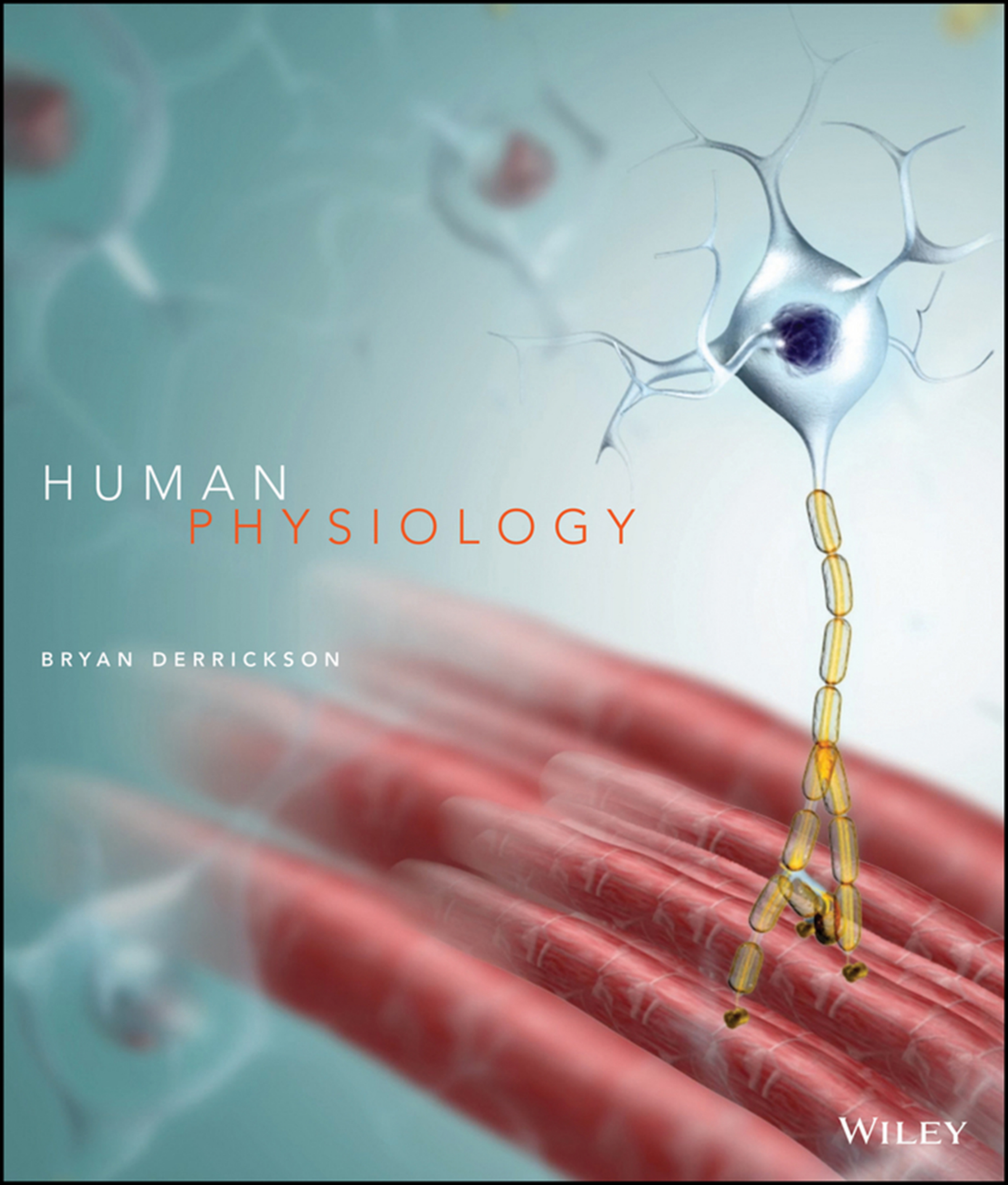
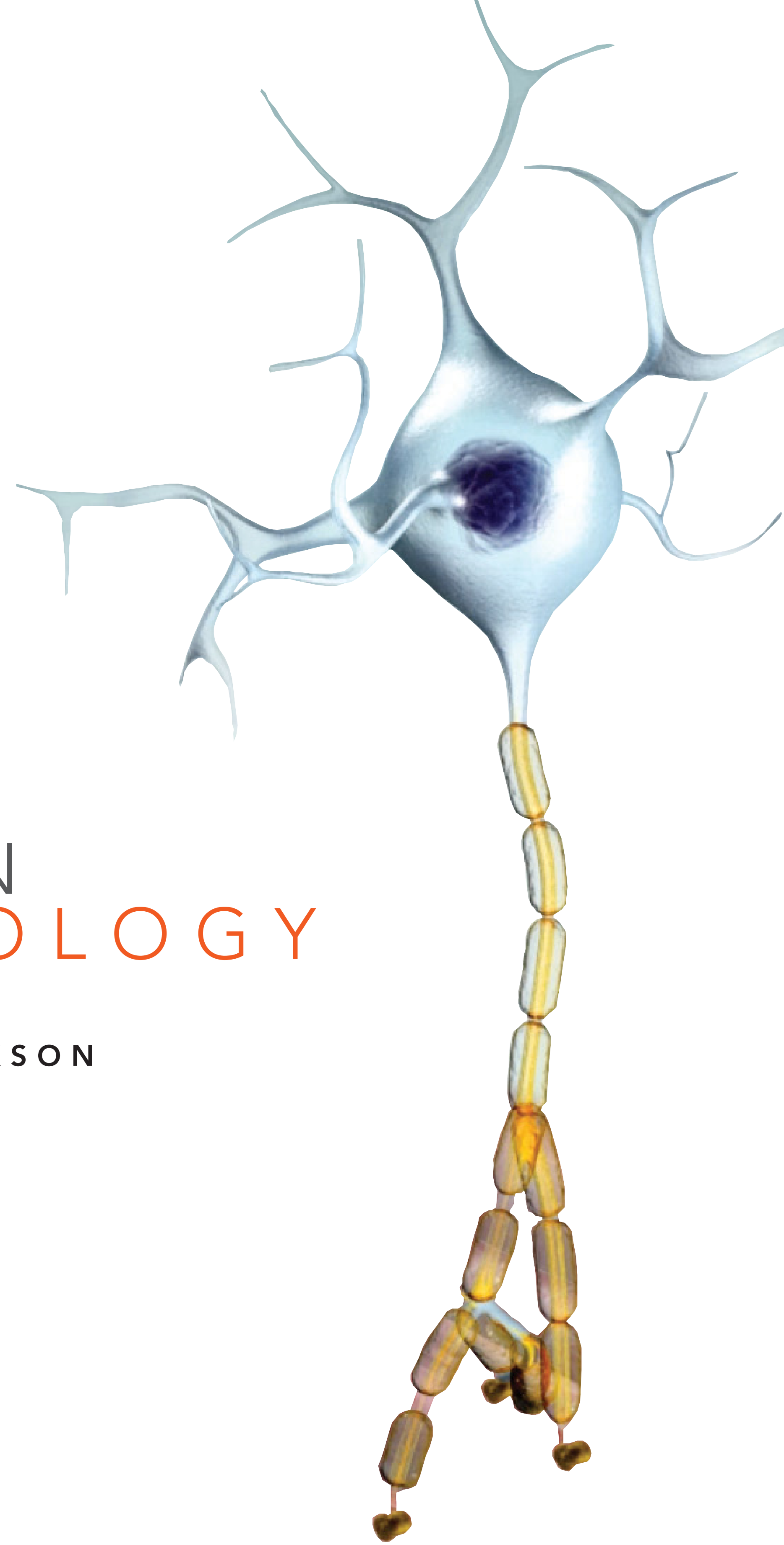


