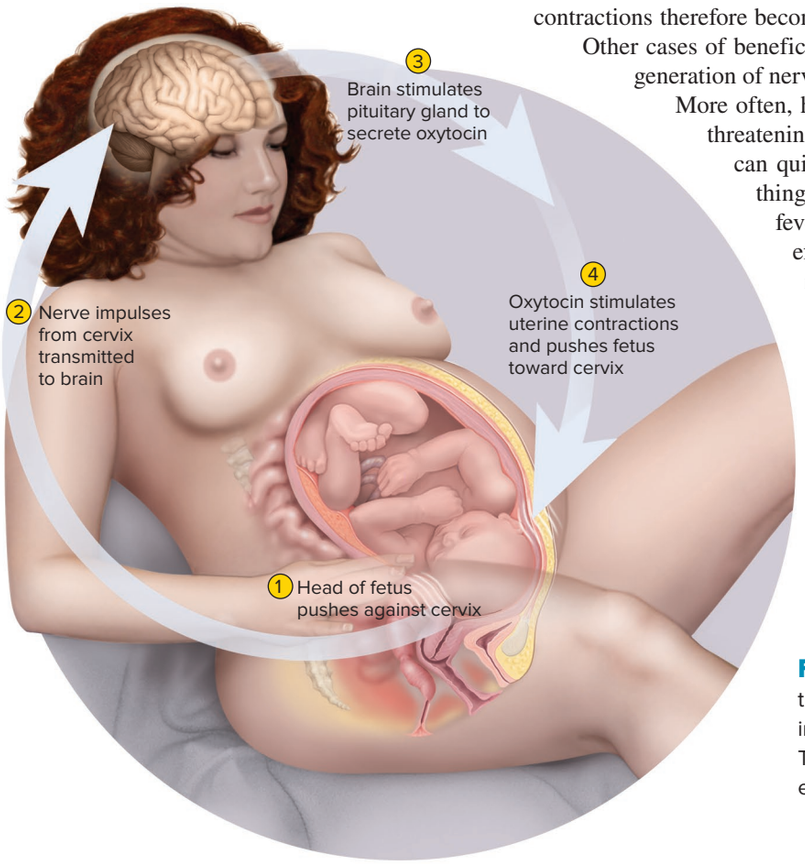


Figure 1.5 Positive Feedback in Childbirth. Repetition of this cycle of events has a self-amplifying effect, intensifying labor contractions until the infant is born. This is one case in which positive feedback has a beneficial outcome.

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

Apply What You Know

In a heart attack, the death of cardiac muscle reduces the heart's pumping effectiveness. Thus, blood flow throughout the body slows down. This leads to widespread blood clotting. Blood clots block the flow of blood to the cardiac muscle, so the muscle is less nourished and still more of it dies. Is this positive feedback, negative feedback, or neither? Explain.

1.2d Physiological Variation

Earlier we considered the clinical importance of variations in human anatomy, but physiology is even more variable. Physiological variables differ with sex, age, weight, diet, degree of physical activity, and environment, among other things. If an introductory textbook states a typical human heart rate, blood pressure, red blood cell count, or body temperature, it is generally assumed that such values are for a healthy young adult unless otherwise stated. Health-care professionals take sex and age into account when they perform medical assessments and determine drug dosages, for example. Failure to do so can lead to medical mistakes such as overmedication of the elderly or medicating women on the basis of research that was done on men.

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

4. *What is the difference between growth and development?*
5. *Explain why positive feedback is likely to cause a loss of homeostasis, and why negative feedback can restore homeostasis.*
6. *Why is it better to define* homeostasis *as a dynamic equilibrium than to define it as a state of internal constancy?*

1.3 The Human Body Plan

Expected Learning Outcomes

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

a. list the levels of human complexity in order from the whole organism down to atoms;
b. define or demonstrate the *anatomical position* and explain its importance in descriptive anatomy;
c. define the three major anatomical planes of the body;
d. identify the major anatomical regions of the body;
e. describe the body's cavities and the membranes that line them; and
f. name the 11 organ systems, their principal organs, and their functions.

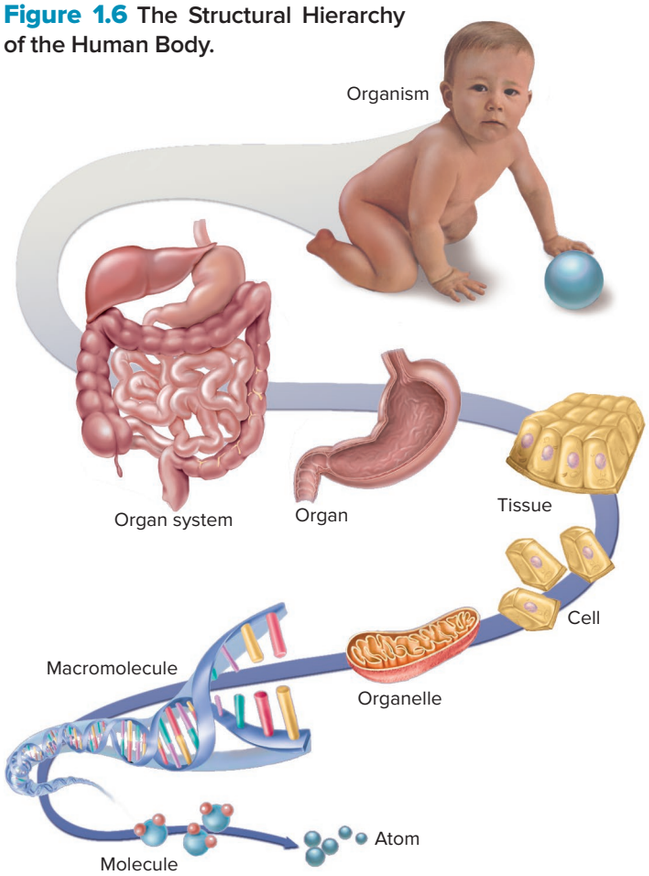
This section gives a broad overview of the structural organization of the human body, providing a vocabulary and a context for the study of specific regions and organ systems in the chapters to follow. We also preview the major organs and functions of the body's 11 organ systems.

1.3a Levels of Human Structure

The human body is organized into levels ranging from the whole organism to atoms and molecules. Consider for a moment this analogy: The English language, like the human body, is very complex, yet an infinite variety of ideas can be conveyed with a limited number of words. All words in the English language are, in turn, composed of various combinations of just 26 letters. Between an essay and the alphabet are successively simpler levels of organization: paragraphs, sentences, words, and syllables. Humans have an analogous hierarchy of complexity (**fig. 1.6**), as follows:

The organism is composed of organ systems,
organ systems are composed of organs,
organs are composed of tissues,
tissues are composed of cells,
cells are composed (in part) of organelles,
organelles are composed of molecules, and
molecules are composed of atoms.

Figure 1.6 The Structural Hierarchy of the Human Body.



The **organism** is a single, complete individual.

An **organ system** is a group of organs that carry out a basic function such as circulation, respiration, or digestion. The human body has 11 organ systems, defined and illustrated later in this chapter. Usually, the organs of a system are physically interconnected, such as the esophagus, stomach, small intestine, and large intestine that form the digestive system.

An **organ** is a structure composed of two or more tissue types that work together to carry out a particular function. Organs have definite anatomical boundaries and are visibly distinguishable from adjacent structures. They include not only what people traditionally think of as the "internal organs," such as the heart and kidneys, but less obvious examples such as the skin, muscles, and bones. Most familiar organs are visible to the naked eye. However, there are organs within organs—the large organs contain smaller organs, some of which are microscopic. The skin, for example, is the body's largest organ. Included within it are thousands of smaller organs: hair follicles, nails, sweat glands, nerves, and blood vessels.

A **tissue** is a group of similar cells and cell products that forms a discrete region of an organ and performs a specific function. The body is composed of only four primary classes of tissue—epithelial, connective, nervous, and muscular tissues. *Histology,* the study of tissues, is the subject of chapter 4.

Cells are the smallest units of an organism that carry out all the basic functions of life; nothing simpler than a cell is considered alive. A cell is a microscopic compartment enclosed in a film called the *plasma membrane.* It usually contains one nucleus and a variety of other organelles. *Cytology,* the study of cells, is the subject of chapter 3.

Organelles[13] are microscopic structures that carry out a cell's individual functions. Examples include nuclei, mitochondria, centrioles, and lysosomes.

[13] *elle* = little

Organelles and other cellular components are composed of **molecules.** A molecule is a particle composed of at least two **atoms.** Atoms and molecules are described in chapter 2.

1.3b Anatomical Position

In describing the human body, anatomists assume that it is in **anatomical position** (fig. 1.7)—that of a person standing upright with the feet flat on the floor, arms at the sides, and the palms and face directed toward the observer. Without such a frame of reference, to say that a structure such as the sternum or thyroid gland is "above the heart" would be vague, because it would depend on whether the subject was standing, lying face down *(prone),* or lying face up *(supine).* From the perspective of anatomical position, however, we can describe the thyroid gland as *superior* to the heart, and the sternum as *anterior (ventral)* to it. These descriptions remain valid regardless of the subject's position.

