INTRODUCTORY ANATOMY AND PHYSIOLOGY (APTEKAR)



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Introductory Anatomy and Physiology (Aptekar)

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TABLE OF CONTENTS

Licensing

1: Introduction to the Human Body

- 1.1: The Human Body - Introduction
- 1.2: Overview of Anatomy and Physiology
- 1.3: Structural Organization of the Human Body
- 1.4: Functions of Human Life
- 1.5: Requirements for Human Life
- 1.6: Homeostasis
- 1.7: Anatomical Terminology

2: Cells and Tissues

- 2.1: Cells Introduction- Case Study- The Importance of Cells
- 2.2: Discovery of Cells and Cell Theory
- 2.3: Variation in Cells
- 2.4: Plasma Membrane
- 2.5: Cytoplasm and Cytoskeleton
- 2.6: Cell Organelles
- 2.7: Cell Transport
- 2.8: Active Transport and Homeostasis
- 2.9: Cell Reproduction- Mitosis and Meiosis
- 2.10: Human Cells and Tissues
- 2.11: Case Study Conclusion- Tired and Chapter Summary

3: Integumentary System

- 3.1: Case Study- Skin Cancer
- 3.2: Introduction to the Integumentary System
- 3.3: Layers of the Skin
- 3.4: Accessory Structures of the Skin
- 3.5: Functions of the Integumentary System
- 3.6: Diseases, Disorders, and Injuries of the Integumentary System
- 3.7: Case Study Conclusion- Skin Cancer and Chapter Summary

4: Skeletal System

- 4.1: Case Study- Your Support System
- 4.2: Introduction to the Skeletal System
- 4.3: Divisions of the Skeletal System
- 4.4: Structure of Bone
- 4.5: Bone Growth, Remodeling, and Repair
- 4.6: Joints
- 4.7: Disorders of the Skeletal System
- 4.8: Case Study Conclusion- Heels and Chapter Summary

5: Muscular System

- 5.1: Case Study- Muscles and Movement
- 5.2: Introduction to the Muscular System
- 5.3: Types of Muscle Tissue
- 5.4: Naming Skeletal Muscle
- 5.5: Skeletal Muscle Functions and Structures
- 5.6: Muscle Contraction
- 5.7: Physical Exercise
- 5.8: Disorders of the Muscular System
- 5.9: Case Study Conclusion- Needing to Relax and Chapter Summary

6: Nervous System

- 6.1: Case Study- The Control Center of Your Body
- 6.2: Introduction to the Nervous System
- 6.3: Neurons
- 6.4: Nerve Impulses
- 6.5: Central Nervous System
- 6.6: Peripheral Nervous System
- 6.7: Psychoactive Drugs
- 6.8: Case Study Conclusion- Memory and Chapter Summary

7: Senses

- 7.1: Introduction to the Senses
- 7.2: Vision
- 7.3: Hearing and Balance
- 7.4: Taste and Smell
- 7.5: Touch

8: Endocrine System

- 8.1: Case Study- Hormones and Health
- 8.2: Introduction to the Endocrine System
- 8.3: Endocrine Hormones
- 8.4: Pituitary Gland and Hypothalamus
- 8.5: Thyroid Gland
- 8.6: Parathyroid Glands
- 8.7: Adrenal Glands
- 8.8: Pancreas
- 8.9: Case Study Conclusion- Hormonal and Chapter Summary

9: Cardiovascular System - Blood

- 9.1: Blood- Introduction
- 9.2: An Overview of Blood
- 9.3: Production of the Formed Elements
- 9.4: Erythrocytes
- 9.5: Leukocytes and Platelets
- 9.6: Hemostasis
- 9.7: Blood Typing

- 9.9: Blood- Chapter Review

10: Cardiovascular System- Heart and Blood Vessels

- 10.1: Case Study- Your Body's Transportation System
- 10.2: Introduction to the Cardiovascular System
- 10.3: Heart
- 10.4: Cardiac Cycle and Electrical Activity
- 10.5: Cardiac Cycle
- 10.6: Blood Vessels
- 10.7: Cardiovascular Disease
- 10.8: Case Study Conclusion- Flight and Chapter Summary

11: Lymphatic and Immune Systems

- 11.1: Case Study- Your Defense System
- 11.2: Introduction to the Immune System
- 11.3: Lymphatic System
- 11.4: Innate Immune System
- 11.5: Adaptive Immune System
- 11.6: Disorders of the Immune System
- 11.7: Human Microbiome
- 11.8: Case Study Conclusion- Lymphoma and Chapter Summary

12: Respiratory System

- 12.1: Case Study- Respiratory System and Gas Exchange
- 12.2: Structure and Function of the Respiratory System
- 12.3: Breathing
- 12.4: Disorders of the Respiratory System
- 12.5: Smoking and Health
- 12.6: Case Study Conclusion- Bronchitis and Chapter Summary

13: Digestive System

- 13.1: Case Study- Food Processing
- 13.2: Introduction to the Digestive System
- 13.3: Digestion and Absorption
- 13.4: Upper Gastrointestinal Tract
- 13.5: Lower Gastrointestinal Tract
- 13.6: Accessory Organs of Digestion
- 13.7: Disorders of the Gastrointestinal Tract
- 13.8: Case Study Conclusion- Celiac and Chapter Summary

14: Urinary System

- 14.1: Case Study- Waste Management
- 14.2: Introduction to the Urinary System
- 14.3: Kidneys
- 14.4: Ureters, Urinary Bladder, and Urethra
- 14.5: Disorders of the Urinary System
- 14.6: Case Study Conclusion- Alcohol and Chapter Summary

15: Reproductive System

- 15.1: Case Study- Making Babies
- 15.2: Introduction to the Reproductive System
- 15.3: Structures of the Male Reproductive System
- 15.4: Functions of the Male Reproductive System
- 15.5: Disorders of the Male Reproductive System
- 15.6: Structures of the Female Reproductive System
- 15.7: Menstrual Cycle
- 15.8: Functions of the Female Reproductive System
- 15.9: Disorders of the Female Reproductive System
- 15.10: Infertility
- 15.11: Contraception
- 15.12: Case Study Conclusion- Trying to Conceive and Chapter Summary

Index

Glossary

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Licensing

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CHAPTER OVERVIEW

1: Introduction to the Human Body

This chapter begins with an overview of anatomy and physiology and a preview of the body regions and functions. It then covers the characteristics of life and how the body works to maintain stable conditions. It introduces a set of standard terms for body structures and for planes and positions in the body that will serve as a foundation for more comprehensive information covered later in the text. It ends with examples of medical imaging used to see inside the living body.

1.1: The Human Body - Introduction
1.2: Overview of Anatomy and Physiology
1.3: Structural Organization of the Human Body
1.4: Functions of Human Life
1.5: Requirements for Human Life
1.6: Homeostasis
1.7: Anatomical Terminology

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1.1: The Human Body - Introduction



Figure 1.1.1: Blood **Pressure.** A proficiency in anatomy and physiology is fundamental to any career in the health professions. (credit: Bryan Mason/flickr)

Though you may approach a course in anatomy and physiology strictly as a requirement for your field of study, the knowledge you gain in this course will serve you well in many aspects of your life. An understanding of anatomy and physiology is not only fundamental to any career in the health professions, but it can also benefit your own health. Familiarity with the human body can help you make healthful choices and prompt you to take appropriate action when signs of illness arise. Your knowledge in this field will help you understand news about nutrition, medications, medical devices, and procedures and help you understand genetic or infectious diseases. At some point, everyone will have a problem with some aspect of his or her body and your knowledge can help you to be a better parent, spouse, partner, friend, colleague, or caregiver.

This chapter begins with an overview of anatomy and physiology and a preview of the body regions and functions. It then covers the characteristics of life and how the body works to maintain stable conditions. It introduces a set of standard terms for body structures and for planes and positions in the body that will serve as a foundation for more comprehensive information covered later in the text. It ends with examples of medical imaging used to see inside the living body.

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1.2: Overview of Anatomy and Physiology

Learning Objectives

- Compare and contrast anatomy and physiology, including their specializations and methods of study
- Discuss the fundamental relationship between anatomy and physiology

Human **anatomy** is the scientific study of the body's structures. Some of these structures are very small and can only be observed and analyzed with the assistance of a microscope. Other larger structures can readily be seen, manipulated, measured, and weighed. The word "anatomy" comes from a Greek root that means "to cut apart." Human anatomy was first studied by observing the exterior of the body and observing the wounds of soldiers and other injuries. Later, physicians were allowed to dissect bodies of the dead to augment their knowledge. When a body is dissected, its structures are cut apart in order to observe their physical attributes and their relationships to one another. Dissection is still used in medical schools, anatomy courses, and in pathology labs. In order to observe structures in living people, however, a number of imaging techniques have been developed. These techniques allow clinicians to visualize structures inside the living body such as a cancerous tumor or a fractured bone.

Like most scientific disciplines, anatomy has areas of specialization. **Gross anatomy** is the study of the larger structures of the body, those visible without the aid of magnification (Figure 1.2.1.*a*). Macro- means "large," thus, gross anatomy is also referred to as macroscopic anatomy. In contrast, micro- means "small," and **microscopic anatomy** is the study of structures that can be observed only with the use of a microscope or other magnification devices (Figure 1.2.1.*b*). Microscopic anatomy includes cytology, the study of cells and histology, the study of tissues. As the technology of microscopes has advanced, anatomists have been able to observe smaller and smaller structures of the body, from slices of large structures like the heart, to the three-dimensional structures of large molecules in the body.

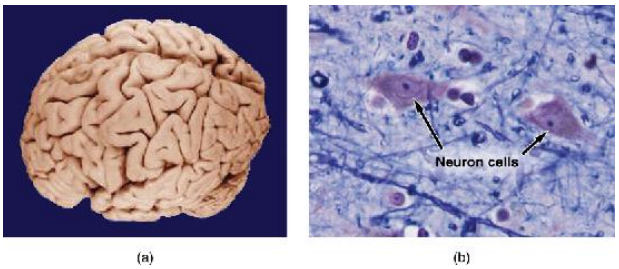


Figure 1.2.1: Gross and Microscopic Anatomy. (a) Gross anatomy considers large structures such as the brain. (b) Microscopic anatomy can deal with the same structures, though at a different scale. This is a micrograph of nerve cells from the brain. LM × 1600. (credit a: "WriterHound"/Wikimedia Commons; credit b: Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Anatomists take two general approaches to the study of the body's structures: regional and systemic. **Regional anatomy** is the study of the interrelationships of all of the structures in a specific body region, such as the abdomen. Studying regional anatomy helps us appreciate the interrelationships of body structures, such as how muscles, nerves, blood vessels, and other structures work together to serve a particular body region. In contrast, **systemic anatomy** is the study of the structures that make up a discrete body system—that is, a group of structures that work together to perform a unique body function. For example, a systemic anatomical study of the muscular system would consider all of the skeletal muscles of the body.

Whereas anatomy is about structure, physiology is about function. Human **physiology** is the scientific study of the chemistry and physics of the structures of the body and the ways in which they work together to support the functions of life. Much of the study of physiology centers on the body's tendency toward homeostasis. **Homeostasis** is the state of steady internal conditions maintained by living things. The study of physiology certainly includes observation, both with the naked eye and with microscopes, as well as manipulations and measurements. However, current advances in physiology usually depend on carefully designed laboratory experiments that reveal the functions of the many structures and chemical compounds that make up the human body.

Like anatomists, physiologists typically specialize in a particular branch of physiology. For example, neurophysiology is the study of the brain, spinal cord, and nerves and how these work together to perform functions as complex and diverse as vision,

movement, and thinking. Physiologists may work from the organ level (exploring, for example, what different parts of the brain do) to the molecular level (such as exploring how an electrochemical signal travels along nerves).

Form is closely related to function in all living things. For example, the thin flap of your eyelid can snap down to clear away dust particles and almost instantaneously slide back up to allow you to see again. At the microscopic level, the arrangement and function of the nerves and muscles that serve the eyelid allow for its quick action and retreat. At a smaller level of analysis, the function of these nerves and muscles likewise relies on the interactions of specific molecules and ions. Even the three-dimensional structure of certain molecules is essential to their function.

Your study of anatomy and physiology will make more sense if you continually relate the form of the structures you are studying to their function. In fact, it can be somewhat frustrating to attempt to study anatomy without an understanding of the physiology that a body structure supports. Imagine, for example, trying to appreciate the unique arrangement of the bones of the human hand if you had no conception of the function of the hand. Fortunately, your understanding of how the human hand manipulates tools—from pens to cell phones—helps you appreciate the unique alignment of the thumb in opposition to the four fingers, making your hand a structure that allows you to pinch and grasp objects and type text messages.

Chapter Review

Human anatomy is the scientific study of the body's structures. In the past, anatomy has primarily been studied via observing injuries, and later by the dissection of anatomical structures of cadavers, but in the past century, computer-assisted imaging techniques have allowed clinicians to look inside the living body. Human physiology is the scientific study of the chemistry and physics of the structures of the body. Physiology explains how the structures of the body work together to maintain life. It is difficult to study structure (anatomy) without knowledge of function (physiology). The two disciplines are typically studied together because form and function are closely related in all living things.

Review Questions

Q. Which of the following specialties might focus on studying all of the structures of the ankle and foot?

A. microscopic anatomy

B. muscle anatomy

C. regional anatomy

D. systemic anatomy

Answer: C

Q. A scientist wants to study how the body uses foods and fluids during a marathon run. This scientist is most likely a(n) _____.

A. exercise physiologist

B. microscopic anatomist

C. regional physiologist

D. systemic anatomist

Answer: A

Critical Thinking Questions

Q. Name at least three reasons to study anatomy and physiology.

A. An understanding of anatomy and physiology is essential for any career in the health professions. It can also help you make choices that promote your health, respond appropriately to signs of illness, make sense of health-related news, and help you in your roles as a parent, spouse, partner, friend, colleague, and caregiver.

Q. For whom would an appreciation of the structural characteristics of the human heart come more easily: an alien who lands on Earth, abducts a human, and dissects his heart, or an anatomy and physiology student performing a dissection of the heart on her very first day of class? Why?

> A. A student would more readily appreciate the structures revealed in the dissection. Even though the student has not yet studied the workings of the heart and blood vessels in her class, she has experienced her heart beating every moment of her life, has probably felt her pulse, and likely has at least a basic understanding of the role of the heart in pumping blood throughout her body. This understanding of the heart's function (physiology) would support her study of the heart's form (anatomy).

Glossary

anatomy

science that studies the form and composition of the body's structures

gross anatomy

study of the larger structures of the body, typically with the unaided eye; also referred to macroscopic anatomy

homeostasis

steady state of body systems that living organisms maintain

microscopic anatomy

study of very small structures of the body using magnification

physiology

science that studies the chemistry, biochemistry, and physics of the body's functions

regional anatomy

study of the structures that contribute to specific body regions

systemic anatomy

study of the structures that contribute to specific body systems

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1.3: Structural Organization of the Human Body

Learning Objectives

- Describe the structure of the human body in terms of six levels of organization
- List the eleven organ systems of the human body and identify at least one organ and one major function of each

Before you begin to study the different structures and functions of the human body, it is helpful to consider its basic architecture; that is, how its smallest parts are assembled into larger structures. It is convenient to consider the structures of the body in terms of fundamental levels of organization that increase in complexity: subatomic particles, atoms, molecules, organelles, cells, tissues, organs, organ systems, organisms and biosphere (Figure 1.3.1).

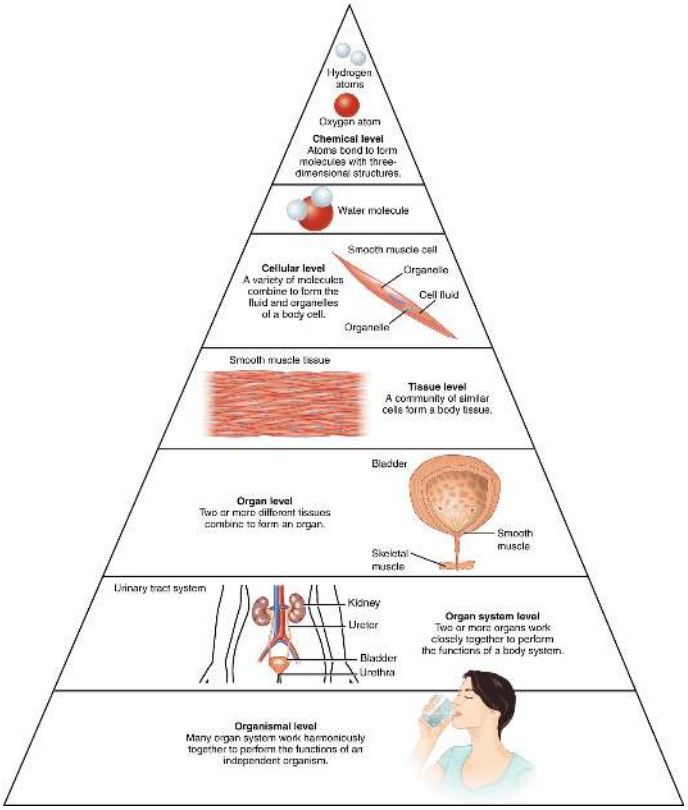


Figure 1.3.1: Levels of Structural Organization of the Human Body. The organization of the body often is discussed in terms of six distinct levels of increasing complexity, from the smallest chemical building blocks to a unique human organism.

The Levels of Organization

To study the chemical level of organization, scientists consider the simplest building blocks of matter: subatomic particles, atoms and molecules. All matter in the universe is composed of one or more unique pure substances called elements, familiar examples of which are hydrogen, oxygen, carbon, nitrogen, calcium, and iron. The smallest unit of any of these pure substances (elements) is an atom. Atoms are made up of subatomic particles such as the proton, electron and neutron. Two or more atoms combine to form a molecule, such as the water molecules, proteins, and sugars found in living things. Molecules are the chemical building blocks of all body structures.

A **cell** is the smallest independently functioning unit of a living organism. Even bacteria, which are extremely small, independently-living organisms, have a cellular structure. Each bacterium is a single cell. All living structures of human anatomy contain cells, and almost all functions of human physiology are performed in cells or are initiated by cells.

A human cell typically consists of flexible membranes that enclose cytoplasm, a water-based cellular fluid together with a variety of tiny functioning units called **organelles**. In humans, as in all organisms, cells perform all functions of life. A **tissue** is a group of

many similar cells (though sometimes composed of a few related types) that work together to perform a specific function. An **organ** is an anatomically distinct structure of the body composed of two or more tissue types. Each organ performs one or more specific physiological functions. An **organ system** is a group of organs that work together to perform major functions or meet physiological needs of the body.

This book covers eleven distinct organ systems in the human body (Figure 1.3.2 and Figure 1.3.3). Assigning organs to organ systems can be imprecise since organs that "belong" to one system can also have functions integral to another system. In fact, most organs contribute to more than one system.

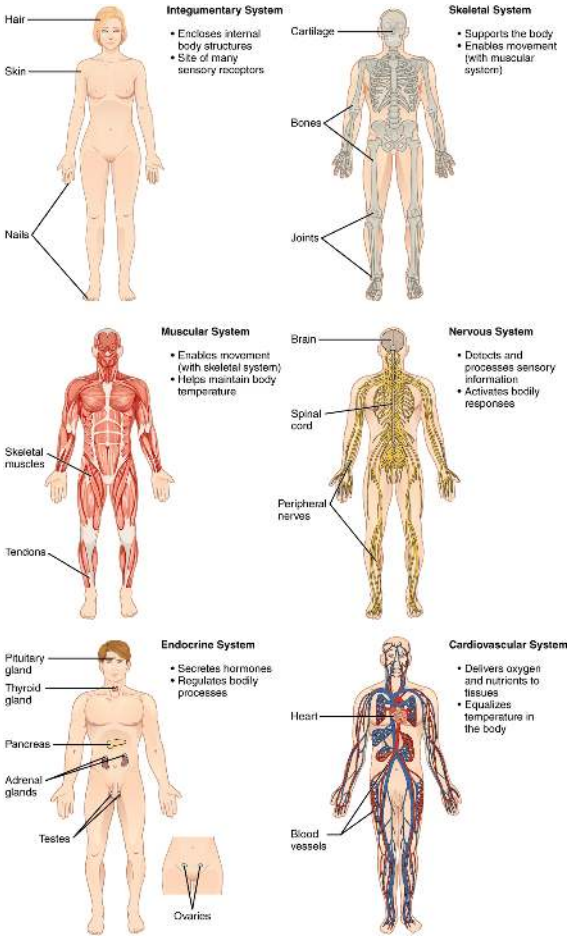


Figure 1.3.2: Organ Systems of the Human Body. Organs that work together are grouped into organ systems.

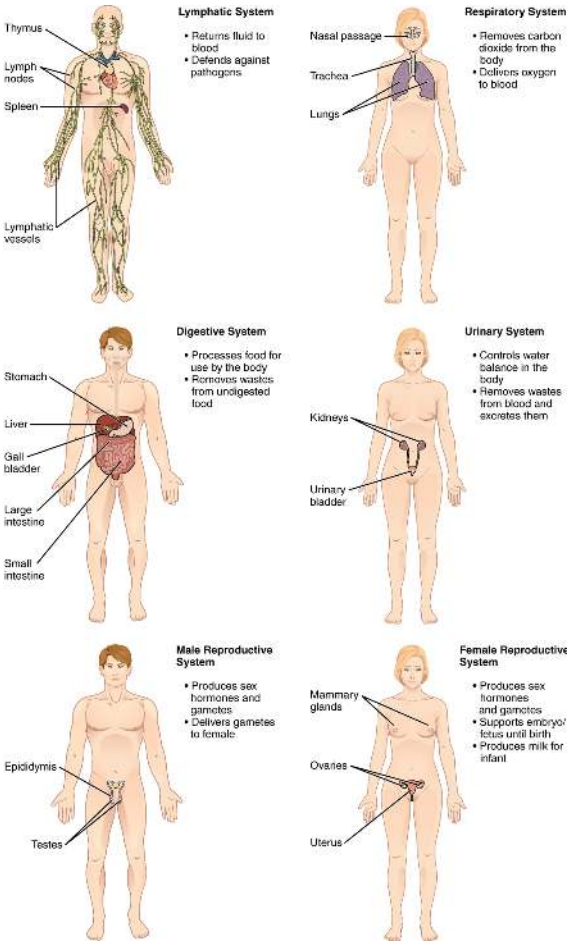


Figure 1.3.3: Organ Systems of the Human Body (continued). Organs that work together are grouped into organ systems.

The organism level is the highest level of organization. An **organism** is a living being that has a cellular structure and that can independently perform all physiologic functions necessary for life. In multicellular organisms, including humans, all cells, tissues, organs, and organ systems of the body work together to maintain the life and health of the organism.

Chapter Review

Life processes of the human body are maintained at several levels of structural organization. These include the chemical, cellular, tissue, organ, organ system, and the organism level. Higher levels of organization are built from lower levels. Therefore, molecules combine to form cells, cells combine to form tissues, tissues combine to form organs, organs combine to form organ systems, and organ systems combine to form organisms.

Review Questions

Q. The smallest independently functioning unit of an organism is a(n) _____.

A. cell

B. molecule

C. organ

D. tissue

Answer: A

Q. A collection of similar tissues that performs a specific function is an _____.

A. organ

B. organelle

C. organism

D. organ system

Answer: A

Q. The body system responsible for structural support and movement is the _____.

A. cardiovascular system

B. endocrine system

C. muscular system

D. skeletal system

Answer: D

Critical Thinking Questions

Q. Name the six levels of organization of the human body.

A. Chemical, cellular, tissue, organ, organ system, organism.

Q. The female ovaries and the male testes are a part of which body system? Can these organs be members of more than one organ system? Why or why not?

A. The female ovaries and the male testes are parts of the reproductive system. But they also secrete hormones, as does the endocrine system, therefore ovaries and testes function within both the endocrine and reproductive systems.

Glossary

cell
smallest independently functioning unit of all organisms; in animals, a cell contains cytoplasm, composed of fluid and organelles

organ
functionally distinct structure composed of two or more types of tissues

organ system
group of organs that work together to carry out a particular function

organism
living being that has a cellular structure and that can independently perform all physiologic functions necessary for life

tissue
group of similar or closely related cells that act together to perform a specific function

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1.4: Functions of Human Life

Learning Objectives

- Explain the importance of organization to the function of the human organism
- Distinguish between metabolism, anabolism, and catabolism
- Provide at least two examples of human responsiveness and human movement
- Compare and contrast growth, differentiation, and reproduction

The different organ systems each have different functions and therefore unique roles to perform in physiology. These many functions can be summarized in terms of a few that we might consider definitive of human life: organization, metabolism, responsiveness, movement, development, and reproduction.

Organization

A human body consists of trillions of cells organized in a way that maintains distinct internal compartments. These compartments keep body cells separated from external environmental threats and keep the cells moist and nourished. They also separate internal body fluids from the countless microorganisms that grow on body surfaces, including the lining of certain tracts, or passageways. The intestinal tract, for example, is home to even more bacteria cells than the total of all human cells in the body, yet these bacteria are outside the body and cannot be allowed to circulate freely inside the body.

Cells, for example, have a cell membrane (also referred to as the plasma membrane) that keeps the intracellular environment—the fluids and organelles—separate from the extracellular environment. Blood vessels keep blood inside a closed circulatory system, and nerves and muscles are wrapped in connective tissue sheaths that separate them from surrounding structures. In the chest and abdomen, a variety of internal membranes keep major organs such as the lungs, heart, and kidneys separate from others.

The body's largest organ system is the integumentary system, which includes the skin and its associated structures, such as hair and nails. The surface tissue of skin is a barrier that protects internal structures and fluids from potentially harmful microorganisms and other toxins.

Metabolism

The first law of thermodynamics holds that energy can neither be created nor destroyed—it can only change form. Your basic function as an organism is to consume (ingest) energy and molecules in the foods you eat, convert some of it into fuel for movement, sustain your body functions, and build and maintain your body structures. There are two types of reactions that accomplish this:**anabolism** and **catabolism**.

- **Anabolism** is the process whereby smaller, simpler molecules are combined into larger, more complex substances. Your body can assemble, by utilizing energy, the complex chemicals it needs by combining small molecules derived from the foods you eat
- **Catabolism** is the process by which larger more complex substances are broken down into smaller simpler molecules. Catabolism releases energy. The complex molecules found in foods are broken down so the body can use their parts to assemble the structures and substances needed for life.

Taken together, these two processes are called metabolism. **Metabolism** is the sum of all anabolic and catabolic reactions that take place in the body (Figure 1.4.1). Both anabolism and catabolism occur simultaneously and continuously to keep you alive.

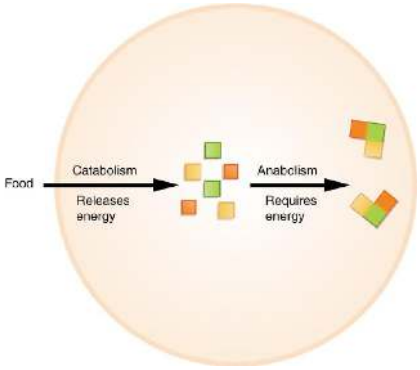
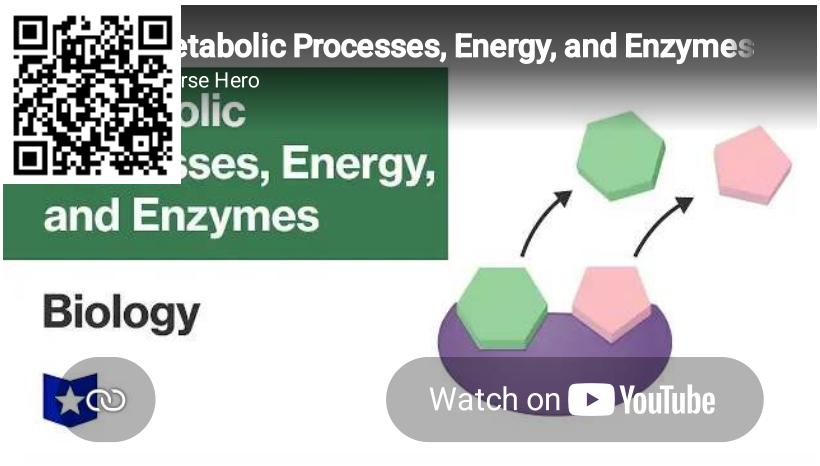


Figure 1.4.1: Metabolism. Anabolic reactions are building reactions, and they consume energy. Catabolic reactions break materials down and release energy. Metabolism includes both anabolic and catabolic reactions.

Every cell in your body makes use of a chemical compound, adenosine triphosphate (ATP), to store and release energy. The cell stores energy in the synthesis (anabolism) of ATP, then moves the ATP molecules to the location where energy is needed to fuel cellular activities. Then the ATP is broken down (catabolism) and a controlled amount of energy is released, which is used by the cell to perform a particular job.

QR Code representing a URL

View this animation to learn more about metabolic processes. What kind of catabolism occurs in the heart?



Responsiveness

Responsiveness is the ability of an organism to adjust to changes in its internal and external environments. An example of responsiveness to external stimuli could include moving toward sources of food and water and away from perceived dangers. Changes in an organism's internal environment, such as increased body temperature, can cause the responses of sweating and the dilation of blood vessels in the skin in order to decrease body temperature, as shown by the runners in Figure 1.4.2.

Movement

Human movement includes not only actions at the joints of the body, but also the motion of individual organs and even individual cells. As you read these words, red and white blood cells are moving throughout your body, muscle cells are contracting and relaxing to maintain your posture and to focus your vision, and glands are secreting chemicals to regulate body functions. Your body is coordinating the action of entire muscle groups to enable you to move air into and out of your lungs, to push blood throughout your body, and to propel the food you have eaten through your digestive tract. Consciously, of course, you contract your skeletal muscles to move the bones of your skeleton to get from one place to another (as the runners are doing in Figure 1.4.2), and to carry out all of the activities of your daily life.



Figure 1.4.2: Marathon **Runners.** Runners demonstrate two characteristics of living humans—responsiveness and movement. Anatomic structures and physiological processes allow runners to coordinate the action of muscle groups and sweat in response to rising internal body temperature. (credit: Phil Roeder/flickr)

Development, growth and reproduction

Development is all of the changes the body goes through in life. Development includes the processes of differentiation, growth, and renewal.

Growth is the increase in body size. Humans, like all multicellular organisms, grow by increasing the number of existing cells, increasing the amount of non-cellular material around cells (such as mineral deposits in bone), and, within very narrow limits, increasing the size of existing cells.

Reproduction is the formation of a new organism from parent organisms. In humans, reproduction is carried out by the male and female reproductive systems. Because death will come to all complex organisms, without reproduction, the line of organisms would end.

Chapter Review

Most processes that occur in the human body are not consciously controlled. They occur continuously to build, maintain, and sustain life. These processes include: organization, in terms of the maintenance of essential body boundaries; metabolism, including energy transfer via anabolic and catabolic reactions; responsiveness; movement; and growth, differentiation, reproduction, and renewal.

Interactive Link Questions

View this animation to learn more about metabolic processes. What kind of catabolism occurs in the heart?

Answer: Fatty acid catabolism.

Review Questions

Q. Metabolism can be defined as the _____.

A. adjustment by an organism to external or internal changes

B. process whereby all unspecialized cells become specialized to perform distinct functions

C. process whereby new cells are formed to replace worn-out cells

D. sum of all chemical reactions in an organism

Answer: D

Q. Adenosine triphosphate (ATP) is an important molecule because it _____.

A. is the result of catabolism

B. release energy in uncontrolled bursts

C. stores energy for use by body cells

D. All of the above

Answer: C

Q. Cancer cells can be characterized as “generic” cells that perform no specialized body function. Thus cancer cells lack _____.

A. differentiation

B. reproduction

C. responsiveness

D. both reproduction and responsiveness

Answer: A

Critical Thinking Questions

Q. Explain why the smell of smoke when you are sitting at a campfire does not trigger alarm, but the smell of smoke in your residence hall does.

A. When you are sitting at a campfire, your sense of smell adapts to the smell of smoke. Only if that smell were to suddenly and dramatically intensify would you be likely to notice and respond. In contrast, the smell of even a trace of smoke would be new and highly unusual in your residence hall, and would be perceived as danger.

Q. Identify three different ways that growth can occur in the human body.

A. Growth can occur by increasing the number of existing cells, increasing the size of existing cells, or increasing the amount of non-cellular material around cells.

Glossary

anabolism
assembly of more complex molecules from simpler molecules

catabolism
breaking down of more complex molecules into simpler molecules

development
changes an organism goes through during its life

differentiation
process by which unspecialized cells become specialized in structure and function

growth
process of increasing in size

metabolism
sum of all of the body's chemical reactions

renewal
process by which worn-out cells are replaced

reproduction
process by which new organisms are generated

responsiveness
ability of an organisms or a system to adjust to changes in conditions

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1.5: Requirements for Human Life

Learning Objectives

- Discuss the role of oxygen and nutrients in maintaining human survival
- Explain why extreme heat and extreme cold threaten human survival
- Explain how the pressure exerted by gases and fluids influences human survival

Humans have been adapting to life on Earth for at least the past 200,000 years. Earth and its atmosphere have provided us with air to breathe, water to drink, and food to eat, but these are not the only requirements for survival. Although you may rarely think about it, you also cannot live outside of a certain range of temperature and pressure that the surface of our planet and its atmosphere provides. The next sections explore these four requirements of life.

Oxygen

Atmospheric air is only about 20 percent oxygen, but that oxygen is a key component of the chemical reactions that keep the body alive, including the reactions that produce ATP. Brain cells are especially sensitive to lack of oxygen because of their requirement for a high-and-steady production of ATP. Brain damage is likely within five minutes without oxygen, and death is likely within ten minutes.

Nutrients

A **nutrient** is a substance in foods and beverages that is essential to human survival. The three basic classes of nutrients are water, the energy-yielding and body-building nutrients, and the micronutrients (vitamins and minerals).

The most critical nutrient is water. Depending on the environmental temperature and our state of health, we may be able to survive for only a few days without water. The body's functional chemicals are dissolved and transported in water, and the chemical reactions of life take place in water. Moreover, water is the largest component of cells, blood, and the fluid between cells, and water makes up about 70 percent of an adult's body mass. Water also helps regulate our internal temperature and cushions, protects, and lubricates joints and many other body structures.

The energy-yielding nutrients are primarily carbohydrates and lipids, while proteins mainly supply the amino acids that are the building blocks of the body itself. You ingest these in plant and animal foods and beverages, and the digestive system breaks them down into molecules small enough to be absorbed. The breakdown products of carbohydrates and lipids can then be used in the metabolic processes that convert them to ATP. Although you might feel as if you are starving after missing a single meal, you can survive without consuming the energy-yielding nutrients for at least several weeks.

Water and the energy-yielding nutrients are also referred to as macronutrients because the body needs them in large amounts. In contrast, micronutrients are vitamins and minerals. These elements and compounds participate in many essential chemical reactions and processes, such nerve impulses, and some, such as calcium, also contribute to the body's structure. Your body can store some of the micronutrients in its tissues, and draw on those reserves if you fail to consume them in your diet for a few days or weeks. Some others micronutrients, such as vitamin C and most of the B vitamins, are water-soluble and cannot be stored, so you need to consume them every day or two.

Narrow Range of Temperature

You have probably seen news stories about athletes who died of heat stroke, or hikers who died of exposure to cold. Such deaths occur because the chemical reactions upon which the body depends can only take place within a narrow range of body temperature, from just below to just above 37°C (98.6°F). When body temperature rises well above or drops well below normal, certain proteins (enzymes) that facilitate chemical reactions lose their normal structure and their ability to function and the chemical reactions of metabolism cannot proceed.

That said, the body can respond effectively to short-term exposure to heat (Figure 1.5.1) or cold. One of the body's responses to heat is, of course, sweating. As sweat evaporates from skin, it removes some thermal energy from the body, cooling it. Adequate water (from the extracellular fluid in the body) is necessary to produce sweat, so adequate fluid intake is essential to balance that

loss during the sweat response. Not surprisingly, the sweat response is much less effective in a humid environment because the air is already saturated with water. Thus, the sweat on the skin's surface is not able to evaporate, and internal body temperature can get dangerously high.



Figure 1.5.1: Extreme **Heat.** Humans adapt to some degree to repeated exposure to high temperatures. (credit: McKay Savage/flickr)

The body can also respond effectively to short-term exposure to cold. One response to cold is shivering, which is random muscle movement that generates heat. Another response is increased breakdown of stored energy to generate heat. When that energy reserve is depleted, however, and the core temperature begins to drop significantly, red blood cells will lose their ability to give up oxygen, denying the brain of this critical component of ATP production. This lack of oxygen can cause confusion, lethargy, and eventually loss of consciousness and death. The body responds to cold by reducing blood circulation to the extremities, the hands and feet, in order to prevent blood from cooling there and so that the body's core can stay warm. Even when core body temperature remains stable, however, tissues exposed to severe cold, especially the fingers and toes, can develop frostbite when blood flow to the extremities has been much reduced. This form of tissue damage can be permanent and lead to gangrene, requiring amputation of the affected region.

EVERYDAY CONNECTION

Controlled Hypothermia

As you have learned, the body continuously engages in coordinated physiological processes to maintain a stable temperature. In some cases, however, overriding this system can be useful, or even life-saving. Hypothermia is the clinical term for an abnormally low body temperature (hypo- = "below" or "under"). Controlled hypothermia is clinically induced hypothermia performed in order to reduce the metabolic rate of an organ or of a person's entire body.

Controlled hypothermia often is used, for example, during open-heart surgery because it decreases the metabolic needs of the brain, heart, and other organs, reducing the risk of damage to them. When controlled hypothermia is used clinically, the patient is given medication to prevent shivering. The body is then cooled to 25–32°C (79–89°F). The heart is stopped and an external heart-lung pump maintains circulation to the patient's body. The heart is cooled further and is maintained at a temperature below 15°C (60°F) for the duration of the surgery. This very cold temperature helps the heart muscle to tolerate its lack of blood supply during the surgery.

Some emergency department physicians use controlled hypothermia to reduce damage to the heart in patients who have suffered a cardiac arrest. In the emergency department, the physician induces coma and lowers the patient's body temperature to approximately 91 degrees. This condition, which is maintained for 24 hours, slows the patient's metabolic rate. Because the patient's organs require less blood to function, the heart's workload is reduced.

Narrow Range of Atmospheric Pressure

Pressure is a force exerted by a substance that is in contact with another substance. Atmospheric pressure is pressure exerted by the mixture of gases (primarily nitrogen and oxygen) in the Earth's atmosphere. Although you may not perceive it, atmospheric pressure is constantly pressing down on your body. This pressure keeps gases within your body, such as the gaseous nitrogen in body fluids, dissolved. If you were suddenly ejected from a space ship above Earth's atmosphere, you would go from a situation of normal pressure to one of very low pressure. The pressure of the nitrogen gas in your blood would be much higher than the pressure of nitrogen in the space surrounding your body. As a result, the nitrogen gas in your blood would expand, forming bubbles that could block blood vessels and even cause cells to break apart.

Atmospheric pressure does more than just keep blood gases dissolved. Your ability to breathe—that is, to take in oxygen and release carbon dioxide—also depends upon a precise atmospheric pressure. Altitude sickness occurs in part because the atmosphere at high altitudes exerts less pressure, reducing the exchange of these gases, and causing shortness of breath, confusion, headache, lethargy, and nausea. Mountain climbers carry oxygen to reduce the effects of both low oxygen levels and low barometric pressure at higher altitudes (Figure 1.5.2).



Figure 1.5.2: Harsh **Conditions.** *Climbers on Mount Everest must accommodate extreme cold, low oxygen levels, and low barometric pressure in an environment hostile to human life. (credit: Melanie Ko/flickr)*

HOMEOSTATIC IMBALANCES

Decompression Sickness

Decompression sickness (DCS) is a condition in which gases dissolved in the blood or in other body tissues are no longer dissolved following a reduction in pressure on the body. This condition affects underwater divers who surface from a deep dive too quickly, and it can affect pilots flying at high altitudes in planes with unpressurized cabins. Divers often call this condition “the bends,” a reference to joint pain that is a symptom of DCS.

In all cases, DCS is brought about by a reduction in barometric pressure. At high altitude, barometric pressure is much less than on Earth’s surface because pressure is produced by the weight of the column of air above the body pressing down on the body. The very great pressures on divers in deep water are likewise from the weight of a column of water pressing down on the body. For divers, DCS occurs at normal barometric pressure (at sea level), but it is brought on by the relatively rapid decrease of pressure as divers rise from the high pressure conditions of deep water to the now low, by comparison, pressure at sea level. Not surprisingly, diving in deep mountain lakes, where barometric pressure at the surface of the lake is less than that at sea level is more likely to result in DCS than diving in water at sea level.

In DCS, gases dissolved in the blood (primarily nitrogen) come rapidly out of solution, forming bubbles in the blood and in other body tissues. This occurs because when pressure of a gas over a liquid is decreased, the amount of gas that can remain dissolved in the liquid also is decreased. It is air pressure that keeps your normal blood gases dissolved in the blood. When pressure is reduced, less gas remains dissolved. You have seen this in effect when you open a carbonated drink. Removing the seal of the bottle reduces the pressure of the gas over the liquid. This in turn causes bubbles as dissolved gases (in this case, carbon dioxide) come out of solution in the liquid.