HUMAN PHYSIOLOGY

BRYAN DERRICKSON

WILEY

HUMAN PHYSIOLOGY



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About the Author

Courtesy of Bryan Derrickson

Bryan Derrickson is Professor of Biology at Valencia College in Orlando, Florida, where he teaches human anatomy and physiology as well as general biology and human sexuality. He received his bachelor's degree in biology from Morehouse College and his Ph.D. in cell biology from Duke University. Bryan's study at Duke was in the Physiology Division within the Department of Cell Biology, so while his degree is in cell biology, his training focused on physiology. At Valencia, he frequently serves on faculty hiring committees. He has served as a member of the Faculty Senate, which is the governing body of the college, and as a member of the Faculty Academy Committee (now called the Teaching and Learning Academy), which sets the standards for the acquisition of tenure by faculty members. Nationally, he is a member of the Human Anatomy and Physiology Society (HAPS) and the National Association of Biology Teachers (NABT). Bryan has always wanted to teach. Inspired by several biology professors while in college, he decided to pursue physiology with an eye to teaching at the college level. He is completely dedicated to the success of his students. He particularly enjoys the challenges of his diverse student population, in terms of their age, ethnicity, and academic ability, and finds being able to reach all of them, despite their differences, a rewarding experience. His students continually recognize Bryan's efforts and care by nominating him for a campus award known as the "Valencia Professor Who Makes Valencia a Better Place to Start." Bryan has received this award three times.

In honor of my mother, **Rosalind Gilmer Derrickson** **B.H.D.**

Courtesy of Bryan Derrickson

Preface

Welcome to your course in human physiology! Many of you are taking this course because you hope to pursue a career in medicine or one of the allied health professions. Others of you may be taking the course because you are simply interested in learning how your own amazing body functions. Whatever your motivations, ***Human Physiology,*** and ***WileyPLUS Learning Space*** have all the content and tools needed to ensure that you receive a solid foundation and the knowledge and skills to reach your desired goals.

I am passionate about the discipline of physiology, and have an equally strong passion for teaching. Physiology is a fascinating subject and I enjoy conveying this information to students and guiding them through the intricacies of the many complex functions of the human body. I wrote this text because of my desire to share the story of physiology with a wider audience.

Human Physiology is a comprehensive text that uses four main underlying principles in physiology as a foundation for specific details of all the systems of the human body. These principles include *homeostasis, mechanisms of action, communication,* and *integration*. As you progress through the text, you will discover these underlying themes supporting your understanding of core physiological concepts.

Most importantly, I endeavored to distinguish this text by uniquely combining three powerful elements: (1) clear, easy-to-follow writing style supported with carefully developed figures; (2) an emphasis on the development of vital critical thinking skills; and (3) a fully integrated digital platform rich in interactive activities and media. Together these elements provide a superior level of coverage that helps prepare you for successful careers in medicine and allied health.

THE NARRATIVE AND VISUALS

Each chapter in ***Human Physiology*** is written in a style that is very straightforward and easy to understand. This type of writing style facilitates comprehension and retention of key physiological concepts. Words can convey a lot when carefully chosen, but if you are like most students today, visual representation of the material is of equal importance to you. You'll find clear visual explanations that bring the words on the page to life. In addition, each chapter is filled with boxed information on relevant clinical connections and other real-life examples that will stir your interest in, and solidify understanding of, the relevant science at hand.

CRITICAL THINKING

Understanding how to think critically about the scientific information presented is vital to your success. ***Human Physiology, 1st edition*** and ***WileyPLUS Learning Space*** have several features that give you the opportunity to hone this essential skill. *Critical Thinking* exercises help you to think logically and critically about real-life scenarios that involve important physiological concepts. *Research to Reality* is a unique feature that provides you with the opportunity to analyze and interpret real scientific data from primary research articles. *Physiological Equation* boxes describe key physiological equations that you can use to analyze and quantify certain physiological parameters. *Ponder This* questions at the end of each chapter provide additional opportunities to think critically about physiological information.

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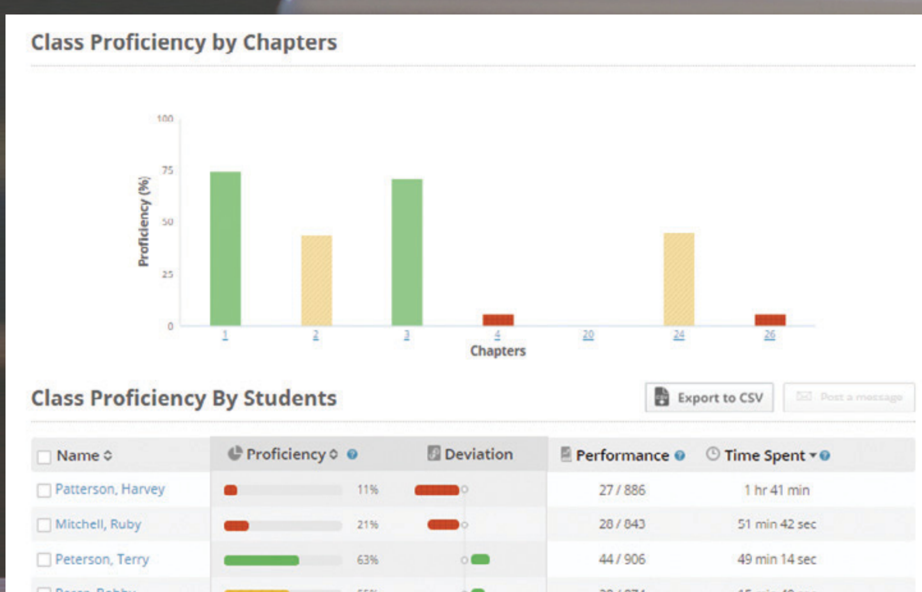

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David Mallory, Marshall University, was instrumental in the design and execution of the ***Critical Thinking Boxes*** and step-by-step questions found in each chapter. His choice of topics for these boxes adds great interest and really highlights the connections to the concepts at hand. Thank you so much, David.