Unless stated otherwise, assume that all anatomical descriptions refer to anatomical position. Bear in mind that if a subject is facing you in anatomical position, the subject's left will be on your right and vice versa. In most anatomical illustrations, for example, the appendix appears on the left side of the page, though it is located on the right side of the abdomen.

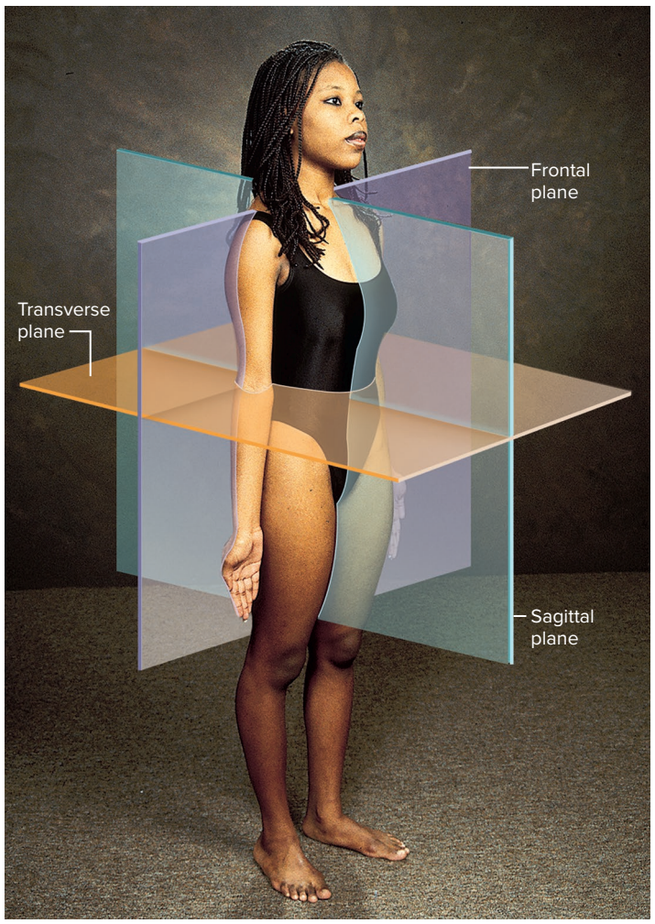


Figure 1.7 Anatomical Position and Planes of Reference.
Ken Saladin/Joe DeGrandis, photographer

1.3c Anatomical Planes

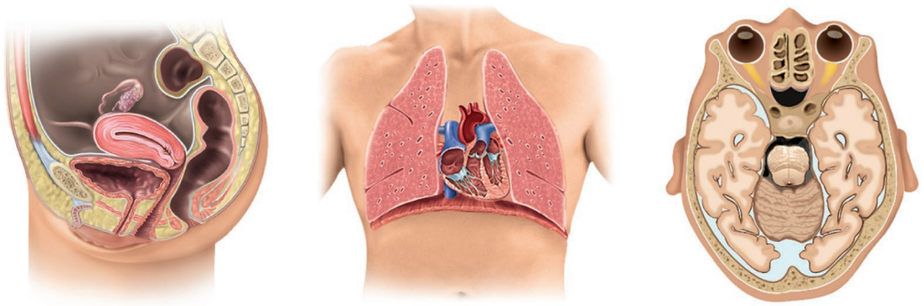
Many views of the body are based on real or imaginary "slices" called sections or planes. *Section* implies an actual cut or slice to reveal internal anatomy, whereas *plane* implies an imaginary flat surface passing through the body. The three major anatomical planes are *sagittal, frontal,* and *transverse* (fig. 1.7).

A **sagittal**[14] **plane** (SADJ-ih-tul) extends vertically and divides the body or an organ into right and left portions. The **median (midsagittal) plane** passes through the midline of the body and divides it into *equal* right and left halves. Other planes parallel to this but off-center are called *parasagittal*[15] *planes* and divide the body into unequal right and left portions. The head and pelvic organs are commonly illustrated on the median plane (fig. 1.8a).

A **frontal (coronal**[16]**) plane** also extends vertically, but it is perpendicular to the sagittal plane and divides the body into anterior (front) and posterior (back) portions. A frontal section of the head, for example, would divide it into one portion bearing the face and another bearing the back of the head. Contents of the thoracic and abdominal cavities are commonly shown in frontal section (fig. 1.8b).

A **transverse (horizontal) plane** passes across the body or an organ perpendicular to its long axis; therefore, it divides the body or organ into superior (upper) and inferior (lower) portions. Many CT and MRI scans are transverse sections (fig. 1.8c; see also fig. 1.1c–e).

[14] *sagitta* = arrow
[15] *para* = next to
[16] *corona* = crown; *al* = like



(a) Sagittal section (b) Frontal section (c) Transverse section

Figure 1.8 Sections of the Body in the Three Primary Anatomical Planes. (a) Sagittal section of the pelvic region. (b) Frontal section of the thoracic region. (c) Transverse section of the head at the level of the eyes.

1.3d Major Body Regions

Knowledge of the external anatomy and landmarks of the body is important in performing a physical examination, reporting patient complaints, and many other clinical procedures. The body is divided into two major regions called the *axial* and *appendicular regions,* each with many smaller regions.

The **axial region** consists of the **head, neck (cervical**[17] **region),** and **trunk.** The trunk is further divided into the **thoracic region** above the diaphragm and the **abdominal** and **pelvic regions** below it.

One way of referring to the locations of abdominopelvic structures is to divide the region into quadrants. Two perpendicular lines intersecting at the umbilicus (navel) divide the area into a **right upper quadrant (RUQ), right lower quadrant (RLQ), left upper quadrant (LUQ),** and **left lower quadrant (LLQ)** (**fig. 1.9a, b**). The quadrant scheme is often used to describe the site of an abdominal pain or abnormality.

[17] *cervic* = neck

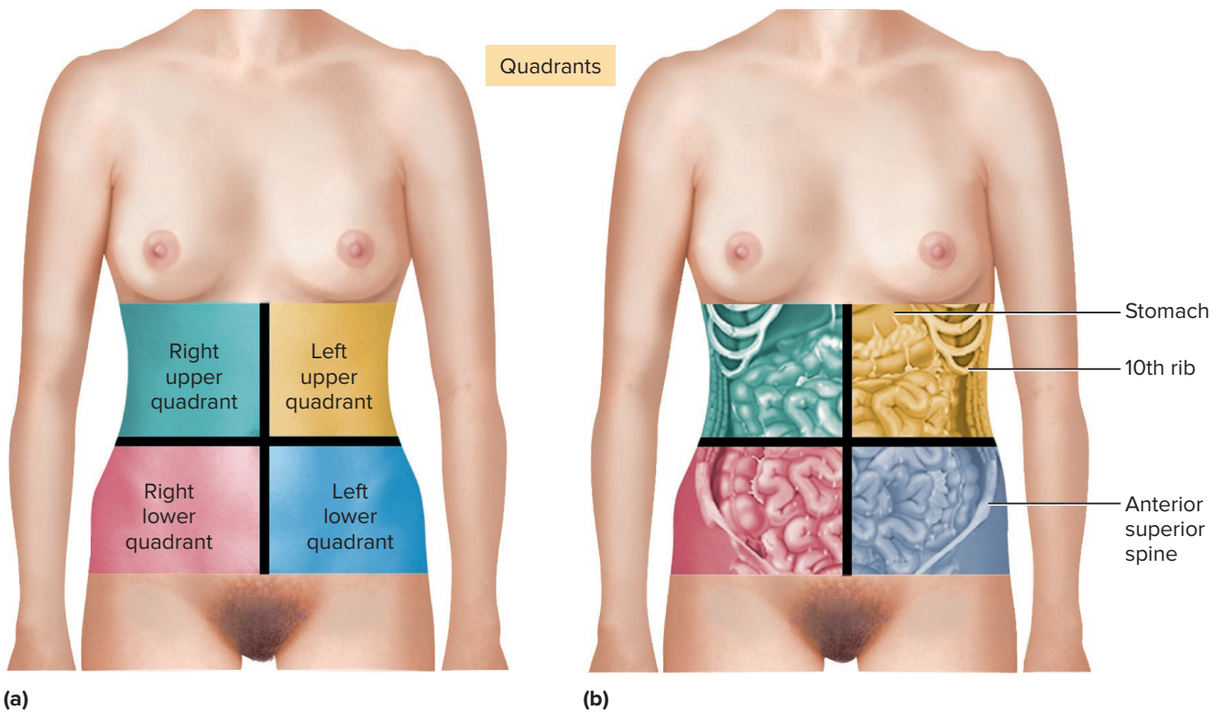


Figure 1.9 Quadrants of the Abdominopelvic Region. (a) The four quadrants of the abdominopelvic region. (b) Internal anatomy correlated with the four quadrants. APR