The most common symptoms of DCS are pain in the joints, with headache and disturbances of vision occurring in 10 percent to 15 percent of cases. Left untreated, very severe DCS can result in death. Immediate treatment is with pure oxygen. The affected person is then moved into a hyperbaric chamber. A hyperbaric chamber is a reinforced, closed chamber that is pressurized to greater than atmospheric pressure. It treats DCS by repressurizing the body so that pressure can then be removed much more gradually. Because the hyperbaric chamber introduces oxygen to the body at high pressure, it increases the concentration of oxygen in the blood. This has the effect of replacing some of the nitrogen in the blood with oxygen, which is easier to tolerate out of solution.

The dynamic pressure of body fluids is also important to human survival. For example, blood pressure, which is the pressure exerted by blood as it flows within blood vessels, must be great enough to enable blood to reach all body tissues, and yet low enough to ensure that the delicate blood vessels can withstand the friction and force of the pulsating flow of pressurized blood.

Chapter Review

Humans cannot survive for more than a few minutes without oxygen, for more than several days without water, and for more than several weeks without carbohydrates, lipids, proteins, vitamins, and minerals. Although the body can respond to high temperatures by sweating and to low temperatures by shivering and increased fuel consumption, long-term exposure to extreme heat and cold is not compatible with survival. The body requires a precise atmospheric pressure to maintain its gases in solution and to facilitate respiration—the intake of oxygen and the release of carbon dioxide. Humans also require blood pressure high enough to ensure that blood reaches all body tissues but low enough to avoid damage to blood vessels.

Review Questions

Q. Humans have the most urgent need for a continuous supply of _____.

A. food

B. nitrogen

C. oxygen

D. water

Answer: C

Q. Which of the following statements about nutrients is true?

A. All classes of nutrients are essential to human survival.

B. Because the body cannot store any micronutrients, they need to be consumed nearly every day.

C. Carbohydrates, lipids, and proteins are micronutrients.

D. Macronutrients are vitamins and minerals.

Answer: A

Q. C.J. is stuck in her car during a bitterly cold blizzard. Her body responds to the cold by _____.

A. increasing the blood to her hands and feet

B. becoming lethargic to conserve heat

C. breaking down stored energy

D. significantly increasing blood oxygen levels

Answer: C

Critical Thinking Questions

Q. When you open a bottle of sparkling water, the carbon dioxide gas in the bottle form bubbles. If the bottle is left open, the water will eventually “go flat.” Explain these phenomena in terms of atmospheric pressure.

A. In a sealed bottle of sparkling water, carbon dioxide gas is kept dissolved in the water under a very high pressure. When you open the bottle, the pressure of the gas above the liquid changes from artificially high to normal atmospheric pressure. The dissolved carbon dioxide gas expands, and rises in bubbles to the surface. When a bottle of sparkling water is left open, it eventually goes flat because its gases continue to move out of solution until the pressure in the water is approximately equal to atmospheric pressure.

Q. On his midsummer trek through the desert, Josh ran out of water. Why is this particularly dangerous?

A. The primary way that the body responds to high environmental heat is by sweating; however, sweating requires water, which comes from body fluids, including blood plasma. If Josh becomes dehydrated, he will be unable to sweat adequately to cool his body, and he will be at risk for heat stroke as his blood pressure drops too much from the loss of water from the blood plasma.

Glossary

nutrient

chemical obtained from foods and beverages that is critical to human survival

pressure

force exerted by a substance in contact with another substance

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1.6: Homeostasis

Learning Objectives

- Discuss the role of homeostasis in healthy functioning
- Contrast negative and positive feedback, giving one physiologic example of each mechanism

Maintaining homeostasis requires that the body continuously monitor its internal conditions. From body temperature to blood pressure to levels of certain nutrients, each physiological condition has a particular set point. A **set point** is the physiological value around which the normal range fluctuates. A **normal range** is the restricted set of values that is optimally healthful and stable. For example, the set point for normal human body temperature is approximately 37°C (98.6°F) Physiological parameters, such as body temperature and blood pressure, tend to fluctuate within a normal range a few degrees above and below that point. Control centers in the brain and other parts of the body monitor and react to deviations from homeostasis using negative feedback. **Negative feedback** is a mechanism that reverses a deviation from the set point. Therefore, negative feedback maintains body parameters within their normal range. The maintenance of homeostasis by negative feedback goes on throughout the body at all times, and an understanding of negative feedback is thus fundamental to an understanding of human physiology.

Negative Feedback

A negative feedback system has three basic components (Figure 1.6.1.*a*). A **sensor**, also referred to a receptor, is a component of a feedback system that monitors a physiological value. This value is reported to the control center. The **control center** is the component in a feedback system that compares the value to the normal range. If the value deviates too much from the set point, then the control center activates an effector. An **effector** is the component in a feedback system that causes a change to reverse the situation and return the value to the normal range.

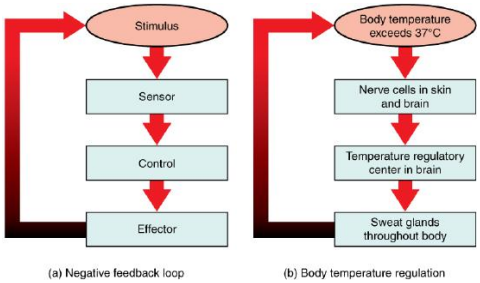


Figure 1.6.1: Negative Feedback **Loop.** In a negative feedback loop, a stimulus—a deviation from a set point—is resisted through a physiological process that returns the body to homeostasis. (a) A negative feedback loop has four basic parts. (b) Body temperature is regulated by negative feedback.

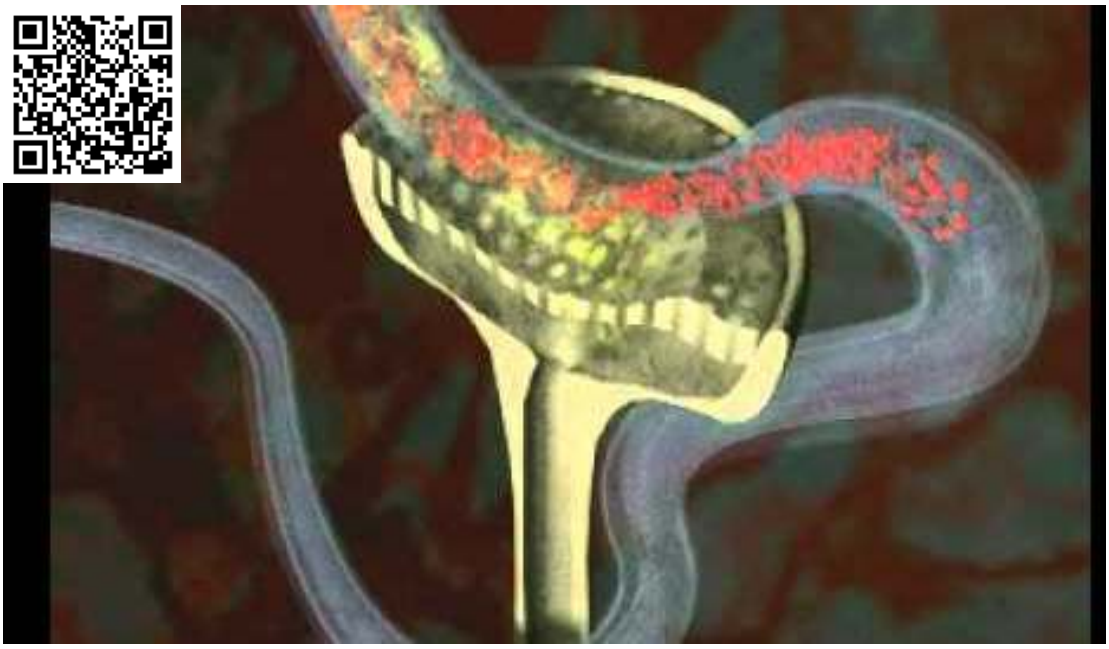
In order to set the system in motion, a stimulus must drive a physiological parameter beyond its normal range (that is, beyond homeostasis). This stimulus is “heard” by a specific sensor. For example, in the control of blood glucose, specific endocrine cells in the pancreas detect excess glucose (the stimulus) in the bloodstream. These pancreatic beta cells respond to the increased level of blood glucose by releasing the hormone insulin into the bloodstream. The insulin signals skeletal muscle fibers, fat cells (adipocytes), and liver cells to take up the excess glucose, removing it from the bloodstream. As glucose concentration in the bloodstream drops, the decrease in concentration—the actual negative feedback—is detected by pancreatic alpha cells, and insulin release stops. This prevents blood sugar levels from continuing to drop below the normal range.

Humans have a similar temperature regulation feedback system that works by promoting either heat loss or heat gain (Figure 1.6.1.*b*). When the brain’s temperature regulation center receives data from the sensors indicating that the body’s temperature exceeds its normal range, it stimulates a cluster of brain cells referred to as the “heat-loss center.” This stimulation has three major effects:

- Blood vessels in the skin begin to dilate allowing more blood from the body core to flow to the surface of the skin allowing the heat to radiate into the environment.
- As blood flow to the skin increases, sweat glands are activated to increase their output. As the sweat evaporates from the skin surface into the surrounding air, it takes heat with it.
- The depth of respiration increases, and a person may breathe through an open mouth instead of through the nasal passageways. This further increases heat loss from the lungs.

In contrast, activation of the brain’s heat-gain center by exposure to cold reduces blood flow to the skin, and blood returning from the limbs is diverted into a network of deep veins. This arrangement traps heat closer to the body core and restricts heat loss. If heat loss is severe, the brain triggers an increase in random signals to skeletal muscles, causing them to contract and producing shivering. The muscle contractions of shivering release heat while using up ATP. The brain triggers the thyroid gland in the endocrine system to release thyroid hormone, which increases metabolic activity and heat production in cells throughout the body. The brain also signals the adrenal glands to release epinephrine (adrenaline), a hormone

that causes the breakdown of glycogen into glucose, which can be used as an energy source. The breakdown of glycogen into glucose also results in increased metabolism and heat production.



Water concentration in the body is critical for proper functioning. A person's body retains very tight control on water levels without conscious control by the person. Watch this video to learn more about water concentration in the body. Which organ has primary control over the amount of water in the body?

Positive Feedback

Positive feedback intensifies a change in the body's physiological condition rather than reversing it. A deviation from the normal range results in more change, and the system moves farther away from the normal range. Positive feedback in the body is normal only when there is a definite end point. Childbirth and the body's response to blood loss are two examples of positive feedback loops that are normal but are activated only when needed.

Childbirth at full term is an example of a situation in which the maintenance of the existing body state is not desired. Enormous changes in the mother's body are required to expel the baby at the end of pregnancy. And the events of childbirth, once begun, must progress rapidly to a conclusion or the life of the mother and the baby are at risk. The extreme muscular work of labor and delivery are the result of a positive feedback system (Figure 1.6.2).

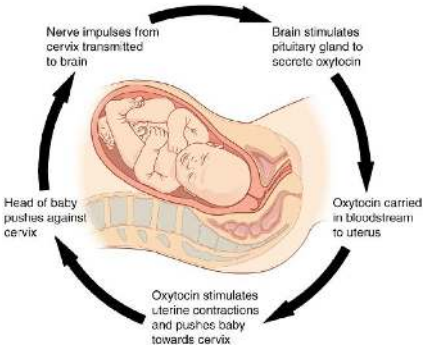


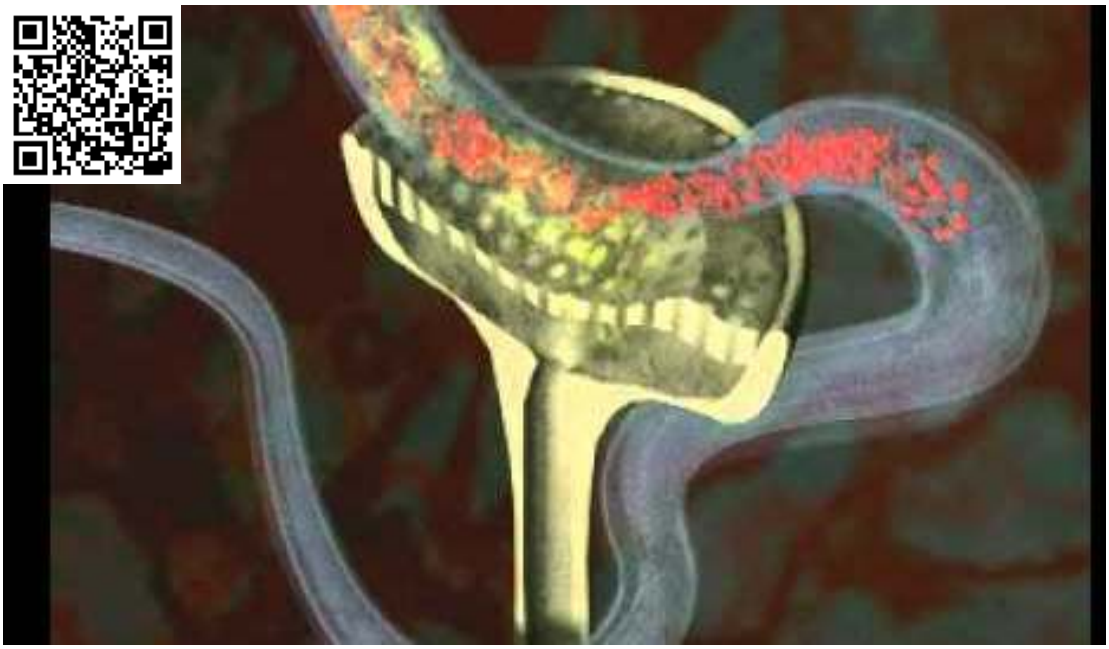
Figure 1.6.2: Positive Feedback Loop. Normal childbirth is driven by a positive feedback loop. A positive feedback loop results in a change in the body's status, rather than a return to homeostasis.

The first contractions of labor (the stimulus) push the baby toward the cervix (the lowest part of the uterus). The cervix contains stretch-sensitive nerve cells that monitor the degree of stretching (the sensors). These nerve cells send messages to the brain, which in turn causes the pituitary gland at the base of the brain to release the hormone oxytocin into the bloodstream. Oxytocin causes stronger contractions of the smooth muscles in of the uterus (the effectors), pushing the baby further down the birth canal. This causes even greater stretching of the cervix. The cycle of stretching, oxytocin release, and increasingly more forceful contractions stops only when the baby is born. At this point, the stretching of the cervix halts, stopping the release of oxytocin.

A second example of positive feedback centers on reversing extreme damage to the body. Following a penetrating wound, the most immediate threat is excessive blood loss. Less blood circulating means reduced blood pressure and reduced perfusion (penetration of blood) to the brain and other vital organs. If perfusion is severely reduced, vital organs will shut down and the person will die. The body responds to this potential catastrophe by releasing substances in the injured blood vessel wall that begin the process of blood clotting. As each step of clotting occurs, it stimulates the release of more clotting substances. This accelerates the processes of clotting and sealing off the damaged area. Clotting is contained in a local area based on the tightly controlled availability of clotting proteins. This is an adaptive, life-saving cascade of events.

Interactive Link Questions

Water concentration in the body is critical for proper functioning. A person's body retains very tight control on water levels without conscious control by the person. Watch this video to learn more about water concentration in the body. Which organ has primary control over the amount of water in the body?



Answer: The kidneys.

Review Questions

After you eat lunch, nerve cells in your stomach respond to the distension (the stimulus) resulting from the food. They relay this information to _____.

A. a control center

B. a set point

C. effectors

D. sensors

Answer: A

Stimulation of the heat-loss center causes _____.

A. blood vessels in the skin to constrict

B. breathing to become slow and shallow

C. sweat glands to increase their output

D. All of the above

Answer: C

Which of the following is an example of a normal physiologic process that uses a positive feedback loop?

A. blood pressure regulation

B. childbirth

C. regulation of fluid balance

D. temperature regulation

Answer: B

Critical Thinking Questions

Q. Identify the four components of a negative feedback loop and explain what would happen if secretion of a body chemical controlled by a negative feedback system became too great.

A. The four components of a negative feedback loop are: stimulus, sensor, control center, and effector. If too great a quantity of the chemical were excreted, sensors would activate a control center, which would in turn activate an effector. In this case, the effector (the secreting cells) would be adjusted downward.

Q. What regulatory processes would your body use if you were trapped by a blizzard in an unheated, uninsulated cabin in the woods?

A. Any prolonged exposure to extreme cold would activate the brain's heat-gain center. This would reduce blood flow to your skin, and shunt blood returning from your limbs away from the digits and into a network of deep veins. Your brain's heat-gain center would also increase your muscle contraction, causing you to shiver. This increases the energy consumption of skeletal muscle and generates more heat. Your body would also produce thyroid hormone and epinephrine, chemicals that promote increased metabolism and heat production.

Chapter Review

Homeostasis is the activity of cells throughout the body to maintain the physiological state within a narrow range that is compatible with life. Homeostasis is regulated by negative feedback loops and, much less frequently, by positive feedback loops. Both have the same components of a stimulus, sensor, control center, and effector; however, negative feedback loops work to prevent an excessive response to the stimulus, whereas positive feedback loops intensify the response until an end point is reached.

Glossary

control center
compares values to their normal range; deviations cause the activation of an effector

effector
organ that can cause a change in a value

negative feedback
homeostatic mechanism that tends to stabilize an upset in the body's physiological condition by preventing an excessive response to a stimulus, typically as the stimulus is removed

normal range
range of values around the set point that do not cause a reaction by the control center

positive feedback
mechanism that intensifies a change in the body's physiological condition in response to a stimulus

sensor
(also, receptor) reports a monitored physiological value to the control center

set point
ideal value for a physiological parameter; the level or small range within which a physiological parameter such as blood pressure is stable and optimally healthful, that is, within its parameters of homeostasis

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1.7: Anatomical Terminology

Learning Objectives

- Demonstrate the anatomical position
- Describe the human body using directional and regional terms
- Identify three planes most commonly used in te study of anatomy
- Distinguish between the posterior (dorsal) and anterior (ventral) body cavities, identifying their subdivisions and representative organs found in each
- Describe serous membrane and explain its function

Anatomists and health care providers use terminology that can be bewildering to the uninitiated. However, the purpose of this language is not to confuse, but rather to increase precision and reduce medical errors. For example, is a scar “above the wrist” located on the forearm two or three inches away from the hand? Or is it at the base of the hand? Is it on the palm-side or back-side? By using precise anatomical terminology, we eliminate ambiguity. Anatomical terms derive from ancient Greek and Latin words. Because these languages are no longer used in everyday conversation, the meaning of their words does not change.

Anatomical terms are made up of roots, prefixes, and suffixes. The root of a term often refers to an organ, tissue, or condition, whereas the prefix or suffix often describes the root. For example, in the disorder hypertension, the prefix “hyper-” means “high” or “over,” and the root word “tension” refers to pressure, so the word “hypertension” refers to abnormally high blood pressure.

Anatomical Position

To further increase precision, anatomists standardize the way in which they view the body. Just as maps are normally oriented with north at the top, the standard body “map,” or **anatomical position**, is that of the body standing upright, with the feet at shoulder width and parallel, toes forward. The upper limbs are held out to each side, and the palms of the hands face forward as illustrated in Figure 1.7.1. Using this standard position reduces confusion. It does not matter how the body being described is oriented, the terms are used as if it is in anatomical position. For example, a scar in the “anterior (front) carpal (wrist) region” would be present on the palm side of the wrist. The term “anterior” would be used even if the hand were palm down on a table.

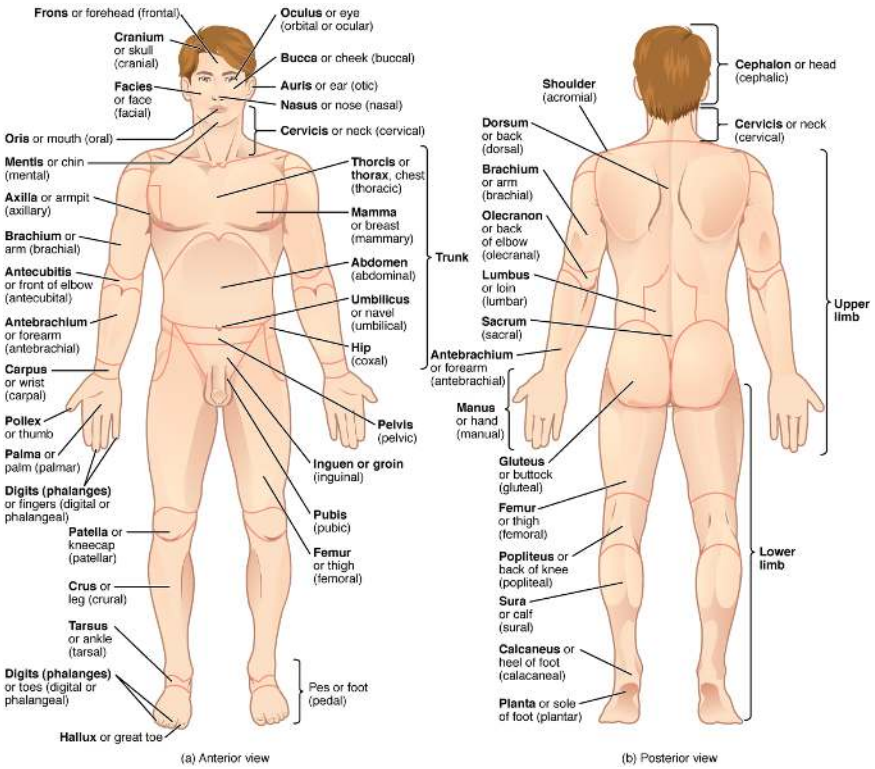


Figure 1.7.1: Regions of the Human **Body.** The human body is shown in anatomical position in an (a) anterior view and a (b) posterior view. The regions of the body are labeled in boldface.

A body that is lying down is described as either prone or supine. **Prone** describes a face-down orientation, and **supine** describes a face up orientation. These terms are sometimes used in describing the position of the body during specific physical examinations or surgical procedures.

Regional Terms

The human body's numerous regions have specific terms to help increase precision (see Figure 1.7.1). Notice that the term "brachium" or "arm" is reserved for the "upper arm" and "antebrachium" or "forearm" is used rather than "lower arm." Similarly, "femur" or "thigh" is correct, and "leg" or "crus" is reserved for the portion of the lower limb between the knee and the ankle. You will be able to describe the body's regions using the terms from the figure.

Directional Terms

Certain directional anatomical terms appear throughout this and any other anatomy textbook (Figure 1.7.2). These terms are essential for describing the relative locations of different body structures. For instance, an anatomist might describe one band of tissue as "inferior to" another or a physician might describe a tumor as "superficial to" a deeper body structure. Commit these terms to memory to avoid confusion when you are studying or describing the locations of particular body parts.

- **Anterior** (or **ventral**) Describes the front or direction toward the front of the body. The toes are anterior to the foot.
- **Posterior** (or **dorsal**) Describes the back or direction toward the back of the body. The popliteus is posterior to the patella.
- **Superior** (or **cranial**) describes a position above or higher than another part of the body proper. The orbits are superior to the oris.
- **Inferior** (or **caudal**) describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column). The pelvis is inferior to the abdomen.
- **Lateral** describes the side or direction toward the side of the body. The thumb (pollex) is lateral to the digits.
- **Medial** describes the middle or direction toward the middle of the body. The hallux is the medial toe.
- **Proximal** describes a position in a limb that is nearer to the point of attachment or the trunk of the body. The brachium is proximal to the antebrachium.
- **Distal** describes a position in a limb that is farther from the point of attachment or the trunk of the body. The crus is distal to the femur.
- **Superficial** describes a position closer to the surface of the body. The skin is superficial to the bones.
- **Deep** describes a position farther from the surface of the body. The brain is deep to the skull.

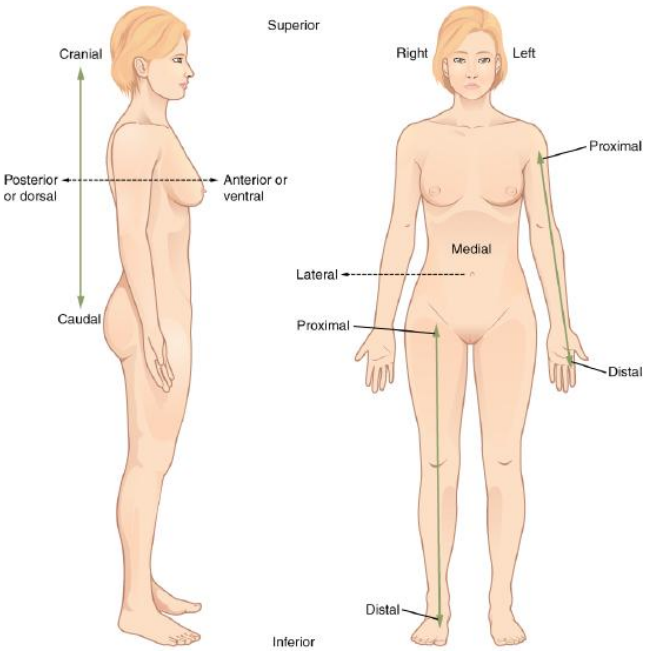


Figure 1.7.2: Directional Terms Applied to the Human Body. Paired directional terms are shown as applied to the human body.

Body Planes

A section is a two-dimensional surface of a three-dimensional structure that has been cut. Modern medical imaging devices enable clinicians to obtain “virtual sections” of living bodies. We call these scans. Body sections and scans can be correctly interpreted, however, only if the viewer understands the plane along which the section was made. A **plane** is an imaginary two-dimensional surface that passes through the body. There are three planes commonly referred to in anatomy and medicine, as illustrated in Figure 1.7.3.

- The **sagittal plane**is the plane that divides the body or an organ vertically into right and left sides. If this vertical plane runs directly down the middle of the body, it is called the midsagittal or median plane. If it divides the body into unequal right and left sides, it is called a parasagittal plane or less commonly a longitudinal section.
- The **frontal plane**is the plane that divides the body or an organ into an anterior (front) portion and a posterior (rear) portion. The frontal plane is often referred to as a coronal plane. (“Corona” is Latin for “crown.”)
- The **transverse plane**is the plane that divides the body or organ horizontally into upper and lower portions. Transverse planes produce images referred to as cross sections.

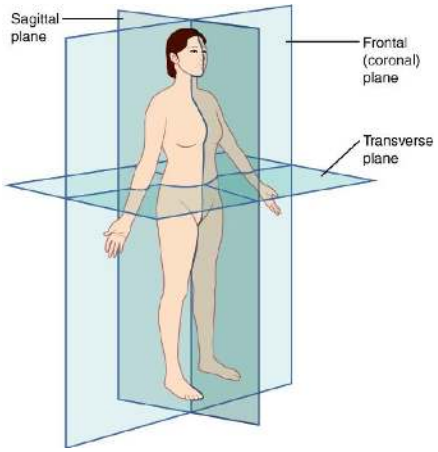


Figure 1.7.3: Planes of the Body. The three planes most commonly used in anatomical and medical imaging are the sagittal, frontal (or coronal), and transverse plane.

Body Cavities and Serous Membranes

The body maintains its internal organization by means of membranes, sheaths, and other structures that separate compartments. The **dorsal (posterior) cavity** and the **ventral (anterior) cavity** are the largest body compartments (Figure 1.7.4). These cavities contain and protect delicate internal organs, and the ventral cavity allows for significant changes in the size and shape of the organs as they perform their functions. The lungs, heart, stomach, and intestines, for example, can expand and contract without distorting other tissues or disrupting the activity of nearby organs.

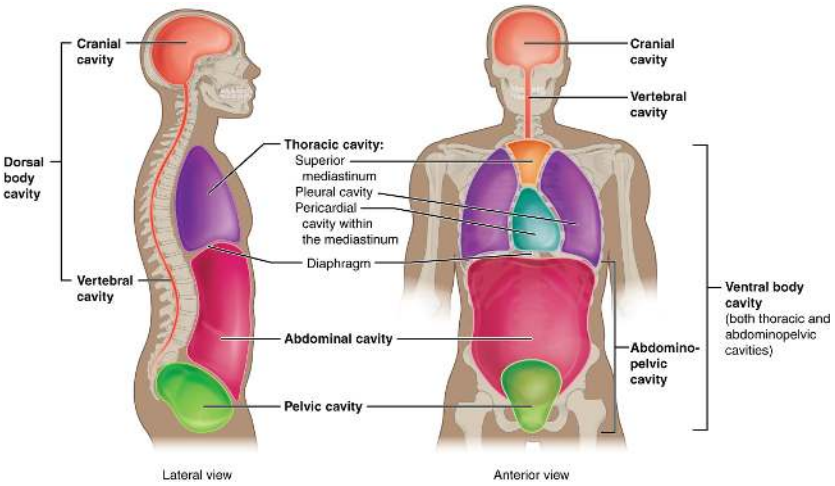


Figure 1.7.4: Dorsal and Ventral Body **Cavities.** The ventral cavity includes the thoracic and abdominopelvic cavities and their subdivisions. The dorsal cavity includes the cranial and spinal cavities.

Subdivisions of the Posterior (Dorsal) and Anterior (Ventral) Cavities

The posterior (dorsal) and anterior (ventral) cavities are each subdivided into smaller cavities. In the posterior (dorsal) cavity, the **cranial cavity** houses the brain, and the **spinal cavity** (or vertebral cavity) encloses the spinal cord. Just as the brain and spinal cord make up a continuous, uninterrupted structure, the cranial and spinal cavities that house them are also continuous. The brain and spinal cord are protected by the bones of the skull and vertebral column and by cerebrospinal fluid, a colorless fluid produced by the brain, which cushions the brain and spinal cord within the posterior (dorsal) cavity.

The anterior (ventral) cavity has two main subdivisions: the thoracic cavity and the abdominopelvic cavity (see Figure 1.7.4). The **thoracic cavity** is the more superior subdivision of the anterior cavity, and it is enclosed by the rib cage. The thoracic cavity contains the lungs and the heart, which is located in the mediastinum. The diaphragm forms the floor of the thoracic cavity and separates it from the more inferior abdominopelvic cavity. The **abdominopelvic cavity** is the largest cavity in the body. Although no membrane physically divides the abdominopelvic cavity, it can be useful to distinguish between the abdominal cavity, the division that houses the digestive organs, and the pelvic cavity, the division that houses the organs of reproduction.

Abdominal Regions and Quadrants

To promote clear communication, for instance about the location of a patient's abdominal pain or a suspicious mass, health care providers typically divide up the cavity into either nine regions or four quadrants (Figure 1.7.5).

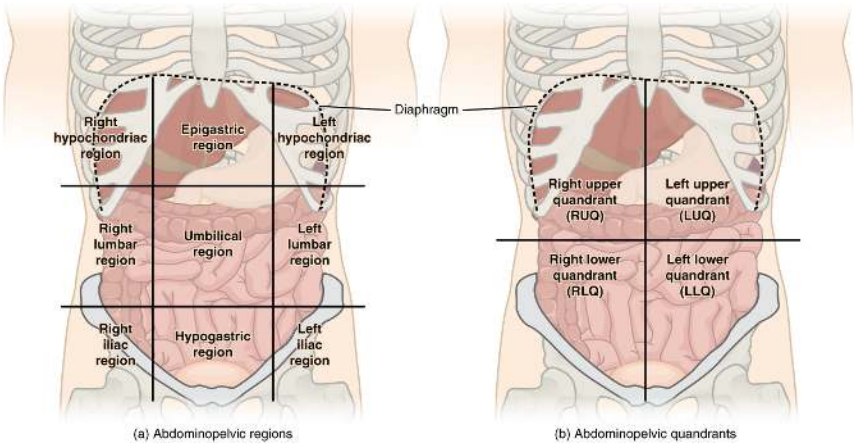


Figure 1.7.5: Regions and Quadrants of the Peritoneal **Cavity.** There are (a) nine abdominal regions and (b) four abdominal quadrants in the peritoneal cavity.

The more detailed regional approach subdivides the cavity with one horizontal line immediately inferior to the ribs and one immediately superior to the pelvis, and two vertical lines drawn as if dropped from the midpoint of each clavicle (collarbone). There are nine resulting regions. The simpler quadrants approach, which is more commonly used in medicine, subdivides the cavity with one horizontal and one vertical line that intersect at the patient's umbilicus (navel).

Membranes of the Anterior (Ventral) Body Cavity

A **serous membrane** (also referred to a serosa) is one of the thin membranes that cover the walls and organs in the thoracic and abdominopelvic cavities. The parietal layers of the membranes line the walls of the body cavity (pariet- refers to a cavity wall). The visceral layer of the membrane covers the organs (the viscera). Between the parietal and visceral layers is a very thin, fluid-filled serous space, or cavity (Figure 1.7.6).

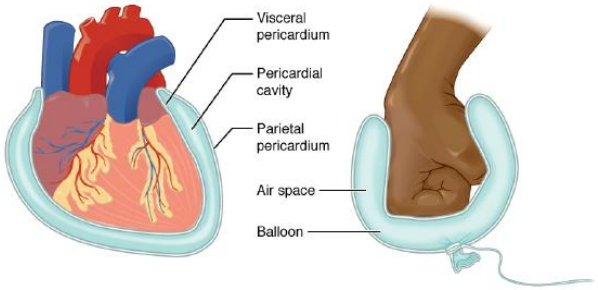


Figure 1.7.6: Serous Membrane. Serous membrane lines the pericardial cavity and reflects back to cover the heart—much the same way that an underinflated balloon would form two layers surrounding a fist.

There are three serous cavities and their associated membranes. The **pleura** is the serous membrane that surrounds the lungs in the pleural cavity; the **pericardium** is the serous membrane that surrounds the heart in the pericardial cavity; and the **peritoneum** is the serous membrane that surrounds several organs in the abdominopelvic cavity. The serous fluid produced by the serous membranes reduces friction between the walls of the cavities and the internal organs when they move, such as when the lungs inflate or the heart beats. Both the parietal and visceral serosa secrete the thin, slippery serous fluid that prevents friction when an organ slides past the walls of a cavity. In the pleural cavities, pleural fluid prevents friction between the lungs and the walls of the cavity. In the pericardial sac, pericardial fluid prevents friction between the heart and the walls of the pericardial sac. And in the peritoneal cavity, peritoneal fluid prevents friction between abdominal and pelvic organs and the wall of the cavity. The serous membranes therefore provide additional protection to the viscera they enclose by reducing friction that could lead to inflammation of the organs.

Chapter Review

Ancient Greek and Latin words are used to build anatomical terms. A standard reference position for mapping the body's structures is the normal anatomical position. Regions of the body are identified using terms such as "occipital" that are more precise than common words and phrases such as "the back of the head." Directional terms such as anterior and posterior are essential for accurately describing the relative locations of body structures. Images of the body's interior commonly align along one of three planes: the sagittal, frontal, or transverse. The body's organs are organized in one of two main cavities—dorsal (also referred to posterior) and ventral (also referred to anterior)—which are further sub-divided according to the structures present in each area. The serous membranes have two layers—parietal and visceral—surrounding a fluid filled space. Serous membranes cover the lungs (pleural serosa), heart (pericardial serosa), and some abdominopelvic organs (peritoneal serosa).

Review Chapter

Q. What is the position of the body when it is in the "normal anatomical position?"

A. The person is prone with upper limbs, including palms, touching sides and lower limbs touching at sides.

B. The person is standing facing the observer, with upper limbs extended out at a ninety-degree angle from the torso and lower limbs in a wide stance with feet pointing laterally

C. The person is supine with upper limbs, including palms, touching sides and lower limbs touching at sides.

D. None of the above

Answer: D

Q. To make a banana split, you halve a banana into two long, thin, right and left sides along the _____.

A. coronal plane

B. longitudinal plane

C. midsagittal plane

D. transverse plane

Answer: C

Q. The lumbar region is _____.

A. inferior to the gluteal region

B. inferior to the umbilical region

C. superior to the cervical region

D. superior to the popliteal region

Answer: D

Q. The heart is within the _____.

A. cranial cavity

B. mediastinum

C. posterior (dorsal) cavity

D. All of the above

Answer: B

Critical Thinking Question

Q. In which direction would an MRI scanner move to produce sequential images of the body in the frontal plane, and in which direction would an MRI scanner move to produce sequential images of the body in the sagittal plane?

> A. If the body were supine or prone, the MRI scanner would move from top to bottom to produce frontal sections, which would divide the body into anterior and posterior portions, as in “cutting” a deck of cards. Again, if the body were supine or prone, to produce sagittal sections, the scanner would move from left to right or from right to left to divide the body lengthwise into left and right portions.

Q. If a bullet were to penetrate a lung, which three anterior thoracic body cavities would it enter, and which layer of the serous membrane would it encounter first?

> A. The bullet would enter the ventral, thoracic, and pleural cavities, and it would encounter the parietal layer of serous membrane first.

Glossary

abdominopelvic cavity
division of the anterior (ventral) cavity that houses the abdominal and pelvic viscera

anatomical position
standard reference position used for describing locations and directions on the human body

anterior
describes the front or direction toward the front of the body; also referred to as ventral

anterior cavity
larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membrane-lined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as ventral cavity

caudal
describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as inferior

cranial
describes a position above or higher than another part of the body proper; also referred to as superior

cranial cavity
division of the posterior (dorsal) cavity that houses the brain

deep
describes a position farther from the surface of the body

distal
describes a position farther from the point of attachment or the trunk of the body

dorsal
describes the back or direction toward the back of the body; also referred to as posterior

dorsal cavity
posterior body cavity that houses the brain and spinal cord; also referred to the posterior body cavity

frontal plane
two-dimensional, vertical plane that divides the body or organ into anterior and posterior portions

inferior
describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as caudal

lateral
describes the side or direction toward the side of the body

medial
describes the middle or direction toward the middle of the body

pericardium
sac that encloses the heart

peritoneum
serous membrane that lines the abdominopelvic cavity and covers the organs found there

plane
imaginary two-dimensional surface that passes through the body

pleura
serous membrane that lines the pleural cavity and covers the lungs

posterior
describes the back or direction toward the back of the body; also referred to as dorsal

posterior cavity
posterior body cavity that houses the brain and spinal cord; also referred to as dorsal cavity

prone
face down

proximal
describes a position nearer to the point of attachment or the trunk of the body

sagittal plane
two-dimensional, vertical plane that divides the body or organ into right and left sides

section
in anatomy, a single flat surface of a three-dimensional structure that has been cut through

serous membrane
membrane that covers organs and reduces friction; also referred to as serosa

serosa
membrane that covers organs and reduces friction; also referred to as serous membrane

spinal cavity
division of the dorsal cavity that houses the spinal cord; also referred to as vertebral cavity

superficial
describes a position nearer to the surface of the body

superior
describes a position above or higher than another part of the body proper; also referred to as cranial

supine

face up

thoracic cavity

division of the anterior (ventral) cavity that houses the heart, lungs, esophagus, and trachea

transverse plane

two-dimensional, horizontal plane that divides the body or organ into superior and inferior portions

ventral

describes the front or direction toward the front of the body; also referred to as anterior

ventral cavity

larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membrane-lined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as anterior body cavity

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CHAPTER OVERVIEW

2: CELLS AND TISSUES

This chapter outlines the discovery of cells and cell theory. It identifies ways in which all cells are alike and ways in which they vary. The chapter describes in detail important cell structures and their functions; and it explains how cells obtain energy, grow, and divide. The chapter also describes the different types of human tissue; epithelial tissue, connective tissue, muscle tissue, and nervous tissue.

2.1: Cells Introduction- Case Study- The Importance of Cells

2.2: Discovery of Cells and Cell Theory

2.3: Variation in Cells

2.4: Plasma Membrane

2.5: Cytoplasm and Cytoskeleton

2.6: Cell Organelles

2.7: Cell Transport

2.8: Active Transport and Homeostasis

2.9: Cell Reproduction- Mitosis and Meiosis

2.10: Human Cells and Tissues

2.11: Case Study Conclusion- Tired and Chapter Summary

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2.1: CELLS INTRODUCTION- CASE STUDY- THE IMPORTANCE OF CELLS

CASE STUDY: MORE THAN JUST TIRED

We all get tired sometimes, especially if we have been doing a lot of physical activity. But for Jasmin, a 34-year-old former high school track star who is now a recreational runner, her tiredness was going far beyond what she thought should be normal for someone who is generally in good physical shape. She was experiencing extreme fatigue after her runs, as well as muscle cramping, spasms, and an unusual sense of heaviness in her legs. At first, she chalked it up to getting older, but her exhaustion and pain worsened to the point where this former athlete could no longer run for more than a few minutes at a time. She also began to experience other unusual symptoms, such as blurry vision and vomiting for no apparent reason.



Figure **2.1.1**: Exhausted

Concerned, she went to her doctor. Her doctor ran many tests and consulted with several specialists. After several months, Jasmin is finally diagnosed with a mitochondrial disease. Jasmin is surprised. She has an 8-year-old niece with a mitochondrial disease, but her niece's symptoms started when she was very young, and included seizures and learning disabilities. How can Jasmin have the same disease but different symptoms? Why did she not have problems until adulthood while her niece had symptoms at an early age? And what are mitochondria anyway?