Lynn Diener, Mount Mary University, researched and chose most of the primary research papers used in the ***Research to Reality*** activities. She used her expertise and experience in implementing this kind of investigation in her own classes to bring this unique feature to this project. I am very grateful, Lynn.

Heidi Bustamante, University of Colorado, Boulder, excels at writing thoughtful questions that challenge students to critically think about what they have learned. I am so happy that she chose to enhance this text by writing the end-of-chapter *Ponder This* questions. I really appreciate your work, Heidi.

I am also very grateful that Wiley commissioned a board of academic advisors with expertise in teaching physiology to help inform not only individual resources integrated with this text, but also as a sounding board for all of us as we progressed through development.

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I thank the following group of academics who have contributed to the creation and integration of this text with ***WileyPLUS Learning Space*** with ***ORION***. Their thoughtful execution of resources and assessment has raised the bar for excellence. Thank you, so very much.

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The development of a first edition text and media for a course as complex as human physiology is a long process and would not be possible without the continued involvement of those "in the trenches" teaching the course, who guided and informed our choices all along the way. I am very grateful to my colleagues who have reviewed the drafts of manuscript, participated in focus groups and workshops, or offered suggestions for improvement.

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Brief Contents

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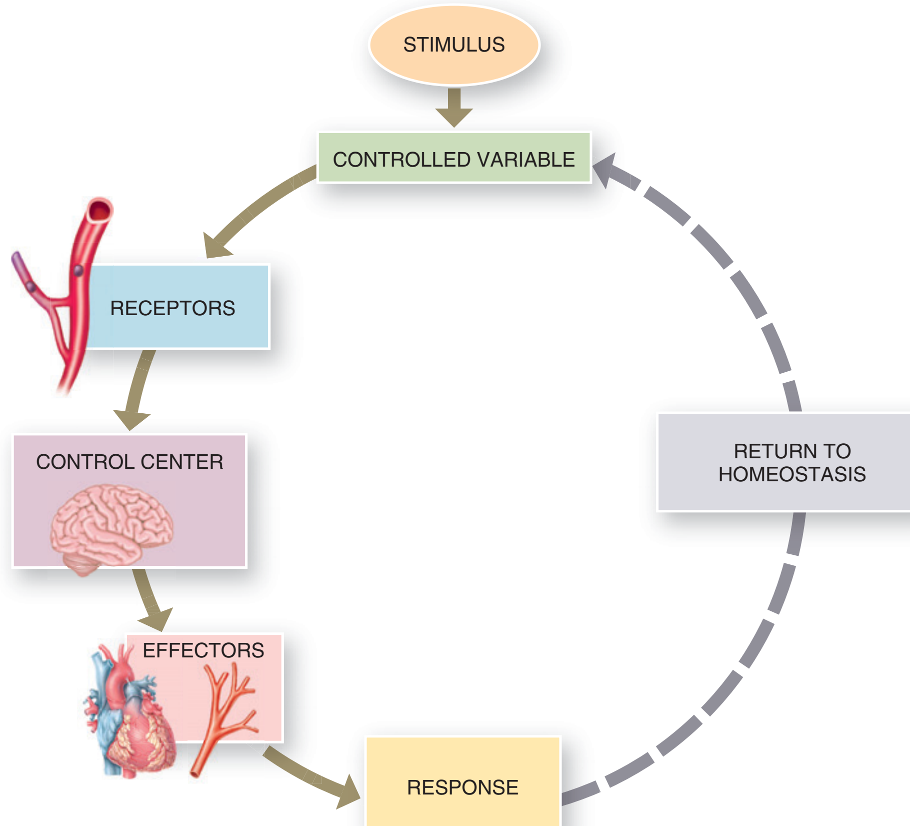


1 An Introduction to Physiology

The Human Body and Homeostasis

Humans have many ways to maintain homeostasis, the state of relative stability of the body's internal environment. Disruptions to homeostasis often set in motion corrective cycles, called feedback systems, that help restore the conditions needed for health and life.

LOOKING BACK TO MOVE AHEAD...

- One of the fundamental principles of biology is the cell theory, which states that (1) the cell is basic unit of life; (2) all organisms are composed of one or more cells; and (3) cells arise from pre-existing cells.
- Organisms are classified into three domains: Bacteria, Archaea, and Eukarya; humans belong to domain Eukarya, kingdom Animalia, phylum Chordata, subphylum Vertebrata, and class Mammalia.
- All organisms have a binomial (a two-part Latin scientific name) that consists of a genus and species; the binomial for humans is *Homo sapiens*, which means "wise man" (*homo-* = *man; sapiens* = wise).
- Compared to other organisms, humans have several distinguishing features: erect posture; bipedal locomotion (ability to walk on two legs); and a large, well-developed brain that allows for analytical skills and complex thought.

Your fascinating journey through the human body begins with an overview of the meaning of physiology, followed by a discussion of the organization of the human body and the properties that it shares with all living things. Next, you will discover how the body regulates its own internal environment through an unceasing process known as homeostasis. You will then explore physiology as a science—its historical background and the general methods of acquiring and organizing physiological information. The chapter concludes with a discussion of the key themes of physiology.

1.1 Physiology Defined

OBJECTIVE

- Define physiology and identify several of its subdisciplines.

Physiology (fiz′-ē-OL-ō-jē) is the study of the functions of an organism and its constituent parts. This text focuses on *human physiology*—how the parts of the human body work. Human physiology considers topics such as the molecular mechanism responsible for muscle contraction; communication between cells using chemical messengers; the parts of the brain involved in language comprehension and expression; and the maintenance of blood pressure by the coordinated efforts of the heart, kidneys, brain, and glands. Because physiology has a broad scope, it is divided into many subdisciplines, several of which are described in TABLE 1.1.