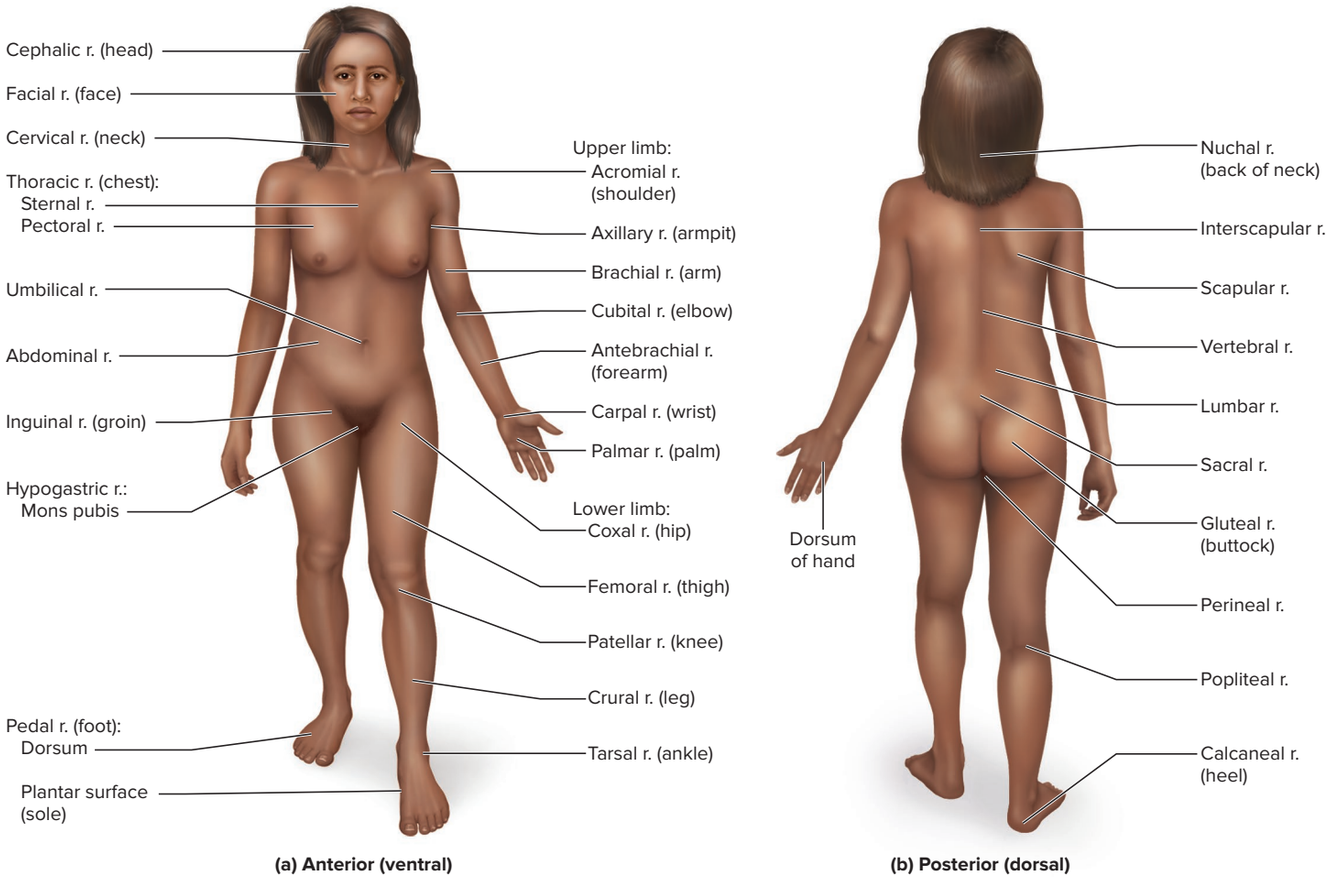


Figure 1.10 External Body Regions (r. = region). APR

The **appendicular region** (AP-en-DIC-you-lur) of the body consists of the upper and lower limbs (also called *appendages* or *extremities*). The **upper limb** includes the **arm (brachial region)** (BRAY-kee-ul), **forearm (antebrachial**[18] **region**) (AN-teh-BRAY-kee-ul), **wrist (carpal region), hand,** and **fingers (digits).** The lower limb includes the **thigh (femoral region), leg (crural region), ankle (tarsal region), foot,** and **toes (digits).** In strict anatomical terms, *arm* refers only to that part of the upper limb between the shoulder and elbow. *Leg* refers only to that part of the lower limb between the knee and ankle. **Figure 1.10** identifies several smaller body regions.

A **segment** of a limb is a region between one joint and the next. The arm, for example, is the segment between the shoulder and elbow joints, and the forearm is the segment between the elbow and wrist joints. When you flex your fingers, you can easily see that your thumb has two segments (proximal and distal—terms defined in table 1.3), whereas the other four digits have three segments (proximal, middle, and distal). The segment concept is especially useful in describing the locations of bones and muscles and the movements of the joints.

[18] *ante* = fore, before; *brachi* = arm

Table 1.1 Body Cavities and Membranes

Name of Cavity	Principal Viscera	Serous Membranes
Cranial Cavity	Brain	Meninges
Vertebral Canal	Spinal cord	Meninges
Thoracic Cavity		
Pleural cavities (2)	Lungs	Pleurae
Pericardial cavity	Heart	Pericardium
Abdominopelvic Cavity		
Abdominal cavity	Digestive organs, spleen, kidneys	Peritoneum
Pelvic cavity	Bladder, rectum, reproductive organs	Peritoneum

1.3e Body Cavities and Membranes

The axial region of the body has cavities containing the "internal organs" or **viscera** (VISS-er-uh) (singular, *viscus*[19]) (table 1.1). These cavities are lined by thin **serous membranes,** which secrete a lubricating film of moisture similar to blood serum (hence the name *serous*). These membranes are distinct from the mucous membranes that line the digestive, respiratory, urinary, and reproductive tracts—passages open to the exterior. Serous and mucous membranes are further described in chapter 4.

The **cranial cavity** (CRAY-nee-ul) is enclosed by the skull and contains the brain. The **vertebral canal,** continuous with the cranial cavity, is a space about as wide as your finger that passes down the vertebral column (spine) (fig. 1.11a). Both of these cavities are lined by three membranes called **meninges** (meh-NIN-jeez). Among other functions, they protect the delicate nervous tissue from the hard protective bone that encloses it. The meninges are discussed in more detail in chapter 9.

A muscular sheet, the **diaphragm,** separates the **thoracic cavity** above it from the **abdominopelvic cavity** below. The thoracic cavity is additionally divided into right, left, and median portions by a partition called the **mediastinum**[20] (ME-dee-ah-STY-num) (fig. 1.11b). The mediastinum is the region between the lungs extending from the base of the neck to the diaphragm. It contains the esophagus, trachea, and the heart and major blood vessels attached to it. The heart is enveloped by a two-layered serous membrane called the **pericardium.**[21] The anatomy of the pericardium and its relationship with the heart are further described in chapter 13. The right and left sides of the thoracic cavity contain the lungs, which are each enfolded in another two-layered serous membrane, the **pleura**[22] (PLOOR-uh) (plural, *pleurae*). The anatomy of the pleurae and their relationship with the lungs are detailed in chapter 15.

The abdominopelvic cavity can be subdivided into the **abdominal cavity** and **pelvic cavity,** although the two form one continuous space; they are not separated by a wall the way the abdominal and thoracic cavities are separated by the diaphragm. The dividing line between them is the margin of the pelvic inlet (see fig. 6.30a in section 6.4). The abdominal cavity contains most of the digestive organs, as well as the spleen, kidneys, and ureters. The pelvic cavity is markedly narrower and its lower end tilts posteriorly (fig. 1.11a). It contains the lowermost portion of the large intestine, the urinary bladder and urethra, and the reproductive organs.