CHAPTER OVERVIEW: CELLS

As you will learn in this chapter, mitochondria are important structures within our cells. This chapter will describe cells, which are the basic unit of structure and function in all living organisms. Specifically, you will learn:

- How cells were discovered, their common structures, and the principles of cell theory.
- The importance of size and shape in the functions of cells.
- The differences between eukaryotic cells (such as those in humans and other animals) and prokaryotic cells (such as bacteria).
- The structures and functions of parts of cells including mitochondria, the plasma membrane, cytoplasm, cytoskeleton, nucleus, ribosomes, Golgi apparatus, endoplasmic reticulum, vesicles, and vacuoles.
- How the processes of passive and active transport move substances into and out of cells and help maintain homeostasis.
- How organisms cells reproduce and the cell division processes of mitosis and meiosis.
- The variety of different specialized cell types in humans, the four major types of human tissues, and some of their functions.

As you read this chapter, think about the following questions related to Jasmin's disease:

1. What are mitochondria? What is their structure, function, and where did they come from during evolution?
2. Why are fatigue and "exercise intolerance," such as Jasmin's extreme exhaustion after running, common symptoms of mitochondrial diseases?
3. Why do you think Jasmin has symptoms that affect so many different parts of her body including her legs, eyes, and digestive system?

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2.2: DISCOVERY OF CELLS AND CELL THEORY

A BIG BLUE CELL

What is this incredible object? Would it surprise you to learn that it is a human cell? The cell is actually too small to see with the unaided eye. It is visible here in such detail because it is being viewed with a very powerful microscope. Cells may be small in size, but they are extremely important for life. Like all other living things, you are made of cells. Cells are the basis of life, and without cells, life as we know it would not exist. You will learn more about these amazing building blocks of life when you read this section.

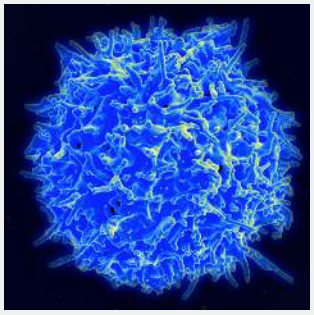


Figure **2.2.1**: Healthy human T-cell

If you look at a living matter with a microscope — even a simple light microscope — you will see that it consists of cells. **Cells** are the basic units of the structure and function of living things. They are the smallest units that can carry out the processes of life. All organisms are made up of one or more cells, and all cells have many of the same structures and carry out the same basic life processes. Knowing the structure of cells and the processes they carry out is necessary to understanding life itself.

DISCOVERY OF CELLS

The first time the word *cell* was used to refer to these tiny units of life was in 1665 by a British scientist named Robert Hooke. Hooke was one of the earliest scientists to study living things under a microscope. The microscopes of his day were not very strong, but Hooke was still able to make an important discovery. When he looked at a thin slice of cork under his microscope, he was surprised to see what looked like a honeycomb. Hooke made the drawing in the figure below to show what he saw. As you can see, the cork was made up of many tiny units, which Hooke called cells.

Soon after Robert Hooke discovered cells in cork, Anton van Leeuwenhoek in Holland made other important discoveries using a microscope. Leeuwenhoek made his own microscope lenses, and he was so good at it that his microscope was more powerful than other microscopes of his day. In fact, Leeuwenhoek's microscope was almost as strong as modern light microscopes. Using his microscope, Leeuwenhoek was the first person to observe human cells and bacteria.

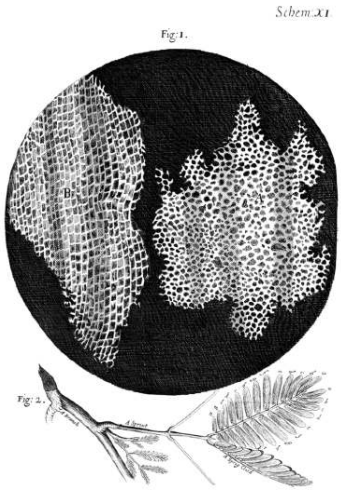


Figure **2.2.2**: Robert Hooke sketched these cork cells as they appeared under a simple light microscope.

CELL THEORY

By the early 1800s, scientists had observed the cells of many different organisms. These observations led two German scientists, named Theodor Schwann and Matthias Jakob Schleiden, to propose that cells are the basic building blocks of all living things. Around 1850, a German doctor named Rudolf Virchow was studying cells under a microscope when he happened to see them dividing and forming new cells. He realized that living cells produce new cells through division. Based on this realization, Virchow proposed that living cells arise only from other living cells.

The ideas of all three scientists — Schwann, Schleiden, and Virchow — led to **cell theory**, which is one of the fundamental theories unifying all of biology. Cell theory states that:

- All organisms are made of one or more cells.
- All the life functions of organisms occur within cells.
- All cells come from already existing cells.

SEEING INSIDE CELLS

Starting with Robert Hooke in the 1600s, the **microscope** opened up an amazing new world — the world of life at the level of the cell. As microscopes continued to improve, more discoveries were made about the cells of living things. However, by the late 1800s, light microscopes had reached their limit. Objects much smaller than cells, including the structures inside cells, were too small to be seen with even the strongest light microscope.

Then, in the 1950s, a new type of the microscope was invented. Called the electron microscope, it used a beam of electrons instead of light to observe extremely small objects. With an electron microscope, scientists could finally see the tiny structures inside cells. In fact, they could even see individual molecules and atoms. The electron microscope had a huge impact on biology. It allowed scientists to study organisms at the level of their molecules and led

to the emergence of the field of cell biology. With the electron microscope, many more cell discoveries were made. Figure **2.2.3** shows how the cell structures called **organelles** appear when scanned by an electron microscope.

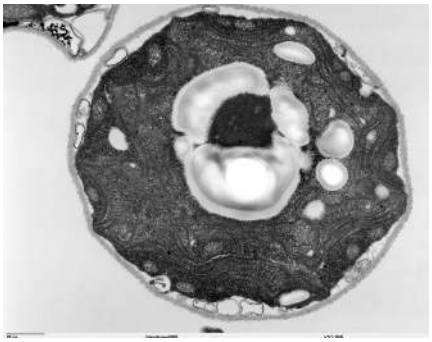


Figure **2.2.3**: An electron microscope produced this image of the structures inside a cell.

STRUCTURES SHARED BY ALL CELLS

Although cells are diverse, all cells have certain parts in common. These parts include a plasma membrane, cytoplasm, ribosomes, and DNA.

1. The **plasma membrane** (also called the cell membrane) is a thin coat of phospholipids that surrounds a cell. It forms the physical boundary between the cell and its environment, so you can think of it as the "skin" of the cell.
2. **Cytoplasm** refers to all of the cellular material inside the plasma membrane. The Cytoplasm is made up of a watery substance called cytosol and contains other cell structures such as ribosomes.
3. **Ribosomes** are structures in the cytoplasm where proteins are made.
4. **DNA** is a nucleic acid found in cells. It contains the genetic instructions that cells need to make proteins.

These parts are common to all cells, from organisms as different as bacteria and human beings. How did all known organisms come to have such similar cells? The similarities show that all life on Earth has a common evolutionary history.

REVIEW

1. Describe cells.
2. Explain how cells were discovered.
3. Outline how cell theory developed.
4. Identify structures shared by all cells.
5. *True or False.* Cork is not a living organism.
6. *True or False.* Some organisms are made of only one cell.
7. *True or False.* Ribosomes are found outside of the cytoplasm of a cell.
8. Proteins are made on _____ .
9. What are the differences between a light microscope and an electron microscope?
10. The first microscopes were made around
    A. 1965
    B. 1665
    C. 1950
    D. 1776
11. Which of these scientists made each of the following discoveries? (Anton van Leeuwenhoek; Robert Hooke; Rudolf Virchow)
    A. Observed some of the first cells and first used the term "cell"
    B. Observed the first human cells
    C. Observed cells dividing
12. Robert Hooke sketched what looked like honeycombs, or repeated circular or square units when he observed plant cells under a microscope.
    A. What is each unit?
    B. Of the shared parts of all cells, what makes up the outer surface of each unit?
    C. Of the shared parts of all cells, what makes up the inside of each unit?

EXPLORE MORE

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2.3: VARIATION IN CELLS

BACTERIA ATTACK!

Figure **2.3.1** shows a bacterial cell (colored green) attacking human red blood cells. The bacterium causes a disease called relapsing fever. The bacterial and human cells look very different in size and shape. Although all living cells have certain things in common — such as a plasma membrane and cytoplasm — different types of cells, even within the same organism, may have their own unique structures and functions. Cells with different functions generally have different shapes that suit them for their particular job. Cells vary not only in shape but also in size, as this example shows. In most organisms, however, even the largest cells are no bigger than the period at the end of this sentence. Why are cells so small?



Figure **2.3.1**: Bacterial cell attacking a human red blood cell

EXPLAINING CELL SIZE

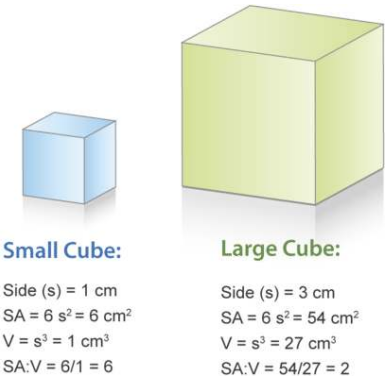


Figure **2.3.2**: Surface Area to Volume Comparison. A larger cube has a smaller surface area (SA) to volume (V) ratio than a smaller cube. This also holds true for cells and limits how large they can be.

Table **2.3.1**: Characteristics of small and large cubes

Characteristic	Small Cube	Large Cube
sides (S)	$1cm$	$3cm$
Surface Area (SA)	$6S^2 = 6 \times 1^2 = 6cm^2$	$6S^2 = 6 \times 3^2 = 54cm^2$
Volume (V)	$S^3 = 1^3 = 1cm^3$	$S^3 = 3^3 = 27cm^3$
SA:V	$SA/V = 6/1 = 6$	$SA/V = 54/27 = 2$

Most organisms, even very large ones, have microscopic cells. Why don't cells get bigger instead of remaining tiny and multiplying? What limits cell size?

The answers to these questions are clear once you know how a cell functions. To carry out life processes, a cell must be able to quickly pass substances into and out of the cell. For example, it must be able to pass nutrients and oxygen into the cell and waste products out of the cell. Anything that enters or leaves a cell must cross its outer surface. It is this need to pass substances across the surface that limits how large a cell can be.

Look at the two cubes in Figure **2.3.2**. As this figure and table show, a larger cube has less surface area relative to its volume than a smaller cube. This relationship also applies to cells; a larger cell has less surface area relative to its volume than a smaller cell. A cell with a larger volume also needs more nutrients and oxygen and produces more wastes. Because all of these substances must pass through the surface of the cell, a cell with a large volume will not have enough surface area to allow it to meet its needs. The larger the cell is, the smaller its ratio of surface area to volume, and the harder it will be for the cell to get rid of its wastes and take in necessary substances. This is what limits the size of the cell.

CELL FORM AND FUNCTION

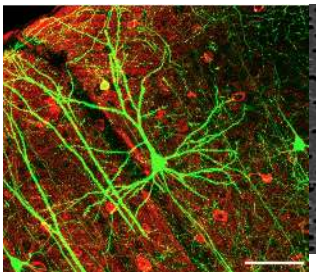


Figure **2.3.3**: Human nerve cell

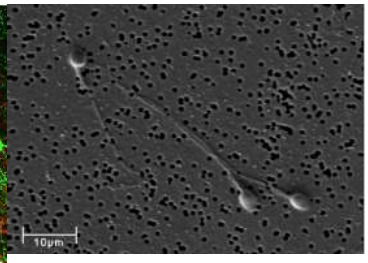


Figure **2.3.4**: Human sperm cells

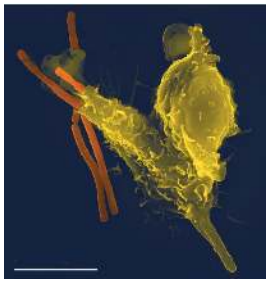


Figure **2.3.5**: Human white blood cell

Cells with different functions often have different shapes. The cells in Figure **2.3.3** - Figure **2.3.5** are just a few examples of the many different shapes that human cells may have. Each type of cell in the figure has characteristics that help it do its job. For example, the job of the nerve cell is to carry messages to other cells. The nerve cell has many long extensions that reach out in all directions, allowing it to pass messages to many other cells at once. Do you see the tail of each tiny sperm cell? Its tail helps a sperm cell "swim" through fluids in the female reproductive tract in order to reach an egg cell. The white blood cell has the job of destroying bacteria and other pathogens. Figure **2.3.5** shows the large white blood cell (in yellow) engulfing and destroying bacteria (in orange).

CELLS WITH AND WITHOUT A NUCLEUS

There is a basic cell structure that is present in many but not all living cells: the nucleus. The nucleus of a cell is a structure in the cytoplasm that is surrounded by a membrane (the nuclear membrane) and contains DNA. Based on whether or not they have a nucleus, there are two basic types of cells: prokaryotic cells and eukaryotic cells.

PROKARYOTIC CELLS

Prokaryotic cells are cells without a nucleus. The DNA in prokaryotic cells is in the cytoplasm rather than enclosed within a nuclear membrane. Prokaryotic cells are found in single-celled organisms, such as the bacterium represented by the model below. Organisms with prokaryotic cells are called **prokaryotes**. They were the first type of organisms to evolve and are still the most common organisms today.

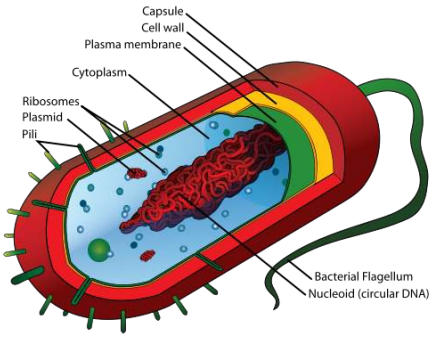


Figure **2.3.6**: Prokaryotic Cell. This diagram shows the structure of a typical prokaryotic cell, a bacterium. Like other prokaryotic cells, this bacterial cell lacks a nucleus but has other cell parts, including a plasma membrane, cytoplasm, ribosomes, and DNA.

Table **2.3.2**: Prokaryotic cell structures

Cell Structure	Description
Flagellum	Long projection(s) outside of the cell in some bacteria; aids in the motility
Pili	Small projections outside of the cell; aid in attachment
Capsule	A thick protective layer outside the cell wall of some bacteria
Cell wall	Outer layer of bacterial cells; more chemically complex than eukaryotic cell walls
Plasma Membrane	Phospholipid bilayer marking the outside of the cytoplasm
Cytoplasm	The fluid portion of the cell
Ribosome	Involved in protein synthesis
Nucleoid	Circular DNA found in the cytoplasm
Plasmid	Small loops of DNA found in some bacteria

EUKARYOTIC CELLS

Eukaryotic cells are cells that contain a nucleus. A typical eukaryotic cell is represented by the model below. Eukaryotic cells are usually larger than prokaryotic cells. They are found in some single-celled and all multicellular organisms. Organisms with eukaryotic cells are called **eukaryotes**, and they range from fungi to people.

Besides a nucleus, eukaryotic cells also contain other organelles. An **organelle** is a structure within the cytoplasm that performs a specific job in the cell. Organelles called mitochondria, for example, provide energy to the cell, and organelles called vacuoles store substances in the cell. Organelles allow eukaryotic cells to carry out more functions than prokaryotic cells can.

Table **2.3.3**: Eukaryotic cell structures

Structure	Location	Description
Flagellum	Outside the cell	A projection used for locomotion in some eukaryotic cells
Plasma Membrane	Outer layer of cell	Phospholipid bilayer enclosing the cytoplasm
Cytoplasm	Bound by the plasma membrane	Entire region between the plasma membrane and the nuclear envelope, consisting of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals
Golgi Vesicles (Golgi Apparatus)	Cytoplasm	A series of stacked membranes that sorts, tags, and packages lipids and proteins for distribution
Ribosomes	free-floating or on rough ER	Involved in protein synthesis
Rough Endoplasmic Reticulum	Cytoplasm	Interconnected membranous structures that are studded with ribosomes and engage in protein modification and phospholipid synthesis
Smooth Endoplasmic Reticulum	Cytoplasm	Interconnected membranous structures that have few or no ribosomes on its cytoplasmic surface and synthesize carbohydrates, lipids, and steroid hormones; detoxifies certain chemicals (like pesticides, preservatives, medications, and environmental pollutants), and stores calcium ions
Mitochondria	Cytoplasm	(singular = mitochondrion) cellular organelles responsible for carrying out cellular respiration, resulting in producing ATP, the cell's main energy-carrying molecule
Peroxisome	Cytoplasm	The small, round organelle that contains hydrogen peroxide, and detoxifies many poisons
Lysosome	Cytoplasm	Organelle in an animal cell that functions as the cell's digestive component; it breaks down proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles
Secretory Vesicle	Cytoplasm	Small, membrane-bound sac that functions in cellular storage and transport; its membrane is capable of fusing with the plasma membrane and the membranes of the endoplasmic reticulum and Golgi apparatus
Centrosome (with 2 centrioles)	Cytoplasm	Region in animal cells made of two centrioles that serve as an organizing center for microtubules
Actin Filaments	Cytoskeleton	The cytoskeleton's narrowest element; it provides rigidity and shape to the cell and enables cellular movements
Intermediate Filaments	Cytoskeleton	Cytoskeletal component, comprised of several fibrous protein intertwined strands, that bears tension, supports cell-cell junctions, and anchors cells to extracellular structures
Microtubules	Cytoskeleton	The cytoskeleton's widest element; provides a track along which vesicles move through the cell, pulls replicated chromosomes to opposite ends of a dividing cell, and is the structural element of centrioles
Cytoskeleton	Throughout cell	Protein fiber network that collectively maintains the cell's shape, secures some organelles in specific positions and allows cytoplasm and vesicles to move within the cell
Nucleus	Cytoplasm	Cell organelle that houses the cell's DNA and directs ribosome and protein synthesis
Nuclear Pore	Nucleus	Pores in the nuclear envelope allow substances to enter and exit the nucleus.
Nuclear Envelope	Nucleus	Double-membrane structure that constitutes the nucleus' outermost portion
Chromatin	Nucleus	Protein-DNA complex that serves as the chromosomes' building material
Nucleolus	Nucleus	Darkly staining body within the nucleus that is responsible for assembling ribosome subunits

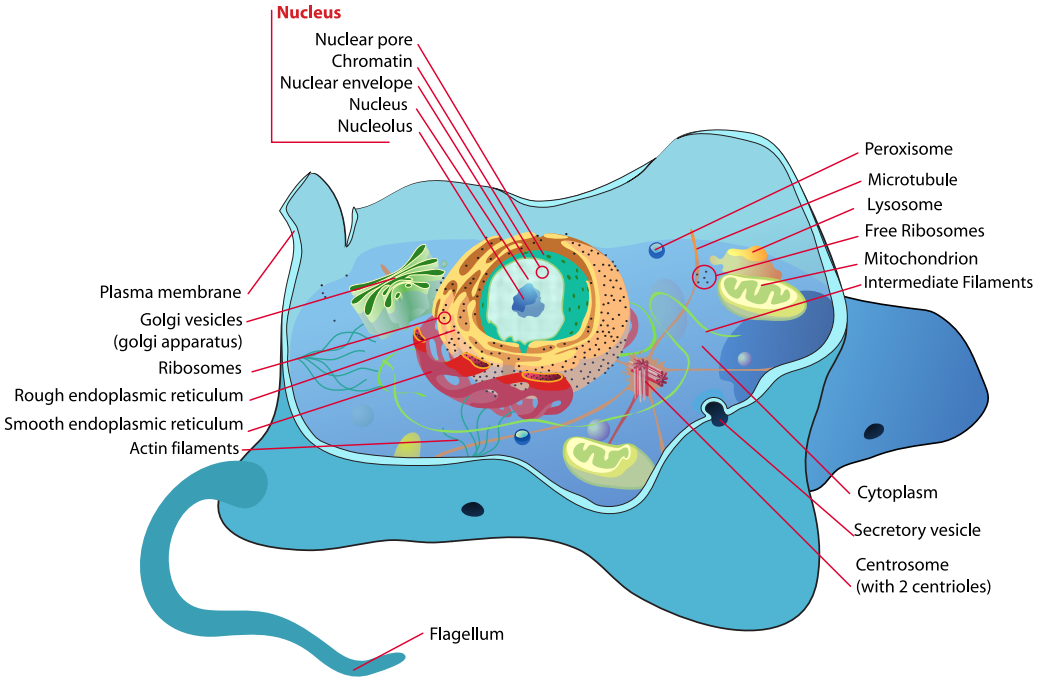


Figure **2.3.7**: Eukaryotic Cell. Compare and contrast the eukaryotic cell shown here with the prokaryotic cell. What similarities and differences can you identify?

REVIEW

1. Explain why most cells are very small.
2. Discuss variations in the form and function of cells.
3. Compare and contrast prokaryotic and eukaryotic cells.
4. *True or False.* Prokaryotic cells do not have mitochondria.
5. *True or False.* Prokaryotic cells do not have DNA.
6. *True or False.* All single-celled organisms are prokaryotes.
7. Which was the first type of organism to evolve – eukaryotes or prokaryotes? Based on their structures, does this make sense to you? Explain your answer.
8. Do human cells have organelles? Explain your answer.
9. Which are usually larger – prokaryotic or eukaryotic cells? What do you think this means for their relative ability to take in needed substances and release wastes? Discuss your answer.
10. DNA in eukaryotes is enclosed within the _____ _____.
11. Name three different types of cells in humans.
12. Which organelle provides energy in eukaryotic cells?
13. What is the function of a vacuole in a cell?

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2.4: PLASMA MEMBRANE

A BAG FULL OF JELL-O

This simple, cut-away model of an animal cell (Figure **2.4.1**) shows that a cell resembles a plastic bag full of Jell-O. Its basic structure is a plasma membrane filled with cytoplasm. Like Jell-O containing mixed fruit, the cytoplasm of the cell also contains various structures, such as a nucleus and other organelles. Your body is made up of trillions of cells, but all of them perform the same basic life functions. They all obtain and use energy, respond to the environment, and reproduce. How do your cells carry out these basic functions and keep themselves — and you — alive? To answer these questions, you need to know more about the structures that make up cells, starting with the plasma membrane.



Figure **2.4.1**: Animal cell model

The plasma membrane is a structure that forms a barrier between the cytoplasm inside the cell and the environment outside the cell. Without the plasma membrane, there would be no cell. The membrane also protects and supports the cell and controls everything that enters and leaves it. It allows only certain substances to pass through while keeping others in or out. To understand how the plasma membrane controls what passes into or out of the cell, you need to know its basic structure.

PHOSPHOLIPID BILAYER

The **plasma membrane** is composed mainly of **phospholipids**, which consist of fatty acids and alcohol. The phospholipids in the plasma membrane are arranged in two layers, called a **phospholipid bilayer**, with a hydrophobic, or water-hating, interior and a hydrophilic, or water-loving, exterior. Each phospholipid molecule has a head and two tails. The head “loves” water (hydrophilic) and the tails “fear” water (hydrophobic). The water-fearing tails are on the interior of the membrane, whereas the water-loving heads point outwards, toward either the cytoplasm or the fluid that surrounds the cell. The polar head group and fatty acid chains are attached by a 3-carbon glycerol unit. Figure **2.4.2** shows a single phospholipid next to a phospholipid bilayer.

Molecules that are hydrophobic can easily pass through the plasma membrane if they are small enough because they are water-hating like the interior of the membrane. Molecules that are hydrophilic, on the other hand, cannot pass through the plasma membrane — at least not without help — because they are water-loving like the exterior of the membrane.

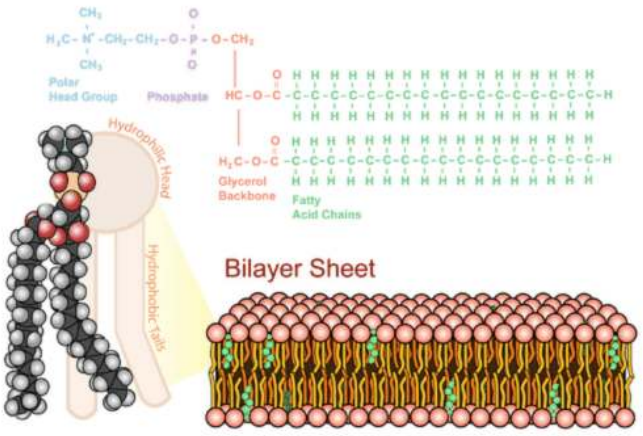


Figure **2.4.2**: Phospholipid and a phospholipid Bilayer.

OTHER MOLECULES IN THE PLASMA MEMBRANE

The plasma membrane also contains other molecules, primarily other lipids and proteins. The green molecules in Figure **2.4.2**, for example, are the lipid cholesterol. Molecules of the steroid lipid cholesterol help the plasma membrane keep its shape. (Figure **2.4.3**) shows the cholesterol molecules as yellow structures within the center of the phospholipid bilayer. Other structures shown in (Figure **2.4.3**):

- Protein channels. These span the full membrane and have a space within them because they are used to transport materials into or out of the cell.
- Transmembrane proteins. The root "trans" explains that these span (go "across") the membrane. Transmembrane proteins can have a variety of functions.
- Peripheral proteins. These are found only on one side of the membrane. They can be found on either the cytoplasmic side or the outside of the membrane.
- Glycoproteins. These consist of a protein in the plasma membrane with chains of carbohydrates projecting out of the cell.
- Glycolipids. These are chains of carbohydrates attached directly to a lipid in the membrane. Both glycoproteins and glycolipids act as labels to identify the cell.
- Filaments of cytoskeleton are found along the cytoplasmic side of the membrane and provide a scaffolding for the membrane.

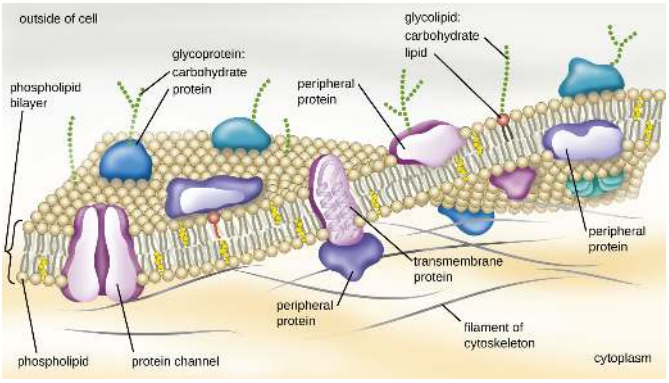


Figure **2.4.3**: The figure illustrates the major components of the phospholipid bilayer.

ADDITIONAL FUNCTIONS OF THE PLASMA MEMBRANE

The plasma membrane may have extensions, such as whip-like **flagella** or brush-like **cilia**, that give it other functions. In single-celled organisms, like those shown below, these membrane extensions may help the organisms move. In multicellular organisms, the extensions have different functions. For example, the cilia on human lung cells sweep foreign particles and mucus toward the mouth and nose.

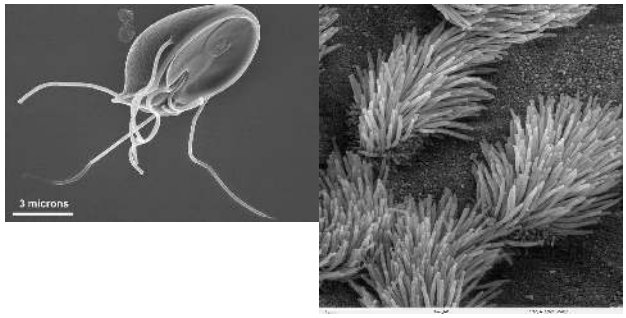


Figure **2.4.4**: Flagella of Giardia (left) and cilia of human respiratory mucosa (right). Flagella and cilia are extensions of the plasma membrane of many cells.

FEATURE: MY HUMAN BODY

If you smoke and need another reason to quit, here's a good one. We usually think of lung cancer as a major disease caused by smoking. But smoking can have devastating effects on the body's ability to protect itself from repeated, serious respiratory infections, such as bronchitis and pneumonia.

Cilia are microscopic, hair-like projects on cells that line the respiratory, reproductive, and digestive systems. Cilia in the respiratory system line most of your airways where they have the job of trapping and removing dust, germs, and other foreign particles before they can make you sick. Cilia secrete mucus that traps particles, and they move in a continuous wave-like motion that sweeps the mucus and particles upward toward the throat, where they can be expelled from the body. When you are sick and cough up phlegm, that's what you are doing.

Smoking prevents cilia from performing these important functions. Chemicals in tobacco smoke paralyze the cilia so they can't sweep mucus out of the airways and they also inhibit the cilia from producing mucus. Fortunately, these effects start to wear off soon after the last exposure to tobacco smoke. If you stop smoking, your cilia will return to normal. Even if prolonged smoking has destroyed cilia, they will regrow and resume functioning in a matter of months after you stop smoking.

REVIEW

1. What are the general functions of the plasma membrane?
2. Describe the phospholipid bilayer of the plasma membrane.
3. Identify other molecules in the plasma membrane, and state their functions.
4. Why do some cells have plasma membrane extensions such as flagella and cilia?
5. Explain why hydrophilic molecules cannot easily pass through the cell membrane. What type of molecule in the cell membrane might help hydrophilic molecules pass through it?
6. Which part of a phospholipid molecule in the plasma membrane is made of fatty acid chains? Is this part hydrophobic or hydrophilic?
7. The two layers of phospholipids in the plasma membrane are called a phospholipid _____.
8. *True or False.* The flagella on your lung cells sweep foreign particles and mucus toward your mouth and nose.
9. *True or False.* Small hydrophobic molecules can easily pass through the plasma membrane.
10. *True or False.* The side of the cell membrane that faces the cytoplasm is hydrophilic.
11. Steroid hormones can pass directly through cell membranes. Why do you think this is the case?
12. Some antibiotics work by making holes in the plasma membrane of bacterial cells. How do you think this kills the cells?
13. What is the name of the long, whip-like extensions of the plasma membrane that helps some single-celled organisms move?

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2.5: CYTOPLASM AND CYTOSKELETON

A PEEK INSIDE THE CELL

Figure **2.5.1** may look like a colorful work of abstract art or maybe an ultra-modern carpet design, but it's neither. It is actually a model of the interior of a cell. It's an artist's representation of what you might see if you could take a peek inside one of these basic building blocks of living things. A cell's interior is obviously a crowded and busy space. It contains cytoplasm, dissolved substances, and many structures; and it's a hive of countless biochemical activities all going on at once.

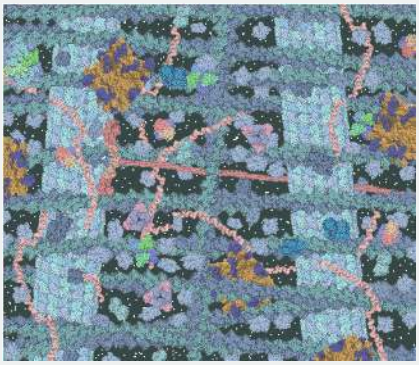


Figure **2.5.1**: Picture of cytosol, showing microtubules (light blue), actin filaments (dark blue), ribosomes (yellow and purple), soluble proteins (light blue), kinesin (red), small molecules (white) and RNA (pink).

CYTOPLASM

The **cytoplasm** is a thick, usually colorless solution that fills each cell and is enclosed by the cell membrane. Cytoplasm presses against the cell membrane, filling out the cell and giving it its shape. Sometimes cytoplasm acts like a watery solution and sometimes it takes on a more gel-like consistency. In eukaryotic cells, the cytoplasm includes all of the material inside the cell but outside the nucleus, which contains its own watery substance called **nucleoplasm**. All of the organelles in eukaryotic cells, such as the endoplasmic reticulum and mitochondria, are located in the cytoplasm. The cytoplasm helps to keep them in place. It is also the site of most metabolic activities in the cell, and it allows materials to pass easily throughout the cell.

The portion of the cytoplasm surrounding organelles is called cytosol, which is the liquid part of the cytoplasm. It is composed of about 80 percent water and also contains dissolved salts, fatty acids, sugars, amino acids, and proteins such as enzymes. These dissolved substances are needed to keep the cell alive and carry out metabolic processes. For example, enzymes dissolved in cytosol break down larger molecules into smaller products that can then be used by organelles of the cell. Waste products are also dissolved in the cytosol before they are taken in by vacuoles or expelled from the cell.

Though prokaryotic cells do not have organelles (they do have ribosomes), they still have cytoplasm. It is within the cytoplasm that most cellular activities occur, including the many metabolic pathways that occur within organelles, such as photosynthesis and aerobic respiration.

CYTOSKELETON

Although cytoplasm may appear to have no form or structure, it is actually highly organized. A framework of protein scaffolds called the **cytoskeleton** provides the cytoplasm and the cell with structure. The cytoskeleton consists of thread-like filaments and tubules that criss-cross the cytoplasm. You can see these filaments and tubules in the cells in Figure **2.5.2**. As its name suggests, the cytoskeleton is like a cellular “skeleton.” It helps the cell maintain its shape and also helps to hold cell structures such as organelles in place within the cytoplasm.

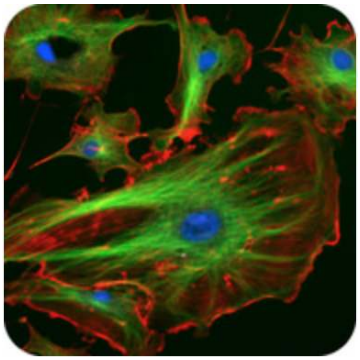


Figure **2.5.2**: Cytoskeleton. The cytoskeleton gives the cell an internal structure, like the frame of a house. In this photograph, actin filaments and tubules of the cytoskeleton are green and red, respectively. The blue dots are cell nuclei.

The eukaryotic cytoskeleton is made up of a network of long, thin protein fibers. These threadlike proteins continually rebuild to adapt to the cell's constantly changing needs. Three main kinds of cytoskeleton fibers are microtubules, intermediate filaments, and microfilaments (Table **2.5.1**).

- **Microtubules** are the thickest of the cytoskeleton structures. They are most commonly made of filaments which are polymers of alpha and beta-tubulin and radiate outwards from an area near the nucleus called the centrosome. Two forms of tubulin form dimers (pairs) which come together to form the hollow cylinders. The cylinders are twisted around each other to form the microtubules. Microtubules help the cell keep its shape. They hold organelles in place and allow them to move around the cell, and they form the mitotic spindle during cell division. Microtubules also make up parts of cilia and flagella, the organelles that help a cell move.
- **Microfilaments** are made of two thin **actin** chains that are twisted around one another. Microfilaments are mostly concentrated just beneath the cell membrane, where they support the cell and help the cell keep its shape. Microfilaments form cytoplasmatic extensions, such as **microvilli** and pseudopodia, which allow certain cells to move. The actin and myosin protein interact to cause a contraction in muscle cells. Microfilaments

are found in almost every cell and are numerous in muscle cells and in cells that move by changing shape, such as phagocytes (white blood cells that search the body for bacteria and other invaders).

- **Intermediate filaments (IF)** differ in make-up from one cell type to another. The IF may be composed of **vimentin**, **keratin**, **desmin**, or **lamin**. Each cell type can have a unique combination of IFs. For example, intermediate filaments made of keratin are found in skin, hair, and nail cells. IFs organize the inside structure of the cell by holding organelles and providing strength. They are also structural components of the nuclear envelope. Intermediate filaments made of the protein keratin are found in skin, hair, and nail cells.

Table **2.5.1**: Cytoskeleton Structure

Characteristic	Microtubules	Intermediate Filaments	Microfilaments
Fiber Diameter	About 25 nm	8 to 11 nm	Around 7 nm
Protein Composition	Tubulin with two subunits, alpha, and beta-tubulin	One of the different types of proteins such as lamin, vimentin, desmin, and keratin	Actin
Shape	Hollow cylinders made of two protein chains twisted around each other	Protein fiber coils twisted into each other	Two actin chains twisted around one another
Main Functions	Organelle and vesicle movement; form mitotic spindles during cell reproduction; cell motility (in cilia and flagella)	Organize cell shape; positions organelles in cytoplasm structural support of the nuclear envelope and sarcomeres; involved in cell-to-cell and cell-to-matrix junctions	Keep cellular shape; allows movement of certain cells by forming cytoplasmatic extensions or contraction of actin fibers; involved in some cell-to-cell or cell-to-matrix junctions

FEATURE: HUMAN BIOLOGY IN THE NEWS

News about an important study of the cytoplasm of eukaryotic cells appeared early in 2016. Researchers in Dresden, Germany discovered that when cells are deprived of adequate nutrients, they may essentially shut down and become dormant. Specifically, when cells do not get enough nutrients, they shut down their metabolism, their energy level drops, and the pH of their cytoplasm decreases. Their normally liquid cytoplasm also assumes a solid state. The cells appear dead and as though a kind of rigor mortis has set in. The researchers think that these changes protect the sensitive structures inside the cells and allow the cells to survive difficult conditions. If nutrients are returned to the cells, they can emerge from their dormant state unharmed. They will continue to grow and multiply when conditions improve.

This important basic science research was carried out on a nonhuman organism: one-celled fungi called yeasts. Nonetheless, it may have important implications for humans because yeasts have eukaryotic cells with many of the same structures as human cells. Yeast cells appear to be able to "trick" death by shutting down all life processes in a controlled way. Researchers hope to learn with the continued research on whether human cells can be taught this "trick" as well.

REVIEW

1. Describe the composition of cytoplasm.
2. What are some of the functions of cytoplasm?
3. Outline the structure and functions of the cytoskeleton.
4. Is the cytoplasm made of cells? Why or why not?
5. Name two types of cytoskeletal structures.
6. *True or False.* The cytoplasm is usually green.
7. *True or False.* The nucleus of a cell is filled with cytoplasm.
8. In Figure **2.5.2** of the different cytoskeletal structures above (shown in red and green), what do you notice about these different structures?
9. Describe one example of a metabolic process that occurs in the cytosol.
10. In eukaryotic cells, all of the material inside of the cell but outside of the nucleus is called the _____.
11. What is the liquid part of the cytoplasm called?
12. What chemical substance makes up most of the cytosol?
13. When yeast cells deprived of nutrients go dormant, their cytoplasm assumes a solid-state. What effect do you think a solid cytoplasm would have on normal cellular processes? Explain your answer.
14. What is the difference between cytoplasm and cytosol?
15. Name the three main parts of the cytoskeleton.
16. List two functions of the eukaryotic cytoskeleton

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2.6: CELL ORGANELLES

RIBOSOME REVIEW

Figure **2.6.1** represents an important structure in living cells. It is a component of a ribosome, the cell structure where proteins are synthesized. Large ribosomal subunit (50S) of *Haloarcula marismortui*, facing the 30S subunit. The ribosomal proteins are shown in blue, the rRNA in ochre (a shade of brown and yellow), the active site in red. All living cells contain ribosomes, whether they are prokaryotic or eukaryotic cells. However, only eukaryotic cells also contain a nucleus and several other types of organelles.

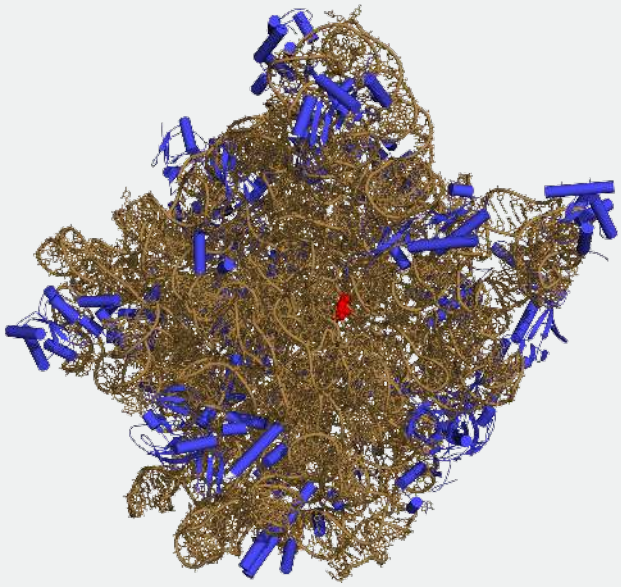


Figure **2.6.1**: Ribosomal subunit

An organelle is a structure within the cytoplasm of a eukaryotic cell that is enclosed within a membrane and performs a specific job. Organelles are involved in many vital cell functions. Organelles in animal cells include the nucleus, mitochondria, endoplasmic reticulum, Golgi apparatus, vesicles, and vacuoles. Ribosomes are not enclosed within a membrane but are still commonly referred to as organelles in eukaryotic cells.

THE NUCLEUS

The nucleus is the largest organelle in a eukaryotic cell and is considered to be the cell's control center. It contains most of the cell's DNA, which makes up chromosomes and is encoded with the genetic instructions for making proteins. The function of the nucleus is to regulate gene expression, including controlling which proteins the cell makes. In addition to DNA, the nucleus contains a thick liquid called nucleoplasm that is similar in composition to the cytosol found in the cytoplasm outside the nucleus (Figure **2.6.2**). Most eukaryotic cells contain just a single nucleus, but some types of cells, such as red blood cells, contain no nucleus. A few other types of cells, such as muscle cells, contain multiple nuclei.