TABLE 1.1 Selected Subdisciplines of Physiology

Subdiscipline	Study of . . .
Molecular physiology	Functions of individual molecules, such as proteins.
Cell physiology	Functions of cells.
Neurophysiology	Functions of the nervous system.
Endocrinology	Hormones (chemical regulators in the blood) and how they control body functions.
Cardiovascular physiology	Functions of the heart, blood vessels, and blood.
Immunology	How the body defends itself against disease-causing agents.
Respiratory physiology	Functions of the air passageways and lungs.
Renal physiology	Functions of the kidneys.
Gastrointestinal physiology	Functions of the stomach and intestines.
Integrative physiology	How different parts of the body work together to accomplish a particular function.
Exercise physiology	Changes in cell and organ functions as a result of muscular activity.
Pathophysiology	Functional changes associated with disease and aging.

Whereas physiology deals with body functions, *anatomy* is the study of body structure. However, the two cannot truly be separated: The function of a body part is a reflection of its structure. For example, the walls of the air sacs in the lungs are very thin, permitting rapid movement of inhaled oxygen into the blood. By contrast, the lining of the urinary bladder is much thicker to prevent the escape of urine into the pelvic cavity, yet its construction allows for considerable stretching as the urinary bladder fills with urine. Because structure and function are so closely related, as the function of a body part is discussed in the text, relevant information about its structure is provided to help clarify your understanding of the topic.

CHECKPOINT

1. Which subdiscipline of physiology would most likely explore how the kidneys and lungs work together to maintain the acid–base balance of your body fluids? (*Hint:* Refer to TABLE 1.1).

1.2 Levels of Organization in the Body

OBJECTIVES

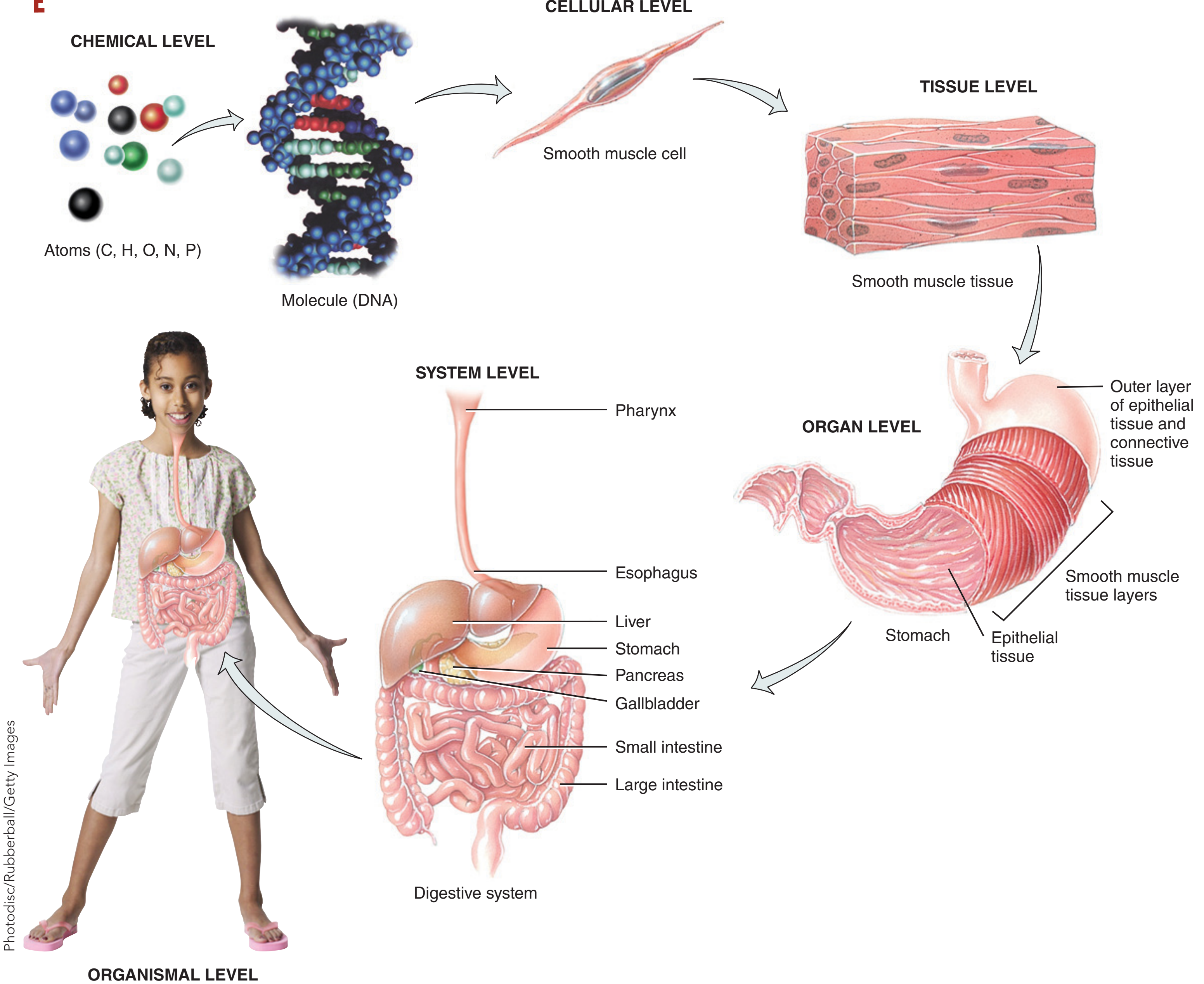
- Describe the levels of organization that comprise the human body.
- Explain the functions of the twelve body systems.

As you study physiology, your exploration of the human body will extend from atoms and molecules to the whole person. From the smallest to the largest, six levels of organization will help you to understand how the body functions: the chemical, cellular, tissue, organ, system, and organismal levels of organization (FIGURE 1.1).

- ***Chemical level.*** This very basic level includes **atoms**, the smallest units of matter that participate in chemical reactions, and **molecules**, two or more atoms joined together. Certain atoms, such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), calcium (Ca), and sulfur (S), are essential for maintaining life. Two familiar molecules found in the body are deoxyribonucleic acid (DNA), the genetic material passed from one generation to the next, and glucose, the main type of sugar in the bloodstream. Chapter 2 focuses on the chemical level of organization.
- ***Cellular level.*** Molecules combine to form **cells**, the basic structural and functional units of an organism. Cells are the smallest units capable of performing all life processes. Among the many kinds of cells in your body are epithelial cells, connective tissue cells, muscle cells, and neurons (nerve cells). FIGURE 1.1 shows a smooth muscle cell, one of the three types of muscle cells in the body.

FIGURE 1.1 Levels of organization in the human body.