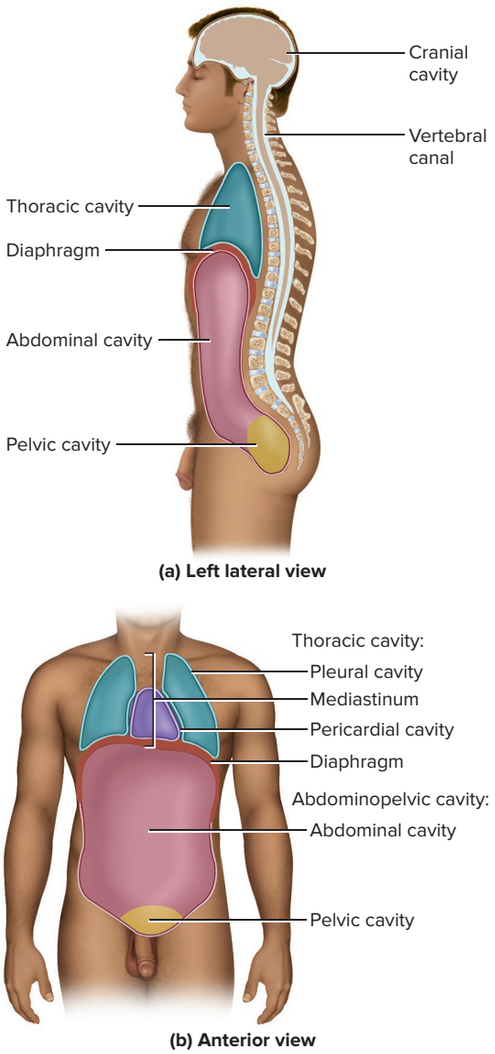
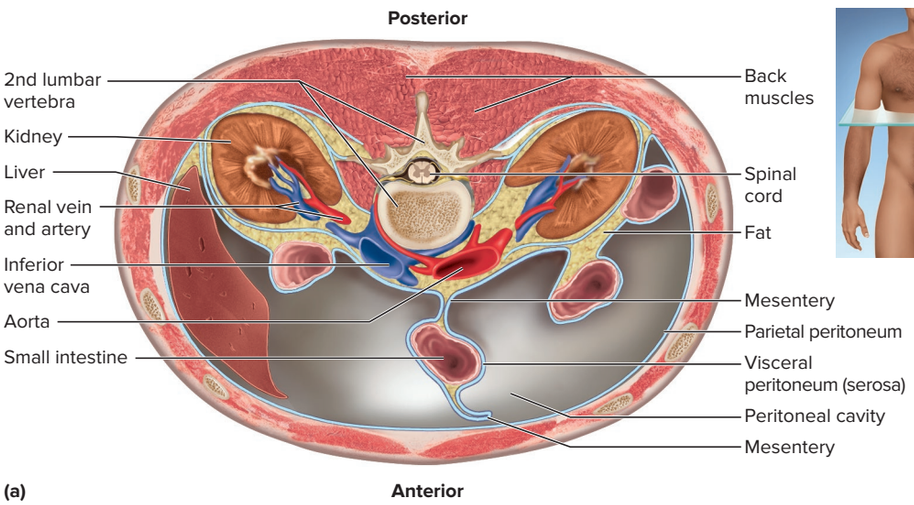


Figure 1.11 The Major Body Cavities. APR

[19] *viscus* = body organ
[20] *mediastinum* = in the middle
[21] *peri* = around; *cardi* = heart
[22] *pleur* = rib, side

The abdominopelvic cavity is lined by a two-layered serous membrane called the **peritoneum**[23] (PERR-ih-toe-NEE-um). The outer layer, lining the abdominal wall, is called the *parietal peritoneum.* Along the posterior midline of the abdominal wall, it turns inward and becomes another layer, the *visceral peritoneum,* suspending certain abdominal viscera from the body wall and covering their outer surfaces (**fig. 1.12**). The space between the parietal and visceral peritoneum is called the **peritoneal cavity.** The visceral peritoneum is also called a **mesentery**[24] (MESS-en-tare-ee) at points where

[23] *peri* = around; *tone* = stretched
[24] *mes* = in the middle; *enter* = intestine



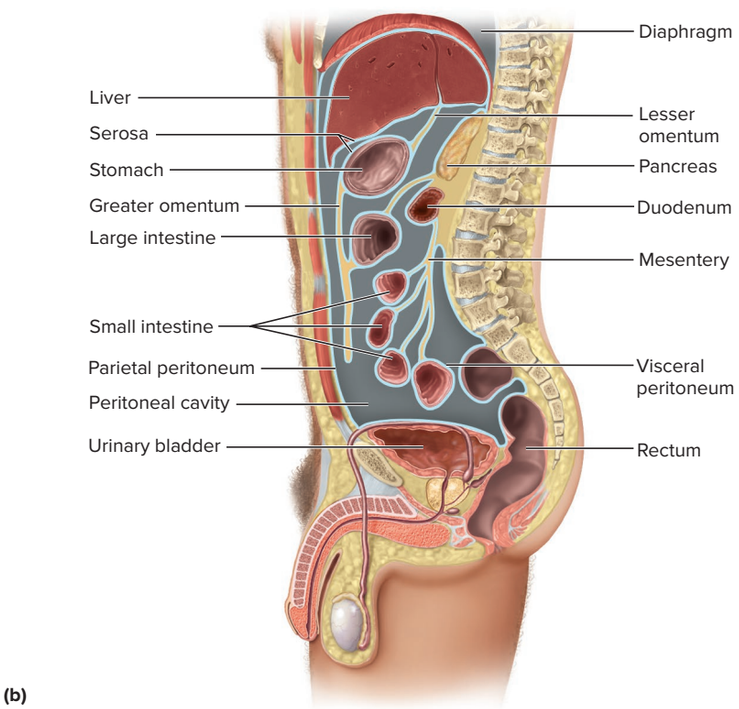


Figure 1.12 The Peritoneal Cavity and Retroperitoneal Organs. (a) Cross section at the upper abdominal level shown in the figure on the right. The gray space is the peritoneal cavity (with most organs omitted), enclosed in peritoneum (the thin blue line). Note that the peritoneum forms the outer layer (serosa) of some viscera. Viscera toward the top of the figure (kidneys, inferior vena cava, aorta) are in the abdominal cavity but not in the peritoneal cavity; they are retroperitoneal. The intestine and liver are intraperitoneal. (b) Left lateral view showing abdominal viscera suspended by mesenteries from the body wall. APR

Clinical Application 1.2

PERITONITIS

Peritonitis is inflammation of the peritoneum. It is a critical, life-threatening condition necessitating prompt treatment. The most serious cause of peritonitis is a perforation in the digestive tract, such as an abdominal bullet wound or a ruptured appendix. Digestive juices cause immediate chemical inflammation of the peritoneum, followed by microbial inflammation as intestinal bacteria invade the body cavity. Anything that perforates the abdominal wall can also lead to peritonitis, such as abdominal trauma or surgery. So, too, can free blood in the abdominal cavity, as from a ruptured aneurysm (a weak point in a blood vessel) or ectopic pregnancy (implantation of an embryo anywhere other than the uterus); blood itself is a chemical irritant to the peritoneum. Peritonitis tends to shift fluid from the circulation into the abdominal cavity. Death can follow within a few days from severe electrolyte imbalance, respiratory distress, kidney failure, and a widespread blood clotting called disseminated intravascular coagulation.

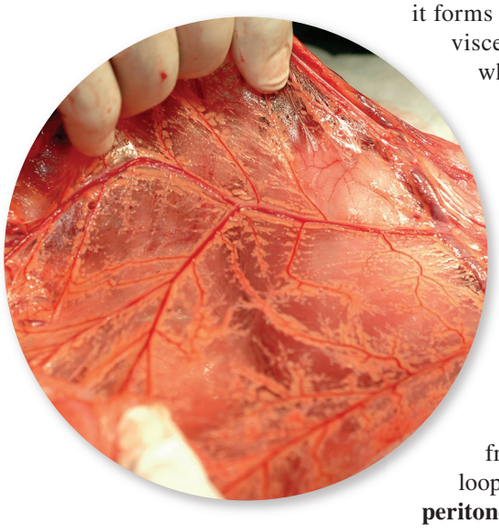


Figure 1.13 Mesentery. This is a translucent serous membrane associated with the small intestine and other abdominal organs. Mesenteries contain blood vessels, lymphatic vessels, and nerves supplying the viscera.

MedicImage/Universal Images Group/Getty Images

it forms a membranous curtain suspending and anchoring the viscera (fig. 1.13), and a **serosa** (seer-OH-sa) at points where it enfolds and covers the outer surfaces of organs such as the stomach and small intestine. These relationships of the peritoneum, serosa, and peritoneal cavity with the abdominal digestive organs are detailed in chapter 17.

Some organs of the abdominal cavity lie against the posterior body wall and are covered by peritoneum only on the side facing the peritoneal cavity. They are said to have a **retroperitoneal**[25] position. Examples include the kidneys, aorta, and inferior vena cava, as shown in figure 1.12a and the duodenum and pancreas, as shown in figure 1.12b. Organs that are encircled by peritoneum and suspended from the posterior body wall by mesenteries, such as the loops of small intestine shown in those figures, are **intraperitoneal.**[26]

1.3f Organ Systems

The human body has 11 organ systems (fig. 1.14) and an immune system, which is better described as a population of cells that inhabit multiple organs rather than as an organ system. These systems are classified in the following list by their principal functions, but this is an unavoidably flawed classification. Some organs belong to two or more systems—for example, the male urethra is part of both the urinary and reproductive systems; the pancreas is part of the digestive and endocrine systems; and the mammary glands can be considered part of the integumentary and female reproductive systems.