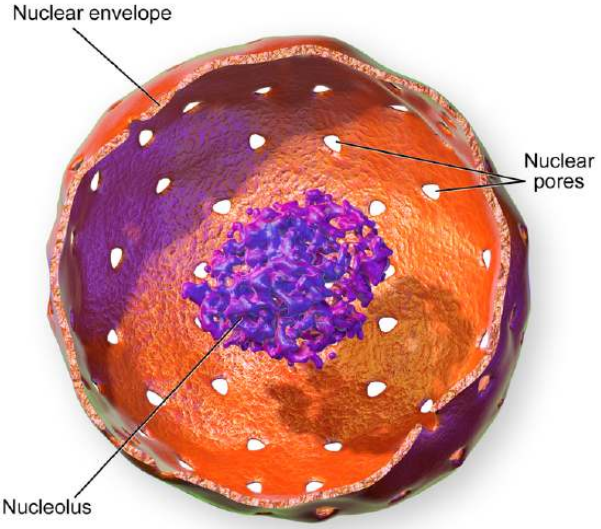


Figure **2.6.2**: This closeup of a cell nucleus shows that it is surrounded by a structure called the nuclear envelope, which contains tiny perforations, or pores. The nucleus also contains a dense center called the nucleolus.

As you can see from the model in Figure **2.6.2**, the membrane enclosing the nucleus is called the **nuclear envelope**. This is actually a double membrane that encloses the entire organelle and isolates its contents from the cellular cytoplasm. Tiny holes, called **nuclear pores**, allow large molecules to pass through the nuclear envelope with the help of special proteins. Large proteins and RNA molecules must be able to pass through the nuclear envelope so proteins can be synthesized in the cytoplasm and the genetic material can be maintained inside the nucleus. The **nucleolus** shown in the model below is mainly involved in the assembly of ribosomes. After being produced in the nucleolus, ribosomes are exported to the cytoplasm where they are involved in the synthesis of proteins.

MITOCHONDRIA

The **mitochondrion** (plural, **mitochondria)** is an organelle that makes energy available to the cell (Figure **2.6.3**). This is why mitochondria are sometimes referred to as the power plants of the cell. They use energy from organic compounds such as glucose to make molecules of **ATP (adenosine triphosphate)**, an energy-carrying molecule that is used almost universally inside cells for energy.

Scientists think that mitochondria were once free-living organisms because they contain their own DNA. They theorize that ancient prokaryotes infected (or were engulfed by) larger prokaryotic cells, and the two organisms evolved a symbiotic relationship that benefited both of them. The larger cells provided the smaller prokaryotes with a place to live. In return, the larger cells got extra energy from the smaller prokaryotes. Eventually, the smaller prokaryotes became permanent guests of the larger cells, as organelles inside them. This theory is called the **endosymbiotic theory**, and it is widely accepted by biologists today

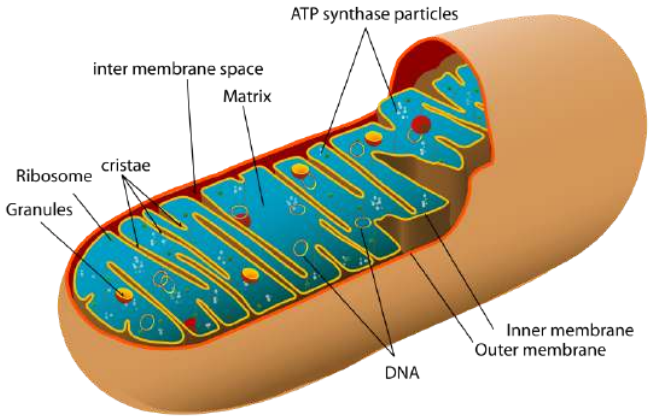


Figure **2.6.3**: Mitochondria, organelles specialized to carry out aerobic respiration, contain an inner membrane folded into cristae, which form two separate compartments: the inner membrane space and the matrix. The Krebs Cycle takes place in the matrix. The electron transport chain is embedded in the inner membrane and uses both compartments to make ATP by chemiosmosis. Mitochondria have their own DNA and ribosomes, resembling those of prokaryotic organisms.

MITOCHONDRIAL COMPARTMENTS

The double membrane nature of the mitochondria results in five distinct compartments, each with an important role in cellular respiration. These compartments are:

1. the outer mitochondrial membrane,
2. the intermembrane space (the space between the outer and inner membranes),
3. the inner mitochondrial membrane,
4. the cristae (formed by infoldings of the inner membrane), and
5. the matrix (space within the inner membrane).

ENDOPLASMIC RETICULUM

The *endoplasmic reticulum* **(ER)** (plural, reticuli) is a network of phospholipid membranes that form hollow tubes, flattened sheets, and round sacs. These flattened, hollow folds and sacs are called *cisternae*. The ER has two major functions:

- Transport: Molecules, such as proteins, can move from place to place inside the ER, much like on an intracellular highway.
- Synthesis: Ribosomes that are attached to the ER, similar to unattached ribosomes, make proteins. Lipids are also produced in the ER.

There are two types of endoplasmic reticulum, rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER):

- **Rough endoplasmic reticulum** is studded with ribosomes, which gives it a “rough” appearance. These ribosomes make proteins that are then transported from the ER in small sacs called transport vesicles. The transport vesicles pinch off the ends of the ER. The rough endoplasmic reticulum works with the Golgi apparatus to move new proteins to their proper destinations in the cell. The membrane of the RER is continuous with the outer layer of the nuclear envelope.
- **Smooth endoplasmic reticulum** does not have any ribosomes attached to it, and so it has a smooth appearance. SER has many different functions, some of which include lipid synthesis, calcium ion storage, and drug detoxification. The smooth endoplasmic reticulum is found in both animal and plant cells and it serves different functions in each. The SER is made up of tubules and vesicles that branch out to form a network. In some cells, there are dilated areas like the sacs of RER. Smooth endoplasmic reticulum and RER form an interconnected network.

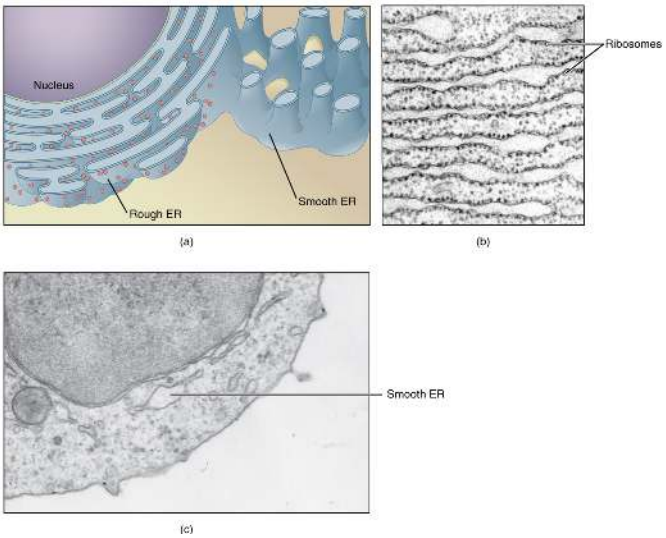


Figure **2.6.4**: The ER is a winding network of thin membranous sacs found in close association with the cell nucleus. The smooth and rough endoplasmic reticula are very different in appearance and function (source: mouse tissue). (b) Rough ER is studded with numerous ribosomes, which are sites of protein synthesis (source: mouse tissue). EM × 110,000. (c) Smooth ER synthesizes phospholipids, steroid hormones, regulates the concentration of cellular Ca^{2+}, metabolizes some carbohydrates, and breaks down certain toxins.

GOLGI APPARATUS

The **Golgi apparatus** (Figure **2.6.5**) is a large organelle that processes proteins and prepares them for use both inside and outside the cell. It was identified in 1898 by the Italian physician Camillo Golgi. The Golgi apparatus modifies, sorts, and packages different substances for secretion out of the cell, or for use within the cell. The Golgi apparatus is found close to the nucleus of the cell where it modifies proteins that have been delivered in transport vesicles from the Rough Endoplasmic Reticulum. It is also involved in the transport of lipids around the cell. Pieces of the Golgi membrane pinch off to form vesicles that transport molecules around the cell. The Golgi apparatus can be thought of as similar to a post office; it packages and labels "items" and then sends them to different parts of the cell. The Golgi apparatus tends to be larger and more numerous in cells that synthesize and secrete large quantities of materials; for example, the plasma B cells and the antibody-secreting cells of the immune system have prominent Golgi complexes.

The Golgi apparatus manipulates products from the Rough Endoplasmic Reticulum (ER) and also produces new organelles called lysosomes. Proteins and other products of the ER are sent to the Golgi apparatus, which organizes, modifies, packages, and tags them. Some of these products are transported to other areas of the cell and some are exported from the cell through exocytosis. Enzymatic proteins are packaged as new lysosomes.

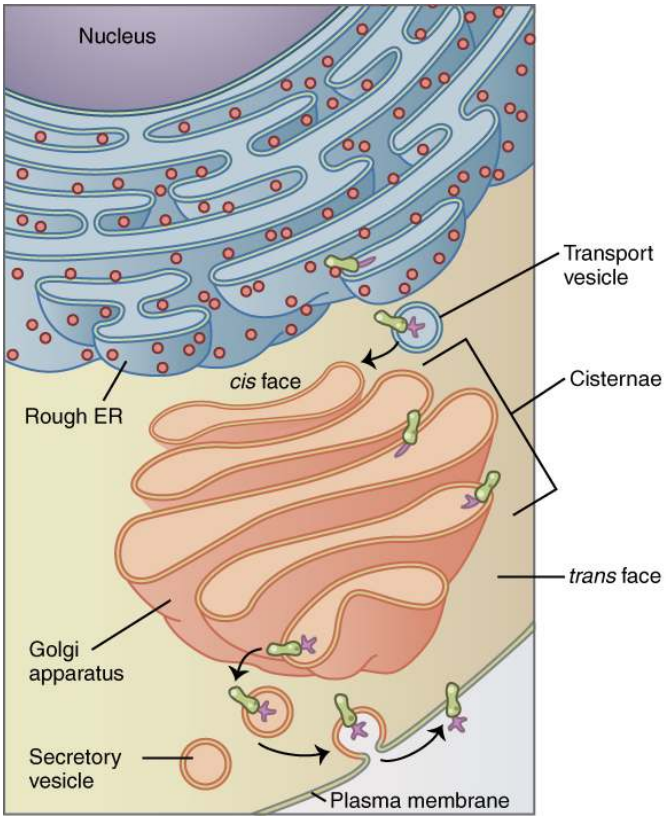


Figure 2.6.5: The rough ER is continuous with the nuclear envelope and has ribosomes on it's surface. The ribosomes produce proteins such as the one shown which remains bound to the membrane of the rough ER. The membrane of the rough ER pinches off to form a transport vesicle containing the protein. The vesicle fuses with the cis face of the Golgi apparatus. The protein is now found on the membrane of the Golgi apparatus and travels along the cisternae. Once it reaches the trans face of the Golgi apparatus, it gets packaged into a secretory vesicle that sends the protein to the plasma membrane.

The stack of **cisternae** has four functional regions: the **cis-Golgi network**, medial-Golgi, endo-Golgi, and trans-Golgi network. Vesicles from the ER fuse with the network and subsequently progress through the stack from the cis- to the **trans-Golgi network**, where they are packaged and sent to their destination. Each cisterna includes special Golgi enzymes which modify or help to modify proteins that travel through it. Proteins may be modified by the addition of a carbohydrate group (glycosylation) or phosphate group (phosphorylation). These modifications may form a signal sequence on the protein, which determines the final destination of the protein. For example, the addition of mannose-6-phosphate signals the protein for lysosomes.

VESICLES AND VACUOLES

Both **vesicles** and **vacuoles** are sac-like organelles that store and transport materials in the cell. Vesicles are much smaller than vacuoles and have a variety of functions. The vesicles that pinch off from the membranes of the ER and Golgi apparatus store and transport protein and lipid molecules. You can see an example of this type of transport vesicle in the figure above. Some vesicles are used as chambers for biochemical reactions. Other vesicles include:

- Lysosomes, which use enzymes to break down foreign matter and dead cells.
- Peroxisomes, which use oxygen to break down poisons.
- Transport vesicles, transport contents between organelle as well as between cell exterior and interior.

CENTRIOLES

Centrioles are organelles involved in cell division. The function of centrioles is to help organize the chromosomes before cell division occurs so that each daughter cell has the correct number of chromosomes after the cell divides. Centrioles are found only in animal cells and are located near the nucleus. Each centriole is made mainly of a protein named **tubulin**. The centriole is cylindrical in shape and consists of many microtubules, as shown in the model pictured below.

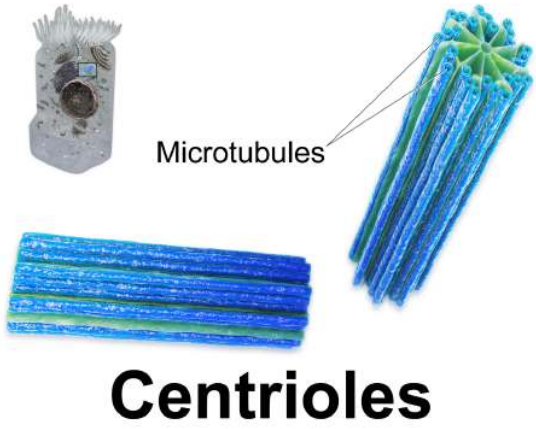


Figure 2.6.6: Centrioles are tiny cylinders near the nucleus, enlarged here to show their tubular structure.

RIBOSOMES

Ribosomes are small structures where proteins are made. Although they are not enclosed within a membrane, they are frequently considered organelles. Each ribosome is formed of two subunits, like the one pictured at the top of this section. Both subunits consist of proteins and RNA. RNA from the nucleus carries the genetic code, copied from DNA, which remains in the nucleus. At the ribosome, the genetic code in RNA is used to assemble and join together amino acids to make proteins. Ribosomes can be found alone or in groups within the cytoplasm as well as on the RER.

REVIEW

1. Define organelle.
2. Describe the structure and function of the nucleus.
3. Explain how the nucleus, ribosomes, rough endoplasmic reticulum, and Golgi apparatus work together to make and transport proteins.
4. Why are mitochondria referred to as the power plants of the cell?
5. What roles are played by vesicles and vacuoles?
6. Why do all cells need ribosomes, even prokaryotic cells that lack a nucleus and other cell organelles?
7. Explain endosymbiotic theory as it relates to mitochondria. What is one piece of evidence that supports this theory?
8. Lysosomes and peroxisomes are types of:
   A. A. Organelles
   B. B. Vesicles
   C. C. Vacuoles
   D. D. Both A and B
9. Which of the following organelles fits best with each description of function? Choose only one organelle for each answer: Golgi apparatus, centrioles, nucleolus, nucleus, rough endoplasmic reticulum
   A. a. Contains the genetic instructions for the production of proteins
   B. b. Organizes chromosomes before cell division
   C. c. Provides a framework for ribosomes
   D. d. Packages and labels proteins
   E. e. Assembles ribosomes
10. *True or False*. All eukaryotic cells have a nucleus.
11. *True or False*. The outer surface of the nucleus of a eukaryotic cell is not completely solid.

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2.7: CELL TRANSPORT

LETTING IN THE LIGHT

Look at the big windows and glass doors in this house. Imagine all the light they must let in on a sunny day. Now imagine living in a house that has walls without any windows or doors. Nothing could enter or leave. Or imagine living in a house with holes in the walls instead of windows and doors. Things could enter or leave, but you couldn't control what came in or went out. Only if a house has walls with windows and doors that can be opened or closed you can control what enters or leaves. For example, windows and doors allow you to let in light and the family dog and keep out rain and bugs.



Figure **2.7.1**: A house with windows

TRANSPORT ACROSS MEMBRANES

If a cell were a house, the plasma membrane would be walls with windows and doors. Moving things in and out of the cell is an important role of the plasma membrane. It controls everything that enters and leaves the cell. There are two basic ways that substances can cross the plasma membrane: passive transport, which requires no energy; and active transport, which requires energy. Passive transport is explained in this section and Active transport is explained in the next section, Active Transport and Homeostasis. Various types of cell transport are summarized in the concept map in Figure **2.7.2**.

TRANSPORT WITHOUT ENERGY

Passive transport occurs when substances cross the plasma membrane without any input of energy from the cell. No energy is needed because the substances are moving from an area where they have a higher concentration to an area where they have a lower concentration. Water solutions are very important in biology. When water is mixed with other molecules this mixture is called a **solution**. Water is the **solvent** and the dissolved substance is the **solute**. A solution is characterized by the solute. For example, water and sugar would be characterized as a sugar solution. More the particles of a solute in a given volume, the higher the concentration. The particles of solute always move from an area where it is more concentrated to an area where it is less concentrated. It's a little like a ball rolling down a hill. It goes by itself without any input of extra energy.

The different categories of cell transport are outlined in Figure **2.7.2**. Cell transport can be classified as follows:

- Passive Transport which includes
  - Simple Diffusion
  - Osmosis
  - Facilitated Diffusion
- Active Transport can involve either a pump or a vesicle
  - Pump Transport can be
    - primary
    - secondary
  - Vesicle Transport can involve
    - Exocytosis
    - Endocytosis which includes
      - Pinocytosis
      - Phagocytosis
      - Receptor-Mediated Endocytosis

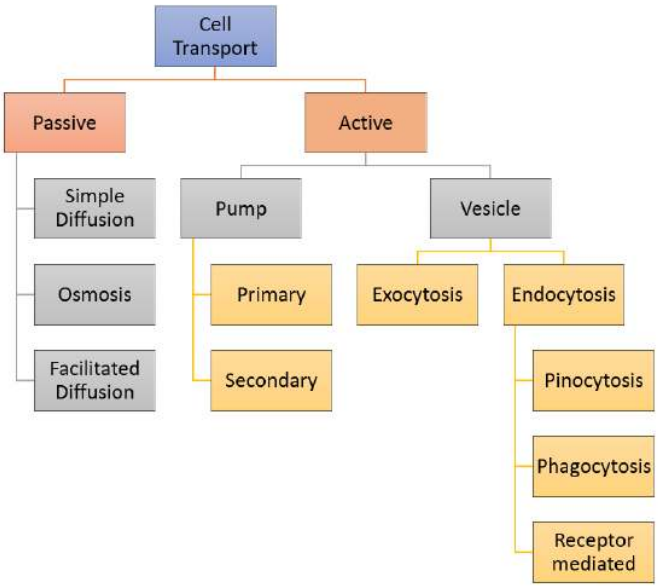


Figure **2.7.2**: The Cell Transport Concept Map illustrates various types of cell transports that happen at the plasma membrane

SIMPLE DIFFUSION

Diffusion Although you may not know what diffusion is, you have experienced the process. Can you remember walking into the front door of your home and smelling a pleasant aroma coming from the kitchen? It was the diffusion of particles from the kitchen to the front door of the house that allowed you to detect the odors. **Diffusion** is defined as the net movement of particles from an area of greater concentration to an area of lesser concentration.

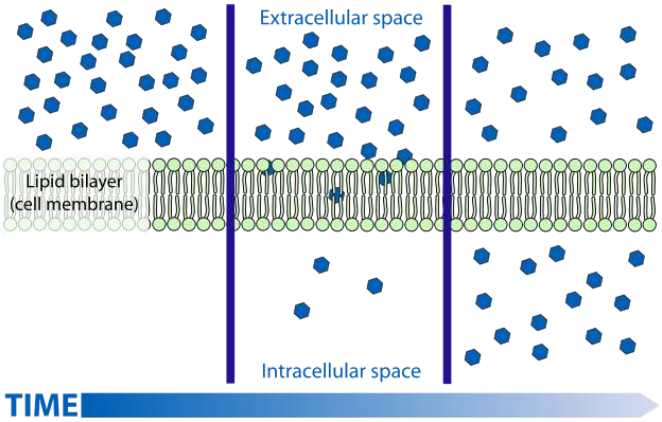


Figure **2.7.3**. Simple diffusion shows as a timeline with the outside of the cell (extracellular space) separated from the inside of the cell (intracellular space) by the cell membrane. In the beginning of the timeline there are many molecules outside of the cell and none inside. Over time, they diffuse into the cell until there is an equal amount outside and inside.

The molecules in a gas, a liquid, or a solid are in constant motion due to their kinetic energy. Molecules are in constant movement and collide with each other. These collisions cause the molecules to move in random directions. Over time, however, more molecules will be propelled into the less concentrated area. Thus, the net movement of molecules is always from more tightly packed areas to less tightly packed areas. Many things can diffuse. Odors diffuse through the air, salt diffuses through water and nutrients diffuse from the blood to the body tissues. This spread of particles through the random motion from an area of high concentration to an area of lower concentration is known as diffusion. This unequal distribution of molecules is called a concentration gradient. Once the molecules become uniformly distributed, a dynamic equilibrium exists. The equilibrium is said to be dynamic because molecules continue to move, but despite this change, there is no net change in concentration over time. Both living and nonliving systems experience the process of diffusion. In living systems, diffusion is responsible for the movement of a large number of substances, such as gases and small uncharged molecules, into and out of cells.

OSMOSIS

Osmosis is a specific type of diffusion; it is the passage of water from a region of high water concentration through a semi-permeable membrane to a region of low water concentration. Water moves in or out of a cell until its concentration is the same on both sides of the plasma membrane.

Semi-permeable membranes are very thin layers of material that allow some things to pass through them but prevent other things from passing through. Cell membranes are an example of semi-permeable membranes. Cell membranes allow small molecules such as oxygen, water carbon dioxide, and oxygen to pass through but do not allow larger molecules like glucose, sucrose, proteins, and starch to enter the cell directly.

The classic example used to demonstrate osmosis and osmotic pressure is to immerse cells into sugar solutions of various concentrations. There are three possible relationships that cells can encounter when placed into a sugar solution. Figure **2.7.4** shows what happens in osmosis through the semi-permeable membrane of the cells.

A. The concentration of solute in the solution can be **greater than** the concentration of solute in the cells. This cell is described as being in a **hypertonic solution** (hyper = greater than normal). The net flow or water will be out of the cell.
B. The concentration of solute in the solution can be **equal to** the concentration of solute in cells. In this situation, the cell is in an **isotonic solution** (iso = equal or the same as normal). The amount of water entering the cell is the same as the amount leaving the cell.
C. The concentration of solute in the solution can be **less than** the concentration of solute in the cells. This cell is in a **hypotonic solution** (hypo = less than normal). The net flow of water will be into the cell.

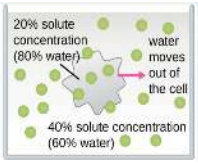


Figure **2.7.4.*A***: **Hypertonic solution.** A solution that has a higher solute concentration than another solution. Water particles will move out of the cell, causing crenation.

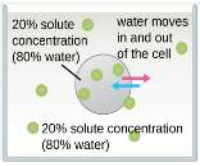


Figure **2.7.4.*B***: **Isotonic solution.** A solution that has the same solute concentration as another solution. There is no net movement of water particles, and the overall concentration on both sides of the cell membrane remains constant.

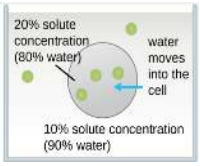


Figure **2.7.4.*C***: **Hypotonic solution.** A solution that has a lower solute concentration than another solution. Water particles will move into the cell, causing the cell to expand and eventually lyse.

Figure **2.7.5** demonstrates the specific outcomes of osmosis in red blood cells.

A. **Hypertonic solution.** The red blood cell will appear to shrink as the water flows out of the cell and into the surrounding environment.
B. **Isotonic solution.** The red blood cell will retain its normal shape in this environment as the amount of water entering the cell is the same as the amount leaving the cell.
C. **Hypotonic solution**. The red blood cell in this environment will become visibly swollen and potentially rupture as water rushes into the cell.

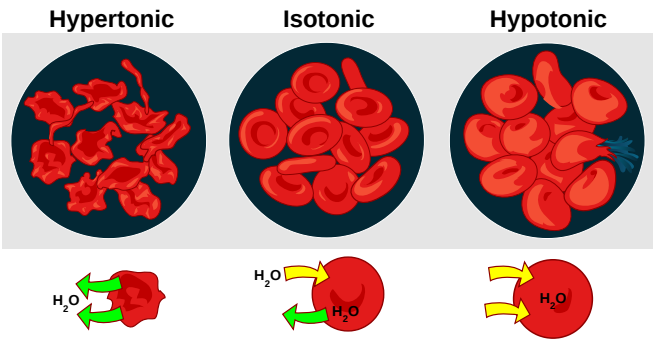


Figure **2.7.5**: Osmosis demonstration with Red Blood cells places in a hypertonic, isotonic, and hypotonic solution.

FACILITATED DIFFUSION

Water and many other substances cannot simply diffuse across a membrane. Hydrophilic molecules, charged ions, and relatively large molecules such as glucose all need help with diffusion. The help comes from special proteins in the membrane known as **transport proteins**. Diffusion with the help of transport proteins is called **facilitated diffusion**. There are several types of transport proteins, including channel proteins and carrier proteins (Figure **2.7.6**)

- Channel proteins form pores, or tiny holes, in the membrane. This allows water molecules and small ions to pass through the membrane without coming into contact with the hydrophobic tails of the lipid molecules in the interior of the membrane.
- Carrier proteins bind with specific ions or molecules, and in doing so, they change shape. As carrier proteins change shape, they carry the ions or molecules across the membrane.

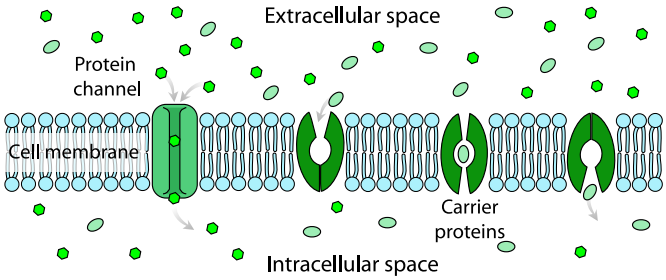


Figure **2.7.6**: Facilitated Diffusion Across a Cell Membrane. Channel proteins and carrier proteins help substances diffuse across a cell membrane. In this diagram, the channel and carrier proteins are helping substances move into the cell (from the extracellular space to the intracellular space). The channel protein has an opening that allows the substances to cross. In a carrier protein, the substance binds to the protein, which then causes the protein to changes shape, thereby releasing the substance into the cell.

REVIEW

1. What is the main difference between passive and active transport?
2. Summarize three different ways that passive transport can occur, and give an example of a substance that is transported in each way.
3. Explain how transport across the plasma membrane is related to the homeostasis of the cell.
4. Why can generally only very small, hydrophobic molecules across the cell membrane by simple diffusion?
5. Explain how facilitated diffusion assists in osmosis in cells. Be sure to define osmosis and facilitated diffusion in your answer.
6. Imagine a hypothetical cell with a higher concentration of glucose inside the cell than outside. Answer the following questions about this cell, assuming all transport across the membrane is passive, not active.
   A. Can the glucose simply diffuse across the cell membrane? Why or why not?
   B. Assuming that there are glucose transport proteins in the cell membrane, which way would glucose flow – into or out of the cell? Explain your answer.
   C. If the concentration of glucose was equal inside and outside of the cell, do you think there would be a net flow of glucose across the cell membrane in one direction or the other? Explain your answer.
7. What are the similarities and differences between channel proteins and carrier proteins?
8. *True or False.* Only active transport, not passive transport, involves transport proteins.
9. *True or False.* Oxygen and carbon dioxide can squeeze between the lipid molecules in the plasma membrane.
10. *True or False.* Ions easily diffuse across the cell membrane by simple diffusion.
11. Controlling what enters and leaves the cell is an important function of the:
    A. nucleus
    B. vesicle
    C. plasma membrane
    D. Golgi apparatus

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2.8: ACTIVE TRANSPORT AND HOMEOSTASIS

LIKE PUSHING A HUMVEE UPHILL

You can tell by their faces that these airmen are expending a lot of energy trying to push this Humvee up a slope. The men are participating in a competition that tests their brute strength against that of other teams. The Humvee weighs about 13,000 pounds, so it takes every ounce of energy they can muster to move it uphill against the force of gravity. Transport of some substances across a plasma membrane is a little like pushing a Humvee uphill — it can't be done without adding energy.



Figure **2.8.1**: Pushing a machine up a hill.

WHAT IS ACTIVE TRANSPORT?

Some substances can pass into or out of a cell across the plasma membrane without any energy required because they are moving from an area of higher concentration to an area of lower concentration. This type of transport is called passive transport as you learned in the last section. Other substances require energy to cross a plasma membrane often because they are moving from an area of lower concentration to an area of higher concentration. This type of transport is called **active transport**. The energy for active transport comes from the energy-carrying molecule called ATP (adenosine triphosphate). Active transport may also require transport proteins, such as carrier proteins, which are embedded in the plasma membrane. Two types of active transport are pump and vesicle transport.

PUMP

Two pump mechanisms (primary and secondary active transports) exist for the transport of small-molecular weight material and macromolecules. The **primary active transport** moves ions across a membrane and creates a difference in charge across that membrane. The primary active transport system uses ATP to move a substance, such as an ion, into the cell, and often at the same time, a second substance is moved out of the cell. The **sodium-potassium pump** is a mechanism of active transport that moves sodium ions out of the cell and potassium ions into the cells — in all the trillions of cells in the body! Both ions are moved from areas of lower to higher concentration, so energy is needed for this "uphill" process. The energy is provided by ATP. The sodium-potassium pump also requires carrier proteins. Carrier proteins bind with specific ions or molecules, and in doing so, they change shape. As carrier proteins change shape, they carry the ions or molecules across the membrane. Figure **2.8.2** shows in greater detail how the sodium-potassium pump works and the specific roles played by carrier proteins in this process.

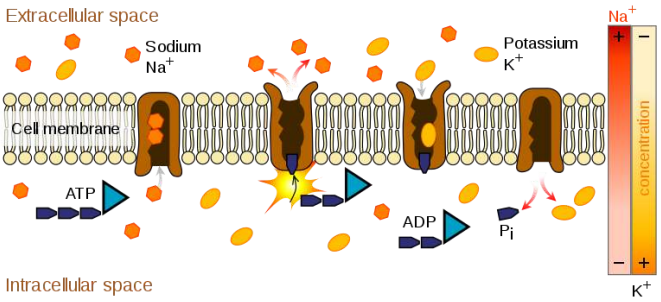


Figure **2.8.2**: The sodium-potassium pump. The sodium-potassium pump moves sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. First, three sodium ions bind with a carrier protein in the cell membrane. Then, the carrier protein receives a phosphate group from ATP. When ATP loses a phosphate group, energy is released. The carrier protein changes shape, and as it does, it pumps the three sodium ions out of the cell. At that point, two potassium ions bind to the carrier protein. The process is reversed, and the potassium ions are pumped into the cell.

To appreciate the importance of the sodium-potassium pump, you need to know more about the roles of sodium and potassium in the body. Both are essential dietary minerals, meaning you have to obtain them in the foods you eat. Both sodium and potassium are also electrolytes, meaning that they dissociate into ions (charged particles) in solution, which allows them to conduct electricity. Normal body functions require a very narrow range of concentrations of sodium and potassium ions in body fluids, both inside and outside of cells.

- Sodium is the principal ion in the fluid outside of cells. Normal sodium concentrations are about 10 times higher outside than inside of cells.
- Potassium is the principal ion in the fluid inside of cells. Normal potassium concentrations are about 30 times higher inside than outside of cells.

These differences in concentration create an electrical gradient across the cell membrane, called the membrane potential. the **secondary active transport** describes the movement of material using the energy of the electrochemical gradient established by the primary active transport. Using the energy of the electrochemical gradient created by the primary active transport system, other substances such as amino acids and glucose can be brought into the cell through membrane channels. ATP itself is formed through secondary active transport using a hydrogen ion gradient in the mitochondrion. Tightly controlling the membrane potential is critical for vital body functions, including the transmission of nerve impulses and the contraction of muscles. A large percentage of the

body's energy goes to maintaining this potential across the membranes of its trillions of cells with the sodium-potassium pump.

VESICLE TRANSPORT

Some molecules, such as proteins, are too large to pass through the plasma membrane, regardless of their concentration inside and outside the cell. Very large molecules cross the plasma membrane with a different sort of help, called **vesicle transport**. Vesicle transport requires energy, so it is also a form of active transport. There are two types of vesicle transport: endocytosis and exocytosis.

ENDOCYTOSIS

Endocytosis is a type of vesicle transport that moves a substance into the cell. The plasma membrane completely engulfs the substance, a vesicle pinches off from the membrane, and the vesicle carries the substance into the cell. It is used by all cells of the body because most substances important to them are polar and consist of big molecules, and thus cannot pass through the hydrophobic plasma membrane. When an entire cell or other solid particle is engulfed, the process is called **phagocytosis**. When fluid is engulfed, the process is called **pinocytosis**. When the content is taken in specifically with the help of receptors on the plasma membrane, it is called **receptor-mediated endocytosis**.

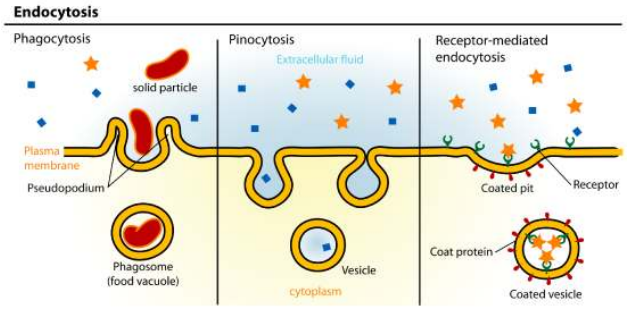


Figure **2.8.3**: (On the right) Phagocytosis is when the plasma membrane wraps around a solid particle outside the cell using projections called pseudopodia. The membrane then pinches off to form a phagosome (food vacuole). (Middle)Pinocytosis is when the membrane folds to form a vesicle that carries substances dissolved in the extracellular fluid. (On the left) Receptor-mediated endocytosis occurs when the receptors on the plasma membrane bind to specific particles. The coated pit region of the membrane forms a coated vesicle containing the receptors with their bound particles.

A targeted variation of endocytosis employs binding proteins in the plasma membrane that are specific for certain substances. The particles bind to the proteins and the plasma membrane invaginates, bringing the substance and the proteins into the cell. If passage across the membrane of the target of **receptor-mediated endocytosis** is ineffective, it will not be removed from the tissue fluids or blood. Instead, it will stay in those fluids and increase in concentration. Some human diseases are caused by a failure of receptor-mediated endocytosis. For example, the form of cholesterol termed low-density lipoprotein or LDL (also referred to as “bad” cholesterol) is removed from the blood by receptor-mediated endocytosis. In the human genetic disease familial hypercholesterolemia, the LDL receptors are defective or missing entirely. People with this condition have life-threatening levels of cholesterol in their blood because their cells cannot clear the chemical from their blood.

EXOCYTOSIS

Exocytosis is a type of vesicle transport that moves a substance out of the cell. A vesicle containing the substance moves through the cytoplasm to the cell membrane. Then, the vesicle membrane fuses with the cell membrane, and the substance is released outside the cell.

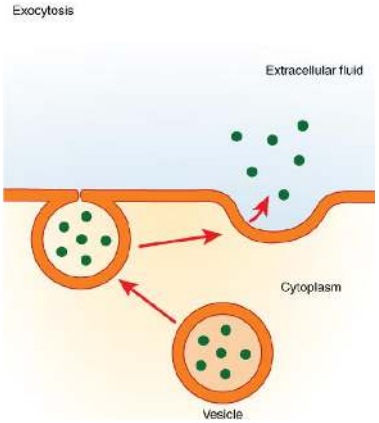


Figure **2.8.4**: Exocytosis is much like endocytosis in reverse. Material destined for export is packaged into a vesicle inside the cell. The membrane of the vesicle fuses with the cell membrane, and the contents are released into the extracellular space.

HOMEOSTASIS AND CELL FUNCTION

For a cell to function normally, a stable state must be maintained inside the cell. For example, the concentration of salts, nutrients, and other substances must be kept within a certain range. The process of maintaining stable conditions inside a cell (or an entire organism) is homeostasis. Homeostasis requires constant adjustments because conditions are always changing both inside and outside the cell. The processes described in this and previous lessons play important roles in homeostasis. By moving substances into and out of cells, they keep conditions within normal ranges inside the cells and the organism as a whole.

FEATURE:FEATURE: MY HUMAN BODY

Maintaining the proper balance of sodium and potassium in body fluids by active transport is necessary for life itself, so it's no surprise that getting the right balance of sodium and potassium in the diet is important for good health. Imbalances may increase the risk of high blood pressure, heart disease, diabetes, and other disorders.

If you are like the majority of Americans, sodium and potassium are out of balance in your diet. You are likely to consume too much sodium and too little potassium. Follow these guidelines to help ensure that these minerals are in balance in the foods you eat:

- Total sodium intake should be less than 2300 mg/day. Most salt in the diet is found in processed foods or added with a salt shaker. Stop adding salt and start checking food labels for sodium content. Foods considered low in sodium have less than 140 mg/serving (or 5% daily value).
- Total potassium intake should be 4700 mg/day. It's easy to add potassium to the diet by choosing the right foods, and there are plenty of choices. Most fruits and vegetables are high in potassium, but especially potatoes, bananas, oranges, apricots, plums, leafy greens, tomatoes, lima beans, and avocado. Other foods with substantial amounts of potassium are fish, meat, poultry, and whole grains.

REVIEW

1. Define active transport.
2. What is the sodium-potassium pump? Why is it so important?
3. Name two types of vesicle transport. Which type moves substances out of the cell?
4. What are the similarities and differences between phagocytosis and pinocytosis?
5. The sodium-potassium pump is a:
   A. Phospholipid
   B. Protein
   C. Carbohydrate
   D. Ion
6. What is the functional significance of the shape change of the carrier protein in the sodium-potassium pump after the sodium ions bind?
7. A potentially deadly poison derived from plants called ouabain blocks the sodium-potassium pump and prevents it from working. What do you think this does to the sodium and potassium balance in cells? Explain your answer.
8. True or False. The sodium-potassium pump uses one protein to pump both sodium and potassium.
9. True or False. Vesicles are made of the nuclear membrane.
10. What is an electrical gradient across the cell membrane called?
11. Chemical signaling molecules called neurotransmitters are released from nerve cells (neurons) through vesicles. This is an example of:
    A. Pinocytosis
    B. Phagocytosis
    C. Endocytosis
    D. Exocytosis
12. The energy for active transport comes from
    A. ATP
    B. RNA
    C. Carrier proteins
    D. Sodium ions
13. Transport proteins that move substances into and out of a cell are located in which structure?

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2.9: CELL REPRODUCTION- MITOSIS AND MEIOSIS

MITOSIS OR MEIOSIS?

Figure **2.9.1** shows a tiny embryo just beginning to form. Once an egg is fertilized, the resulting single cell must divide many times to develop a fetus. Both mitosis and meiosis involve cell division; is this type of cell division an example of mitosis or meiosis? The answer is mitosis. With each division, you are making a genetically exact copy of the parent cell, which only happens through mitosis.



Figure **2.9.1**: 4-celled embryo

CELL REPRODUCTION

You have probably have heard of the importance and prevalence of cell division. While there are a few cells in the body that do not undergo cell division (such as gametes, red blood cells, most neurons, and some muscle cells), most somatic cells divide regularly. A **somatic cell** is a general term for a body cell, and all human cells, except for the cells that produce eggs and sperm (which are referred to as **germ cells**), are somatic cells. Somatic cells contain *two* copies of each of their chromosomes (one copy received from each parent). A **homologous** pair of **chromosomes** is the two copies of a single chromosome found in each somatic cell. The human is a diploid organism, having 23 homologous pairs of chromosomes in each of the somatic cells. The condition of having pairs of chromosomes is known as diploidy.

Cells in the body replace themselves over the lifetime of a person. For example, the cells lining the gastrointestinal tract must be frequently replaced when constantly "worn off" by the movement of food through the gut. But what triggers a cell to divide, and how does it prepare for and complete cell division? The cell cycle is the sequence of events in the life of the cell from the moment it is created at the end of a previous cycle of cell division until it then divides itself, generating two new cells.

THE CELL CYCLE

Cell division is the process in which one cell, called the parent cell, divides to form two new cells, referred to as daughter cells. How this happens depends on whether the cell is prokaryotic or eukaryotic. Cell division is simpler in prokaryotes than eukaryotes because prokaryotic cells themselves are simpler. Prokaryotic cells, like bacteria cells, have a single circular chromosome, no nucleus, and few other organelles. Eukaryotic cells, including human cells, in contrast, have multiple chromosomes contained within a nucleus and many other organelles. All of these cell parts must be duplicated and then separated when the cell divides. Cell division is just one of several stages that a cell goes through during its lifetime. The **cell cycle** is a repeating series of events that include growth, DNA synthesis, and cell division. The cell cycle in prokaryotes is quite simple: the cell grows, its DNA replicates, and the cell divides. This form of division in prokaryotes is called asexual reproduction. In eukaryotes, the cell cycle is more complicated.