The levels of organization in the body are chemical, cellular, tissue, organ, system, and organismal.



Which level of organization is composed of two or more different types of tissues that work together to perform a specific function?

- ***Tissue level.*** A **tissue** is a group of similar cells that work together to perform a particular function. There are just four basic types of tissue in your body: epithelial tissue, connective tissue, muscle tissue, and nervous tissue. *Epithelial tissue* covers body surfaces, lines hollow organs and ducts, and forms glands. *Connective tissue* supports and protects body organs, stores energy reserves as fat, and helps provide the body with immunity to disease-causing agents. *Muscle tissue* contracts to produce movement, maintain posture, and generate heat. *Nervous tissue* detects and responds to changes in the body's external or internal environment. Shown in FIGURE 1.1 is smooth muscle tissue, which consists of tightly packed smooth muscle cells. The cellular and tissue levels of organization are described in Chapter 3.
- ***Organ level.*** An **organ** is a structure composed of two or more different types of tissues. It has a specific function and usually (but not always) has a recognizable shape. Examples of organs are the stomach, heart, liver, lungs, brain, and skin. FIGURE 1.1 shows how several types of tissues comprise the stomach. The stomach's outer covering is a layer of epithelial tissue and connective tissue that reduces friction when the stomach moves and rubs against other organs. Underneath are smooth muscle tissue layers, which contract to churn and mix food and then push it into the next digestive organ,

the small intestine. The innermost lining is an epithelial tissue layer that produces fluid and chemicals responsible for digestion.

- ***System level.*** A **system,** also known as an **organ system,** consists of related organs with a common function. An example of a system is the digestive system, which breaks down and absorbs food. Its organs include the mouth, salivary glands, pharynx (throat), esophagus, stomach, small intestine, large intestine, liver, gallbladder, and pancreas. Sometimes an organ is part of more than one system. The pancreas, for example, is part of both the digestive system and the hormone-producing endocrine system. TABLE 1.2 introduces the components and functions of the twelve systems of the body.
- ***Organismal level.*** An **organism** is any living individual. All of the organ systems of the body collectively form the organism. In other words, the organism is the totality of all of its organ systems functioning together to maintain life.

In a complex hierarchy such as the body's organizational plan, as each level gives rise to the next highest level, new properties emerge that are not present at the levels below. These **emergent properties** are caused by the interactions of the simpler components of the lower levels of organization. For example, emotions, thoughts, memories, and intelligence are emergent properties of the brain (organ level) that are not present at lower levels of brain organization such as nervous tissue (tissue level) or individual neurons (cellular level). However, as the cells and tissues of the brain interact with each other in a variety of different ways, the brain's emergent properties arise. Because emergent properties depend on the interactions of lower-level components,

TABLE 1.2 The Twelve Systems of the Human Body

System	Components	Functions
Nervous	Brain, spinal cord, nerves, and special sense organs, such as the eyes and ears.	Generates action potentials to regulate body activities; detects changes in the body's external and internal environments, interprets the changes, and responds by causing muscular contractions or glandular secretions.
Muscular	Muscles composed of skeletal muscle tissue, so-called because it is usually attached to bones.	Produces body movements, such as walking; stabilizes body position (posture); generates heat.
Skeletal	Bones, joints, and associated cartilages.	Supports and protects the body; aids body movements; houses cells that produce blood cells.
Endocrine	Hormone-producing glands (pituitary gland, thyroid gland, parathyroid glands, adrenal glands, and pineal gland) and hormone-producing cells in several other organs and tissues.	Regulates body activities by releasing hormones, which are chemical messengers transported in blood from an endocrine gland or tissue to a target organ.
Cardiovascular	Heart, blood vessels, and blood.	The heart pumps blood through blood vessels; blood carries oxygen and nutrients to cells and carries carbon dioxide and other wastes away from cells.
Immune	Lymphocytes (white blood cells), lymph nodes, bone marrow, thymus, spleen, tonsils, and lymphoid tissue of the gut.	Defends body against microbes and other foreign substances.
Lymphatic	Lymphatic vessels, lymph, lymph nodes, bone marrow, thymus, spleen, tonsils, and lymphoid tissue of the gut.	Drains excess interstitial fluid; returns filtered plasma proteins back to the blood; carries out immune responses (part of the lymphatic system also functions as the immune system); transports dietary lipids.
Integumentary	Skin and associated structures, such as hair, nails, sweat glands, and oil glands.	Protects the body from the external environment; helps regulate body temperature; eliminates some wastes.
Respiratory	Nose, pharynx (throat), larynx (voice box), trachea (windpipe), bronchi, and lungs.	Transfers oxygen from inhaled air to blood and carbon dioxide from blood to exhaled air; helps regulate acid–base balance of body fluids.
Urinary	Kidneys, ureters, urinary bladder, and urethra.	Eliminates wastes and excess substances in urine; regulates volume and chemical composition of blood; helps regulate acid–base balance of body fluids.
Digestive	Mouth, pharynx (throat), esophagus, stomach, small and large intestines, salivary glands, liver, gallbladder, and pancreas.	Achieves physical and chemical breakdown of food; absorbs nutrients; eliminates solid wastes.
Reproductive	Gonads (testes in males and ovaries in females) and associated organs (epididymis, vas deferens, and penis in males; fallopian tubes, uterus, and vagina in females).	Gonads produce gametes (sperm or eggs) that unite to form a new organism; gonads also release hormones that regulate reproduction and other body processes; associated organs transport and store gametes.

they are not properties of any single one of these simpler components and cannot be predicted just by knowing that these components exist. The interaction of the components of the body to give rise to emergent properties is an example of integration. **Integration** is the process by which several components work together for a common, unified purpose. Thus, the body is much more than the sum of its parts: It is the result of integrated activities between components at essentially all levels of organization.

CHECKPOINT

2. Define the following terms: atom, molecule, cell, tissue, organ, system, and organism.
3. Refer to TABLE 1.2. Which body systems help eliminate wastes?
4. What is an emergent property?

1.3 Life Processes

OBJECTIVE

- Identify the important life processes of the human body.