[25] *retro* = behind
[26] *intra* = within

The human organ systems

Systems of protection, support, and movement
- Integumentary system
- Skeletal system
- Muscular system

Systems of internal communication and integration
- Nervous system
- Endocrine system

Systems of fluid transport
- Circulatory system
- Lymphatic system

Systems of intake and output
- Respiratory system
- Urinary system
- Digestive system

Systems of reproduction
- Male reproductive system
- Female reproductive system

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

7. *Rearrange the following alphabetical list in order from the largest, most complex components of the body to the smallest, simplest ones: cells, molecules, organelles, organs, organ systems, tissues.*
8. *Examine figures 1.1 and 1.12 and identify whether each figure shows the body on a frontal, sagittal, or transverse plane.*
9. *Identify each of the following regions as belonging to the upper limb, lower limb, or axial region of the body: cubital, pectoral, gluteal, antebrachial, calcaneal, patellar, nuchal, thoracic, and left upper quadrant.*
10. *Name the body cavity in which each of the following viscera is found: spinal cord, liver, lung, spleen, heart, pancreas, gallbladder, and kidney.*

1.4 The Language of Medicine

Expected Learning Outcomes

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

a. explain why precision is important in the use of medical terms;
b. demonstrate how to break medical terms into their roots, prefixes, and suffixes;
c. identify the relationships between singular and plural forms of a medical term; and
d. define directional terms for the locations of anatomical structures relative to each other.

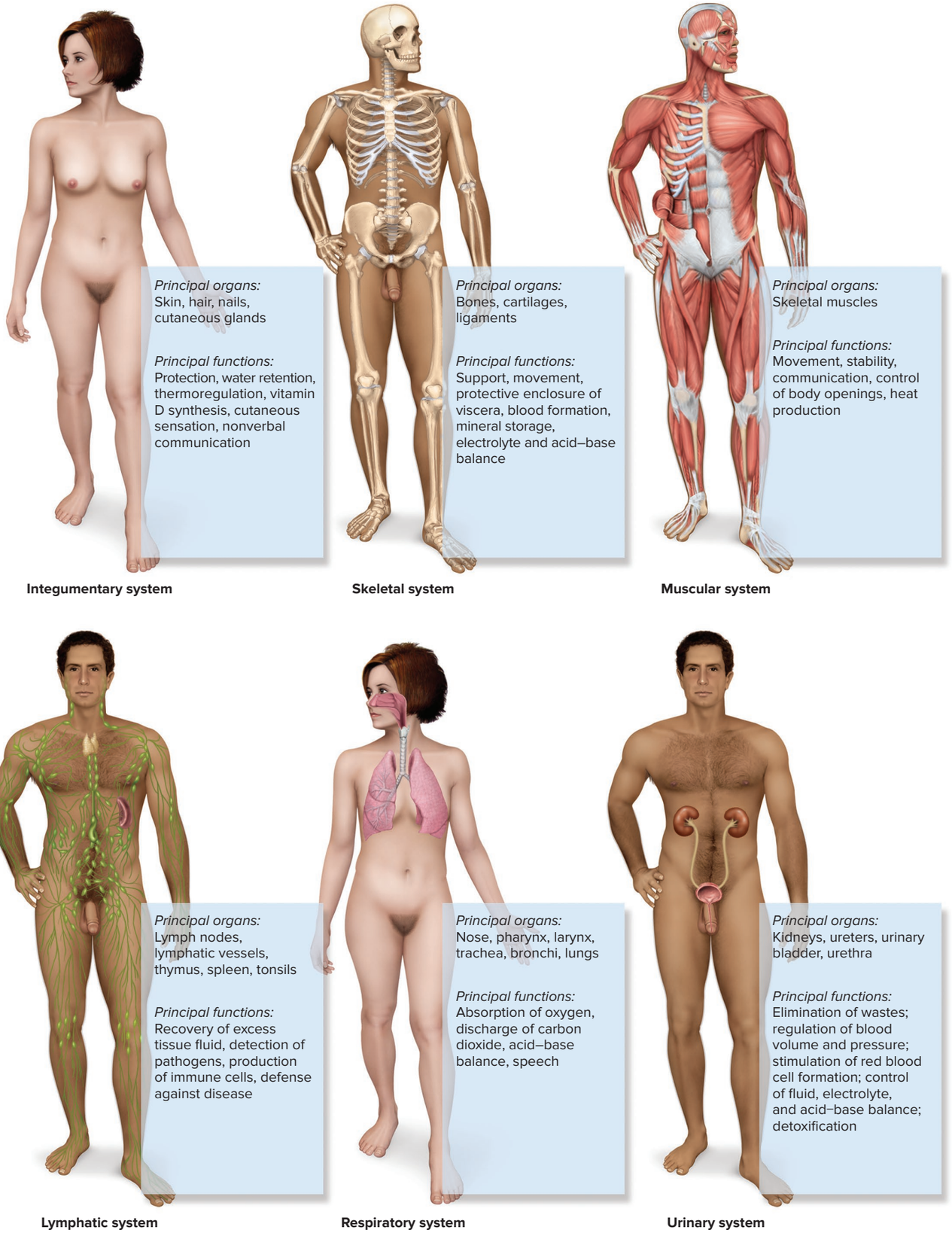


Figure 1.14 The Human Organ Systems.

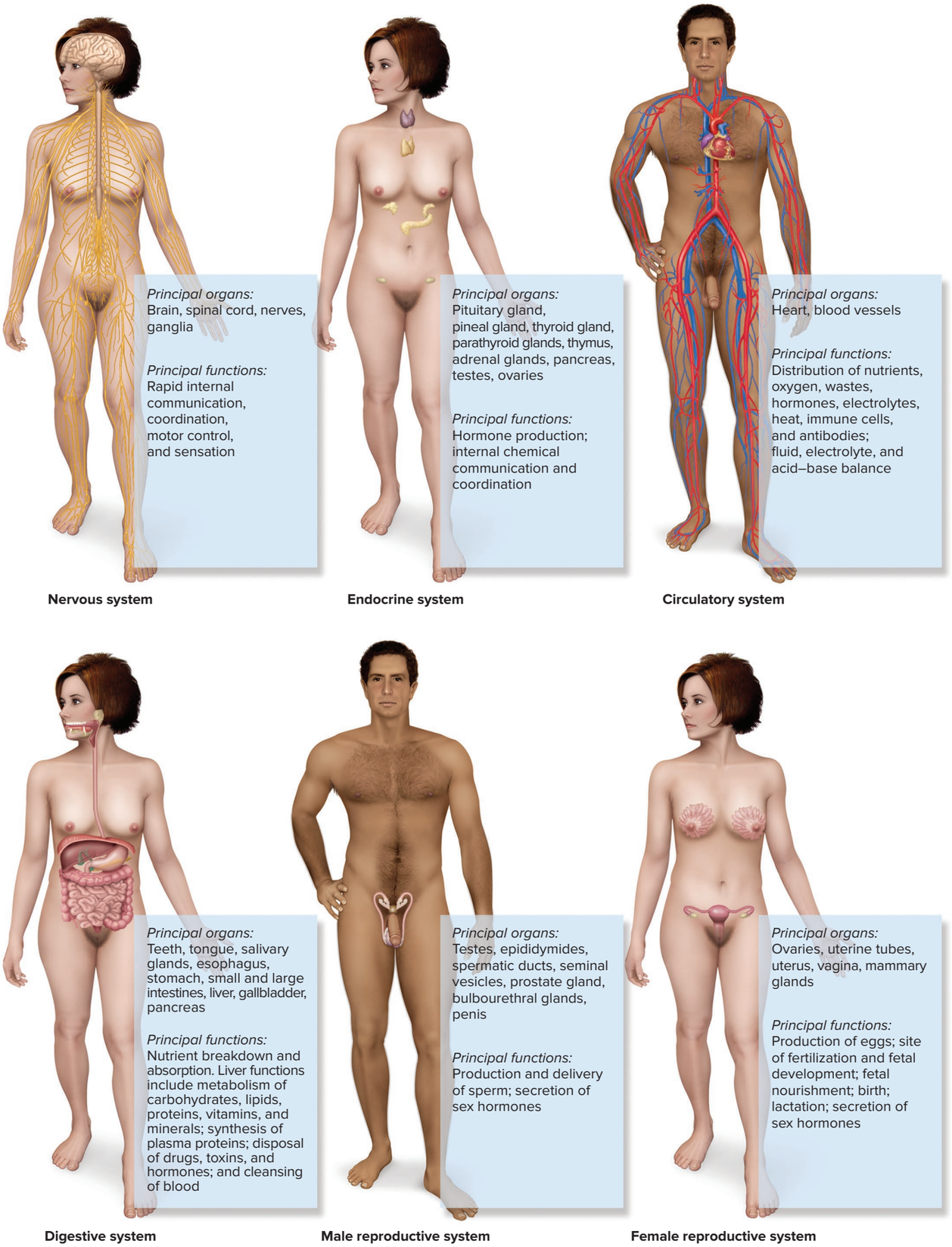


Figure 1.14 The Human Organ Systems (*continued*).