MITOSIS VS. MEIOSIS

Most human cells divide their nucleus by a process called **mitosis** that results in two cells that are genetically identical to the parent cell and to each other. In mitosis the parent cell and the daughter cells all have two copies of each type of chromosome (they are **diploid**). Somatic cells reproduce by mitosis.

Meiosis is a specialized cell division that only occurs in germ cells that divide to produce sperm or eggs. It produces cells that have only one copy of each type of chromosome (are **haploid**)

Both **mitosis** and **meiosis** result in eukaryotic cell division. The primary difference between these divisions is the differing goals of each process. The goal of mitosis is to produce two **daughter cells** that are genetically identical to the parent cell. Mitosis happens when you grow, and to replace injured and worn out cells. You want all your new cells to have the same DNA as the previous cells. The goal of meiosis is to produce sperm or eggs, also known as **gametes**. The resulting gametes are not genetically identical to the parent cell. Gametes are **haploid** cells, with only half the DNA present in the **diploid** parent cell. This is necessary so that when a sperm and an egg combine at **fertilization**, the resulting **zygote** (the fertilized egg) has the correct amount of DNA—not twice as much as the parents. The zygote then begins to divide through mitosis.

Table **2.9.1**: comparison of mitosis and meiosis

	Mitosis	Meiosis
Purpose	To produce new cells	To produce gametes
Number of Cells Produced	2	4
Rounds of Cell Division	1	2
Haploid or Diploid	Diploid	Haploid
Are daughter cells identical to parent cells?	Yes	No
Are daughter cells identical to each other?	Yes	No

Figure **2.9.2** shows a comparison of mitosis, meiosis, and binary fission.

- Binary fission occurs in bacteria. Note that bacterial cells have a single loop of DNA. The DNA of the cell is replicated. Each loop of DNA moves to the opposite side of the cell and the cell splits in half.
- Mitosis and Meiosis both occur in eukaryotic cells. In the example below the cell has 4 total chromosomes. These are replicated during the S phase (the DNA synthesis phase).
    - In mitosis, the chromosomes line up in the center of the cell. Then, sister chromatids separate and move to the opposite poles of the cell. The cell divides, producing two cells with 4 total chromosomes
    - In meiosis, the homologous chromosomes line up in the center of the cell. Then each chromosome moves to opposite poles and the cell divides.
        - Next, the chromosomes line up in the center of the cell. Then, sister chromatids separate and move to the opposite poles of the cell. This produces four cells with 2 chromosomes each. These are the gametes.
        - Two gametes combine to form a zygote with 4 total chromosomes.

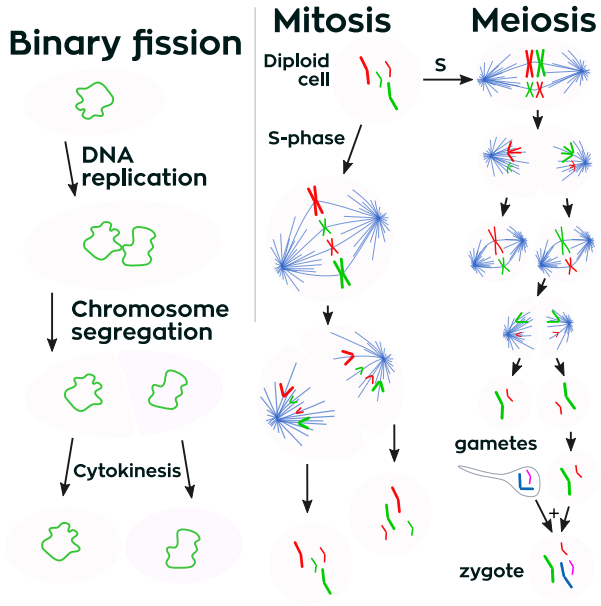


Figure **2.9.2**: A comparison between binary fission, mitosis, and meiosis.

REVIEW

1. What is the goal of mitosis? Or meiosis?
2. How many cells are created from cytokinesis following mitosis? Following meiosis?
3. Which process, mitosis or meiosis, creates genetically identical cells?
4. "Gametes are haploid cells." What does this sentence mean?

EXPLORE MORE

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2.10: HUMAN CELLS AND TISSUES

DUST MOP

This photo in Figure **2.10.1** looks like a close-up of an old-fashioned dust mop, and the object it shows has a somewhat similar function. However, the object is greatly enlarged in the photo. Can you guess what it is? The answer may surprise you. It is a scanning electron micrograph of human epithelial cells that line the bronchial passages. The floppy, dust-mop-like extensions are actually microscopic structures called cilia projecting from the outer surface of the epithelial cells. The function of the cilia is to trap dust, pathogens, and other particles in the air before it enters the lungs. The cilia also sway back and forth to sweep the trapped particles upward toward the throat, from which they can be expelled from the body.

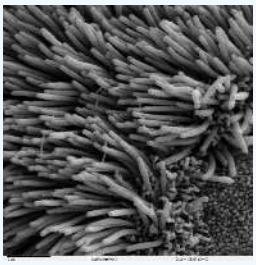


Figure **2.10.1**: Scanning electron microscope image of lung trachea epithelium. There are both ciliated and on-ciliated cells in this epithelium. Note the difference in size between the cilia and the microvilli (on the non-ciliated cell surface)

HUMAN CELLS

Like the ciliated bronchial cells in the micrograph above, many other cells in the human body are very distinctive and well suited for special functions. To perform their special functions, cells may vary in a number of ways.

VARIATION IN HUMAN CELLS

Some cells act as individual cells and are not attached to one another. Red blood cells are a good example. Their main function is to transport oxygen to other cells throughout the body, so they must be able to move freely through the circulatory system. Many other cells, in contrast, act together with other similar cells as part of the same tissue, so they are attached to one another and cannot move freely. For example, epithelial cells lining the respiratory tract are attached to each other to form a continuous surface that protects the respiratory system from particles and other hazards in the air.

Many cells can divide readily and form new cells. Skin cells are constantly dying and being shed from the body and replaced by new skin cells, and bone cells can divide to form new bone for growth or repair. Some other cells, in contrast, such as certain nerve cells, can divide and form new cells only under exceptional circumstances. That's why nervous system injuries such as a severed spinal cord generally cannot heal by the production of new cells, resulting in a permanent loss of function.

Many human cells have the primary job of producing and secreting a particular substance, such as a hormone or an enzyme. For example, special cells in the pancreas produce and secrete the hormone insulin, which regulates the level of glucose in the blood. Some of the epithelial cells that line the bronchial passages produce mucus, a sticky substance that helps trap particles in the air before it passes into the lungs.

DIFFERENT BUT IDENTICAL

All the different cell types within an individual human organism are genetically identical, so no matter how different the cells are, they all have the same genes. How can such different types of cells arise? The answer is the differential regulation of genes. Cells with the same genes can be very different because different genes are expressed depending on the cell type.

EXAMPLES OF HUMAN CELL TYPES

Many common types of human cells — such as bone cells and white blood cells — actually consist of several subtypes of cells. Each subtype, in turn, has a special structure and function. A closer look at these cell types will give you a better appreciation for the diversity of structures and functions of human cells.

BONE CELLS

There are four main subtypes of bone cells, as shown in Figure **2.10.2**. Each type has a different form and function:

1. Osteocytes are star-shaped bone cells that make up the majority of bone tissue. They are the most common cells in mature bone and can live as long as the organism itself. They also control the function of bone cells called osteoblasts and osteoclasts.
2. Osteoblasts are cells with single nuclei that synthesize new bone. They function in organized groups of connected cells called osteons to form the organic and mineral matrix of bone.
3. Osteogenic cells are undifferentiated stem cells that differentiate to form osteoblasts in the tissue that covers the outside of the bone.
4. Osteoclasts are very large, multinucleated cells that are responsible for the breakdown of bones through resorption. The breakdown of bone is very important in bone health because it allows for bone remodeling.

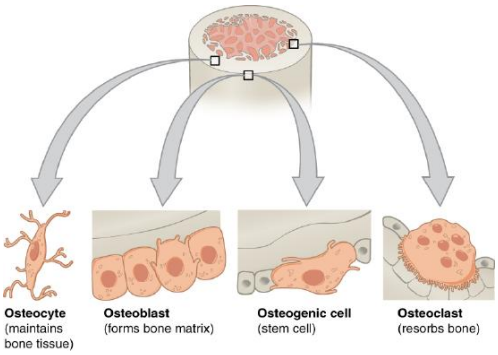


Figure **2.10.2**: Four sub-types of bone cells in the human skeletal system: Osteocytes (maintain bone tissues), Osteoblast (form bone matrix), Osteogenic cells (stem cell), Osteoclasts (reabsorb bone)

WHITE BLOOD CELLS

White blood cells (also called leukocytes) are even more variable than bone cells. Five subtypes of white blood cells are shown in Figure **2.10.3**. All of them are immune system cells involved in defending the body, but each subtype has a different function. They also differ in the normal proportion of all leukocytes they make up.

1. Monocytes make up about 5 percent of leukocytes. They are the biggest cells with extensions and a kidney-shaped nucleus. They engulf and destroy (phagocytize) pathogens in tissues.
2. Eosinophils make up about 2 percent of leukocytes. They have and a bilobed nucleus. They attack larger parasites and set off allergic responses.
3. Basophils make up less than 1 percent of leukocytes. Like eosinophils, these cells also have granules and a bilobed nucleus. They release proteins called histamines that are involved in inflammation.
4. Lymphocytes make up about 30 percent of leukocytes. These are small cells with a large circular nucleus. They include B cells and T cells. B cells produce antibodies against non-self antigens, and T cells destroy virus-infected cells and cancer cells.
5. Neutrophils are the most numerous white blood cells, making up about 62 percent of leukocytes. They have granules and a multilobed nucleus. They phagocytize single-celled bacteria and fungi in the blood.

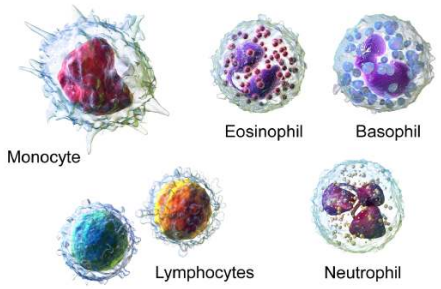


Figure **2.10.3**: Five sub-types of human white blood cells in the human immune system: monocyte, eosinophil, basophil, lymphocyte, neutrophil

TISSUES

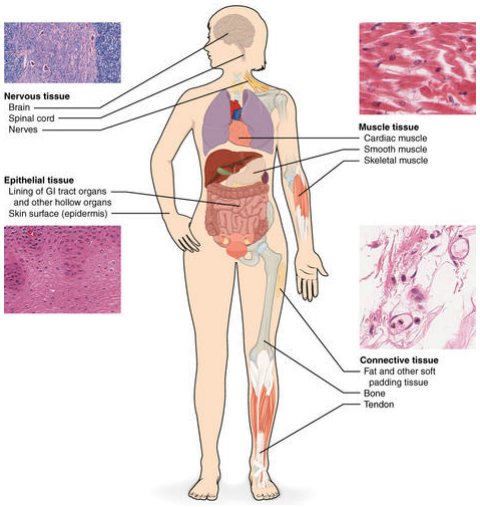


Figure **2.10.4**: There are 4 different types of tissues in our body. Nervous tissue is found in the brain, spinal cord, and nerves. Muscular tissue such as cardiac, smooth, and skeletal muscle. Epithelial tissue lines the GI tract organs and other hollow organs and is found on the skin surface (epidermis). Connective tissue such as fat and other soft padding tissue, bone, and tendon.

Groups of connected cells form tissues. The cells in a tissue may all be the same type or they may be of multiple types. In either case, the cells in the tissue work together to carry out a specific function. There are four main types of human tissues: connective, epithelial, muscle, and nervous tissues.

CONNECTIVE TISSUE

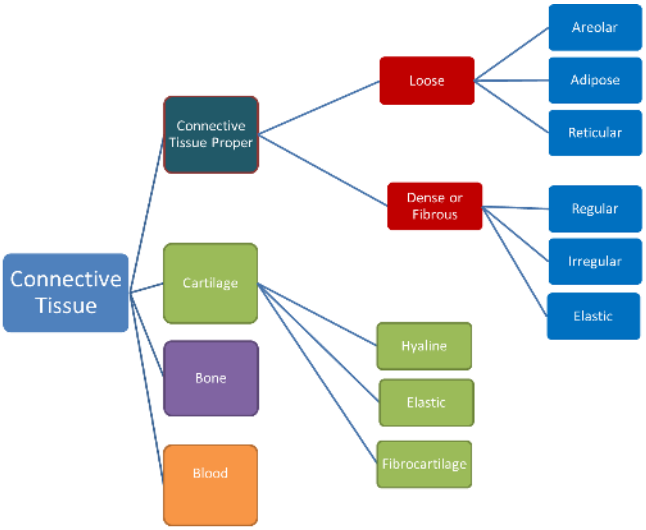


Figure **2.10.5**: The image summarizes the various categories of connective tissues found in the human body. Connective tissue can be classified as connective tissue proper, cartilage, bone, or blood. Cartilage can be classified as hyaline cartilage, elastic cartilage, or fibrocartilage. Connective tissue proper can be classified as loose and dense or fibrous. Loose connective tissue can be classified as areolar, adipose, or reticular. Dense or fibrous connective tissue can be classified as regular, irregular, and elastic.

The most diverse and abundant of all tissues, connective tissue holds cells together and supports the body. Connective tissue is made up of cells suspended in a non-cellular matrix. The matrix (also known as

ground substance) is secreted by the connective tissue cells and determines the characteristics of the connective tissue. It is the consistency of the matrix that determines the function of the connective tissue. The matrix can be liquid, gel-like or solid, all depending on the type of connective tissue. For example, the extracellular matrix of bone is a rigid mineral framework. The extracellular matrix of blood is liquid plasma. Connective tissues such as bone and cartilage generally form the body's structure. There are many sub-types of the four major types of tissues in a human body, see the flow chart in Figure **2.10.5**.

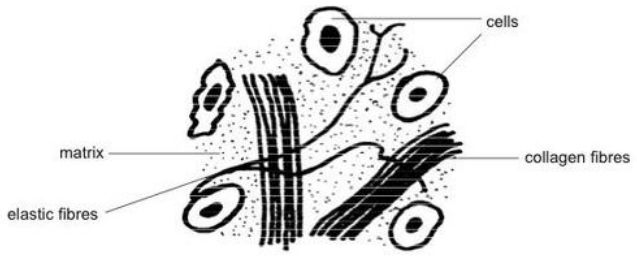


Figure **2.10.6**: General features of connective tissues. The Matrix of most connective tissues is made up of ground substance and protein fibers. There are cells suspended in the matrix.

CONNECTIVE TISSUE PROPER

Fibroblast cells are responsible for synthesizing protein fibers for the matrix. **Collagen fibers** are strong, **elastic fibers** are flexible and **reticular fibers** form a supportive framework for organs and basement membranes. There are two subcategories of connective tissue proper.

LOOSE CONNECTIVE TISSUE

Thin and soft, this tissue contains many collagen and elastic fibers in a jell-like matrix. The cells in loose connective tissue are not close together. This tissue functions in binding the skin to underlying structures. There are three types of loose connective tissue.

1. **Areolar connective tissue** is a common form of loose connective tissue. It is found in the skin and mucous membranes, where it binds the skin or membrane to underlying tissues such as muscles. It is also found around blood vessels and internal organs where it links and supports them.
2. **Adipose connective tissue** is commonly known as fat. This tissue contains fat cells that are specialized for lipid storage. In addition to storing energy, this tissue also cushions and protects the organs.
3. **Reticular connective tissue** is mostly composed of reticular protein fibers which make a skeleton, known as stroma, for the lymphatic and white blood cells. This type of tissue is found in the spleen and other lymphatic system structures.

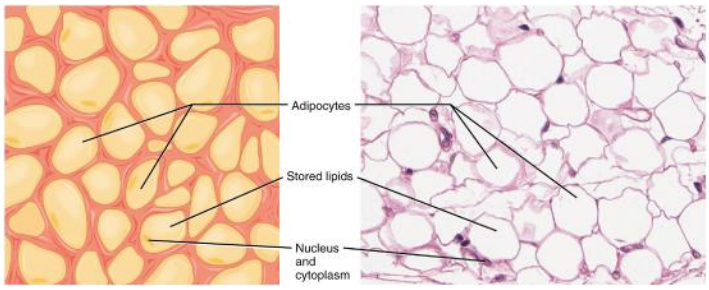


Figure **2.10.7**: Adipose Connective Tissue consists of fat cells (adipocytes with a nucleus and stored lipids in their cytoplasm) with a little extracellular matrix. It stores fat for energy and provides insulation.

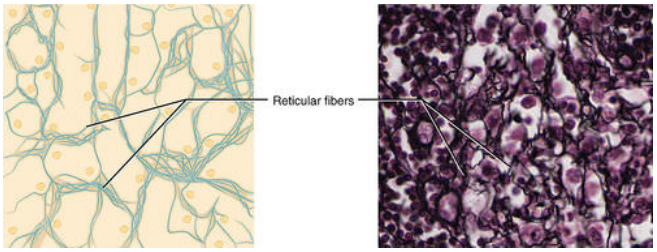


Figure **2.10.8**: Reticular Connective Tissue. This is a loose connective tissue made up of a network of reticular fibers that provides a supportive framework for soft organs

DENSE CONNECTIVE TISSUE PROPER

This tissue consists of three categories, dense regular connective tissue, dense irregular connective tissue, and elastic connective tissue. These tissues differ on the arrangement and composition of the fibrous elements of the extracellular matrix.

1. **Dense regular connective tissue** has extracellular fibers that all run in the same direction and plane. Muscle tendons are a type of dense regular connective tissue.
2. **Dense irregular connective tissue** contains collagen and elastic fibers which are found running in all different directions and planes. The dermis of the skin is composed of dense irregular connective tissue.
3. **Elastic connective tissue**: Made up of freely branching elastic fibers with fibroblasts in the spaces between the fibers, this tissue allows the kind of stretch that is found in the walls of arteries.

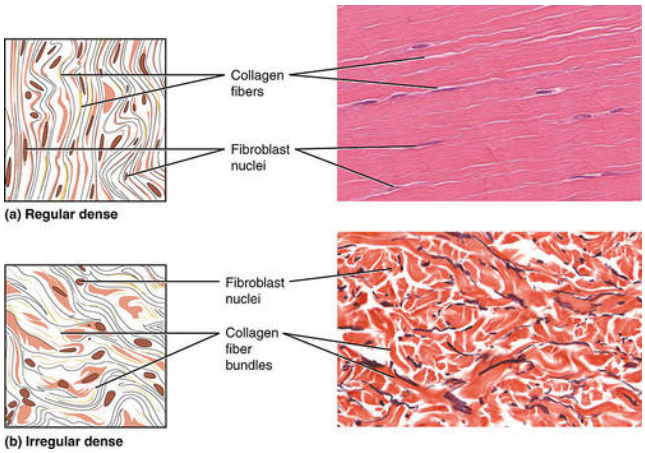


Figure **2.10.9**: (a) Dense regular connective tissue consists of collagen fibers packed into parallel bundles. (b) Dense irregular connective tissue consists of collagen fibers interwoven into a mesh-like network..

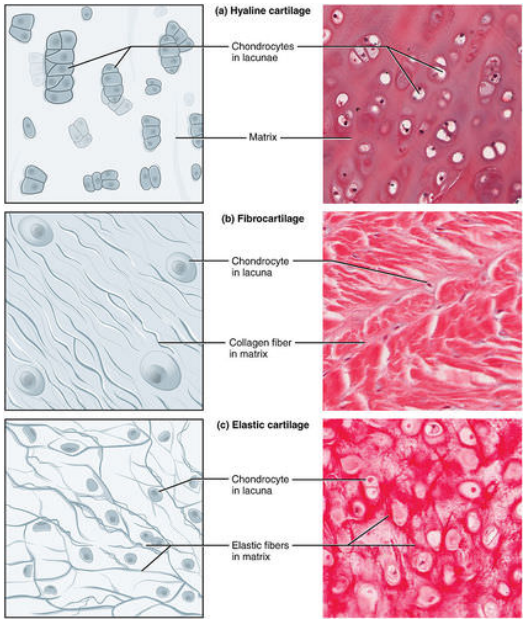


Figure **2.10.10**: Cartilage is a connective tissue consisting of collagenous fibers embedded in a firm matrix of chondroitin sulfates. (a) Hyaline cartilage has chondrocytes in lacunae within a matrix. (b) Fibrocartilage has chondrocytes in lacunae within collage fibers in a matrix. (c) Elastic cartilage has chondrocytes in lacunae within elastic fibers in a matrix.

CARTILAGE

This connective tissue is relatively solid and is a non-vascularized tissue (does not have a blood supply). The matrix is produced by cells called chondroblasts. When these cells slow down, they reside is small spaces called lacunae. These mature cells in the lacunae are called chondrocytes. There are three types of cartilage: hyaline cartilage, elastic cartilage, and fibrocartilage.

1. **Hyaline cartilage** is the most common type of cartilage, contains many collagen fibers and is found in many places including the nose, between the ribs and the sternum and in the rings of the trachea.
2. **Elastic cartilage** has many elastic fibers in the matrix and supports the shape of the ears and forms part of the larynx.
3. **Fibrocartilage** is tough and contains many collagen fibers and is responsible for cushioning the knee joint and for forming the disks between the vertebrae.

BONE

Bone is a hard, mineralized tissue found in the skeleton. The bone matrix contains many collagen fibers as well as inorganic mineral salts, calcium carbonate, and calcium phosphate, all features that make it a very rigid structure. Bone cells, called **osteoblasts**, secrete the osteoid substance that eventually hardens around the cells to form an ossified matrix. The **osteon** forms the basic unit of compact bone. Within the

osteon, the osteocytes (mature bone cells) are located in lacunae. Because the bone matrix is very dense, the osteocytes get their nutrition from the central canal via tiny canals called canaliculi.

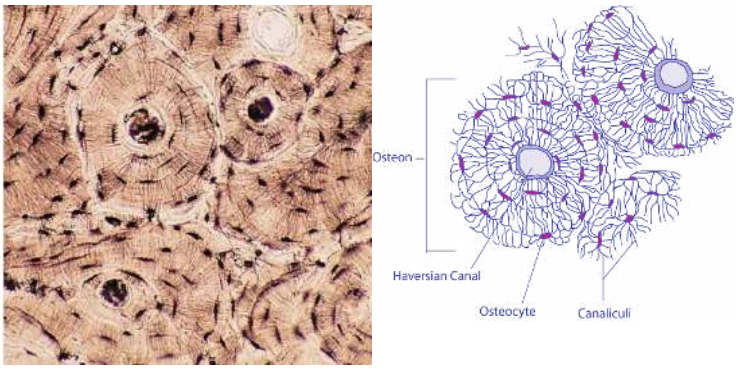


Figure **2.10.11**: The image shows a micrograph as well as an illustration of the cross-section of the compact bone tissue. The osteons are concentric structures that are composed of osteocytes in the lacunae and central (Haversian) canal. The small tunnels, canaliculi, connect osteocytes in the different layers of an osteon.

BLOOD

Blood is considered a type of fluid connective tissue because the matrix of blood is not solid. The fluid matrix is called plasma, and formed elements of this tissue include white blood cells, red blood cells, and platelets. Read more about the composition and function of blood in the cardiovascular system chapter.

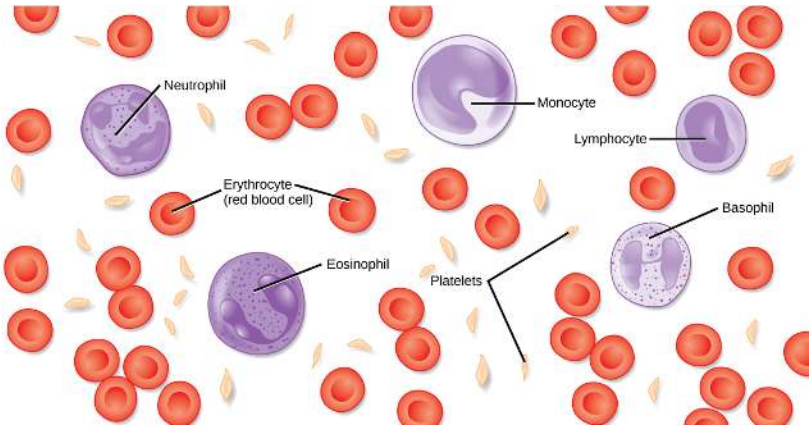


Figure **2.10.12**: The cells and cellular components of human blood are shown. Red blood cells deliver oxygen to the cells and remove carbon dioxide. White blood cells (including neutrophils, monocytes, lymphocytes, eosinophils, and basophils) are involved in the immune response. Platelets form clots that prevent blood loss after injury.

EPITHELIAL TISSUE

Epithelial tissue is made up of cells that line inner and outer body surfaces, such as the skin and the inner surface of the digestive tract. Epithelial tissue that lines inner body surfaces and body openings is called **mucous membrane.** This type of epithelial tissue produces **mucus**, a slimy substance that coats mucous membranes and traps pathogens, particles, and debris. Epithelial tissue protects the body and its internal organs, secretes substances such as hormones in addition to mucus, and absorbs substances such as nutrients.

EPITHELIAL CELL CLASSIFICATION

Most epithelial tissue is described with two names. The first name describes the number of cell layers present and the second describes the shape of the cells. One layer of epithelial cells is called simple and more than one layer of epithelial cells is called stratified. There are three basic shapes of epithelial cells, squamous, cuboidal, and columnar. Squamous cells are thin and flat; cuboidal cells have a shape of a cube; columnar cells have a shape of a pillar. For example, simple squamous epithelial tissue describes a single layer of cells that are flat and scale-like in shape.

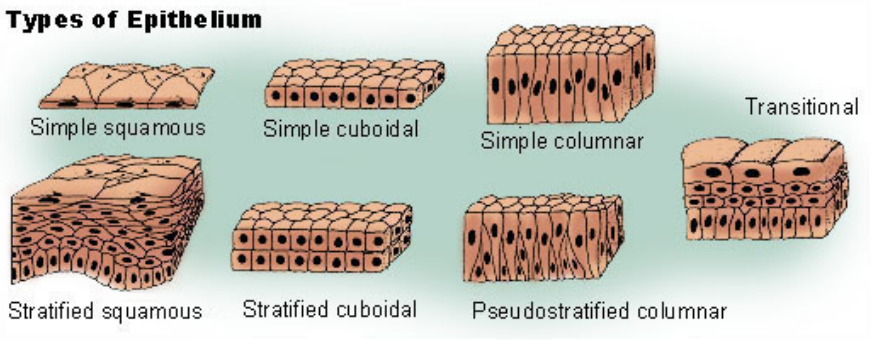


Figure **2.10.13**: Classification of Epithelial Tissues

LOCATIONS AND FUNCTIONS OF EPITHELIAL TISSUES

These tissues are found at various locations in our body and they have many functions. Some locations and functions are listed below:

- Simple squamous epithelium: This tissue is located in the sacs of the lungs and kidney where the exchange of nutrients and gas is essential.
- Simple cuboidal epithelium: This tissue is located in the glands and their ducts and kidneys. The main function of this tissue is secretion.
- Simple Columnar epithelium: This tissue lines the Gastrointestinal tract. The main function of this tissue is absorption and secretion.
- Pseudostratified epithelium: This is a simple tissue with the appearance of stratification. This tissue is located in the respiratory tract. This tissue may contain cilia to move mucus.
- Stratified squamous epithelium: This tissue is located where protection is needed such as skin.
- Stratified cuboidal epithelium: This tissue is located in the sweat glands for protection.
- Stratified columnar epithelium: This tissue is located in some sweat glands. The main function is to protect and secrete sweat components.
- Transitional epithelium: This tissue lines bladder, urethra, and ureters. The tissue allows the urinary organs to expand and stretch.

MUSCLE TISSUE

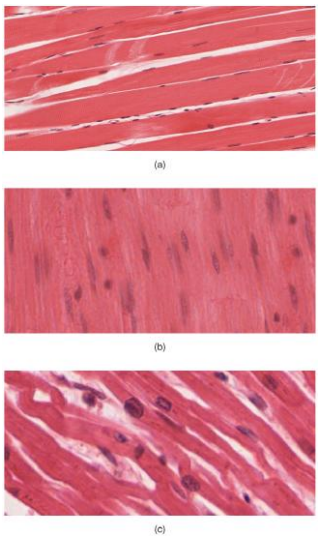


Figure **2.10.14**: The body contains three types of muscle tissue: (a) skeletal muscle, (b) smooth muscle, and (c) cardiac muscle.

Muscle tissue is made up of cells that have the unique ability to contract or become shorter. There are three major types of muscle tissue, as pictured in Figure **2.10.14**: skeletal, smooth, and cardiac muscle tissues.

1. **Skeletal muscles** are striated, or striped in appearance, because of their internal structure. Skeletal muscles are attached to bones, and when they pull on the bones, they enable the body to move. Skeletal muscles are under voluntary control.
2. **Smooth muscles** are nonstriated muscles. They are found in the walls of blood vessels and in the reproductive, gastrointestinal, and respiratory tracts. Smooth muscles are not under voluntary control.
3. **Cardiac muscles** are striated and found only in the heart. Their contractions cause the heart to beat. Cardiac muscles are not under voluntary control.

NERVOUS TISSUE

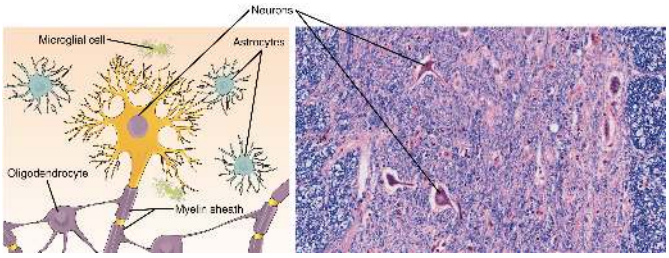


Figure **2.10.15**. This diagram shows some of the cell types that make up nervous tissues.

Nervous tissue is made up of neurons and other types of cells generally called glial cells (Figure **2.10.15**). Neurons are composed of cell body and extensions. The cell body contains the nucleus and the extensions make connections with the other tissues and neurons. Neurons transmit electrical messages and the glial cells play supporting roles. Nervous tissue makes up the central nervous system (mainly the brain and spinal cord) and peripheral nervous system (the network of nerves that runs throughout the rest of the body).

FEATURE: MY HUMAN BODY

If you are a blood donor, then you have donated tissue. Blood is a tissue that you can donate when you are alive. You may have indicated on your driver's license application that you wish to be a tissue donor in the event of your death. Deceased people can donate many different tissues, including skin, bone, heart valves, and the corneas of the eyes. If you are not already registered as a tissue donor, the information below may help you decide if you would like to register.

Each year, approximately 30,000 people donate tissues, which supply tissues for up to 1 million tissue transplants. One tissue donor can enhance or save the life of more than 50 people! Unlike organs, which generally must be transplanted immediately after the donor dies, donated tissues can be processed and stored for a long time for later use. Donated tissues can be used to replace burned skin and damaged bone and to repair ligaments. Corneal tissues can be used for corneal transplants that restore sight in blind people. In fact, each year 48,000 patients have their sight restored with corneal transplants. Unfortunately, there are not enough tissues to go around, and the need for donated tissues keeps rising.

REVIEW

1. Give an example of cells that function individually and move freely, and give an example of cells that act together and are attached to other cells of the same type.
2. What are examples of cells that can readily divide and cells that can divide only under rare circumstances?
3. Identify a type of cell that secretes an important substance and name the substance it secretes.
4. Explain how different cell types come about when all the cells in an individual human being are genetically identical.
5. Compare and contrast four subtypes of human bone cells.
6. Identify three types of human white blood cells, and state their functions.
7. Why are bone and blood both classified as connective tissues?
8. Name another type of connective tissue, and describe its role in the human body.
9. Based on the information in the table above of types of epithelial tissues, list four general functions of this type of tissue in the human body.
10. Compare and contrast the three types of muscle tissues.
11. Identify the four types of nervous tissues, where each type is found, and its basic function.
12. Of the main types of human tissue, name two that can secrete hormones.
13. Cells in a particular tissue:
    A. Are all of the same type
    B. Have different genes from cells in other tissues
    C. Work together to carry out a function
    D. Are always connected physically to each other
14. Why are mucous membranes often located in regions that interface between the body and the outside world?
15. Skin is a type of _____ tissue.
16. Body fat is a type of _____ tissue.

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2.11: CASE STUDY CONCLUSION- TIRED AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: MORE THAN JUST TIRED

Jasmin discovered that her extreme fatigue, muscle pain, vision problems, and vomiting were due to problems in her mitochondria. Mitochondria are small membrane-bound organelles found in eukaryotic cells that provide energy for the cells of the body. They do this by carrying out the final two steps of aerobic cellular respiration, which is the major way that the human body breaks down the sugar glucose from food into a form of energy cells can use, namely the molecule ATP.

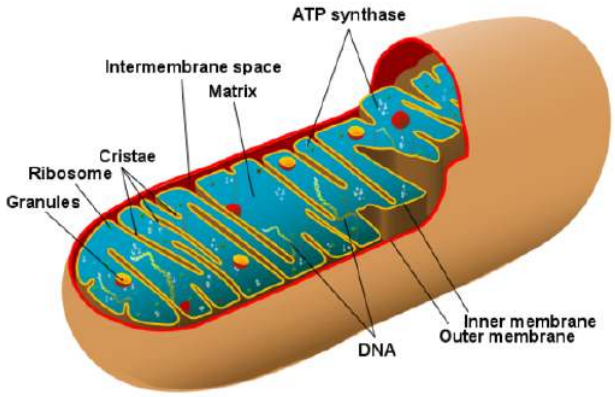


Figure **2.11.1**: Mitochondrial structures. You can see the outer membrane, the inner membrane with cristae, intermembrane space, and matrix with granules, ribosomes, and mitochondrial DNA. ATP synthase is located in the inner membrane.

Because mitochondria provide energy for cells, you can probably easily see why Jasmin was experiencing extreme fatigue, particularly after running. Her damaged mitochondria could not keep up with her need for energy, particularly after intense exercise which requires a lot of additional energy. What is perhaps not so obvious are the reasons for her other symptoms, such as blurry vision, muscle spasms, and vomiting. But all the cells in the body require energy in order to function properly. Mitochondrial diseases can cause problems in mitochondria in any cell of the body, including muscle cells and cells of the nervous system, which includes the brain and nerves. The nervous system and muscles work together to control vision and digestive system functions, such as vomiting, so when they are not functioning properly, a variety of symptoms can emerge. This also explains why Jasmin's niece, who also has mitochondrial disease, has symptoms related to brain function, such as seizures and learning disabilities. Our cells are microscopic and mitochondria are even tinier, but they are essential for the proper functioning of our bodies and when they are damaged, serious health effects can occur.

A seemingly confusing aspect of mitochondrial diseases is that the type of symptoms, severity of symptoms, and age of onset can vary wildly between people — even within the same family! In Jasmin's case, she did not notice symptoms until adulthood, while her niece had more severe symptoms starting at a much younger age. However, this makes sense when you know more about how mitochondrial diseases work.

Inherited mitochondrial diseases can be due to damage in either the DNA in the nucleus of cells or the DNA in the mitochondria themselves. Recall that mitochondria are thought to have evolved from prokaryotic organisms that were once free-living, but then infected or were engulfed by larger cells. One of the pieces of evidence that supports this endosymbiotic theory is that mitochondria have their own, separate DNA. When the mitochondrial DNA is damaged or mutated, it can result in some types of mitochondrial diseases. However, these mutations do not typically affect *all of* the mitochondria in a cell. During cell division, organelles such as mitochondria are replicated and passed down to the new daughter cells. If some of the mitochondria are damaged, and others are not, the daughter cells can have different amounts of damaged mitochondria. This helps explain the wide range of symptoms in people with mitochondrial diseases, even ones in the same family because different cells in their bodies are affected to different extents. Jasmin's niece was affected strongly and her symptoms were noticed early, while Jasmin's symptoms were milder and did not become apparent until adulthood.

There is still much more that needs to be discovered about the different types of mitochondrial diseases. But by learning about cells, their organelles, how they obtain energy, and how they divide, you should now have a better understanding of the biology behind these diseases. Apply your understanding of cells to your own life — can you think of other diseases that affect cellular structures or functions, maybe that even affect people you know? Since your entire body is made of cells, when they are damaged or not functioning properly it can cause a wide variety of health problems.

CHAPTER SUMMARY

In this chapter, you learned many facts about cells. Specifically, you learned that:

- Cells are the basic units of structure and function of living things.
- The first cells, from cork, were observed by Hooke in the 1600s. Soon after, van Leeuwenhoek observed other living cells.
- In the early 1800s, Schwann and Schleiden theorized that cells are the basic building blocks of all living things. Around 1850, Virchow saw cells dividing and added that living cells arise only from other living cells. These ideas led to cell theory, which states that all organisms are made of cells, all life functions occur in cells, and all cells come from other cells.
- The invention of the electron microscope in the 1950s allowed scientists to see organelles and other structures inside cells for the first time.

- There is variation in cells, but all cells have a plasma membrane, cytoplasm, ribosomes, and DNA.
    - The plasma membrane is composed mainly of a bilayer of phospholipid molecules and forms a barrier between the cytoplasm inside the cell and the environment outside the cell. It allows only certain substances to pass in or out of the cell. Some cells have extensions of their plasma membrane with other functions, such as flagella or cilia.
    - The cytoplasm is a thick solution that fills a cell and is enclosed by the cell membrane. It helps give the cell shape, holds organelles, and provides a site for many of the biochemical reactions inside the cell. The liquid part of the cytoplasm is called cytosol.
    - Ribosomes are small structures where proteins are made.
- Cells are usually very small so they have a large enough surface-area-to-volume ratio to maintain normal cell processes. Cells with different functions often have different shapes.
- Prokaryotic cells do not have a nucleus. Eukaryotic cells have a nucleus as well as other organelles. An organelle is a structure within the cytoplasm of a cell that is enclosed within a membrane and performs a specific job.
- The cytoskeleton is a highly organized framework of protein filaments and tubules that criss-cross the cytoplasm of a cell. It gives the cell structure and helps to hold cell structures such as organelles in place.
- The nucleus is the largest organelle in a eukaryotic cell and is considered to be the cell's control center. It contains DNA and controls gene expression, including which proteins the cell makes.
- The mitochondrion is an organelle that makes energy available to cells. According to the widely accepted endosymbiotic theory, mitochondria evolved from prokaryotic cells that were once free-living organisms that infected or were engulfed by larger prokaryotic cells.
- The endoplasmic reticulum (ER) is an organelle that helps make and transport proteins and lipids. Rough endoplasmic reticulum (RER) is studded with ribosomes. Smooth endoplasmic reticulum (SER) has no ribosomes.
- The Golgi apparatus is a large organelle that processes proteins and prepares them for use both inside and outside the cell. It is also involved in the transport of lipids around the cell.
- Vesicles and vacuoles are sac-like organelles that may be used to store and transport materials in the cell or as chambers for biochemical reactions. Lysosomes and peroxisomes are vesicles that break down foreign matter, dead cells, or poisons.
- Centrioles are organelles located near the nucleus that help organize the chromosomes before cell division so each daughter cell receives the correct number of chromosomes.
- There are two basic ways that substances can cross the cell's plasma membrane: passive transport, which requires no energy; and active transport, which requires energy.
- No energy is needed for passive transport because it occurs when substances move naturally from an area of higher concentration to an area of lower concentration. Types of passive transport in cells include:
    - Simple diffusion, which is the movement of a substance due to differences in concentration without any help from other molecules. This is how very small, hydrophobic molecules, such as oxygen and carbon dioxide, enter and leave the cell.
    - Osmosis, which is the diffusion of water molecules across the membrane.
    - Facilitated diffusion, which is the movement of a substance across a membrane due to differences in concentration but only with the help of transport proteins in the membrane, such as channel proteins or carrier proteins. This is how large or hydrophilic molecules and charged ions enter and leave the cell.
- Active transport requires energy to move substances across the plasma membrane, often because the substances are moving from an area of lower concentration to an area of higher concentration or because of their large size. Two examples of active transport are the sodium-potassium pump and vesicle transport.
    - The sodium-potassium pump moves sodium ions out of the cell and potassium ions into the cell, both against a concentration gradient, in order to maintain the proper concentrations of both ions inside and outside the cell and to thereby control membrane potential.
    - Vesicle transport uses vesicles to move large molecules into or out of cells.
- Energy is the ability to do work and is needed by every living cell to carry out life processes.
- The form of energy that living things need is chemical energy, and it comes from food. Food consists of organic molecules that store energy in their chemical bonds.
- Organisms mainly use glucose and ATP for energy. Glucose is the compact, stable form of energy that is carried in the blood and taken up by cells. ATP contains less energy and is used to power cellular processes.
- The cell cycle is a repeating series of events that include growth, DNA synthesis, and cell division. It is more complicated in eukaryotic than prokaryotic cells.
- Mitosis is the type of cell division that produces two diploid daughter cells for the purpose of growth and replacement of body cells.
- Meiosis is the type of cell division that produces four haploid daughter cells that may become gametes.
- A tissue is a group of connected cells that have a similar function. There are four basic types of human tissues that make up all the organs of the human body: epithelial, muscle, nervous, and connective tissues.
    - Connective tissues, such as bone and blood, are made up of cells that are separated by non-living material, called the extracellular matrix.