Certain processes distinguish organisms, or living things, from nonliving things. Following are the six most important life processes of the human body:

1. **Metabolism** is the sum of all of the chemical reactions that occur in the body. One phase of metabolism is **catabolism**, the breakdown of complex chemical substances into simpler components. The other phase of metabolism is **anabolism**, the formation of complex chemical substances from smaller, simpler components. For example, digestive processes catabolize (break down) proteins in food into amino acids. These amino acids are then used to anabolize (build) new proteins that make up body structures such as muscles and bones.
2. **Responsiveness** is the body's ability to detect and respond to changes. For example, a decrease in body temperature represents a change in the internal environment (within the body), and turning your head toward the sound of squealing brakes is a response to change in the external environment (outside the body). Different cells in the body respond to environmental changes in characteristic ways. Neurons respond by generating electrical signals known as *action potentials*. Muscle cells respond by contracting, which generates force to move body parts.
3. **Movement** includes motion of the whole body, individual organs, single cells, and even tiny structures inside cells. For example, the coordinated action of leg muscles moves your whole body from one place to another when you walk or run. After you eat a meal that contains fats, your gallbladder contracts and squirts bile into the gastrointestinal tract to aid in the digestion of these fats. When a body tissue is damaged or infected, certain leukocytes (white blood cells) move from the blood into the affected tissue to help clean up and repair the area. Inside the cell, various parts move from one position to another to carry out their functions.
4. **Growth** is an increase in body size that results from an increase in the size of existing cells, an increase in the number of cells, or both. In addition, a tissue sometimes increases in size because the amount of material between cells increases. In a growing bone, for example, mineral deposits accumulate between bone cells, causing the bone to grow in length and width.
5. **Differentiation** is the development of a cell from an unspecialized to a specialized state. Each type of cell in the body has a specialized structure and function that differs from that of its precursor (ancestor) cells. For example, erythrocytes (red blood cells) and several types of leukocytes all arise from the same unspecialized precursor cells in bone marrow. Such precursor cells, which can divide and give rise to cells that undergo differentiation, are known as **stem cells**. Also through differentiation, a zygote (fertilized egg) develops into an embryo, and then into a fetus, an infant, a child, and finally an adult.
6. **Reproduction** refers either to (1) the formation of new cells for tissue growth, repair, or replacement, or (2) the production of a new individual. The formation of new cells occurs through cell division. The production of a new individual occurs through the fertilization of an egg by a sperm cell to form a zygote, followed by repeated cell divisions and the differentiation of these cells.

When one or more life processes ceases to occur properly, the result is death of cells and tissues, which may lead to death of the organism. Clinically, loss of the heartbeat, absence of spontaneous breathing, and loss of brain functions indicate death in the human body.

CHECKPOINT

5. The formation of a muscle cell from a precursor cell is an example of which of the six life processes in the human body?

1.4 Homeostasis

OBJECTIVES

- Define homeostasis.
- Distinguish between the body's internal environment and external environment.
- Describe the components of a feedback system.
- Contrast the operation of negative and positive feedback systems.
- Explain feedforward control.

The cells that comprise the human body are able to thrive because they live in the relative constancy of the body's internal environment despite continual changes in the body's external environment. The maintenance of relatively stable conditions in the body's internal environment is known as **homeostasis** (hō′mē-ō-STĀ-sis; *homeo-* = sameness; *-stasis* = standing still). It occurs because of the ceaseless interplay of the body's many regulatory processes. Homeostasis is a dynamic steady state. The term *dynamic* is used to refer to homeostasis because each regulated parameter can change over a narrow range that is compatible with life. For example, the level of glucose is maintained between 70 and 110 milligrams of glucose per 100 milliliters of blood. It normally does not fall too low between meals or rise too high even after eating a high-glucose meal. The term *steady state* is used to refer to homeostasis because energy is needed to keep the regulated parameter at a relatively constant level. Steady state is not the same as equilibrium. In an *equilibrium*, conditions remain constant without the expenditure of energy. Each structure in the body, from the cellular level to the systemic level, contributes in some way to keeping the internal environment of the body within normal limits.

Maintenance of Body Fluid Volume and Composition is Essential to Homeostasis

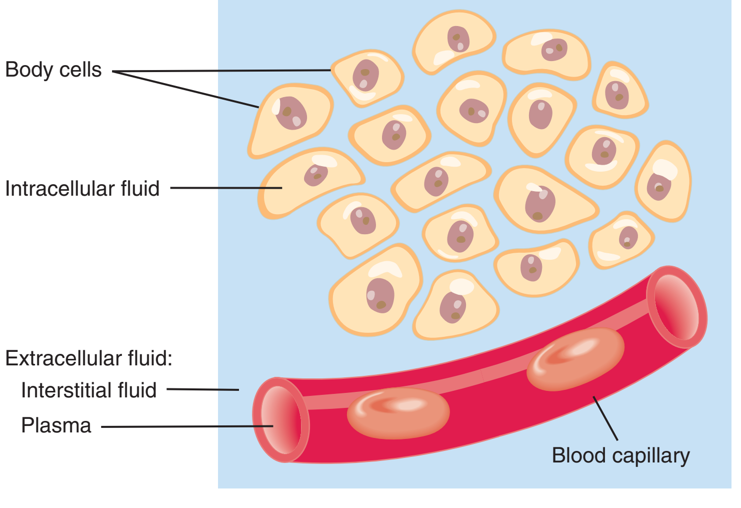
An important aspect of homeostasis is maintaining the volume and composition of **body fluids**, dilute, watery solutions containing dissolved chemicals that are found inside cells as well as surrounding them (**FIGURE 1.2**). In a lean adult, body fluids make up about 55–60% of total body mass; this percentage is lower in an individual with more adipose tissue (fat) because fat cells contain less water than skeletal muscle. About two-thirds of body fluid is **intracellular fluid (ICF)** (*intra-* = inside), the fluid within cells. The other one-third, called **extracellular fluid (ECF)** (*extra-* = outside), is fluid outside body cells. ECF consists of two components: (1) **interstitial fluid** (*inter-* = between), the fluid that fills the narrow spaces between cells, and (2) **plasma**, the fluid portion of blood. Interstitial fluid constitutes about 80% of the ECF, and plasma comprises the remaining 20%.

The proper functioning of body cells depends on precise regulation of the composition of their surrounding fluid. Because extracellular fluid surrounds the cells of the body, it serves as the body's **internal environment**. By contrast, the **external environment** of the body is the space that surrounds the entire body.