One of the greatest challenges faced by students of anatomy and physiology is the vocabulary. In this book, you will encounter such Latin terms as *corpus callosum* (a brain structure) and *extensor carpi radialis longus* (a forearm muscle). You might wonder why structures aren't called by more common names that everyone can understand, and how you will ever remember such formidable terms. This section will give you some answers to these questions and some useful tips on mastering anatomical terminology.

It is of greatest importance to use medical terms precisely. It may seem trivial if you misspell *trapezius* as *trapezium,* but in doing so, you would be changing the name of a back muscle to the name of a wrist bone. A "little" error such as misspelling *malleus* as *malleolus* changes the name of a middle-ear bone to the name of a protuberance of the ankle. A difference of only one letter distinguishes *gustation* (the sense of taste) from *gestation* (pregnancy). The health professions demand precision and accuracy. People's well-being may depend on it, and indeed many patients die simply because of written and oral miscommunication among hospital staff.

Apply What You Know

A student means to write about part of the small intestine called the ileum, but misspells it *ilium*. In complaining about the points lost, the student says, "I was only one letter off!" The instructor says, "But you changed the entire meaning of the word." With the help of a dictionary, explain the instructor's reasoning.

1.4a 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 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.

Scientific terms are typically composed of one or more of the following elements:

- At least one *root (stem)* that bears the core meaning of the word. In *cardiology,* for example, the root is *cardi-* (heart). Many words have two or more roots. In *adipocyte,* the roots are *adip-* (fat) and *-cyte* (cell). Word roots are often linked through an *o* or other vowel to make the word more pronounceable.
- A *prefix* may be present at the beginning of a word to modify its core meaning. For example, *gastric* (pertaining to the stomach or to the belly of a muscle) takes on a variety of new meanings when prefixes are added to it: *epigastric* (above the stomach), *hypogastric* (below the stomach), and *endogastric* (within the stomach).
- A *suffix* may be added to the end of a word to modify its core meaning. For example, *microscope, microscopy, microscopic,* and *microscopist* have different meanings because of their suffixes alone.

Consider another word, *gastroenterology,* a branch of medicine dealing with the stomach and small intestine. It breaks down into

gastro/entero/logy:

gastro = "stomach,"
entero = "small intestine," and
logy = "the study of."

"Dissecting" words in this way and paying attention to the word-origin footnotes throughout this book can help make you more comfortable with the language of anatomy. Breaking a word down and knowing the meaning of its elements make it far easier to pronounce it, spell it, and remember its definition. In appendix D, you will find a lexicon of the word roots, prefixes, and suffixes most frequently used in this book.

1.4b Singular and Plural Forms

A point of confusion for many beginning students is how to recognize the plural forms of medical terms. Few people would fail to recognize that *ovaries* is the plural of *ovary,* but the connection is harder to make in other cases: For example, the plural of *cortex* is *cortices* (COR-ti-sees), and the plural of *corpus* is *corpora.* **Table 1.2** will help you make the connection between common singular and plural noun terminals.

Table 1.2 Singular and Plural Forms of Some Noun Terminals

Singular Ending	Plural Ending	Examples
-a	-ae	pleura, pleurae
-ax	-aces	thorax, thoraces
-en	-ina	lumen, lumina
-ex	-ices	cortex, cortices
-is	-es	testis, testes
-is	-ides	epididymis, epididymides
-ix	-ices	appendix, appendices
-ma	-mata	carcinoma, carcinomata
-on	-a	ganglion, ganglia
-um	-a	septum, septa
-us	-era	viscus, viscera
-us	-i	villus, villi
-us	-ora	corpus, corpora
-x	-ges	phalanx, phalanges
-y	-ies	ovary, ovaries
-yx	-yces	calyx, calyces

1.4c Directional Terminology

In "navigating" the human body and describing the locations of structures, anatomists use a set of standard **directional terms** (table 1.3). You will need to be very familiar with these in order to understand anatomical descriptions later in this book. The terms assume that the body is in anatomical position.

Intermediate directions are often indicated by combinations of these terms. For example, a structure that is *superomedial* to another is above and medial to it; the bridge of the nose is superomedial to the flare of the nostrils.

Because of the bipedal (two-legged), upright stance of humans, some directional terms have different meanings for humans than they do for other animals. *Anterior,* for example, denotes the region of the body that leads the way in normal

Table 1.3 Directional Terms in Human Anatomy APR

Term	Meaning	Examples of Usage
Ventral	Toward the front* or belly	The aorta is *ventral* to the vertebral column.
Dorsal	Toward the back or spine	The vertebral column is *dorsal* to the aorta.
Anterior	Toward the ventral side*	The sternum is *anterior* to the heart.
Posterior	Toward the dorsal side*	The esophagus is *posterior* to the trachea.
Superior	Above	The heart is *superior* to the diaphragm.
Inferior	Below	The liver is *inferior* to the diaphragm.
Medial	Toward the midsagittal plane	The heart is *medial* to the lungs.
Lateral	Away from the midsagittal plane	The eyes are *lateral* to the nose.
Proximal	Closer to the point of attachment or origin	The elbow is *proximal* to the wrist.
Distal	Farther from the point of attachment or origin	The fingernails are at the *distal* ends of the fingers.
Superficial	Closer to the body surface	The skin is *superficial* to the muscles.
Deep	Farther from the body surface	The bones are *deep* to the muscles.

** In humans only; definition differs for other animals.*

CAREER SPOTLIGHT

Radiologic Technologist

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A radiologic technologist is a person who produces medical images for the purposes of diagnosing and treating illnesses and injuries, or who administers radiation therapy. (The profession is not to be confused with *radiologic technician*—one who sets up, maintains, and repairs radiologic equipment.) Radiologic technologists work closely with radiologists—physicians who interpret the images, make diagnoses, and prescribe courses of treatment. Programs in radiologic technology range from a 2-year associate degree to bachelor's and master's degrees. The training of a radiologic technologist is a mixture of medical and physical sciences, including anatomy, physiology, genetics, pathology, chemistry, general and nuclear physics, medical terminology, patient examination and positioning, radiologic instrumentation, and medical imaging sciences. Writing, speech, and figure drawing also provide useful experience; one must also have good analytical thinking skills, attention to detail, compassion, and patience. Entry into the profession requires passing a board examination; earning certification, although optional, is a further step that enhances one's career mobility. Many employers prefer to hire only certified radiologic technologists. Career-long continuing education courses are necessary to keep one's certification current. Specialties in radiologic technology include radiography (X-ray technology), mammography, sonography, fluoroscopy, CT, MRI, PET, nuclear medicine, medical dosimetry, and bone densitometry. Some radiologic technologists go into clinical administration or radiologic education, or work for equipment manufacturers. See appendix B for additional career information.

locomotion. For a four-legged animal such as a cat, this is the head; for a human, however, it is the front of the chest and abdomen. Thus, *anterior* has the same meaning as *ventral* for a human but not for a cat. *Posterior* denotes the region of the body that comes last in normal locomotion—the tail end of a cat but the dorsal side of a human. These differences must be kept in mind when dissecting other animals for comparison to human anatomy.

Before You Go On

Answer these questions from memory to test your understanding of the previous section. Reread the material if you can't answer the questions.

11. *Following the example given for* gastroenterology*, break each of the following words down into their roots, prefixes, and suffixes:* electrocardiography, brachiocephalic, hyperkalemia, substernal, periodontal.
12. *Write the plural form of each of the following terms:* stoma, lacuna, nucleus, epithelium, diagnosis. *Write the singular form of each of the following:* larynges, carpi, ampullae, matrices, ova.
13. *Examine figure 1.10 and use the proper directional term from table 1.3 to describe (a) the location of the axillary region relative to the cubital region; (b) the location of the sacral region relative to the lumbar region; (c) the location of the sternal region relative to the scapular region; and (d) the location of the umbilical region relative to the lumbar region.*

Study Guide

Assess Your Learning Outcomes

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

1.1 Anatomy—The Structural Basis of Human Function

1. The distinction between gross anatomy and histology, and the relationship of histology to histopathology
2. How surface anatomy, systemic anatomy, regional anatomy, and functional morphology differ in their perspectives
3. Why the study of other animal species is important for understanding human functional morphology
4. Distinctions between dissection, palpation, auscultation, percussion, and medical imaging as methods of studying human structure
5. How each of the following methods of medical imaging is performed, and why one might be chosen over the others for specific purposes: radiography, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and sonography
6. Examples of individual anatomical variation and why such variations are important in the practice of medicine