- Epithelial tissues, such as skin and mucous membranes, protect the body and its internal organs and secrete or absorb substances.
- Muscle tissues are made up of cells that have the unique ability to contract. They include skeletal, smooth, and cardiac muscle tissues.
- Nervous tissues are made up of neurons, which transmit electrical messages, and glial cells of various types, which play supporting roles. Types of nervous tissues include gray matter, white matter, nerves, and ganglia.

CHAPTER SUMMARY REVIEW

1. For the following questions, choose whether the description applies to eukaryotic cells, prokaryotic cells, or both.
   A. Has a nuclear membrane
   B. Has a plasma membrane made of a phospholipid bilayer
   C. Can be in a multicellular organism
   D. Has ribosomes
   E. Has an endoplasmic reticulum
   F. Its DNA replicates before cell division
   G. Has a single circular chromosome
   H. Has cytoplasm that splits into two daughter cells during cell division
   I. Has a cell cycle that includes interphase and mitosis
   J. The type of cell that most likely evolved to become mitochondria
2. Name one example of a prokaryotic organism and one example of a eukaryotic organism.
3. Neurons are cells in the nervous system that transmit messages. They use energy to maintain the balance of sodium and potassium ions inside and outside of them, which is critical for their ability to send messages.
   A. What kind of transport is this maintenance of sodium and potassium ion concentrations – active or passive? Explain your reasoning.
   B. What creates the barrier between the inside and the outside of these cells?
   C. What molecule uses energy to maintain the balance of sodium and potassium ions inside and outside of neurons? Describe two reasons why such a molecule is required.
   D. What form of energy is used in this process?
   E. Briefly explain how the energy in the food you eat gets there and provides energy for your neurons in the form necessary to power this process.
4. Explain why the inside of the plasma membrane, the side that faces the cytoplasm of the cell, must be hydrophilic.
5. *True or False.* The cell membrane can also be called the plasma membrane.
6. *True or False.* Each phospholipid molecule in the cell membrane has two heads and a tail.
7. *True or False*. For cells, a smaller size is generally more efficient.
8. *True or False*. DNA is located in the nucleus of prokaryotic cells.
9. *True or False*. Cilia and flagella stick out of the cell membrane but are not made of cell membrane themselves.
10. Which statement about the cell membrane is false?
    A. It encloses the cytoplasm
    B. It protects and supports the cell
    C. It keeps all external substances out of the cell
    D. None of the above
11. During diffusion, substances move from an area of **X?** concentration to an area of **Y?** concentration.
    A. higher, lower
    B. lower, higher
    C. higher, equal
    D. lower, equal
12. What happens during mitosis?
13. What is meiosis?
14. What is diploid? How many chromosomes are in a diploid human cell?
15. What is a zygote? How does the zygote form the organism?
16. Compare and contrast mitosis and meiosis.
17. Compare and contrast the four major types of tissues.
18. Which type of tissue lines the inner and outer surfaces of the body?
19. *True or False.* The extracellular matrix that surrounds cells is always solid.

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CHAPTER OVERVIEW

3: Integumentary System

This chapter describes the structure and functions of the epidermis and dermis, hair, nails, and sweat and sebaceous glands. In addition, the chapter outlines types of skin diseases, disorders, and injuries.

3.1: Case Study- Skin Cancer

3.2: Introduction to the Integumentary System

3.3: Layers of the Skin

3.4: Accessory Structures of the Skin

3.5: Functions of the Integumentary System

3.6: Diseases, Disorders, and Injuries of the Integumentary System

3.7: Case Study Conclusion- Skin Cancer and Chapter Summary

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3.1: CASE STUDY- SKIN CANCER

The summer sun may feel good on your body, but its invisible UV rays wreak havoc on your skin. Exposing the skin to UV light causes photo-aging: premature wrinkling, brown discolorations, and other unattractive signs of sun exposure. Even worse, UV light increases your risk of skin cancer.



Figure **3.1.1**: two individuals sunbathing

Exposure to UV radiation causes about 90% of all skin cancer cases. The connection between skin cancer and UV light is so strong that the World Health Organization has classified UV radiation (whether from tanning beds or the sun) as a Group 1 carcinogen (cancer-causing agent). Group 1 carcinogens are those carcinogens that are known with virtual certainty to cause cancer. In addition to UV light, Group 1 carcinogens include tobacco and plutonium. In terms of the number of cancers caused, UV radiation is far worse than tobacco. More people develop skin cancer because of UV light exposure than develop lung cancer because of smoking. The increase in cancer risk due to UV light is especially great if you have ever had blistering sunburns as a child or teen.

Besides UV light exposure, other risk factors for skin cancer include:

- having light-colored skin
- having a lot of moles
- being diagnosed with precancerous skin lesions
- having a family history of skin cancer
- having a personal history of skin cancer
- having a weakened immune system
- being exposed to other forms of radiation or to certain toxic substances such as arsenic

What exactly is skin cancer? Skin cancer is a disease in which skin cells grow out of control. It is caused mainly by excessive exposure to UV light, which damages DNA. Therefore, skin cancer most often develops on areas of the skin that are frequently exposed to UV light. However, it can also occur in areas that are rarely exposed to UV light. Skin cancer affects people of all skin colors, including those with dark skin. It also affects more people altogether than all other cancers combined. One in five Americans develops skin cancer in his or her lifetime.

At the end of the chapter, you will learn about the different types of skin cancer and how to identify if a growth is a mole or potentially cancerous.

CHAPTER OVERVIEW: INTEGUMENTARY SYSTEM

In this chapter, you will learn about the structure and functions of the integumentary system. Specifically, you will learn about:

- The functions of the organs of the integumentary system—the skin, hair, and nails—including protecting the body, helping to regulate homeostasis, and sensing and interacting with the external world.
- The two main layers of the skin: the thinner outer layer called the epidermis and the thicker inner layer called the dermis.
- The cells and layers of the epidermis and their functions, including synthesizing vitamin D and protecting the body against injury and pathogens, UV light exposure, and water loss.
- The composition and layers of the dermis and their functions, including cushioning other tissues, regulating body temperature, sensing the environment, and excreting wastes.
- The specialized structures in the dermis, which include sweat and sebaceous (oil) glands, hair follicles, and sensory receptors that detect touch, temperature, and pain.
- The structure and biological functions of hair, which include retaining body heat, detecting sensory stimuli, and protecting the body against UV light, pathogens, and small particles.
- The structure and functions of nails, which include protecting the fingers and toes, enhancing the detection of sensory stimuli, and acting like tools.

As you read this chapter and learn more about the skin, think about the following questions:

1. What is skin cancer and how does it form?
2. What are the similarities and differences of various types of cancer?
3. How can people decrease their risk of getting skin cancer?

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3.2: INTRODUCTION TO THE INTEGUMENTARY SYSTEM

ART FOR ALL ERAS

This is Maud Stevens Wagner, a tattoo artist who is pictured in Figure **3.2.1**. Maud was pictured in 1907. Clearly, tattoos are not just a late 20th and early 21st-century trend. They have been popular in many eras and cultures. Tattoos literally illustrate the biggest organ of the human body: the skin. The skin is very thin, but it covers a large area — about 2 m^2 in adults. The skin is the major organ in the integumentary system.



Figure **3.2.1**: Maud Stevens Wagner

WHAT IS THE INTEGUMENTARY SYSTEM?

In addition to the skin, the **integumentary system** includes the hair and nails, which are organs that grow out of the skin. Because the organs of the integumentary system are mostly external to the body, you may think of them as little more than accessories, like clothing or jewelry, but they serve vital physiological functions. They provide a protective covering for the body, sense the environment, and help the body maintain homeostasis.

THE SKIN

The **skin** is remarkable not only because it is the body's largest organ. It is remarkable for other reasons as well. The average square inch of skin has 20 blood vessels, 650 sweat glands, and more than a thousand nerve endings. It also has an incredible 60,000 pigment-producing cells. All of these structures are packed into a stack of cells that is just 2 mm thick, or about as thick as the cover of a book. Although the skin is thin, it consists of two distinct layers, the epidermis and dermis, as shown in Figure **3.2.2**.

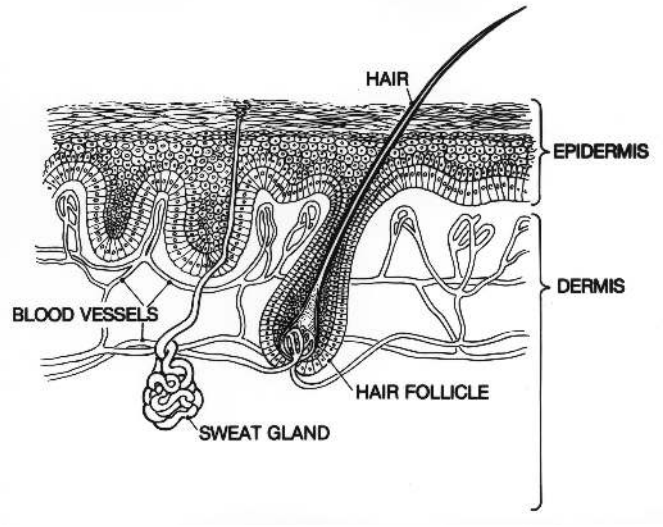


Figure **3.2.2**: The epidermis is the thinner outer layer of skin which is composed of tightly packed epithelial cells. The dermis is the thicker inner layer of skin that contains structures such as blood vessels, hair follicles, and sweat glands.

OUTER LAYER OF SKIN

The outer layer of skin is the epidermis. This layer is thinner than the inner layer, the dermis. The epidermis consists mainly of epithelial cells, called **keratinocytes,** which produce the tough, fibrous protein **keratin.** The innermost cells of the epidermis are stem cells that divide continuously to form new cells. The newly formed cells move up through the epidermis toward the skin surface, while producing more and more keratin. The cells become filled with keratin and die by the time they reach the surface, where they form a protective, waterproof layer. As the dead cells are shed from the surface of the skin, they are replaced by other cells that move up from below. The epidermis also contains melanocytes, the cells that produce the brown pigment melanin, which gives skin most of its color. Although the epidermis contains some sensory receptor cells, called Merkel cells, it contains no nerves, blood vessels, or other structures.

INNER LAYER OF SKIN

The dermis is the inner and thicker layer of skin. It consists mainly of tough connective tissue and is attached to the epidermis by collagen fibers. The dermis contains many structures, as shown in the figure above, including blood vessels, sweat glands, and hair follicles, which are structures where hairs originate. In addition, the dermis contains many sensory receptors, nerves, and oil glands.

FUNCTIONS OF THE SKIN

The skin has multiple roles in the body. Many of these roles are related to homeostasis. The skin's main functions include preventing water loss from the body and serving as a barrier to the entry of microorganisms. Another function of the skin is synthesizing vitamin D, which occurs when the skin is exposed to ultraviolet

(UV) light. Melanin in the epidermis blocks some of the UV light and protects the dermis from its damaging effects.

Another important function of the skin is helping to regulate body temperature. For example, when the body is too warm, the skin lowers body temperature by producing sweat, which cools the body when it evaporates. The skin also increases the amount of blood flowing near the body surface through vasodilation (widening of blood vessels), bringing heat from the body core to radiate out into the environment.

HAIR

Hair is a fiber that is found only in mammals. It consists mainly of keratin-producing keratinocytes. Each hair grows out of a follicle in the dermis. By the time the hair reaches the surface, it consists mainly of dead cells filled with keratin. Hair serves several homeostatic functions. Head hair is important in preventing heat loss from the head and protecting its skin from UV radiation. Hairs in the nose trap dust particles and microorganisms in the air and prevent them from reaching the lungs. Hair all over the body provides sensory input when objects brush against it or it sways in moving air. Eyelashes and eyebrows protect the eyes from water, dirt, and other irritants.

NAILS

Fingernails and toenails consist of dead keratinocytes that are filled with keratin. The keratin makes them hard but flexible, which is important for the functions they serve. Nails prevent injury by forming protective plates over the ends of the fingers and toes. They also enhance sensation by acting as a counterforce to the sensitive fingertips when objects are handled. In addition, fingernails can be used as tools.

INTERACTIONS WITH OTHER ORGAN SYSTEMS

The skin and other parts of the integumentary system work with other organ systems to maintain homeostasis.

- The skin works with the immune system to defend the body from pathogens by serving as a physical barrier to microorganisms.
- Vitamin D is needed by the digestive system to absorb calcium from food. By synthesizing vitamin D, the skin works with the digestive system to ensure that calcium can be absorbed.
- Most immune cells, such as B and T cells have Vitamin D receptors. Vitamin D levels in the body are associated with autoimmune diseases and immune deficiencies.
- To control body temperature, the skin works with the cardiovascular system to either lose body heat or conserve it through vasodilation or vasoconstriction.
- To detect certain sensations from the outside world, the nervous system depends on nerve receptors in the skin.

REVIEW

1. Name the organs of the integumentary system.
2. Compare and contrast the epidermis and dermis.
3. Identify the functions of the skin.
4. What is the composition of hair?
5. Describe three physiological roles played by the hair.
6. What do nails consist of?
7. List two functions of nails.
8. What do the outermost surface of the skin, the nails, and hair have in common, in terms of their composition?
9. The innermost layer of the epidermis consists of _____ cells than the outermost layer of the epidermis.

   A. older

   B. younger

   C. more sweat glands

   D. more blood vessel
10. Identify two types of cells found in the epidermis of the skin and describe their functions.
11. *True or False*. Keratin-producing cells in the epidermis are a type of epithelial cell.
12. *True or False*. Vasodilation is used to warm the body.
13. Which structure and layer of skin do hair grow out of?
14. Identify three main functions of the integumentary system and give an example of each.
15. What are two ways in which the integumentary system protects the body against UV radiation?

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3.3: Layers of the Skin

Learning Objectives

By the end of this section, you will be able to:

- Identify the components of the integumentary system
- Describe the layers of the skin and the functions of each layer
- Identify and describe the hypodermis and deep fascia
- Describe the role of keratinocytes and their life cycle
- Describe the role of melanocytes in skin pigmentation

Although you may not typically think of the skin as an organ, it is in fact made of tissues that work together as a single structure to perform unique and critical functions. The skin and its accessory structures make up the integumentary system, which provides the body with overall protection. The skin is made of multiple layers of cells and tissues, which are held to underlying structures by connective tissue (Figure 3.3.1). The deeper layer of skin is well vascularized (has numerous blood vessels). It also has numerous sensory, and autonomic and sympathetic nerve fibers ensuring communication to and from the brain.

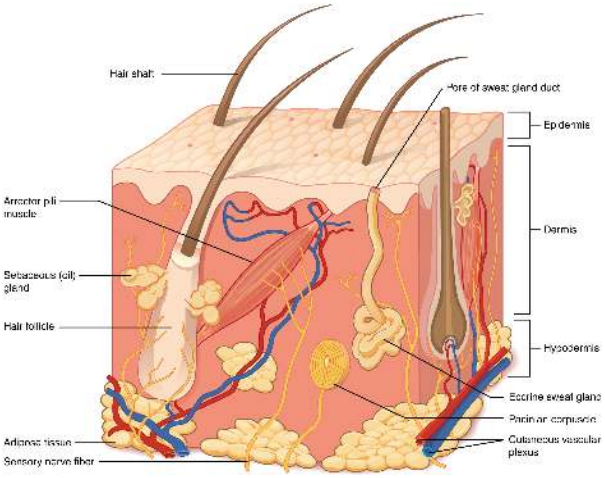


Figure 3.3.1: Layers of Skin The skin is composed of two main layers: the epidermis, made of closely packed epithelial cells, and the dermis, made of dense, irregular connective tissue that houses blood vessels, hair follicles, sweat glands, and other structures. Beneath the dermis lies the hypodermis, which is composed mainly of loose connective and fatty tissues.

Interactive Link

The skin consists of two main layers and a closely associated layer. View this animation to learn more about layers of the skin. What are the basic functions of each of these layers?

The Epidermis

The epidermis is composed of keratinized, stratified squamous epithelium. It is made of four or five layers of epithelial cells, depending on its location in the body. It does not have any blood vessels within it (i.e., it is avascular). Skin that has four layers of cells is referred to as “thin skin.” From deep to superficial, these layers are the stratum basale, stratum spinosum, stratum granulosum, and stratum corneum. Most of the skin can be classified as thin skin. “Thick skin” is found only on the palms of the hands and the soles of the feet. It has a fifth layer, called the stratum lucidum, located between the stratum corneum and the stratum granulosum (Figure 3.3.2).

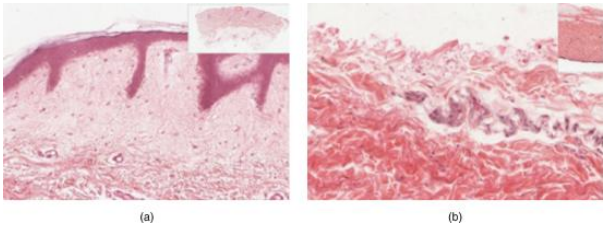


Figure 3.3.2: Thin Skin versus Thick Skin These slides show cross-sections of the epidermis and dermis of (a) thin and (b) thick skin. Note the significant difference in the thickness of the epithelial layer of the thick skin. From top, LM × 40, LM × 40. (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

The cells in all of the layers except the stratum basale are called keratinocytes. A keratinocyte is a cell that manufactures and stores the protein keratin. Keratin is an intracellular fibrous protein that gives hair, nails, and skin their hardness and water-resistant properties. The keratinocytes in the stratum corneum are dead and regularly slough away, being replaced by cells from the deeper layers (Figure 3.3.3).

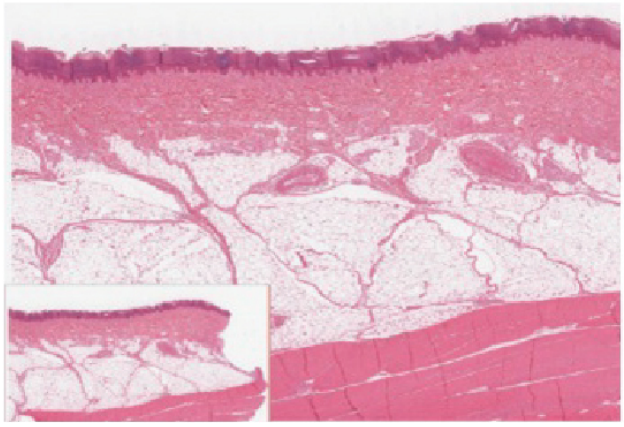


Figure 3.3.3: Epidermis The epidermis is epithelium composed of multiple layers of cells. The basal layer consists of cuboidal cells, whereas the outer layers are squamous, keratinized cells, so the whole epithelium is often described as being keratinized stratified squamous epithelium. LM × 40. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Interactive Link

View the University of Michigan WebScope to explore the tissue sample in greater detail. If you zoom on the cells at the outermost layer of this section of skin, what do you notice about the cells?

Stratum Basale

The stratum basale (also called the stratum germinativum) is the deepest epidermal layer and attaches the epidermis to the basal lamina, below which lie the layers of the dermis. The cells in the stratum basale bond to the dermis via intertwining collagen fibers, referred to as the basement membrane. A finger-like projection, or fold, known as the dermal papilla (plural = dermal papillae) is found in the superficial portion of the dermis. Dermal papillae increase the strength of the connection between the epidermis and dermis; the greater the folding, the stronger the connections made (Figure 3.3.4).

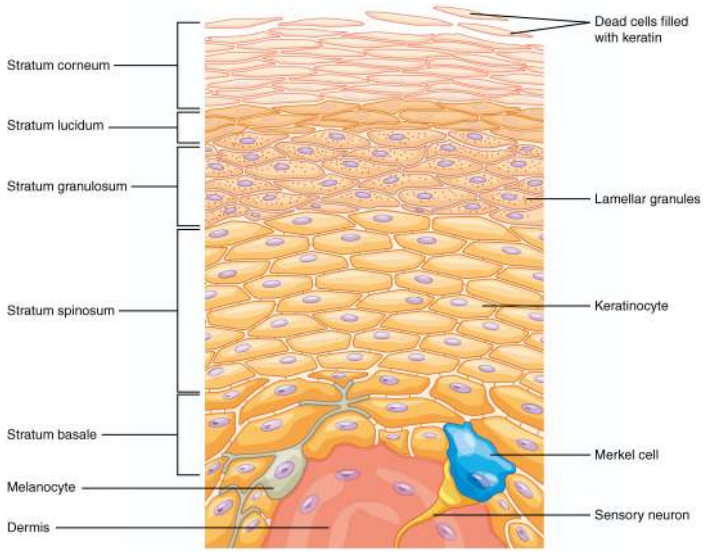


Figure 3.3.4: Layers of the Epidermis The epidermis of thick skin has five layers: stratum basale, stratum spinosum, stratum granulosum, stratum lucidum, and stratum corneum.

The stratum basale is a single layer of cells primarily made of basal cells. A basal cell is a cuboidal-shaped stem cell that is a precursor of the keratinocytes of the epidermis. All of the keratinocytes are produced from this single layer of cells, which are constantly going through mitosis to produce new cells. As new cells are formed, the existing cells are pushed superficially away from the stratum basale. Two other cell types are found dispersed among the basal cells in the stratum basale. The first is a Merkel cell, which functions as a receptor and is responsible for stimulating sensory nerves that the brain perceives as touch. These cells are especially abundant on the surfaces of the hands and feet. The second is a melanocyte, a cell that produces the pigment melanin. Melanin gives hair and skin its color, and also helps protect the living cells of the epidermis from ultraviolet (UV) radiation damage.

In a growing fetus, fingerprints form where the cells of the stratum basale meet the papillae of the underlying dermal layer (papillary layer), resulting in the formation of the ridges on your fingers that you recognize as fingerprints. Fingerprints are unique to each individual and are used for forensic analyses because the patterns do not change with the growth and aging processes.

Stratum Spinosum

As the name suggests, the stratum spinosum is spiny in appearance due to the protruding cell processes that join the cells via a structure called a desmosome. The desmosomes interlock with each other and strengthen the bond between the cells. It is interesting to note that the “spiny” nature of this layer is an artifact of the staining process. Unstained epidermis samples do not exhibit this characteristic appearance. The stratum spinosum is composed of eight to 10 layers of keratinocytes, formed as a result of cell division in the stratum basale (Figure 3.3.5). Interspersed among the keratinocytes of this layer is a type of dendritic cell called the Langerhans cell, which functions as a macrophage by engulfing bacteria, foreign particles, and damaged cells that occur in this layer.

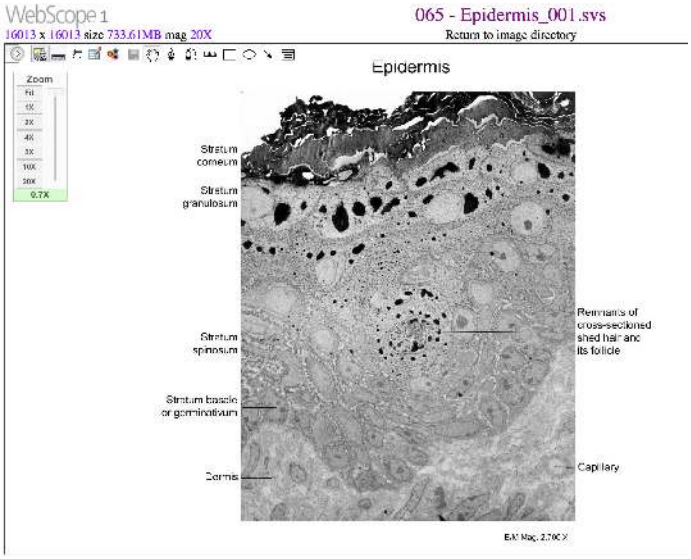


Figure 3.3.5: Cells of the Epidermis The cells in the different layers of the epidermis originate from basal cells located in the stratum basale, yet the cells of each layer are distinctively different. EM × 2700. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Interactive Link

View the University of Michigan WebScope to explore the tissue sample in greater detail. If you zoom on the cells at the outermost layer of this section of skin, what do you notice about the cells?

The keratinocytes in the stratum spinosum begin the synthesis of keratin and release a water-repelling glycolipid that helps prevent water loss from the body, making the skin relatively waterproof. As new keratinocytes are produced atop the stratum basale, the keratinocytes of the stratum spinosum are pushed into the stratum granulosum.

Stratum Granulosum

The stratum granulosum has a grainy appearance due to further changes to the keratinocytes as they are pushed from the stratum spinosum. The cells (three to five layers deep) become flatter, their cell membranes thicken, and they generate large amounts of the proteins keratin, which is fibrous, and keratohyalin, which accumulates as lamellar granules within the cells (see Figure 5.5). These two proteins make up the bulk of the keratinocyte mass in the stratum granulosum and give the layer its grainy appearance. The nuclei and other cell organelles disintegrate as the cells die, leaving behind the keratin, keratohyalin, and cell membranes that will form the stratum lucidum, the stratum corneum, and the accessory structures of hair and nails.

Stratum Lucidum

The stratum lucidum is a smooth, seemingly translucent layer of the epidermis located just above the stratum granulosum and below the stratum corneum. This thin layer of cells is found only in the thick skin of the palms, soles, and digits. The keratinocytes that compose the stratum lucidum are dead and flattened (see Figure 5.5). These cells are densely packed with eleidin, a clear protein, derived from keratohyalin, which gives these cells their transparent (i.e., lucid) appearance.

Stratum Corneum

The stratum corneum is the most superficial layer of the epidermis and is the layer exposed to the outside environment (see Figure 5.5). The increased keratinization (also called cornification) of the cells in this layer gives it its name. There are usually 15 to 30 layers of cells in the stratum corneum. This dry, dead layer helps prevent the penetration of microbes and the dehydration of underlying tissues, and provides a mechanical protection against abrasion for the more delicate, underlying layers. Cells in this layer are shed periodically and are replaced by cells pushed up from the stratum granulosum (or stratum lucidum in the case of the palms and soles of feet). The entire layer is replaced during a period of about 4 weeks. Cosmetic procedures, such as microdermabrasion, help remove some of the dry, upper layer and aim to keep the skin looking “fresh” and healthy.

Dermis

The dermis might be considered the “core” of the integumentary system (derma- = “skin”), as distinct from the epidermis (epi- = “upon” or “over”) and hypodermis (hypo- = “below”). It contains blood and lymph vessels, nerves, and other structures, such as hair follicles and sweat glands. The dermis is made of two layers of connective tissue that compose an interconnected mesh of elastin and collagenous fibers, produced by fibroblasts (Figure 3.3.6).



Figure 3.3.6: Layers of the Dermis This stained slide shows the two components of the dermis—the papillary layer and the reticular layer. Both are made of connective tissue with fibers of collagen extending from one to the other, making the border between the two somewhat indistinct. The dermal papillae extending into the epidermis belong to the papillary layer, whereas the dense collagen fiber bundles below belong to the reticular layer. LM × 10. (credit: modification of work by “kilbad”/Wikimedia Commons)

Papillary Layer

The papillary layer is made of loose, areolar connective tissue, which means the collagen and elastin fibers of this layer form a loose mesh. This superficial layer of the dermis projects into the stratum basale of the epidermis to form finger-like dermal papillae (see Figure 5.7). Within the papillary layer are fibroblasts, a small number of fat cells (adipocytes), and an abundance of small blood vessels. In addition, the papillary layer contains phagocytes, defensive cells that help fight bacteria or other infections that have breached the skin. This layer also contains lymphatic capillaries, nerve fibers, and touch receptors called the Meissner corpuscles.

Reticular Layer

Underlying the papillary layer is the much thicker reticular layer, composed of dense, irregular connective tissue. This layer is well vascularized and has a rich sensory and sympathetic nerve supply. The reticular layer appears reticulated (net-like) due to a tight meshwork of fibers. Elastin fibers provide some elasticity to the skin, enabling movement. Collagen fibers provide structure and tensile strength, with strands of collagen extending into both the papillary layer and the hypodermis. In addition, collagen binds water to keep the skin hydrated. Collagen injections and Retin-A creams help restore skin turgor by either introducing collagen externally or stimulating blood flow and repair of the dermis, respectively.

Hypodermis

The hypodermis (also called the subcutaneous layer or superficial fascia) is a layer directly below the dermis and serves to connect the skin to the underlying fascia (fibrous tissue) of the bones and muscles. It is not strictly a part of the skin, although the border between the hypodermis and dermis can be difficult to distinguish. The hypodermis consists of well-vascularized, loose, areolar connective tissue and adipose tissue, which functions as a mode of fat storage and provides insulation and cushioning for the integument.

Everyday Connection

Lipid Storage

The hypodermis is home to most of the fat that concerns people when they are trying to keep their weight under control. Adipose tissue present in the hypodermis consists of fat-storing cells called adipocytes. This stored fat can serve as an energy reserve, insulate the body to prevent heat loss, and act as a cushion to protect underlying structures from trauma.

Where the fat is deposited and accumulates within the hypodermis depends on hormones (testosterone, estrogen, insulin, glucagon, leptin, and others), as well as genetic factors. Fat distribution changes as our bodies mature and age. Males tend to accumulate fat in different areas (neck, arms, lower back, and abdomen) than do females (breasts, hips, thighs, and buttocks). The body mass index (BMI) is often used as a measure of fat, although this measure is, in fact, derived from a mathematical formula that compares body weight (mass) to height. Therefore, its accuracy as a health indicator can be called into question in individuals who are extremely physically fit.

In many animals, there is a pattern of storing excess calories as fat to be used in times when food is not readily available. In much of the developed world, insufficient exercise coupled with the ready availability and consumption of high-calorie foods have resulted in unwanted accumulations of adipose tissue in many people. Although periodic accumulation of excess fat may have provided an evolutionary advantage to our ancestors, who experienced unpredictable bouts of famine, it is now becoming chronic and considered a major health threat. Recent studies indicate that a distressing percentage of our population is overweight and/or clinically obese. Not only is this a problem for the individuals affected, but it also has a severe impact on our healthcare system. Changes in lifestyle, specifically in diet and exercise, are the best ways to control body fat accumulation, especially when it reaches levels that increase the risk of heart disease and diabetes.

Pigmentation

The color of skin is influenced by a number of pigments, including melanin, carotene, and hemoglobin. Recall that melanin is produced by cells called melanocytes, which are found scattered throughout the stratum basale of the epidermis. The melanin is transferred into the keratinocytes via a cellular vesicle called a melanosome (Figure 3.3.7).

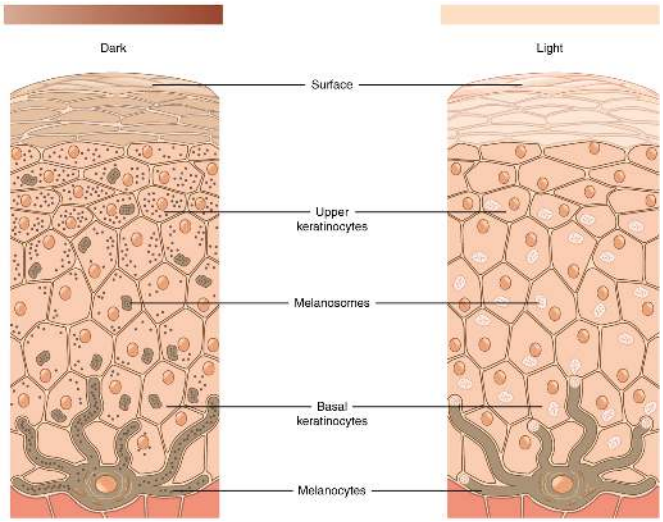


Figure 3.3.7: Skin Pigmentation The relative coloration of the skin depends of the amount of melanin produced by melanocytes in the stratum basale and taken up by keratinocytes.

Melanin occurs in two primary forms. Eumelanin exists as black and brown, whereas pheomelanin provides a red color. Dark-skinned individuals produce more melanin than those with pale skin. Exposure to the UV rays of the sun or a tanning salon causes melanin to be manufactured and built up in keratinocytes, as sun exposure stimulates keratinocytes to secrete chemicals that stimulate melanocytes. The accumulation of melanin in keratinocytes results in the darkening of the skin, or a tan. This increased melanin accumulation protects the DNA of epidermal cells from UV ray damage and the breakdown of folic acid, a nutrient necessary for our health and well-being. In contrast, too much melanin can interfere with the production of vitamin D, an important nutrient involved in calcium absorption. Thus, the amount of melanin present in our skin is dependent on a balance between available sunlight and folic acid destruction, and protection from UV radiation and vitamin D production.

It requires about 10 days after initial sun exposure for melanin synthesis to peak, which is why pale-skinned individuals tend to suffer sunburns of the epidermis initially. Dark-skinned individuals can also get sunburns, but are more protected than are pale-skinned individuals. Melanosomes are temporary structures that are eventually destroyed by fusion with lysosomes; this fact, along with melanin-filled keratinocytes in the stratum corneum sloughing off, makes tanning impermanent.

Too much sun exposure can eventually lead to wrinkling due to the destruction of the cellular structure of the skin, and in severe cases, can cause sufficient DNA damage to result in skin cancer. When there is an irregular accumulation of melanocytes in the skin, freckles appear. Moles are larger masses of melanocytes, and although most are benign, they should be monitored for changes that might indicate the presence of cancer (Figure 3.3.8).



Figure 3.3.8: Moles Moles range from benign accumulations of melanocytes to melanomas. These structures populate the landscape of our skin. (credit: the National Cancer Institute)

Disorders of the...

Integumentary System

The first thing a clinician sees is the skin, and so the examination of the skin should be part of any thorough physical examination. Most skin disorders are relatively benign, but a few, including melanomas, can be fatal if untreated. A couple of the more noticeable disorders, albinism and vitiligo, affect the appearance of the skin and its accessory organs. Although neither is fatal, it would be hard to claim that they are benign, at least to the individuals so afflicted.

Albinism is a genetic disorder that affects (completely or partially) the coloring of skin, hair, and eyes. The defect is primarily due to the inability of melanocytes to produce melanin. Individuals with albinism tend to appear white or very pale due to the lack of melanin in their skin and hair. Recall that melanin helps protect the skin from the harmful effects of UV radiation. Individuals with albinism tend to need more protection from UV radiation, as they are more prone to sunburns and skin cancer. They also tend to be more sensitive to light and have vision problems due to the lack of pigmentation on the retinal wall. Treatment of this disorder usually involves addressing the symptoms, such as limiting UV light exposure to the skin and eyes. In vitiligo, the melanocytes in certain areas lose their ability to produce melanin, possibly due to an autoimmune reaction. This leads to a loss of color in patches (Figure 3.3.9). Neither albinism nor vitiligo directly affects the lifespan of an individual.



Figure 3.3.9: Vitiligo Individuals with vitiligo experience depigmentation that results in lighter colored patches of skin. The condition is especially noticeable

Other changes in the appearance of skin coloration can be indicative of diseases associated with other body systems. Liver disease or liver cancer can cause the accumulation of bile and the yellow pigment bilirubin, leading to the skin appearing

yellow or jaundiced (*jaune* is the French word for “yellow”). Tumors of the pituitary gland can result in the secretion of large amounts of melanocyte-stimulating hormone (MSH), which results in a darkening of the skin. Similarly, Addison’s disease can stimulate the release of excess amounts of adrenocorticotropic hormone (ACTH), which can give the skin a deep bronze color. A sudden drop in oxygenation can affect skin color, causing the skin to initially turn ashen (white). With a prolonged reduction in oxygen levels, dark red deoxyhemoglobin becomes dominant in the blood, making the skin appear blue, a condition referred to as cyanosis (*kyanos* is the Greek word for “blue”). This happens when the oxygen supply is restricted, as when someone is experiencing difficulty in breathing because of asthma or a heart attack. However, in these cases the effect on skin color has nothing do with the skin’s pigmentation.

Interactive Link

This ABC video follows the story of a pair of fraternal African-American twins, one of whom is albino. Watch this video to learn about the challenges these children and their family face. Which ethnicities do you think are exempt from the possibility of albinism?

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3.4: Accessory Structures of the Skin

Learning Objectives

By the end of this section, you will be able to:

- Identify the accessory structures of the skin
- Describe the structure and function of hair and nails
- Describe the structure and function of sweat glands and sebaceous glands

Accessory structures of the skin include hair, nails, sweat glands, and sebaceous glands. These structures embryologically originate from the epidermis and can extend down through the dermis into the hypodermis.

Hair

Hair is a keratinous filament growing out of the epidermis. It is primarily made of dead, keratinized cells. Strands of hair originate in an epidermal penetration of the dermis called the hair follicle. The hair shaft is the part of the hair not anchored to the follicle, and much of this is exposed at the skin's surface. The rest of the hair, which is anchored in the follicle, lies below the surface of the skin and is referred to as the hair root. The hair root ends deep in the dermis at the hair bulb, and includes a layer of mitotically active basal cells called the hair matrix. The hair bulb surrounds the hair papilla, which is made of connective tissue and contains blood capillaries and nerve endings from the dermis (Figure 3.4.1).

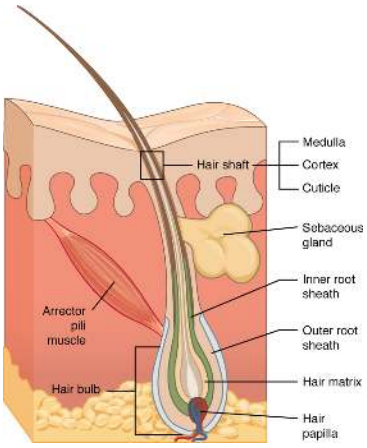


Figure 3.4.1: Hair Hair follicles originate in the epidermis and have many different parts.

Just as the basal layer of the epidermis forms the layers of epidermis that get pushed to the surface as the dead skin on the surface sheds, the basal cells of the hair bulb divide and push cells outward in the hair root and shaft as the hair grows. The medulla forms the central core of the hair, which is surrounded by the cortex, a layer of compressed, keratinized cells that is covered by an outer layer of very hard, keratinized cells known as the cuticle. These layers are depicted in a longitudinal cross-section of the hair follicle (Figure 3.4.2), although not all hair has a medullary layer. Hair texture (straight, curly) is determined by the shape and structure of the cortex, and to the extent that it is present, the medulla. The shape and structure of these layers are, in turn, determined by the shape of the hair follicle. Hair growth begins with the production of keratinocytes by the basal cells of the hair bulb. As new cells are deposited at the hair bulb, the hair shaft is pushed through the follicle toward the surface. Keratinization is completed as the cells are pushed to the skin surface to form the shaft of hair that is externally visible. The external hair is completely dead and composed entirely of keratin. For this reason, our hair does not have sensation. Furthermore, you can cut your hair or shave without damaging the hair structure because the cut is superficial. Most chemical hair removers also act superficially; however, electrolysis and yanking both attempt to destroy the hair bulb so hair cannot grow.

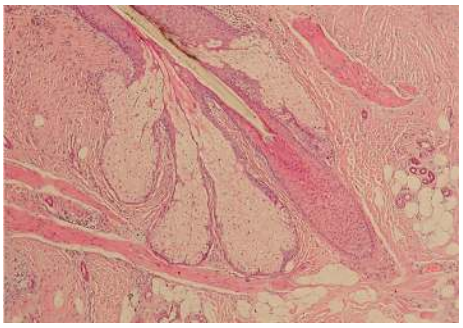


Figure 3.4.2: Hair Follicle The slide shows a cross-section of a hair follicle. Basal cells of the hair matrix in the center differentiate into cells of the inner root sheath. Basal cells at the base of the hair root form the outer root sheath. LM × 4. (credit: modification of work by “kilbad”/Wikimedia Commons)

The wall of the hair follicle is made of three concentric layers of cells. The cells of the internal root sheath surround the root of the growing hair and extend just up to the hair shaft. They are derived from the basal cells of the hair matrix. The external root sheath, which is an extension of the epidermis, encloses the hair root. It is made of basal cells at the base of the hair root and tends to be more keratinous in the upper regions. The glassy membrane is a thick, clear connective tissue sheath covering the hair root, connecting it to the tissue of the dermis.

Interactive Link

The hair follicle is made of multiple layers of cells that form from basal cells in the hair matrix and the hair root. Cells of the hair matrix divide and differentiate to form the layers of the hair. Watch this video to learn more about hair follicles.

Hair serves a variety of functions, including protection, sensory input, thermoregulation, and communication. For example, hair on the head protects the skull from the sun. The hair in the nose and ears, and around the eyes (eyelashes) defends the body by trapping and excluding dust particles that may contain allergens and microbes. Hair of the eyebrows prevents sweat and other particles from dripping into and bothering the eyes. Hair also has a sensory function due to sensory innervation by a hair root plexus surrounding the base of each hair follicle. Hair is extremely sensitive to air movement or other disturbances in the environment, much more so than the skin surface. This feature is also useful for the detection of the presence of insects or other potentially damaging substances on the skin surface. Each hair root is connected to a smooth muscle called the arrector pili that contracts in response to nerve signals from the sympathetic nervous system, making the external hair shaft “stand up.” The primary purpose for this is to trap a layer of air to add insulation. This is visible in humans as goose bumps and even more obvious in animals, such as when a frightened cat raises its fur. Of course, this is much more obvious in organisms with a heavier coat than most humans, such as dogs and cats.