FIGURE 1.3 is a simplified view of the body that shows how a number of organ systems allow substances to be exchanged between the external environment, internal environment, and body cells in order to maintain homeostasis. Note that the integumentary system covers the outer surface of the body. Although this system does not play a major role in the exchange of materials, it protects the internal environment from damaging agents in the external environment. From the external environment, oxygen enters plasma through the respiratory system and nutrients enter plasma through the digestive system. After entering plasma, these substances are transported throughout the body by the cardiovascular system. Oxygen and nutrients eventually leave plasma and enter interstitial fluid by crossing the walls of blood capillaries, the smallest blood vessels of the body. Blood capillaries are specialized to allow the transfer of material between plasma and interstitial fluid. From interstitial fluid, oxygen and nutrients are taken up by cells and metabolized for energy. During this process, the cells produce waste products, which enter interstitial fluid and then move across blood capillary walls into plasma. The cardiovascular system transports these wastes to the appropriate organs for elimination from the body into the external environment. The waste product CO_2 is removed from the body by the respiratory system; nitrogen-containing wastes, such as urea and ammonia, are eliminated from the body by the urinary system.

FIGURE 1.2 Body fluid compartments.

The fluid within cells is intracellular fluid; the fluid outside cells is extracellular fluid, which consists of interstitial fluid and plasma.



What is the difference between interstitial fluid and plasma?

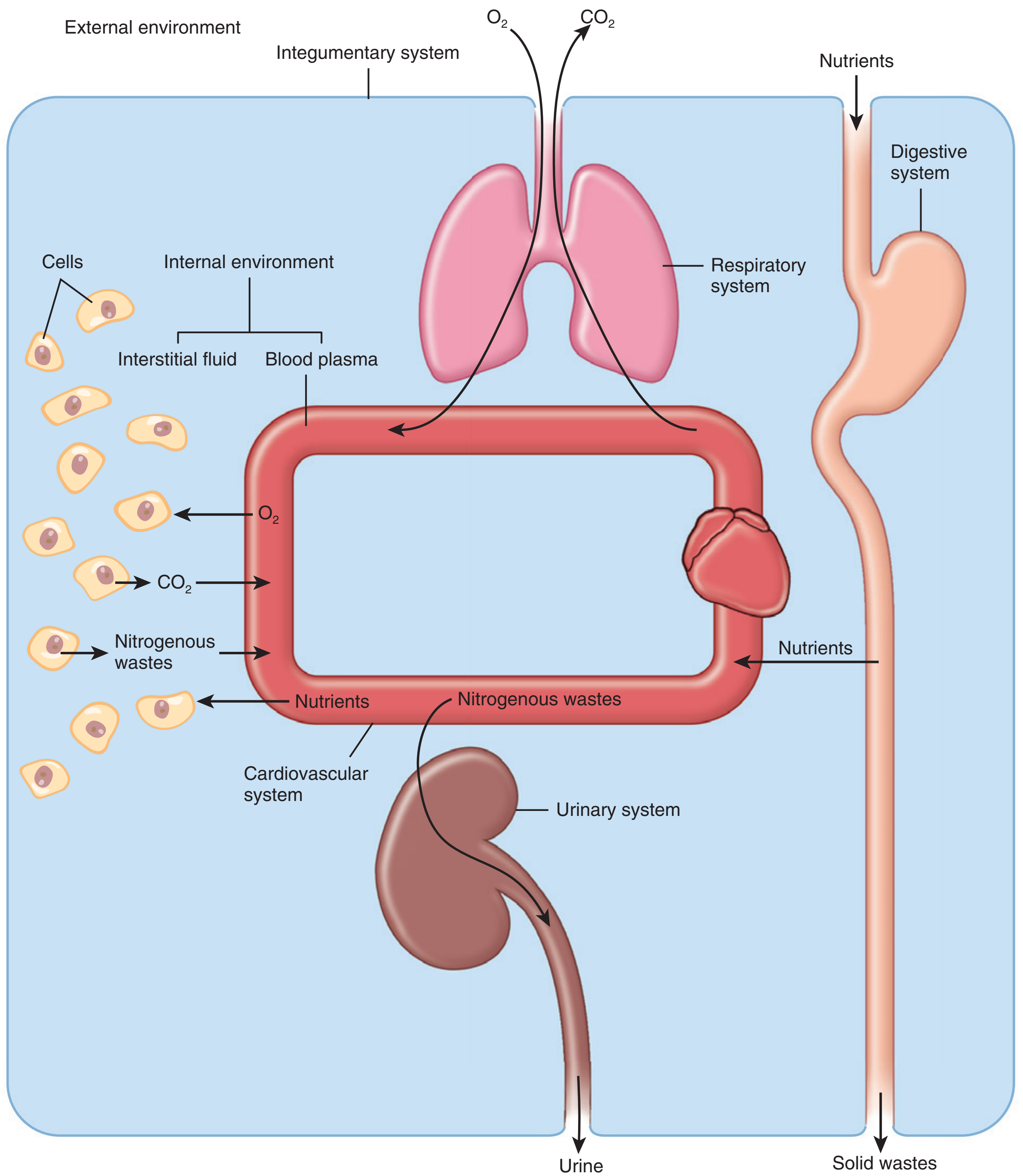
Homeostasis Is Regulated via Feedback Systems and Feedforward Control

Homeostasis in the human body is continually being disturbed. Some disruptions come from the external environment in the form of physical insults such as the intense heat of a hot summer day or a lack of enough oxygen for that two-mile run. Other disruptions originate in the internal environment, such as a blood glucose level that falls too low when you skip breakfast. Homeostatic imbalances may also occur due to psychological stresses in our social environment—the demands of work and school, for example. In most cases the disruption of homeostasis is mild and temporary, and the responses of body cells quickly restore balance in the internal environment. However, in some cases the disruption of homeostasis may be intense and prolonged, as in poisoning, overexposure to temperature extremes, severe infection, or major surgery.

Fortunately, the body has many regulating systems that can usually bring the internal environment back into balance. Most often, the nervous system and the endocrine system, working together or independently, provide the needed corrective measures. The nervous system regulates homeostasis by sending action potentials (electrical signals) to organs that can counteract changes from the balanced state. The endocrine system includes many glands, organs, and tissues that secrete messenger molecules called *hormones* into the blood. Action potentials typically cause rapid changes, but hormones usually work more slowly. Both means of regulation, however, work toward the same end, usually through negative feedback systems.

FIGURE 1.3 A simplified view of exchanges between the external and internal environments. Note that the linings of the respiratory, digestive, and urinary systems are continuous with the external environment.

The internal environment of the body refers to the extracellular fluid (interstitial fluid and plasma) that surrounds body cells.



How does a nutrient in the external environment reach a body cell?