1.2 Physiology—Dynamic Processes in the Living Body

1. The meaning of *physiology,* and the importance of studying the physiology of other species for understanding humans
2. The properties that define something as alive and the difficulty of defining *life* or the moment of death
3. The meaning of *homeostasis,* the role of negative feedback loops in maintaining homeostasis, and the contrast between the set point and a dynamic equilibrium
4. Examples of negative feedback and homeostasis
5. The fundamental components seen in many negative feedback loops
6. How positive feedback differs from negative feedback, and examples of beneficial and harmful effects of positive feedback
7. Why it is clinically important to be aware of individual physiological variation

1.3 The Human Body Plan

1. The eight levels of structural complexity from organism to atoms, and the definitions of such levels as *organ, tissue, cell, organelle,* and others
2. The definition of *anatomical position,* and why anatomical position is such an important frame of reference
3. Definition of the three principal anatomical planes of the human body
4. Components of the axial and appendicular regions of the human body
5. Landmarks that define the four quadrants of the abdomen; names of the quadrants; and some organs that lie within each quadrant
6. Terminology of the surface regions of human anatomy
7. Meaning of the *segments* of an appendage, and examples
8. Differences between the serous and mucous membranes of the body and examples of locations
9. The principal body cavities; names of the membranes that line them; and the most important viscera found in each
10. The meanings of *parietal* and *visceral peritoneum*
11. The location, appearance, and function of the mesenteries, and how the mesenteries are related to the peritoneum and the serosa of the viscera
12. The distinction between intraperitoneal and retroperitoneal organs, and some examples of each
13. The 11 organ systems of the human body, functions of each system, and principal organs of each

1.4 The Language of Medicine

1. Examples of why precision is important in anatomical terminology, and why spelling errors can be more significant than they might seem
2. How to break down biomedical terms into roots, prefixes, and suffixes, and why it is helpful to make a habit of seeing terminology in this way
3. Relationships between the singular and plural forms of the same biomedical nouns
4. The distinctions between *dorsal* and *ventral; anterior* and *posterior; superior* and *inferior; medial* and *lateral; proximal* and *distal;* and *superficial* and *deep*
5. Why *anterior* and *posterior, dorsal* and *ventral* have different meanings for a human than for a cat

Testing Your Recall

1. Structure that can be observed with the naked eye is called
   a. gross anatomy.
   b. histology.
   c. ultrastructure.
   d. comparative anatomy.
   e. cytology.

2. The method of medical imaging that exposes a person to radio waves is
   a. a PET scan.
   b. an MRI scan.
   c. radiology.
   d. sonography.
   e. a CT scan.

3. The tarsal region is _____ to the popliteal region.
   a. dorsal
   b. distal
   c. superior
   d. proximal
   e. appendicular

4. Which of the following regions is *not* part of the upper limb?
   a. palmar
   b. antebrachial
   c. cubital
   d. carpal
   e. popliteal

5. Which of the following is *not* an organ system?
   a. muscular system
   b. endocrine system
   c. immune system
   d. lymphatic system
   e. integumentary system

6. The simplest structures considered to be alive are
   a. cells.
   b. organisms.
   c. the tissues.
   d. the organelles.
   e. organs.

7. Why is the stomach considered to be an organ?
   a. It is part of the digestive system.
   b. It has a specific, complex physiological function.
   c. It is composed of two or more tissues.
   d. It consists of a mass of similar cells that form a specific secretion.
   e. It is physically interconnected with other organs.

8. The lining of the abdominal cavity is
   a. a mucous membrane.
   b. the peritoneum.
   c. the meninges.
   d. the pleura.
   e. the serosa.

9. The word root *patho-* means
   a. doctor.
   b. medicine.
   c. organ.
   d. health.
   e. disease.

10. The prefix *epi-* means
    a. next to.
    b. below.
    c. above.
    d. within.
    e. behind.

11. When a doctor presses on the abdomen to feel the size and texture of the liver, he or she is using a technique of physical examination called _____.

12. A method of medical imaging that uses X-rays and a computer to generate an image of a thin slice of the body is called _____.

13. Most physiological mechanisms serve the purpose of _____, maintaining a stable internal environment in the body.

14. A/an _____ is the simplest body structure to be composed of two or more types of tissue.

15. The carpal region is more commonly known as the _____, and the tarsal region is more commonly known as the _____.

16. In standard directional terms, the sternal region is _____ to the pectoral region.

17. The layer of peritoneum facing the body wall is called the _____ layer, and the layer on the surface of an internal organ is called the _____ layer.

18. Homeostasis is maintained by a cycle of events called a _____, in which the body senses a change and activates mechanisms to minimize or reverse it.

19. The directional terms of human anatomy assume that a person is in _____, which means standing upright with the feet together and the palms, face, and eyes forward.

20. The elbow is said to be _____ to the wrist because it is closer to the upper limb's point of origin (the shoulder).

Answers in Appendix A

What's Wrong with These Statements?

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

1. It is possible to see both eyes in a median section of the head.
2. The diaphragm is ventral to the lungs.
3. A PET scan is a noninvasive method of medical imaging.
4. The pleural and pericardial cavities are lined by mucous membranes.
5. Abnormal skin color or dryness is one piece of information that could be obtained by auscultation.
6. A CT scan is a simpler and safer way than sonography to monitor fetal development.
7. Histopathology is a subdiscipline of gross anatomy.
8. Negative feedback is more often harmful than beneficial to the body.
9. There are more cells than organelles in the human body.
10. The pericardial sac is an internal lining of the heart.

Answers in Appendix A

Testing Your Comprehension

1. Identify which anatomical plane—sagittal, frontal, or transverse—is the only one that could *not* show (a) both the cerebrum and tongue, (b) both eyes, (c) both the hypogastric and gluteal regions, (d) both the sternum and vertebral column, and (e) both the heart and uterus.
2. Name one structure or anatomical feature that could be found in each of the following locations relative to the ribs: medial, lateral, superior, inferior, deep, superficial, posterior, and anterior. Try not to use the same example twice.
3. For each of the following nonbiological processes, state whether you think it is analogous to physiological positive feedback, negative feedback, or neither of these, and justify each answer: (a) a flushed toilet tank refilling to its original resting level; (b) a magnifying glass focusing the sun's rays and catching a piece of paper on fire; (c) a house fire in which heat from the flames ignites adjacent flammable material until, if unchecked, the whole house is consumed; (d) the increasingly loud howl of a loudspeaker as a band is setting up the sound stage for a concert and gets a microphone too close to the speaker.

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Chapter

2

Life, Matter, and Energy

Urea crystals seen with a polarizing microscope. Urea, a product of protein metabolism, is the principal organic waste product of urine.

Eye of Science/Science Source

BASE CAMP

Before ascending to the next level, be sure you're properly equipped with a knowledge of these concepts from chapter 1.

- The concept of metabolism (see "Essential Life Functions" in section 1.2b)
- "Levels of Human Structure" in section 1.3a

Chapter Outline

2.1 Atoms, Ions, and Molecules
- 2.1a Chemical Elements
- 2.1b Atoms
- 2.1c Isotopes and Radioactivity
- 2.1d Ions, Electrolytes, and Free Radicals
- 2.1e Molecules and Chemical Bonds

2.2 Water, Acids, and Bases
- 2.2a Water
- 2.2b Acids, Bases, and pH

2.3 Organic Compounds
- 2.3a Carbohydrates
- 2.3b Lipids
- 2.3c Proteins
- 2.3d Nucleic Acids (DNA and RNA)
- 2.3e Adenosine Triphosphate (ATP)

2.4 Energy and Chemical Reactions
- 2.4a Forms of Energy
- 2.4b Chemical Reactions
- 2.4c Metabolism, Oxidation, and Reduction

Clinical Applications/Perspectives on Health
- Clinical Application 2.1: pH and Drug Action
- Clinical Application 2.2: *Trans* Fats and Cardiovascular Health
- Perspectives on Health

End of Chapter
- Career Spotlight: Medical Technologist
- Study Guide

Why is too much sodium or cholesterol harmful? Why does an iron deficiency cause anemia and a calcium deficiency weaken the bones? Why do some pregnant women suffer convulsions after several days of vomiting? How can radiation cause cancer as well as cure it?

None of these questions can be answered, nor would the rest of this book be intelligible, without understanding the chemistry of life. A little knowledge of chemistry can help you choose a healthy diet, use medications more wisely, evaluate health fads and avoid fraudulent claims, and understand medical treatments and procedures. And so we begin our study of the human body with basic chemistry, the simplest level of the body's structural organization.

2.1 Atoms, Ions, and Molecules

Expected Learning Outcomes

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

a. recognize elements of the human body from their chemical symbols;
b. distinguish between chemical elements and compounds;
c. state the functions of minerals in the body;
d. explain the basis for radioactivity and the uses and hazards of ionizing radiation;
e. distinguish between ions, electrolytes, and free radicals; and
f. define the types of chemical bonds.