Hair Growth

Hair grows and is eventually shed and replaced by new hair. This occurs in three phases. The first is the anagen phase, during which cells divide rapidly at the root of the hair, pushing the hair shaft up and out. The length of this phase is measured in years, typically from 2 to 7 years. The catagen phase lasts only 2 to 3 weeks, and marks a transition from the hair follicle’s active growth. Finally, during the telogen phase, the hair follicle is at rest and no new growth occurs. At the end of this phase, which lasts about 2 to 4 months, another anagen phase begins. The basal cells in the hair matrix then produce a new hair follicle, which pushes the old hair out as the growth cycle repeats itself. Hair typically grows at the rate of 0.3 mm per day during the anagen phase. On average, 50 hairs are lost and replaced per day. Hair loss occurs if there is more hair shed than what is replaced and can happen due to hormonal or dietary changes. Hair loss can also result from the aging process, or the influence of hormones.

Hair Color

Similar to the skin, hair gets its color from the pigment melanin, produced by melanocytes in the hair papilla. Different hair color results from differences in the type of melanin, which is genetically determined. As a person ages, the melanin production decreases, and hair tends to lose its color and becomes gray and/or white.

Nails

The nail bed is a specialized structure of the epidermis that is found at the tips of our fingers and toes. The nail body is formed on the nail bed, and protects the tips of our fingers and toes as they are the farthest extremities and the parts of the body that experience the maximum mechanical stress (Figure 3.4.3). In addition, the nail body forms a back-support for picking up small objects with the fingers. The nail body is composed of densely packed dead keratinocytes. The epidermis in this part of the body has evolved a specialized structure upon which nails can form. The nail body forms at the nail root, which has a matrix of proliferating cells from the stratum basale that enables the nail to grow continuously. The lateral nail fold overlaps the nail on the sides, helping to anchor the nail body. The nail fold that meets the proximal end of the nail body forms the nail cuticle, also called the eponychium. The nail bed is rich in blood vessels, making it appear pink, except at the base, where a thick layer of epithelium over the nail matrix forms a crescent-shaped region called the lunula (the “little moon”). The area beneath the free edge of the nail, furthest from the cuticle, is called the hyponychium. It consists of a thickened layer of stratum corneum.

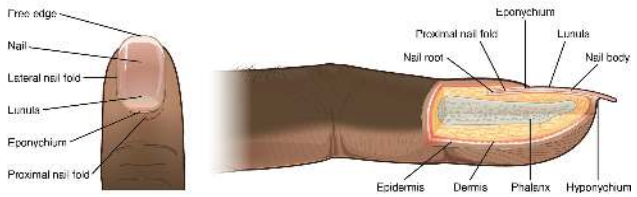


Figure 3.4.3: Nails The nail is an accessory structure of the integumentary system

Interactive Link

Nails are accessory structures of the integumentary system. Visit this link to learn more about the origin and growth of fingernails.

Sweat and Sebaceous Glands

Exocrine Glands

Glands that secrete substances through ducts that carry them to nearby body surfaces are called **exocrine glands.** Exo- means "out", and exocrine glands secrete substances across ("out") epithelial tissue lining the surfaces or cavities of our body or organs. Examples of exocrine glands include the sweat and sebaceous (oil) glands of our integumentary system as well as digestive system glands such as salivary glands and glands that produce digestive enzymes.

In contrast, **endocrine glands** (which we will learn more about in the chapter on the **endocrine system**) release chemical messenger molecules called hormones directly into the bloodstream. Because endocrine hormones are released into the bloodstream, they travel throughout the body wherever blood flows. As a result, endocrine hormones may affect many cells and have body-wide effects.

Sweat Glands

When the body becomes warm, sudoriferous glands produce sweat to cool the body. Sweat glands develop from epidermal projections into the dermis and are classified as merocrine glands; that is, the secretions are excreted by exocytosis through a duct without affecting the cells of the gland. There are two types of sweat glands, each secreting slightly different products.

An eccrine sweat gland is type of gland that produces a hypotonic sweat for thermoregulation. These glands are found all over the skin's surface, but are especially abundant on the palms of the hand, the soles of the feet, and the forehead (Figure 3.4.4). They are coiled glands lying deep in the dermis, with the duct rising up to a pore on the skin surface, where the sweat is released. This type of sweat, released by exocytosis, is hypotonic and composed mostly of water, with some salt, antibodies, traces of metabolic waste, and dermicidin, an antimicrobial peptide. Eccrine glands are a primary component of thermoregulation in humans and thus help to maintain homeostasis.

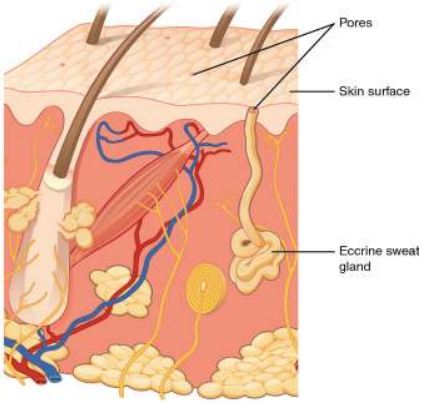


Figure 3.4.4: Eccrine Gland Eccrine glands are coiled glands in the dermis that release sweat that is mostly water.

An apocrine sweat gland is usually associated with hair follicles in densely hairy areas, such as armpits and genital regions. Apocrine sweat glands are larger than eccrine sweat glands and lie deeper in the dermis, sometimes even reaching the hypodermis, with the duct normally emptying into the hair follicle. In addition to water and salts, apocrine sweat includes organic compounds that make the sweat thicker and subject to bacterial decomposition and subsequent smell. The release of this sweat is under both nervous and hormonal control, and plays a role in the poorly understood human pheromone response. Most commercial antiperspirants use an aluminum-based compound as their primary active ingredient to stop sweat. When the antiperspirant enters the sweat gland duct, the aluminum-based compounds precipitate due to a change in pH and form a physical block in the duct, which prevents sweat from coming out of the pore.

Interactive Link

Sweating regulates body temperature. The composition of the sweat determines whether body odor is a byproduct of sweating. Visit this link to learn more about sweating and body odor.

Sebaceous Glands

A sebaceous gland is a type of oil gland that is found all over the body and helps to lubricate and waterproof the skin and hair. Most sebaceous glands are associated with hair follicles. They generate and excrete sebum, a mixture of lipids, onto the skin surface, thereby naturally lubricating the dry and dead layer of keratinized cells of the stratum corneum, keeping it pliable. The fatty acids of sebum also have antibacterial properties, and prevent water loss from the skin in low-humidity environments. The secretion of sebum is stimulated by hormones, many of which do not become active until puberty. Thus, sebaceous glands are relatively inactive during childhood.

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3.5: Functions of the Integumentary System

Learning Objectives

By the end of this section, you will be able to:

- Describe the different functions of the skin and the structures that enable them
- Explain how the skin helps maintain body temperature

The skin and accessory structures perform a variety of essential functions, such as protecting the body from invasion by microorganisms, chemicals, and other environmental factors; preventing dehydration; acting as a sensory organ; modulating body temperature and electrolyte balance; and synthesizing vitamin D. The underlying hypodermis has important roles in storing fats, forming a "cushion" over underlying structures, and providing insulation from cold temperatures.

Protection

The skin protects the rest of the body from the basic elements of nature such as wind, water, and UV sunlight. It acts as a protective barrier against water loss, due to the presence of layers of keratin and glycolipids in the stratum corneum. It also is the first line of defense against abrasive activity due to contact with grit, microbes, or harmful chemicals. Sweat excreted from sweat glands deters microbes from over-colonizing the skin surface by generating dermicidin, which has antibiotic properties.

Everyday Connection

Tattoos and Piercings

The word "armor" evokes several images. You might think of a Roman centurion or a medieval knight in a suit of armor. The skin, in its own way, functions as a form of armor—body armor. It provides a barrier between your vital, life-sustaining organs and the influence of outside elements that could potentially damage them.

For any form of armor, a breach in the protective barrier poses a danger. The skin can be breached when a child skins a knee or an adult has blood drawn—one is accidental and the other medically necessary. However, you also breach this barrier when you choose to "accessorize" your skin with a tattoo or body piercing. Because the needles involved in producing body art and piercings must penetrate the skin, there are dangers associated with the practice. These include allergic reactions; skin infections; blood-borne diseases, such as tetanus, hepatitis C, and hepatitis D; and the growth of scar tissue. Despite the risk, the practice of piercing the skin for decorative purposes has become increasingly popular. According to the American Academy of Dermatology, 24 percent of people from ages 18 to 50 have a tattoo.

Interactive Link

Tattooing has a long history, dating back thousands of years ago. The dyes used in tattooing typically derive from metals. A person with tattoos should be cautious when having a magnetic resonance imaging (MRI) scan because an MRI machine uses powerful magnets to create images of the soft tissues of the body, which could react with the metals contained in the tattoo dyes. Watch this video to learn more about tattooing.

Sensory Function

The fact that you can feel an ant crawling on your skin, allowing you to flick it off before it bites, is because the skin, and especially the hairs projecting from hair follicles in the skin, can sense changes in the environment. The hair root plexus surrounding the base of the hair follicle senses a disturbance, and then transmits the information to the central nervous system (brain and spinal cord), which can then respond by activating the skeletal muscles of your eyes to see the ant and the skeletal muscles of the body to act against the ant.

The skin acts as a sense organ because the epidermis, dermis, and the hypodermis contain specialized sensory nerve structures that detect touch, surface temperature, and pain. These receptors are more concentrated on the tips of the fingers, which are most sensitive to touch, especially the Meissner corpuscle (tactile corpuscle) (Figure 3.5.1), which responds to light touch, and the

Pacinian corpuscle (lamellated corpuscle), which responds to vibration. Merkel cells, seen scattered in the stratum basale, are also touch receptors. In addition to these specialized receptors, there are sensory nerves connected to each hair follicle, pain and temperature receptors scattered throughout the skin, and motor nerves innervate the arrector pili muscles and glands. This rich innervation helps us sense our environment and react accordingly.

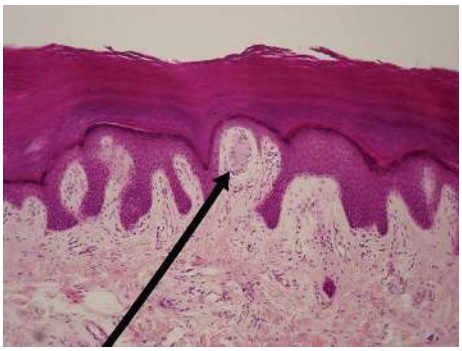


Figure 3.5.1: Light Micrograph of a Meissner Corpuscle In this micrograph of a skin cross-section, you can see a Meissner corpuscle (arrow), a type of touch receptor located in a dermal papilla adjacent to the basement membrane and stratum basale of the overlying epidermis. LM × 100. (credit: “Wbensmith”/Wikimedia Commons)

Thermoregulation

The integumentary system helps regulate body temperature through its tight association with the sympathetic nervous system, the division of the nervous system involved in our fight-or-flight responses. The sympathetic nervous system is continuously monitoring body temperature and initiating appropriate motor responses. Recall that sweat glands, accessory structures to the skin, secrete water, salt, and other substances to cool the body when it becomes warm. Even when the body does not appear to be noticeably sweating, approximately 500 mL of sweat (insensible perspiration) are secreted a day. If the body becomes excessively warm due to high temperatures, vigorous activity (3.5.2**ac**), or a combination of the two, sweat glands will be stimulated by the sympathetic nervous system to produce large amounts of sweat, as much as 0.7 to 1.5 L per hour for an active person. When the sweat evaporates from the skin surface, the body is cooled as body heat is dissipated.

In addition to sweating, arterioles in the dermis dilate so that excess heat carried by the blood can dissipate through the skin and into the surrounding environment (Figure 3.5.2**b**). This accounts for the skin redness that many people experience when exercising.

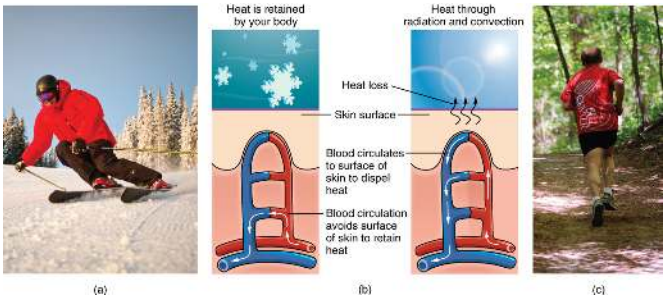


Figure 3.5.2: Thermoregulation During strenuous physical activities, such as skiing (a) or running (c), the dermal blood vessels dilate and sweat secretion increases (b). These mechanisms prevent the body from overheating. In contrast, the dermal blood vessels constrict to minimize heat loss in response to low temperatures (b). (credit a: “Trysil”/flickr; credit c: Ralph Daily)

When body temperatures drop, the arterioles constrict to minimize heat loss, particularly in the ends of the digits and tip of the nose. This reduced circulation can result in the skin taking on a whitish hue. Although the temperature of the skin drops as a result, passive heat loss is prevented, and internal organs and structures remain warm. If the temperature of the skin drops too much (such as environmental temperatures below freezing), the conservation of body core heat can result in the skin actually freezing, a condition called frostbite.

Aging and the...

Integumentary System

All systems in the body accumulate subtle and some not-so-subtle changes as a person ages. Among these changes are reductions in cell division, metabolic activity, blood circulation, hormonal levels, and muscle strength (Figure 3.5.3). In the skin, these changes are reflected in decreased mitosis in the stratum basale, leading to a thinner epidermis. The dermis, which is responsible for the elasticity and resilience of the skin, exhibits a reduced ability to regenerate, which leads to slower wound healing. The hypodermis, with its fat stores, loses structure due to the reduction and redistribution of fat, which in turn contributes to the thinning and sagging of skin.



Figure 3.5.3: Aging Generally, skin, especially on the face and hands, starts to display the first noticeable signs of aging, as it loses its elasticity over time. (credit: Janet Ramsden)

The accessory structures also have lowered activity, generating thinner hair and nails, and reduced amounts of sebum and sweat. A reduced sweating ability can cause some elderly to be intolerant to extreme heat. Other cells in the skin, such as melanocytes and dendritic cells, also become less active, leading to a paler skin tone and lowered immunity. Wrinkling of the skin occurs due to breakdown of its structure, which results from decreased collagen and elastin production in the dermis, weakening of muscles lying under the skin, and the inability of the skin to retain adequate moisture.

Many anti-aging products can be found in stores today. In general, these products try to rehydrate the skin and thereby fill out the wrinkles, and some stimulate skin growth using hormones and growth factors. Additionally, invasive techniques include collagen injections to plump the tissue and injections of BOTOX® (the name brand of the botulinum neurotoxin) that paralyze the muscles that crease the skin and cause wrinkling.

Vitamin D Synthesis

The epidermal layer of human skin synthesizes vitamin D when exposed to UV radiation. In the presence of sunlight, a form of vitamin D_3 called cholecalciferol is synthesized from a derivative of the steroid cholesterol in the skin. The liver converts cholecalciferol to calcidiol, which is then converted to calcitriol (the active chemical form of the vitamin) in the kidneys. Vitamin D is essential for normal absorption of calcium and phosphorous, which are required for healthy bones. The absence of sun exposure can lead to a lack of vitamin D in the body, leading to a condition called rickets, a painful condition in children where the bones are misshapen due to a lack of calcium, causing bowleggedness. Elderly individuals who suffer from vitamin D deficiency can develop a condition called osteomalacia, a softening of the bones. In present day society, vitamin D is added as a supplement to many foods, including milk and orange juice, compensating for the need for sun exposure.

In addition to its essential role in bone health, vitamin D is essential for general immunity against bacterial, viral, and fungal infections. Recent studies are also finding a link between insufficient vitamin D and cancer.

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3.6: Diseases, Disorders, and Injuries of the Integumentary System

Learning Objectives

By the end of this section, you will be able to:

- Describe several different diseases and disorders of the skin
- Describe the effect of injury to the skin and the process of healing

The integumentary system is susceptible to a variety of diseases, disorders, and injuries. These range from annoying but relatively benign bacterial or fungal infections that are categorized as disorders, to skin cancer and severe burns, which can be fatal. In this section, you will learn several of the most common skin conditions.

Diseases

One of the most talked about diseases is skin cancer. Cancer is a broad term that describes diseases caused by abnormal cells in the body dividing uncontrollably. Most cancers are identified by the organ or tissue in which the cancer originates. One common form of cancer is skin cancer. The Skin Cancer Foundation reports that one in five Americans will experience some type of skin cancer in their lifetime. The degradation of the ozone layer in the atmosphere and the resulting increase in exposure to UV radiation has contributed to its rise. Overexposure to UV radiation damages DNA, which can lead to the formation of cancerous lesions. Although melanin offers some protection against DNA damage from the sun, often it is not enough. The fact that cancers can also occur on areas of the body that are normally not exposed to UV radiation suggests that there are additional factors that can lead to cancerous lesions.

In general, cancers result from an accumulation of DNA mutations. These mutations can result in cell populations that do not die when they should and uncontrolled cell proliferation that leads to tumors. Although many tumors are benign (harmless), some produce cells that can mobilize and establish tumors in other organs of the body; this process is referred to as metastasis. Cancers are characterized by their ability to metastasize.

Basal Cell Carcinoma

Basal cell carcinoma is a form of cancer that affects the mitotically active stem cells in the stratum basale of the epidermis. It is the most common of all cancers that occur in the United States and is frequently found on the head, neck, arms, and back, which are areas that are most susceptible to long-term sun exposure. Although UV rays are the main culprit, exposure to other agents, such as radiation and arsenic, can also lead to this type of cancer. Wounds on the skin due to open sores, tattoos, burns, etc. may be predisposing factors as well. Basal cell carcinomas start in the stratum basale and usually spread along this boundary. At some point, they begin to grow toward the surface and become an uneven patch, bump, growth, or scar on the skin surface (Figure 3.6.1). Like most cancers, basal cell carcinomas respond best to treatment when caught early. Treatment options include surgery, freezing (cryosurgery), and topical ointments (Mayo Clinic 2012).



Figure 3.6.1: Basal Cell Carcinoma Basal cell carcinoma can take several different forms. Similar to other forms of skin cancer, it is readily cured if caught early and treated. (credit: John Hendrix, MD)

Squamous Cell Carcinoma

Squamous cell carcinoma is a cancer that affects the keratinocytes of the stratum spinosum and presents as lesions commonly found on the scalp, ears, and hands (Figure 3.6.2). It is the second most common skin cancer. The American Cancer Society reports that two of 10 skin cancers are squamous cell carcinomas, and it is more aggressive than basal cell carcinoma. If not removed, these carcinomas can metastasize. Surgery and radiation are used to cure squamous cell carcinoma.



Figure 3.6.2: Squamous Cell Carcinoma Squamous cell carcinoma presents here as a lesion on an individual's nose. (credit: the National Cancer Institute)

Melanoma

A melanoma is a cancer characterized by the uncontrolled growth of melanocytes, the pigment-producing cells in the epidermis. Typically, a melanoma develops from a mole. It is the most fatal of all skin cancers, as it is highly metastatic and can be difficult to detect before it has spread to other organs. Melanomas usually appear as asymmetrical brown and black patches with uneven borders and a raised surface (Figure 3.6.3). Treatment typically involves surgical excision and immunotherapy.



Figure 3.6.3: Melanoma Melanomas typically present as large brown or black patches with uneven borders and a raised surface. (credit: the National Cancer Institute / Centers for Disease Control)

Doctors often give their patients the following ABCDE mnemonic to help with the diagnosis of early-stage melanoma. If you observe a mole on your body displaying these signs, consult a doctor.

- **A**symmetry – the two sides are not symmetrical
- **B**orders – the edges are irregular in shape
- **C**olor – the color is varied shades of brown or black
- **D**iameter – it is larger than 6 mm (0.24 in)
- **E**volving – its shape has changed

Some specialists cite the following additional signs for the most serious form, nodular melanoma:

- **E**levated – it is raised on the skin surface
- **F**irm – it feels hard to the touch
- **G**rowing – it is getting larger

Skin Disorders

Two common skin disorders are eczema and acne. Eczema is an inflammatory condition and occurs in individuals of all ages. Acne involves the clogging of pores, which can lead to infection and inflammation, and is often seen in adolescents. Other disorders, not discussed here, include seborrheic dermatitis (on the scalp), psoriasis, cold sores, impetigo, scabies, hives, and warts.

Eczema

Eczema is an allergic reaction that manifests as dry, itchy patches of skin that resemble rashes (Figure 3.6.4. It may be accompanied by swelling of the skin, flaking, and in severe cases, bleeding. Many who suffer from eczema have antibodies against dust mites in their blood, but the link between eczema and allergy to dust mites has not been proven. Symptoms are usually managed with moisturizers, corticosteroid creams, and immunosuppressants.



Figure 3.6.4: Eczema Eczema is a common skin disorder that presents as a red, flaky rash. (credit: “Jambula” Wikimedia Commons / NIAID, Flickr)

Acne

Acne is a skin disturbance that typically occurs on areas of the skin that are rich in sebaceous glands (face and back). It is most common along with the onset of puberty due to associated hormonal changes, but can also occur in infants and continue into adulthood. Hormones, such as androgens, stimulate the release of sebum. An overproduction and accumulation of sebum along with keratin can block hair follicles. This plug is initially white. The sebum, when oxidized by exposure to air, turns black. Acne results from infection by acne-causing bacteria (*Propionibacterium* and *Staphylococcus*), which can lead to redness and potential scarring due to the natural wound healing process (Figure 3.6.5).

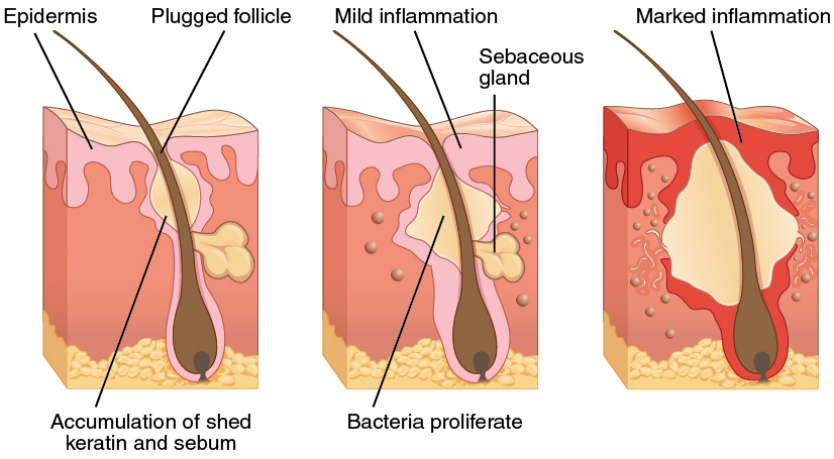


Figure 3.6.5: Acne Acne is a result of over-productive sebaceous glands, which leads to formation of blackheads and inflammation of the skin.

Career Connection

Dermatologist

Have you ever had a rash that did not respond to over-the-counter creams, or a mole that you were concerned about? Dermatologists help patients with these types of problems and more, on a daily basis. Dermatologists are medical doctors who specialize in diagnosing and treating skin disorders. Like all medical doctors, dermatologists earn a medical degree and then complete several years of residency training. In addition, dermatologists may then participate in a dermatology fellowship or complete additional, specialized training in a dermatology practice. If practicing in the United States, dermatologists must pass the United States Medical Licensing Exam (USMLE), become licensed in their state of practice, and be certified by the American Board of Dermatology.

Most dermatologists work in a medical office or private-practice setting. They diagnose skin conditions and rashes, prescribe oral and topical medications to treat skin conditions, and may perform simple procedures, such as mole or wart removal. In addition, they may refer patients to an oncologist if skin cancer that has metastasized is suspected. Recently, cosmetic procedures have also become a prominent part of dermatology. Botox injections, laser treatments, and collagen and dermal filler injections are popular among patients, hoping to reduce the appearance of skin aging.

Dermatology is a competitive specialty in medicine. Limited openings in dermatology residency programs mean that many medical students compete for a few select spots. Dermatology is an appealing specialty to many prospective doctors, because unlike emergency room physicians or surgeons, dermatologists generally do not have to work excessive hours or be “on-call” weekends and holidays. Moreover, the popularity of cosmetic dermatology has made it a growing field with many lucrative opportunities. It is not unusual for dermatology clinics to market themselves exclusively as cosmetic dermatology centers, and for dermatologists to specialize exclusively in these procedures.

Consider visiting a dermatologist to talk about why they entered the field and what the field of dermatology is like. Visit this site for additional information.

Injuries

Because the skin is the part of our bodies that meets the world most directly, it is especially vulnerable to injury. Injuries include burns and wounds, as well as scars and calluses. They can be caused by sharp objects, heat, or excessive pressure or friction to the skin.

Skin injuries set off a healing process that occurs in several overlapping stages. The first step to repairing damaged skin is the formation of a blood clot that helps stop the flow of blood and scabs over with time. Many different types of cells are involved in wound repair, especially if the surface area that needs repair is extensive. Before the basal stem cells of the stratum basale can recreate the epidermis, fibroblasts mobilize and divide rapidly to repair the damaged tissue by collagen deposition, forming granulation tissue. Blood capillaries follow the fibroblasts and help increase blood circulation and oxygen supply to the area. Immune cells, such as macrophages, roam the area and engulf any foreign matter to reduce the chance of infection.

Burns

A burn results when the skin is damaged by intense heat, radiation, electricity, or chemicals. The damage results in the death of skin cells, which can lead to a massive loss of fluid. Dehydration, electrolyte imbalance, and renal and circulatory failure follow, which can be fatal. Burn patients are treated with intravenous fluids to offset dehydration, as well as intravenous nutrients that enable the body to repair tissues and replace lost proteins. Another serious threat to the lives of burn patients is infection. Burned skin is extremely susceptible to bacteria and other pathogens, due to the loss of protection by intact layers of skin.

Burns are sometimes measured in terms of the size of the total surface area affected. This is referred to as the “rule of nines,” which associates specific anatomical areas with a percentage that is a factor of nine (Figure 3.6.6). Burns are also classified by the degree of their severity. A first-degree burn is a superficial burn that affects only the epidermis. Although the skin may be painful and swollen, these burns typically heal on their own within a few days. Mild sunburn fits into the category of a first-degree burn. A second-degree burn goes deeper and affects both the epidermis and a portion of the dermis. These burns result in swelling and a painful blistering of the skin. It is important to keep the burn site clean and sterile to prevent infection. If this is done, the burn will heal within several weeks. A third-degree burn fully extends into the epidermis and dermis, destroying the tissue and affecting the nerve endings and sensory function. These are serious burns that may appear white, red, or black; they require medical attention and will heal slowly without it. A fourth-degree burn is even more severe, affecting the underlying muscle and bone. Oddly, third and fourth-degree burns are usually not as painful because the nerve endings themselves are damaged. Full-thickness burns cannot be repaired by the body, because the local tissues used for repair are damaged and require excision (debridement), or amputation in severe cases, followed by grafting of the skin from an unaffected part of the body, or from skin grown in tissue culture for grafting purposes.

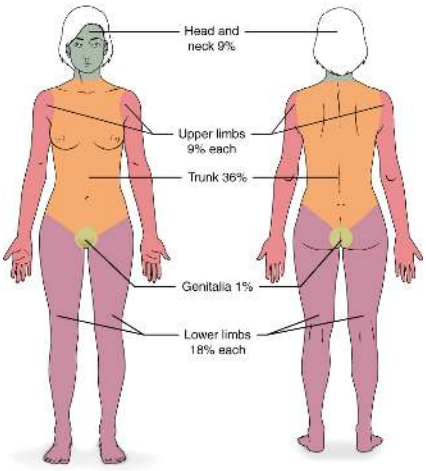


Figure 3.6.6: Calculating the Size of a Burn The size of a burn will guide decisions made about the need for specialized treatment. Specific parts of the body are associated with a percentage of body area.

Interactive Link

Skin grafts are required when the damage from trauma or infection cannot be closed with sutures or staples. Watch this video to learn more about skin grafting procedures.

Scars and Keloids

Most cuts or wounds, with the exception of ones that only scratch the surface (the epidermis), lead to scar formation. A scar is collagen-rich skin formed after the process of wound healing that differs from normal skin. Scarring occurs in cases in which there is repair of skin damage, but the skin fails to regenerate the original skin structure. Fibroblasts generate scar tissue in the form of collagen, and the bulk of repair is due to the basket-weave pattern generated by collagen fibers and does not result in regeneration of the typical cellular structure of skin. Instead, the tissue is fibrous in nature and does not allow for the regeneration of accessory structures, such as hair follicles, sweat glands, or sebaceous glands.

Sometimes, there is an overproduction of scar tissue, because the process of collagen formation does not stop when the wound is healed; this results in the formation of a raised or hypertrophic scar called a keloid. In contrast, scars that result from acne and chickenpox have a sunken appearance and are called atrophic scars.

Scarring of skin after wound healing is a natural process and does not need to be treated further. Application of mineral oil and lotions may reduce the formation of scar tissue. However, modern cosmetic procedures, such as dermabrasion, laser treatments, and filler injections have been invented as remedies for severe scarring. All of these procedures try to reorganize the structure of the epidermis and underlying collagen tissue to make it look more natural.

Bedsores and Stretch Marks

Skin and its underlying tissue can be affected by excessive pressure. One example of this is called a bedsore. Bedsores, also called decubitis ulcers, are caused by constant, long-term, unrelieved pressure on certain body parts that are bony, reducing blood flow to the area and leading to necrosis (tissue death). Bedsores are most common in elderly patients who have debilitating conditions that cause them to be immobile. Most hospitals and long-term care facilities have the practice of turning the patients every few hours to prevent the incidence of bedsores. If left untreated by removal of necrotized tissue, bedsores can be fatal if they become infected.

The skin can also be affected by pressure associated with rapid growth. A stretch mark results when the dermis is stretched beyond its limits of elasticity, as the skin stretches to accommodate the excess pressure. Stretch marks usually accompany rapid weight gain during puberty and pregnancy. They initially have a reddish hue, but lighten over time. Other than for cosmetic reasons, treatment of stretch marks is not required. They occur most commonly over the hips and abdomen.

Calluses

When you wear shoes that do not fit well and are a constant source of abrasion on your toes, you tend to form a callus at the point of contact. This occurs because the basal stem cells in the stratum basale are triggered to divide more often to increase the thickness of the skin at the point of abrasion to protect the rest of the body from further damage. This is an example of a minor or local injury, and the skin manages to react and treat the problem independent of the rest of the body. Calluses can also form on your fingers if they are subject to constant mechanical stress, such as long periods of writing, playing string instruments, or video games. A corn is a specialized form of callus. Corns form from abrasions on the skin that result from an elliptical-type motion.

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3.7: CASE STUDY CONCLUSION- SKIN CANCER AND CHAPTER SUMMARY

CASE STUDY CONCLUSION

Skin cancer begins in the outer layer of skin, the epidermis. There are three common types of skin cancer: basal cell carcinoma, squamous cell carcinoma, and melanoma.

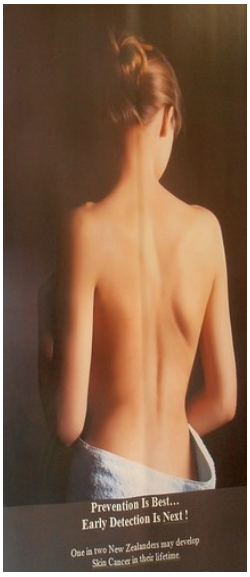


Figure **3.7.1**: cancer screening poster

BASAL CELL CARCINOMA

Basal cell carcinoma occurs in basal cells of the epidermis. Basal cells are stem cells in the stratum basale layer that divide to form all the keratinocytes of the epidermis. Basal cell carcinoma is the most common form of skin cancer. More than four million cases occur in the United States each year. A basal cell carcinoma may appear as a pearly or waxy bump, like the one shown in Figure **3.7.2**. Basal cell carcinomas rarely spread (or undergo **metastasis),** so they can generally be cured with a **biopsy,** in which the lesion is cut out of the skin and analyzed in a medical lab.

SQUAMOUS CELL CARCINOMA

Squamous cell carcinoma occurs in squamous cells of the epidermis. Squamous cells are flattened, keratin-filled cells in the upper layers of the epidermis. Squamous cell carcinoma is the second most common form of skin cancer. More than two million cases occur in the United States each year. A squamous cell carcinoma may appear as a firm, red nodule, or as a flat lesion with a scaly or crusty surface, like the one pictured in Figure **3.7.3**. Squamous cell carcinomas are generally localized and unlikely to metastasize, so they are usually curable surgically.

MELANOMA

Melanoma occurs in the melanocytes of the epidermis. Melanocytes are the melanin-producing cells in the stratum basale of the epidermis. Melanoma is the rarest type of skin cancer, accounting for less than one percent of all skin cancer cases. Melanoma, however, is the most deadly type of skin cancer. It causes the vast majority of skin cancer deaths because melanoma is malignant. If not treated, it will metastasize and spread to other parts of the body. If melanoma is detected early and while it is still localized in the skin, most patients survive for at least five years. If melanoma is discovered only after it has already metastasized to distant organs, there is only a 17 percent chance of patients surviving for five years. You can see an example of melanoma in Figure **3.7.4**.



Figure **3.7.2**: Basal cell carcinoma



Figure **3.7.3**: Squamous cell carcinoma



Figure **3.7.4**: Melanoma

Melanoma can develop anywhere on the body. It may develop in otherwise normal skin, or an existing mole may become cancerous. Signs of melanoma may include a:

- mole that changes in size, feel, or color
- mole that bleeds
- large brown spot on the skin sprinkled with darker specks
- small lesion with an irregular border and parts that appear red, white, blue, or blue-black
- dark lesion on the palms, soles, fingertips, toes, or mucous membranes

As with most types of cancer, skin cancer is the easiest to treat and most likely to be cured the earlier it is detected. The skin is one of the few organs that you can monitor for cancer yourself, as long as you know what to look for. A brown spot on the skin is likely to be a harmless mole, but it could be a sign of skin cancer. As shown in Figure **3.7.5**, unlike moles, skin cancers may be asymmetrical, have irregular borders, be very dark in color, and may have a relatively great diameter. These characteristics can be remembered with the mnemonic ABCD.

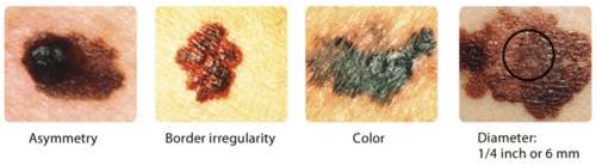


Figure **3.7.5**: ABCDs of skin cancer

With the help of mirrors, you should check all of your skin regularly. Look for new skin growths or changes in any existing moles, freckles, bumps, or birthmarks. Report anything suspicious or different to your doctor.

If you have risk factors for skin cancer, it's a good idea to have an annual skin check by a dermatologist. This helps ensure that cancerous or precancerous lesions will be detected before they grow too large and become difficult to cure—or, in the case of melanoma, before they metastasize.

CHAPTER REVIEW

In this chapter, you learned about the structures and functions of the organs of the integumentary system. Specifically, you learned that:

- The integumentary system consists of the skin, hair, and nails. Functions of the integumentary system include providing a protective covering for the body, sensing the environment, and helping the body maintain homeostasis.
- The skin's main functions include preventing water loss from the body, serving as a barrier to the entry of microorganisms, synthesizing vitamin D, blocking UV light, and helping to regulate body temperature.
- The skin consists of two distinct layers: a thinner outer layer called the epidermis and a thicker inner layer called the dermis.
    - The epidermis consists mainly of epithelial cells called keratinocytes, which produce keratin. New keratinocytes form at the bottom of the epidermis. They become filled with keratin and die as they move upward toward the surface of the skin, where they form a protective, waterproof layer.
    - The dermis consists mainly of tough connective tissues that provide strength and stretch; and almost all skin structures, including blood vessels, sensory receptors, hair follicles, and oil and sweat glands.
- Cell types in the epidermis include keratinocytes which make up 90 percent of epidermal cells; melanocytes that produce melanin; Langerhans cells that fight pathogens in the skin; and Merkel cells that respond to light touch.
- The epidermis in most parts of the body consists of four distinct layers. A fifth layer occurs only in the epidermis of the palms of the hands and soles of the feet.
    - The innermost layer of the epidermis is the stratum basale, which contains stem cells that divide to form new keratinocytes. The next layer is the stratum spinosum, which is the thickest layer and contains Langerhans cells and spiny keratinocytes. This is followed by the stratum granulosum, in which keratinocytes are filling with keratin and starting to die. The stratum lucidum is next, but only on the palms and soles. It consists of translucent dead keratinocytes. The outermost layer is the stratum corneum, which consists of flat, dead, tightly packed keratinocytes that form a tough, waterproof barrier for the rest of the epidermis.
- Functions of the epidermis include protecting underlying tissues from physical damage and pathogens. Melanin in the epidermis absorbs and protects underlying tissues from UV light. The epidermis also prevents the loss of water from the body and synthesizes vitamin D.
    - Melanin is the main pigment that determines the color of human skin. However, the pigments of carotene and hemoglobin also contribute to skin color, especially in the skin with low levels of melanin.
    - The surface of healthy skin normally is covered by vast numbers of bacteria representing about 1,000 species from 19 phyla. Different areas of the body provide diverse habitats for skin microorganisms. Usually, microorganisms on the skin keep each other in check unless their balance is disturbed.
- The thicker inner layer of the skin, the dermis, has two layers. The upper papillary layer has papillae extending upward into the epidermis and loose connective tissues. The lower reticular layer has denser connective tissues and structures such as glands and hair follicles. Glands in the dermis include eccrine and apocrine sweat glands and sebaceous glands. Hair follicles are structures where hairs originate.
- Functions of the dermis include cushioning subcutaneous tissues, regulating body temperature, sensing the environment, and excreting wastes. The dense connective tissues of the dermis provide cushioning. The dermis regulates body temperature mainly by sweating and by vasodilation or vasoconstriction. The many tactile sensory receptors in the dermis make it the main organ for the sense of touch. Wastes excreted in sweat include excess water, electrolytes, and certain metabolic wastes.
- Hair is a filament that grows from a hair follicle in the dermis of the skin. It consists mainly of tightly packed, dead keratinocytes that are filled with keratin. The human body is almost completely covered with hair follicles.
- Hair helps prevent heat loss from the head and protects its skin from UV light. Hair in the nose filters the incoming air, and the eyelashes and eyebrows keep harmful substances out of the eyes. Hair all over the body provides tactile sensory input. The eyebrows also play a role in nonverbal communication.
- The part of the hair that is within the follicle is the hair root. This is the only living part of a hair. The part of the hair that is visible above the skin surface is the hair shaft. It consists of dead cells.
    - Hair growth begins inside a follicle when stem cells within the follicle divide to produce new keratinocytes.
    - A hair shaft has three zones: the outermost zone called the cuticle; the middle zone called the cortex, and the innermost zone called the medulla.
- Genetically controlled, visible characteristics of hair include hair color, hair texture, and the extent of balding in adult males.

Melanin (eumelanin and/or pheomelanin) is the pigment that gives hair its color. Aspects of hair texture include curl pattern, thickness, and consistency.

- Among mammals, humans are nearly unique in having undergone a significant loss of body hair during their evolution, probably because sweat evaporates more quickly from the less hairy skin. Curly hair also is thought to have evolved at some point during human evolution, perhaps because it provided better protection from UV light.
- Hair has social significance for human beings, being an indicator of biological sex, age, and ethnic ancestry. Human hair also has cultural significance. For example, hairstyle may be an indicator of a social group membership.
- Nails consist of sheets of dead, keratin-filled keratinocytes. The keratin in nails makes them hard but flexible. They help protect the ends of the fingers and toes, enhance the sense of touch in the fingertips, and may be used as tools.
- A nail has three main parts: the nail root, which is under the epidermis; the nail plate, which is the visible part of the nail; and the free margin, which is the distal edge of the nail. Other structures under or around a nail include the nail bed, cuticle, and nail fold.
- A nail grows from a deep layer of living epidermal tissues, called the nail matrix, at the proximal end of the nail. Stem cells in the nail matrix keep dividing to allow nail growth, forming first the nail root and then the nail plate as the nail continues to grow longer and emerges from the epidermis.
- Fingernails grow faster than toenails. Actual rates of growth depend on many factors, such as age, sex, and season.
- The color of the nail bed can be used to quickly assess oxygen and blood flow in a patient. How the nail plate grows out can reflect recent health problems, such as illness or nutrient deficiency. Nails — and especially toenails — are prone to fungus infections. Nails are more permeable than skin and can absorb several harmful substances such as herbicides.
- Skin cancer is a disease in which skin cells grow out of control. It is caused mainly by excessive exposure to UV light, which damages DNA. Skin cancer affects more Americans than all other cancers combined.
- There are three common types of skin cancer: basal cell carcinoma, squamous cell carcinoma, and melanoma. Carcinomas are more common and unlikely to metastasize. Melanoma is rare and likely to metastasize. It causes the most skin cancer deaths.
- Besides exposure to UV light, risk factors for skin cancer include having light-colored skin, many moles, and a family history of skin cancer, among several others.