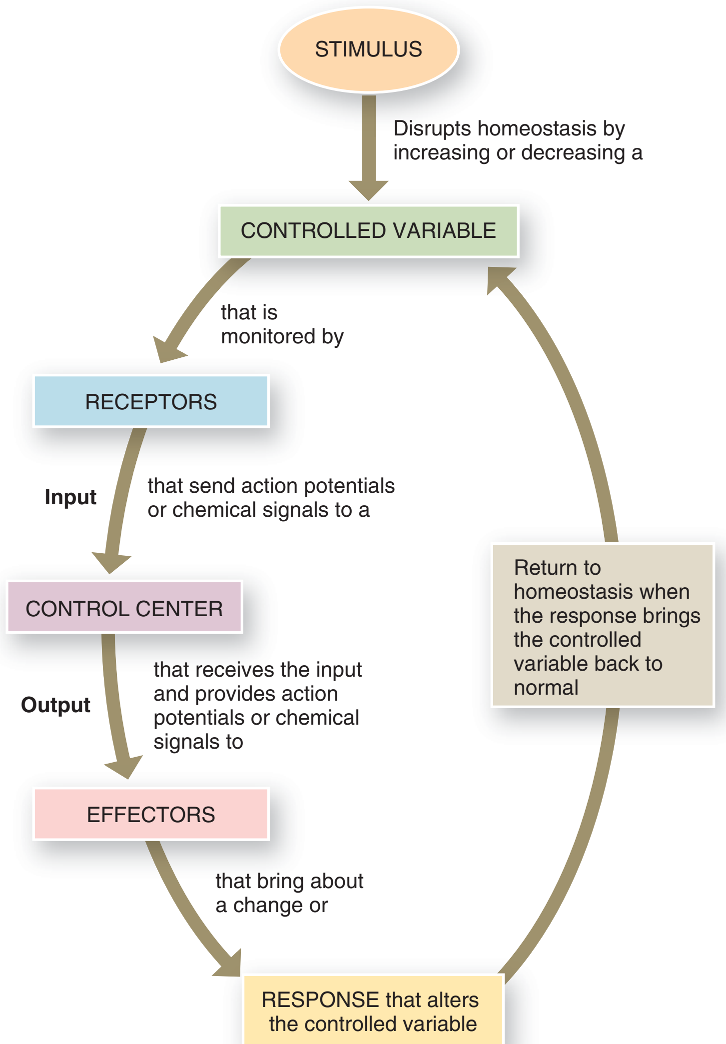
Feedback Systems

The body can regulate its internal environment through many feedback systems. A **feedback system** or *feedback loop* is a cycle of events in which a parameter of the internal environment is monitored, evaluated, changed, remonitored, reevaluated, and so on. Each monitored parameter is called a **controlled variable**. Examples of controlled variables include body temperature, blood pressure, blood glucose level, blood pH, and blood oxygen content. Any disruption that changes a controlled variable is called a *stimulus*. A feedback system includes three basic components—a receptor, a control center, and an effector (FIGURE 1.4).

1. A **receptor** is a body structure that monitors changes in a controlled variable and sends input to a control center. Typically, the

FIGURE 1.4 Operation of a feedback system. The solid return arrow symbolizes feedback.

The three basic components of a feedback system are the receptor, control center, and effector.



What is the main difference between negative and positive feedback systems?

input is in the form of action potentials or chemical signals. For example, certain nerve endings in the skin sense temperature and can detect changes, such as a dramatic drop in temperature.

2. A **control center** in the body determines the narrow range or **set point** within which a controlled variable should be maintained, evaluates the input it receives from receptors, and generates output commands when they are needed. *Output* from the control center typically occurs as action potentials, or hormones or other chemical signals. In the skin temperature example, the brain acts as the control center, receiving action potentials from the skin receptors and generating action potentials as output.
3. An **effector** is a body structure that receives output from the control center and produces a *response* or effect that changes the controlled variable. Nearly every organ or tissue in the body can behave as an effector; in many cases, the effector is a muscle or a gland. When your body temperature drops sharply, your brain (control center) sends action potentials (output) to your skeletal muscles (effectors). The result is shivering, which generates heat and raises your body temperature.

A group of receptors and effectors communicating with their control center forms a feedback system that can regulate a controlled variable in the body's internal environment. In a feedback system, the response of the system "feeds back" information to change the controlled variable in some way, either negating it (negative feedback) or enhancing it (positive feedback).

NEGATIVE FEEDBACK SYSTEMS A **negative feedback system** *reverses* a change in a controlled variable. Most controlled variables in the body, such as body temperature, blood pressure, and blood glucose level, are regulated by negative feedback systems. Consider the regulation of blood pressure. Blood pressure (BP) is the force exerted by blood as it presses against the walls of blood vessels. When the heart beats faster or harder, BP increases. If some internal or external stimulus causes blood pressure (controlled variable) to rise, the following sequence of events occurs (FIGURE 1.5). *Baroreceptors* (the receptors), pressure-sensitive neurons located in the walls of certain blood vessels, detect the higher pressure. These neurons send action potentials (input) to the brain (control center), which interprets the electrical signals and responds by sending action potentials (output) to the heart and blood vessels (the effectors). Heart rate decreases and blood vessels dilate (widen), which cause BP to decrease (response). This sequence of events quickly returns the controlled variable—blood pressure—to normal, and homeostasis is restored. Notice that the activity of the effector causes BP to drop, a result that negates the original stimulus (an increase in BP). This is why it is called a negative feedback system.

POSITIVE FEEDBACK SYSTEMS A **positive feedback system** *strengthens* or *reinforces* a change in a controlled variable. A positive feedback system operates similarly to a negative feedback system except for the way the response affects the controlled variable. The control center still provides commands to an effector, but this time the effector produces a physiological response that adds to or *reinforces* the initial change in the controlled variable. The action of a positive feedback system continues until it is interrupted by some mechanism.

Normal childbirth provides a good example of a positive feedback system (FIGURE 1.6). The first contractions of labor (stimulus) push part of the fetus into the cervix, the lowest part of the uterus, which opens into the vagina. Stretch-sensitive neurons (receptors) monitor the amount of stretching of the cervix (controlled variable). As stretching increases, they send more action potentials (input) to the brain (control center), which in turn causes the pituitary gland to release the hormone oxytocin (output) into the blood. Oxytocin causes muscles in the wall of the uterus (effector) to contract even more forcefully. The contractions push the fetus farther down the uterus, which stretches the cervix even more. The cycle of stretching, hormone release, and ever-stronger contractions is interrupted only by the birth of the baby. Then stretching of the cervix ceases and oxytocin is no longer released.

This example suggests some important differences between positive and negative feedback systems. Because a positive feedback system continually reinforces a change in a controlled variable, some event outside the system must shut it off. If the action of a positive feedback system is not stopped, it can "run away" and may even produce life-threatening conditions in the body. The action of a negative feedback system, by