2.1a Chemical Elements

A chemical **element** is the simplest form of matter to have unique chemical properties. Water, for example, has unique properties, but it can be broken down into two elements, hydrogen and oxygen, each with unique properties of their own. If we break them down any further, however, we find that hydrogen and oxygen are made of protons, neutrons, and electrons—none of which are unique. A proton of gold is identical to a proton of oxygen. Therefore, the elements hydrogen and oxygen are the simplest unique components of water.

There are 91 naturally occurring elements on earth, 24 of which play normal roles in humans. Table 2.1 groups these 24 according to their abundance in the body. Six of them account for 98.5% of the body's weight: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus. The next 0.8% consists of another six elements: sulfur, potassium, sodium, chlorine, magnesium, and iron. The remaining 12 total only 0.7% of body weight; thus, these are known as **trace elements.** Despite their minute quantities, trace elements play vital roles in physiology. Iodine, for example, is an essential component of thyroid hormone. Other elements without natural physiological roles can contaminate the body

Table 2.1 Elements of the Human Body

Name	Symbol		Percentage of Body Weight
Major Elements (Total 98.5%)			
Oxygen	O		65.0
Carbon	C		18.0
Hydrogen	H		10.0
Nitrogen	N		3.0
Calcium	Ca		1.5
Phosphorus	P		1.0
Lesser Elements (Total 0.8%)			
Sulfur	S		0.25
Potassium	K		0.20
Sodium	Na		0.15
Chlorine	Cl		0.15
Magnesium	Mg		0.05
Iron	Fe		0.006
Trace Elements (Total 0.7%)			
Chromium	Cr	Molybdenum	Mo
Cobalt	Co	Selenium	Se
Copper	Cu	Silicon	Si
Fluorine	F	Tin	Sn
Iodine	I	Vanadium	V
Manganese	Mn	Zinc	Zn

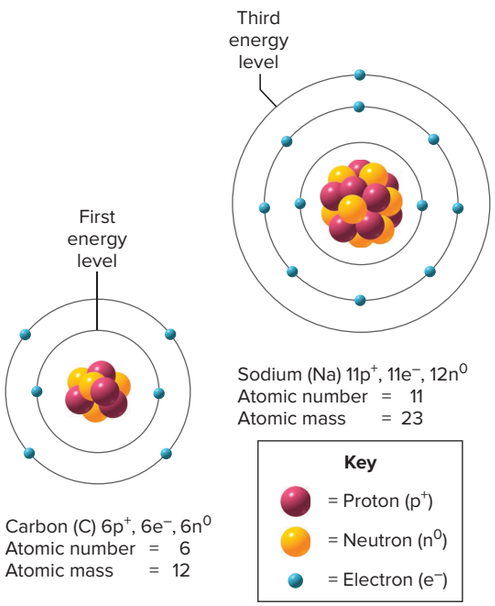


Figure 2.1 Two Representative Elements.

and severely disrupt its functions, as in heavy metal poisoning with lead or mercury.

The elements are represented by one- or two-letter symbols, usually based on their English names: C for carbon, Mg for magnesium, Cl for chlorine, and so forth. A few symbols are based on Latin names, such as K for potassium *(kalium),* Na for sodium *(natrium),* and Fe for iron *(ferrum).* The periodic table of the elements (appendix E) summarizes information on all the natural chemical elements and their relative abundance in the human body.

Several elements are classified as **minerals**—substances extracted from the soil by plants and passed up the food chain to humans and other organisms. Minerals constitute about 4% of the human body by weight. Nearly three-quarters of this is Ca and P; the rest is mainly Cl, Mg, K, Na, and S. Minerals contribute significantly to body structure. The bones and teeth consist partly of crystals of Ca, P, Mg, F, and sulfate ions. In addition, sulfur is a component of many proteins; phosphorus is a major component of DNA and cell membranes; and iron is a component of hemoglobin.

2.1b Atoms

Each chemical element is composed of a unique type of **atom.** At the center of an atom is the **nucleus,** composed of positively charged **protons (p^+)** and uncharged **neutrons (n^0).** The nucleus is orbited by **electrons (e^-),** tiny particles with a negative charge that swarm about the nucleus in concentric regions called *energy levels (electron shells)* (**fig. 2.1**). Each shell holds a limited

number of electrons. Those in the outermost shell, **valence electrons,** determine the formation of chemical bonds. Electrons have a very low mass, even when compared to protons. A person who weighs 64 kg (140 lb) contains less than 24 g (1 oz) of electrons. And yet, these tiny particles determine the chemical properties of atoms and thereby govern chemical reactions and the formation of molecules. Despite their small mass, electrons play a big role in cell structure and function.

2.1c Isotopes and Radioactivity

Not every atom of an element is identical; all elements have two or more varieties called **isotopes,**[1] which differ from each other only in number of neutrons. Most hydrogen atoms, for example, have a nucleus composed of only one proton; this isotope is symbolized ^{1}H. Hydrogen has two other isotopes: *deuterium* (^{2}H) with one proton and one neutron, and *tritium* (^{3}H) with one proton and two neutrons. Over 99% of carbon atoms have a nucleus of six protons and six neutrons, and are called carbon-12 (^{12}C), but a small percentage of carbon atoms are ^{13}C, with seven neutrons, and ^{14}C, with eight.

Many isotopes are unstable and *decay* (break down) to more stable isotopes by giving off radiation. This process of decay is called **radioactivity,** and unstable isotopes are therefore called **radioisotopes.** Every element has at least one radioisotope.

Radioactivity is one form of **ionizing radiation** (ultraviolet radiation and X-rays are others). Ionizing radiation can be very damaging to tissues and is capable of causing cancer, birth defects, or in high doses, immediate death. In controlled, targeted doses, however, it is useful for such purposes as radiography, PET scans, and cancer radiation therapy.

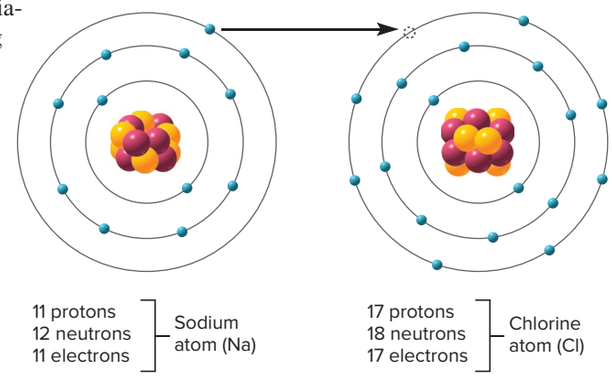
2.1d Ions, Electrolytes, and Free Radicals

Ions are charged particles with unequal numbers of protons and electrons. Ions form because elements with one to three valence electrons tend to give them up, and those with four to seven electrons tend to gain more. If an atom of the first kind is exposed to an atom of the second, electrons may transfer from one to the other and turn both of them into ions. This process is called *ionization.* The particle that gains electrons acquires a surplus negative charge and is called an **anion** (AN-eye-on). The one that loses electrons is left with an excess positive charge (from a surplus of protons) and is called a **cation** (CAT-eye-on).

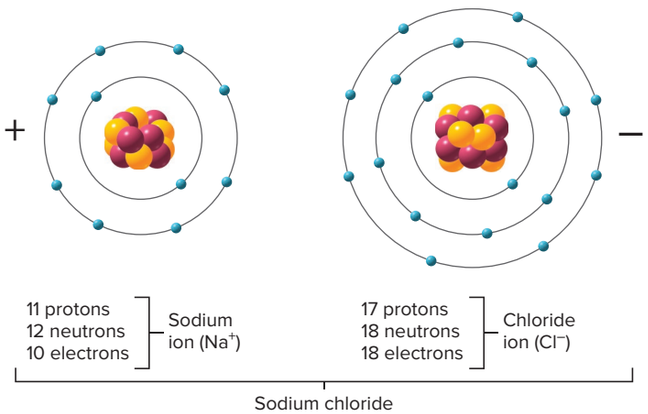
Consider, for example, what happens when sodium and chlorine meet (**fig. 2.2**). Sodium has a total of 11 electrons: 2 in its first (inner) shell, 8 in the second, and 1 in the third (valence) shell. If it gives up the electron in the third shell, its second shell becomes the valence shell and has a stable configuration of 8 electrons. Chlorine has 7 electrons in its valence shell (17 in all). If it can gain one more electron, it can fill the third shell with 8 electrons and become stable. Sodium and chlorine seem "made for each other"—one needs to lose an electron and the other needs to gain one. This is just what they do. When an electron transfers from sodium to chlorine, sodium is left with 11 protons

[1] *iso* = same; *top* = place (same position in the periodic table)

Figure 2.2 Ionization. A sodium atom donates an electron to a chlorine atom. This electron transfer converts the atoms to a positive sodium ion (Na^+) and a negative chloride ion (Cl^-). Attraction of these two oppositely charged ions to each other then constitutes an ionic bond.



1 Transfer of an electron from a sodium atom to a chlorine atom



2 The charged sodium ion (Na^+) and chloride ion (Cl^-) that result