Now that you have learned about the organs on the surface of the body, read the next chapter to travel inside and learn about the skeletal system, which protects and supports us internally, among other functions.

CHAPTER SUMMARY REVIEW

1. What is skin cancer?
2. How common is skin cancer?
3. Compare and contrast the three common types of skin cancer.
4. Identify factors that increase the risk of skin cancer.
5. How does exposure to UV light cause skin cancer?
6. In which layer of the skin does skin cancer normally start?
7. Which two skin cancers described in this section start in the same sublayer? Include the name of the sublayer and the cells affected in each of these cancers in your answer.
8. If a type of skin cancer spreads to other organs, which type is it most likely to be? Explain your answer.
9. *True or False*. A mole is a form of cancer.
10. *True or False*. Exposure to UV light can contribute to wrinkles.
11. *True or False*. Skin cancers are always dark in color.
12. Which form of skin cancer is the most deadly?
13. What are some ways people can reduce their risk of getting skin cancer? Explain your answer.
14. *True or False*. UV radiation causes more cancers than tobacco use.
15. Describe one way in which the integumentary system works with another organ system to carry out a particular function.
16. Put the following layers of skin in order, from the deepest layer to the layer closest to the surface:

    A. papillary layer
    B. stratum basale
    C. reticular layer
    D. stratum spinosum

17. The basement membrane is between the:

    A. Dermis and epidermis
    B. Dermis and the subcutaneous tissues beneath it
    C. Dermis and the hair in the follicle
    D. Nail matrix and the nail bed

18. For each of the descriptions below (A-D), match it to the protein that is best described by it (protein choices: keratin, collagen, melanin, elastin).

    A. Helps provide strength and elasticity in the lower layer of the dermis
    B. Makes up the loosely arranged fibers in the upper layer of the dermis
    C. The predominant protein in hair, skin, and nails
    D. Protects against damage from UV light.

19. Keratinocytes are found in:

    A. Skin
    B. Hair
    C. Nails
    D. All of the above

20. Papillae extend from the :

    A. sebaceous glands to the surface of the skin
    B. sweat glands to the surface of the skin
    C. epidermis down into the dermis

D. dermis up into the epidermis

21. Describe two types of waterproofing used in the integumentary system. Include the types of molecules and where they are located in your answer.
22. Explain why nails enhance touch sensations.
23. Why do you think light-colored skin is a risk factor for skin cancer?
24. Which vitamin is synthesized by the skin?
    A. Vitamin A
    B. Vitamin D
    C. Vitamin B9
    D. Vitamin E
25. Describe the similarities between how the epidermis, hair, and nails all grow.
26. *True or False.* The inside of the mouth is considered to be epidermal tissue.
27. *True or False.* Epidermal cells are filled with an increasing amount of keratin as they go from the lowest layer to the outermost layer.
28. *True or False.* Cells in the stratum corneum of the skin do not have a nucleus or organelles.
29. What does the whitish crescent-shaped area at the base of your nails (towards your hands) represent? What is its function?
30. What is one difference between human hair and the hair of non-human primates?
31. *True or False.* Blood vessels extend through the entire thickness of the skin.
32. *True or False.* Cells that produce melanin are located in the dermis of the skin.
33. Describe the relationship between skin and hair.
34. What kind of skin cancer is a cancer of a type of stem cell?
35. For the skin and hair, describe one way in which they each protect the body against pathogens.
36. If sweat glands are in the dermis, how is sweat released to the surface of the body?
37. Explain why you think that physicians usually insist that patients remove any nail polish before having surgery.
38. *True or False.* Langerhans cells are immune cells located in the epidermis.
39. *True or False.* Fingerprints are due to structures on the surface of the epidermis.
40. Describe generally how the brain gets touch information from the skin.

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CHAPTER OVERVIEW

4: SKELETAL SYSTEM

This chapter describes the structure and functions of the skeletal system and its two major divisions, the axial skeleton and the appendicular skeleton. It details the structure of bone, how bones grow, and how they are remodeled and repaired. The chapter also explains how joints work and how they are classified as well as the causes and effects of major skeletal system disorders.

4.1: Case Study- Your Support System

4.2: Introduction to the Skeletal System

4.3: Divisions of the Skeletal System

4.4: Structure of Bone

4.5: Bone Growth, Remodeling, and Repair

4.6: Joints

4.7: Disorders of the Skeletal System

4.8: Case Study Conclusion- Heels and Chapter Summary

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4.1: CASE STUDY- YOUR SUPPORT SYSTEM

CASE STUDY: A PAIN IN THE FOOT

Amari loves wearing high heels when they go out at night, like the stiletto heels shown in Figure **4.1.1**. Amari uses gender-neutral pronouns, such as they, them, and their. They know high heels are not the most practical shoes, but they like how they look. Lately, Amari has been experiencing pain in the balls of their feet—the area just behind the toes. Even when they trade heels for comfortable sneakers, it still hurts when they stand or walk.



Figure **4.1.1**: high heels

What could be going on? Amari searches online to try to find some answers. They find a reputable source for foot pain information—a website from a professional organization of physicians that peer reviews the content by experts in the field. There, Amari reads about a condition called metatarsalgia, which produces pain in the ball of the foot that sounds very similar to what they are experiencing.

Amari learns that a common cause of metatarsalgia is the wearing of high heels because they push the foot into an abnormal position. This results in excessive pressure being placed onto the ball of the foot. Looking at the photograph above, you can imagine how much of the body weight is focused on the ball of the foot because of the shape of the high heels. If they were not wearing high heels, the weight would be more evenly distributed across the foot.

As they read more about the hazards of high heels, Amari learns that heels can also cause foot deformities such as hammertoes and bunions, small cracks in the bone called stress fractures, and may even contribute to the development of osteoarthritis of the knees at an early age.

These conditions caused by high heels are all problems of the skeletal system, which includes bones and connective tissues that hold bones together and cushion them at joints such as the knee. The skeletal system supports the body's weight and protects internal organs, but as you will learn as you read this chapter, it also carries out a variety of other important physiological functions.

At the end of the chapter, you will find out why high heels can cause these skeletal system problems and the steps Amari takes to recover from their foot pain and prevent long-term injury.

CHAPTER OVERVIEW: SKELETAL SYSTEM

In this chapter, you will learn about the structure, functions, growth, repair, and disorders of the skeletal system. Specifically, you will learn about:

- The components of the skeletal system, which include bones, ligaments, and cartilage.
- The functions of the skeletal system, which include supporting and giving shape to the body, protecting internal organs, facilitating movement, producing blood cells, helping maintain homeostasis, and producing endocrine hormones.
- The organization and functions of the two main divisions of the skeletal system: the axial skeletal system, which includes the skull, spine, and rib cage; and the appendicular skeletal system, which includes the limbs and girdles that attach the limbs to the axial skeleton.
- The tissues and cells that make up bones and their specific functions, including making new bone, breaking down bone, producing blood cells, and regulating mineral homeostasis.
- The different types of bones in the skeletal system, based on shape and location.
- How bones grow, remodel, and repair themselves.
- The different types of joints between bones, where they are located, and the ways in which they allow different types of movement depending on their structure.
- The causes, risk factors, and treatments for the two most common disorders of the skeletal system: osteoporosis and osteoarthritis.

As you read this chapter, think about the following questions:

1. Amari suspects they have a condition called metatarsalgia. This term is related to the term "metatarsals." What are metatarsals, where are they located, and how do you think they are related to metatarsalgia?
2. High heels can cause stress fractures, which are small cracks in the bone that usually appear after repeated mechanical stress, instead of after a significant acute injury. What other condition described in this chapter involves a similar process?
3. What are bunions and osteoarthritis of the knee? Why do you think they can be caused by wearing high heels?

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4.2: INTRODUCTION TO THE SKELETAL SYSTEM

SKULL AND CROSS-BONES

The skull and cross-bones symbol has been used for a very long time to represent death, perhaps because after death and decomposition, bones are all that remain. Many people think of bones as being dead, dry, and brittle. These adjectives may correctly describe the bones of a preserved skeleton, but the bones of a living human being are very much alive. Living bones are also strong and flexible. Bones are the major organs of the skeletal system.



Figure **4.2.1**: skull and cross-bones flag

The **skeletal system** is the organ system that provides an internal framework for the human body. Why do you need a skeletal system? Try to imagine what you would look like without it. You would be a soft, wobbly pile of skin containing muscles and internal organs but no bones. You might look something like a very large slug. Not that you would be able to see yourself — folds of skin would droop down over your eyes and block your vision because of your lack of skull bones. You could push the skin out of the way if you could only move your arms, but you need bones for that as well!

COMPONENTS OF THE SKELETAL SYSTEM

In adults, the skeletal system includes 206 bones, many of which are shown in Figure **4.2.2**. Bones are organs made of dense connective tissues, mainly the tough protein collagen. Bones contain blood vessels, nerves, and other tissues. Bones are hard and rigid due to deposits of calcium and other mineral salts within their living tissues. Locations, where two or more bones meet, are called joints. Many joints allow bones to move like levers. For example, your elbow is a joint that allows you to bend and straighten your arm.

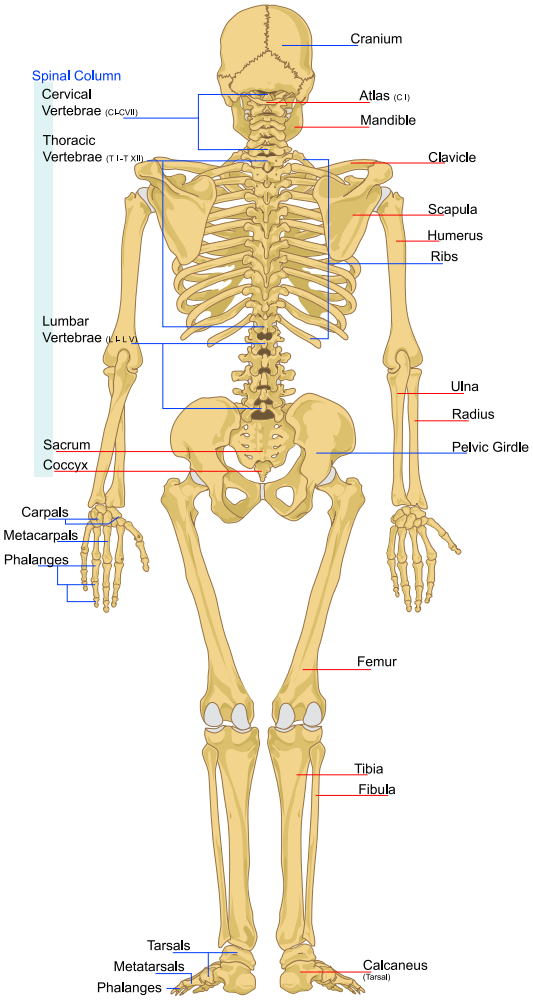


Figure **4.2.2**: Some of the 206 bones are labeled on the adult human skeleton.

Besides bones, the skeletal system includes cartilage and ligaments.

- **Cartilage** is a type of dense connective tissue, made of tough protein fibers. It is strong but flexible and very smooth. It covers the ends of bones at joints, providing a smooth surface for bones to move over.
- **Ligaments** are bands of fibrous connective tissue that hold bones together. They keep the bones of the skeleton in place.

AXIAL AND APPENDICULAR SKELETONS

The skeleton is traditionally divided into two major parts: the axial skeleton and the appendicular skeleton, both of which are pictured in Figure **4.2.3**.

- The axial skeleton forms the axis of the body. It includes the skull, vertebral column (spine), and rib cage. The bones of the axial skeleton, along with ligaments and muscles, allow the human body to maintain its upright posture. The axial skeleton also transmits weight from the head, trunk, and upper extremities

down the back to the lower extremities. In addition, the bones protect the brain and organs in the chest.

- The appendicular skeleton forms the appendages and their attachments to the axial skeleton. It includes the bones of the arms and legs, hands and feet, and shoulder and pelvic girdles. The bones of the appendicular skeleton make possible locomotion and other movements of the appendages. They also protect the major organs of digestion, excretion, and reproduction.

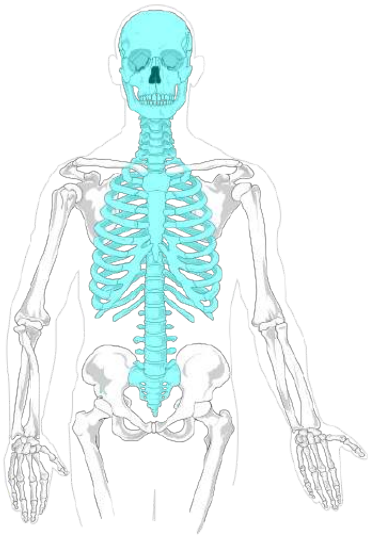


Figure **4.2.3**: Axial skeleton represented in blue

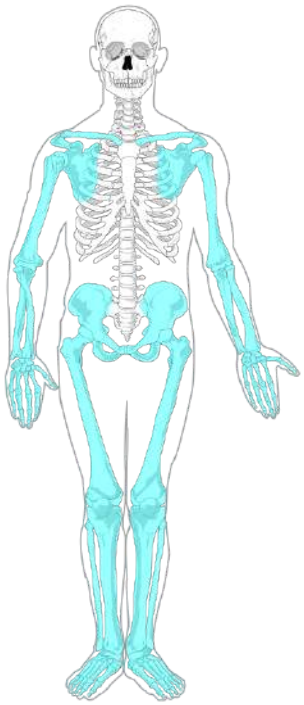


Figure **4.2.3**: Appendicular skeleton represented in blue

FUNCTIONS OF THE SKELETAL SYSTEM

The skeletal system has many different functions that are necessary for human survival. Some of the functions, such as supporting the body, are relatively obvious. Other functions are less obvious but no less important. For example, three tiny bones (hammer, anvil, and stirrup) inside the middle ear transfer sound waves into the inner ear.

SUPPORT, SHAPE, AND PROTECTION

The skeleton supports the body and gives it shape. Without the rigid bones of the skeletal system, the human body would be just a bag of soft tissues, as described above. The bones of the skeleton are very hard and provide protection to the delicate tissues of internal organs. For example, the skull encloses and protects the soft tissues of the brain, and the vertebral column protects the nervous tissues of the spinal cord. The vertebral column, ribs, and sternum (breast bone) protect the heart, lungs, and major blood vessels. Providing protection to these latter internal organs requires the bones to be able to expand and contract. The ribs and the cartilage that connects them to the sternum and vertebrae are capable of small shifts that allow breathing and other internal organ movements.

MOVEMENT

The bones of the skeleton provide attachment surfaces for skeletal muscles. When the muscles contract, they pull on and move the bones. The figure below, for example, shows the muscles attached to the bones at the knee. They help stabilize the joint and allow the leg to bend at the knee. The bones at joints act like levers moving at a fulcrum point, and the muscles attached to the bones apply the force needed for movement.

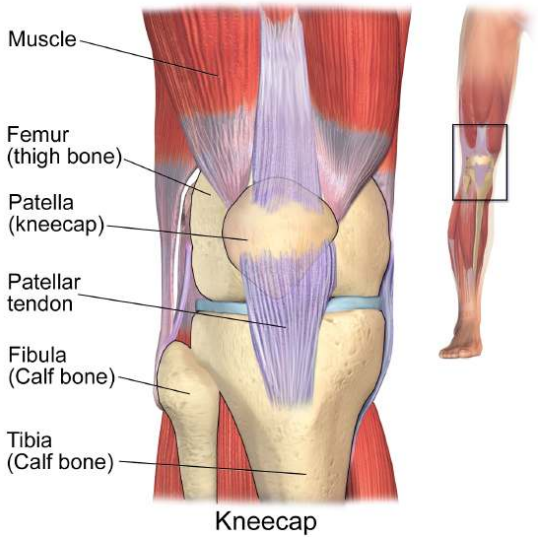


Figure **4.2.4**: Bones that meet at the knee joint include the tibia and fibula in the lower leg, the femur in the upper leg, and the kneecap at the front of the knee. These bones provide attachment surfaces for muscles that move the bones at the joint. Muscles are attached to the bones via tendons.

HEMATOPOIESIS

Hematopoiesis is the process in which blood cells are produced. This process occurs in a tissue called red marrow, which is found

inside some bones, including the pelvis, ribs, and vertebrae. Red marrow synthesizes red blood cells, white blood cells, and platelets. Billions of these blood cells are produced inside the bones every day.

MINERAL STORAGE AND HOMEOSTASIS

Another function of the skeletal system is storing minerals, especially calcium and phosphorus. This storage function is related to the role of bones in maintaining mineral homeostasis. Just the right levels of calcium and other minerals are needed in the blood for the normal functioning of the body. When mineral levels in the blood are too high, bones absorb some of the minerals and store them as mineral salts, which is why bones are so hard. When blood levels of minerals are too low, bones release some of the minerals back into the blood. Bone minerals are alkaline (basic), so their release into the blood buffers the blood against excessive acidity (low pH), whereas their absorption back into bones buffers the blood against excessive alkalinity (high pH). In this way, bones help maintain acid-base homeostasis in the blood.

Another way bones help to maintain homeostasis is by acting as an endocrine organ. One endocrine hormone secreted by bone cells is **osteocalcin,** which helps regulate blood glucose and fat deposition. It increases insulin secretion and also the sensitivity of cells to insulin. In addition, it boosts the number of insulin-producing cells and reduces fat stores.

REVIEW

1. What is the skeletal system? How many bones are there in the adult skeleton?
2. Describe the composition of bones.
3. Besides bones, what other organs are included in the skeletal system?
4. Identify the two major divisions of the skeleton.
5. List several functions of the skeletal system.
6. Discuss sexual dimorphism in the human skeleton.
7. Bones, cartilage, and ligaments are all made of types of _____ tissue.
8. *True or False.* Bones contain living tissue and can affect processes in other parts of the body.
9. *True or False.* Bone cells contract to pull on muscles in order to initiate a movement.
10. If a person has a problem with blood cell production, what type of bone tissue is most likely involved? Explain your answer.
11. Are the pelvic girdles part of the axial or appendicular skeleton?
12. What are three forms of homeostasis that the skeletal system regulates? Briefly explain how each one is regulated by the skeletal system.
13. What do you think would happen to us if we did not have ligaments? Explain your answer.
14. a. Define a joint in the skeletal system.

    b. How is cartilage related to joints?

    c. Identify one joint in the human body and describe its function.

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4.3: DIVISIONS OF THE SKELETAL SYSTEM

SKULLS ON DISPLAY

This somewhat macabre display can be viewed at the Slovak National Museum in Bratislava, Slovakia. The skulls are meant to represent normal human skeletal anatomy. The skull is part of the axial skeleton, which is one of the two major divisions of the human skeleton. The other division is the appendicular skeleton.



Figure **4.3.1**: Skulls on Display

AXIAL SKELETON

The **axial skeleton,** shown in blue in Figure **4.3.2**, consists of a total of 80 bones. Besides the skull, it includes the rib cage and vertebral column. It also includes the three tiny ossicles (hammer, anvil, and stirrup) in the middle ear and the hyoid bone in the throat, to which the tongue and some other soft tissues are attached.

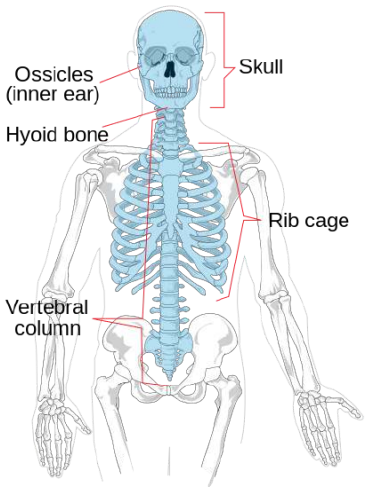


Figure **4.3.2**: The bones of the axial skeleton are shown here in blue.

SKULL

The **skull** is the part of the human skeleton that provides a bony framework for the head. It consists of 22 different bones. There are 8 bones in the cranium, which encloses the brain, and 14 bones in the face.

CRANIUM

The **cranium,** sometimes called the braincase, forms the entire upper portion of the skull. As shown in Figure **4.3.3**, it consists of eight bones: one frontal bone, two parietal bones, two temporal bones, one occipital bone, one sphenoid bone, and one ethmoid bone. The ethmoid bone separates the nasal cavity from the brain. The sphenoid bone is one of several bones, including the frontal bone, that helps form the eye sockets. The other bones of the cranium are large and plate-like. They cover and protect the brain. The bottom of the skull has openings for major blood vessels and nerves. A large opening, called the foramen magnum, allows the spinal cord and brain to connect.

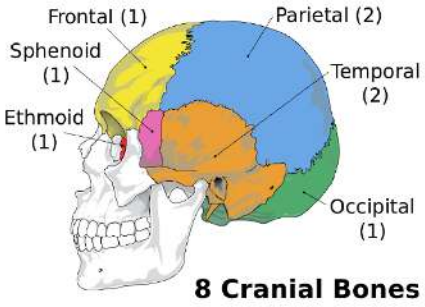


Figure **4.3.3**: The cranium consists of eight bones that are fused together at their joints.

FACIAL BONES

The 14 facial bones of the skull are located below the frontal bone of the cranium. They are depicted in Figure **4.3.4**. Large bones in the face include the upper jawbones, or **maxillae (singular, maxilla),** which form the middle part of the face and the bottom of the two eye sockets. The maxillae are fused together except for an opening between them for the nose. The lower edge of the maxillae contains sockets for the upper teeth. The lower jaw bone, or **mandible,** is also large. The top edge of the mandible contains sockets for the lower teeth. The mandible opens and closes to chew food and is controlled by strong muscles. There are two zygomatic or cheekbones and two nasal bones. The nasal region also contains seven smaller bones, as indicated in the figure.

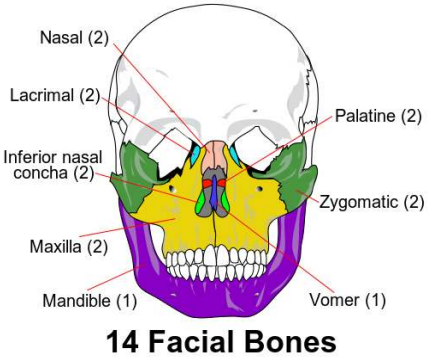


Figure **4.3.4**: The 14 bones that make up the face are labeled in this drawing of the skull.

VERTEBRAL COLUMN

The **vertebral column,** also called the spine or backbone, is the flexible column of **vertebrae (singular, vertebra)** that connects the trunk with the skull and encloses the spinal cord. It consists of 33 vertebrae that are divided into five regions, as shown in Figure **4.3.5**: the cervical, thoracic, lumbar, sacral, and coccygeal regions. From

the neck down, the first 24 vertebrae (cervical, thoracic, and lumbar) are individual bones. The five sacral vertebrae are fused together, as are the four coccygeal vertebrae.

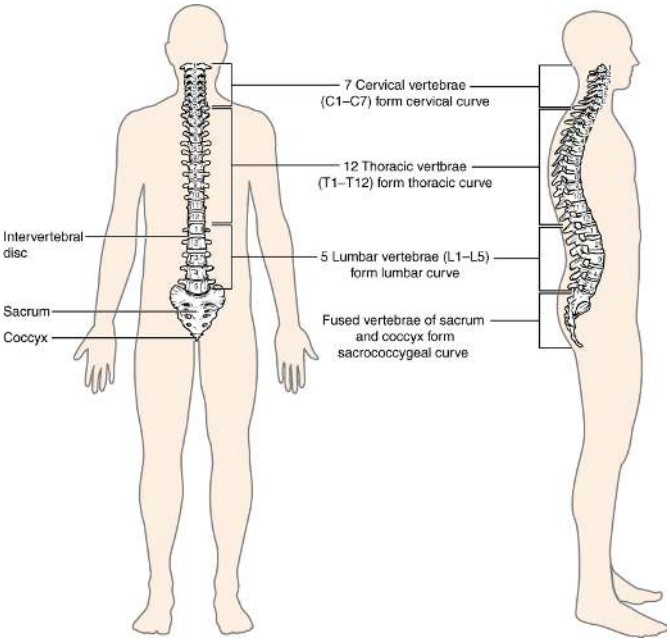


Figure **4.3.5**: The vertebral column consists of 24 individual vertebrae that are separated by intervertebral discs of cartilage. An additional 9 vertebrae are fused together at the base of the spine. Note the S-shaped curve of the vertebral column in the profile view on the right.

The human vertebral column reflects adaptations for upright bipedal locomotion. For example, the vertebral column is less like a rigid column than an S-shaped spring (see a profile view in the figure above). Although newborn infants have a relatively straight spine, the curves develop as the backbone starts taking on its support functions, such as keeping the trunk erect, holding up the head, and helping to anchor the limbs. The S shape of the vertebral column allows it to act as a shock absorber, absorbing much of the jarring of walking and running so the forces are not transmitted directly from the pelvis to the skull. The S shape also helps protect the spine from breaking, which would be more likely with a straight, more rigid vertebral column. In addition, the S shape helps to distribute the weight of the body, and particularly of the internal organs, so the weight load is not all at the bottom, as would occur with a straight spine.

RIB CAGE

The **rib cage** (also called thoracic cage) is aptly named because it forms a sort of cage that holds within it the organs of the upper part of the trunk, including the heart and lungs (Figure **4.3.6**). The rib cage includes the 12 thoracic vertebrae and the breastbone (or sternum) as well as 12 pairs of ribs, which are attached at joints to the vertebrae. The ribs are divided into three groups, called true ribs, false ribs, and floating ribs. The top seven pairs of ribs are true ribs. They are attached by cartilage directly to the sternum. The next three pairs of ribs are false ribs. They are attached by cartilage to the ribs above them, rather than directly to the sternum. The lowest two pairs of ribs are floating ribs. They are attached by cartilage to muscles in the abdominal wall. The attachments of false and floating ribs let the lower part of the rib cage expand to accommodate the internal movements of breathing.

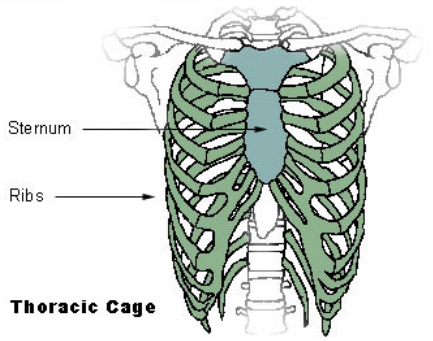


Figure **4.3.6**: The rib cage encloses and protects the thoracic cavity

APPENDICULAR SKELETON

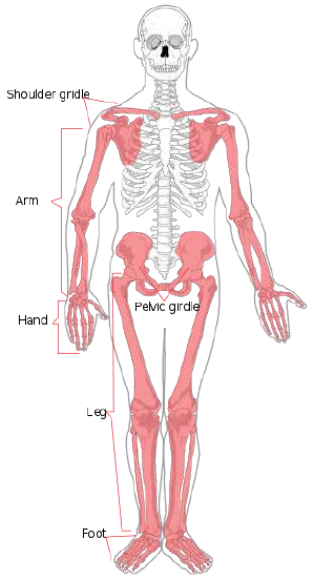


Figure **4.3.7**. The appendicular skeleton (in red) includes the upper and lower appendages and girdles.

The appendicular skeleton, shown in red in Figure **4.3.7**, consists of a total of 126 bones. It includes all the bones of the limbs (arms, legs, hands, and feet) as well as the bones of the shoulder (shoulder girdle) and pelvis (pelvic girdle).

UPPER LIMBS

Each upper limb consists of 30 bones. As shown in Figure **4.3.8**, there is one bone, called the humerus, in each of the upper arms, and there are two bones, called the ulna and radius, in each of the lower arms.

The remaining bones of the upper limb are shown in Figure **4.3.9**. Each wrist contains eight carpal bones, which are arranged in two rows of four bones each; and each hand contains five metacarpal bones. The bones in the fingers of each hand include 14 phalanges (three in each finger except the thumb, which has two phalanges). The thumb has the unique ability to move into opposition with the palm of the hand and with each of the fingers when they are slightly

bent. This allows the hand to handle and manipulate objects such as tools.

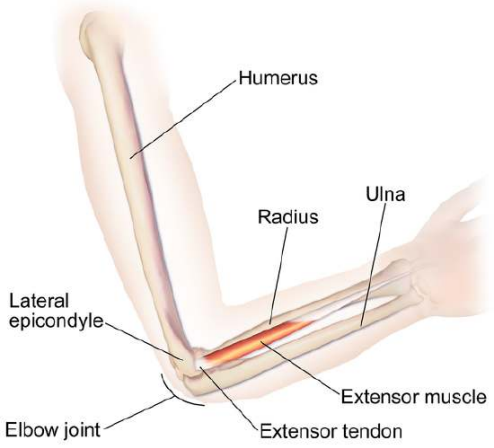


Figure **4.3.8**: In the upper limb, the upper arm contains one bone, Humerus, and the lower arm contains two bone, Ulna and Radius.

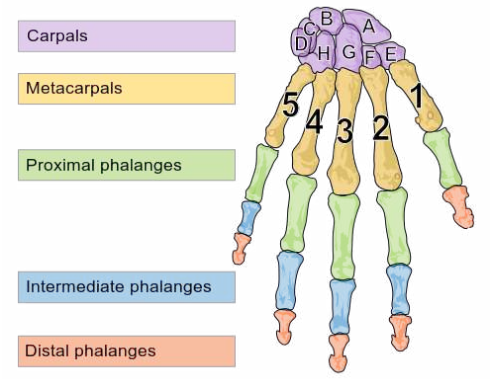


Figure **4.3.9**: Bones of the wrist (carpals A-E) and hand (metacarpals 1-5 and phalanges).

LOWER LIMBS

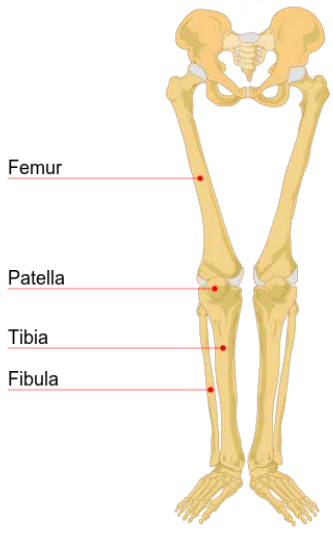


Figure **4.3.10**: Bones of the legs.

Each lower limb consists of 30 bones. As shown in Figure **4.3.10**, there is one bone, called the femur, in each of the upper legs, and there are two bones, called the tibia and fibula, in each of the lower legs. The knee cap, or patella, is an additional leg bone at the front of each knee, which is the largest joint in the human body.

The remaining bones of the lower limbs are shown in Figure **4.3.11**. Each ankle contains seven tarsal bones (including the talus and calcaneus), and each foot contains five metatarsal bones. The tarsals and metatarsals form the ankle, heel, and arch of the foot. They give the foot strength while allowing flexibility. The bones in the toes of each foot consist of 14 phalanges (three in each toe except the big toe, which has two phalanges)

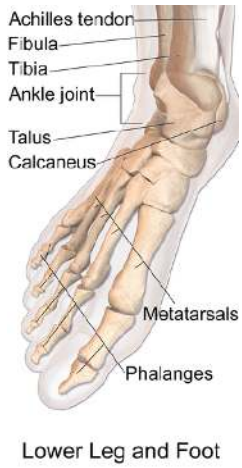


Figure **4.3.11**: Bones of the lower leg (fibula and tibia), ankle (talus), heel (calcaneus), foot (metatarsals), and toes (phalanges).

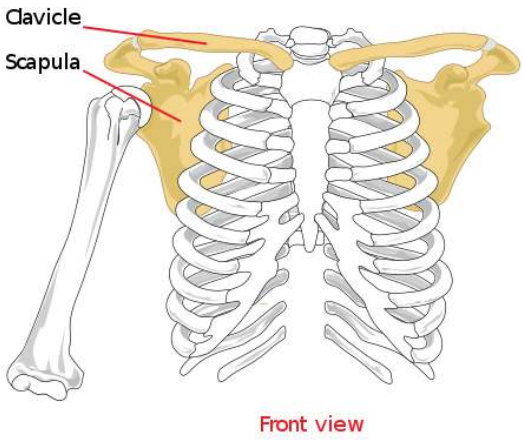


Figure **4.3.12**: Bones of the shoulder girdle are clavicle and scapula.

The pectoral girdle (also called shoulder girdle) attaches the upper limbs to the trunk of the body. Its connection with the axial skeleton is by muscles alone. This allows a considerable range of motion in the upper limbs. The shoulder girdle consists of just two pairs of bones, with one of each pair on opposite sides of the body (Figure **4.3.12**). There is a right and left clavicles (collarbone) and right and left scapulae (shoulder blade). The scapula is a pear-shaped flat bone that helps to form the shoulder joint. The clavicle is a long bone that serves as a strut between the shoulder blade and the sternum.

PELVIC GIRDLE

The **pelvic girdle** attaches the legs to the trunk of the body and also provides a basin to contain and support the organs of the abdomen. It is connected to the vertebral column of the axial skeleton by ligaments. The pelvic girdle consists of two halves, one half for each leg, but the halves are fused with each other in adults at a joint called the pubic symphysis. Each half of the pelvic girdle includes three bones, as shown in the figure below: the ilium (flaring upper part of the pelvic girdle), pubis (lower front), and ischium (lower back). Each of these bones helps form the acetabulum, which is a depression into which the top of the femur (thigh bone) fits. When the body is in a seated position, it rests on protrusions (called tuberosities) of the two ischial bones.

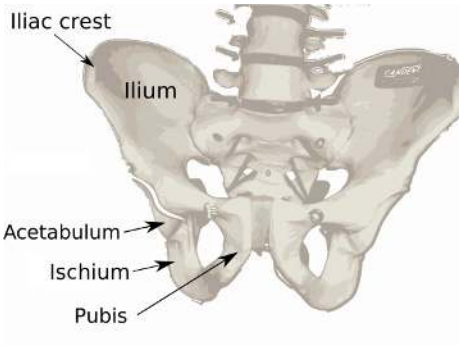


Figure **4.3.13**: Bones of the pelvic girdle.

REVIEW

1. What bones are included in the axial skeleton?
2. Identify the two main parts of the skull. How many bones does each part contain?
3. Describe the vertebral column.
4. What are the advantages of an S-shaped vertebral column?
5. What is the rib cage, and what is its function?
6. What bones are included in the appendicular skeleton?
7. How many bones are found in each upper limb? What are they?
8. Identify the bones in each of the lower limbs.
9. What is the shoulder girdle, and why does it allow considerable upper limb mobility?
10. Describe the pelvic girdle and the bones it contains.
11. *True or False.* False ribs are made of cartilage and are not true rib bones.
12. *True or False.* The jaw contains two maxillae and one mandible.
13. Describe some of the similarities between the upper limbs and the lower limbs.
14. Explain the advantage of having some ribs that are not attached directly to the sternum.
15. Put the following vertebral regions in order, from the closest to the head to the farthest from the head:

    sacral; lumbar; cervical; coccygeal; thoracic

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4.4: STRUCTURE OF BONE

ROASTED BONE MARROW

Do you recognize the food item in the top left of this photo in Figure **4.4.1**? It's roasted bone marrow, still inside the bones. It's considered a delicacy in some cuisines. Marrow is a type of tissue found inside many animal bones, including our own. It's a soft tissue that in adults may be mostly fat. You'll learn more about bone marrow and other tissues that make up bones when you read this concept.



Figure **4.4.1**:Roasted Bone Marrow

Bones are organs that consist primarily of bone tissue, also called osseous tissue. **Bone tissue** is a type of connective tissue consisting mainly of a collagen matrix that is mineralized with calcium and phosphorus crystals. The combination of flexible collagen and hard mineral crystals makes bone tissue hard without making it brittle.

BONE ANATOMY

There are several different types of tissues in bones, including two types of osseous tissues.

TYPES OF OSSEOUS TISSUE

The two different types of osseous tissue are compact bone tissue (also called hard or cortical bone) tissue and spongy bone tissue (also called cancellous or trabecular bone).

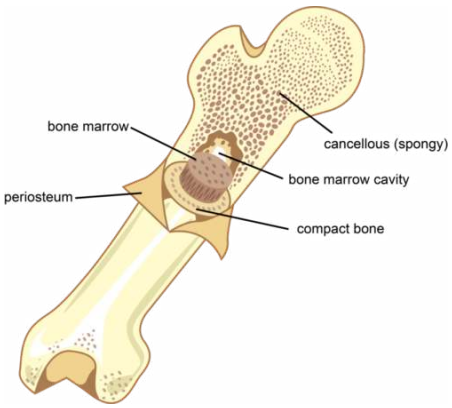


Figure **4.4.2**: Bones are more complex on the inside than you would expect from their outer appearance. There is bone marrow in the hollow part of the long bone. The outer boundary of bone is composed of compact bone tissue, and from the ends, and the rest of the bone interior is composed of cancellous or spongy bone tissue. The bone is covered in connecting tissue called the periosteum.

Compact bone tissue forms the extremely hard outside layer of bones. Cortical bone tissue gives bone its smooth, dense, solid appearance. It accounts for about 80 percent of the total bone mass of the adult skeleton. **Spongy bone tissue** fills part or all of the interior of many bones. As its name suggests, spongy bone is porous like a sponge, containing an irregular network of spaces. This makes spongy bone much less dense than compact bone. Spongy bone has a greater surface area than cortical bone but makes up only 20 percent of bone mass.

Both compact and spongy bone tissues have the same types of cells, but they differ in how the cells are arranged. The cells in the compact bone are arranged in multiple microscopic columns, whereas the cells in the spongy bone are arranged in a looser, more open network. These cellular differences explain why cortical and spongy bone tissues have such different structures.

OTHER TISSUES IN BONES

Besides cortical and spongy bone tissues, bones contain several other tissues, including blood vessels and nerves. In addition, bones contain bone marrow and periosteum. You can see these tissues in Figure **4.4.2**.

- **Bone marrow** is a soft connective tissue that is found inside a cavity, called the marrow cavity. There are two types of marrow in adults, yellow bone marrow, which consists mostly of fat, and red bone marrow. All marrow is red in newborns, but by adulthood, much of the red marrow has changed to yellow marrow. In adults, red marrow is found mainly in the femur, ribs, vertebrae, and pelvic bones. Red bone marrow contains hematopoietic stem cells that give rise to red blood cells, white blood cells, and platelets in the process of hematopoiesis.
- **Periosteum** is a tough, fibrous membrane that covers the outer surface of bones. It provides a protective covering for cortical bone tissue. It is also the source of new bone cells.

BONE CELLS

As shown in Figure **4.4.3**, bone tissues are composed of four different types of bone cells: osteoblasts, osteocytes, osteoclasts, and osteogenic cells.

- **Osteoblasts** are bone cells with a single nucleus that make and mineralize bone matrix. They make a protein mixture that is composed primarily of collagen and creates the organic part of the matrix. They also release calcium and phosphate ions that form mineral crystals within the matrix. In addition, they produce hormones that also play a role in the mineralization of the matrix.
- **Osteocytes** are mainly inactive bone cells that form from osteoblasts that have become entrapped within their own bone matrix. Osteocytes help regulate the formation and breakdown of bone tissue. They have multiple cell projections that are thought to be involved in communication with other bone cells.
- **Osteoclasts** are bone cells with multiple nuclei that resorb bone tissue and break down bone. They dissolve the minerals in bone and release them into the blood.

- **Osteogenic cells** are undifferentiated stem cells. They are the only bone cells that can divide. When they do, they differentiate and develop into osteoblasts.

Bone is a very active tissue. It is constantly remodeled by the work of osteoblasts and osteoclasts. Osteoblasts continuously make new bone, and osteoclasts keep breaking down bone. This allows for minor repair of bones as well as homeostasis of mineral ions in the blood.

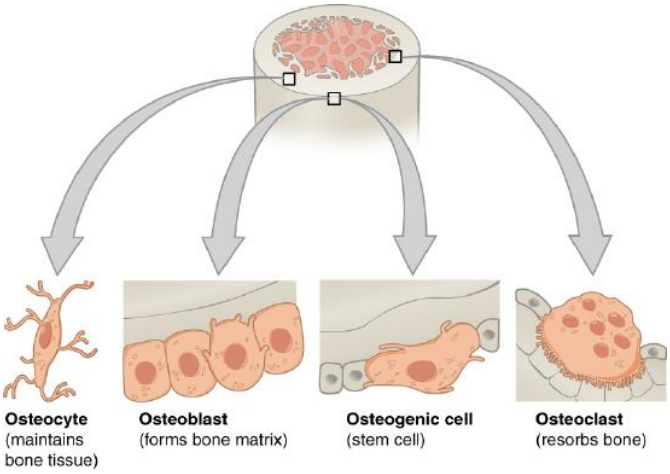


Figure **4.4.3**: Different types of bones cells have different functions.

MICROSCOPIC ANATOMY OF THE COMPACT BONE

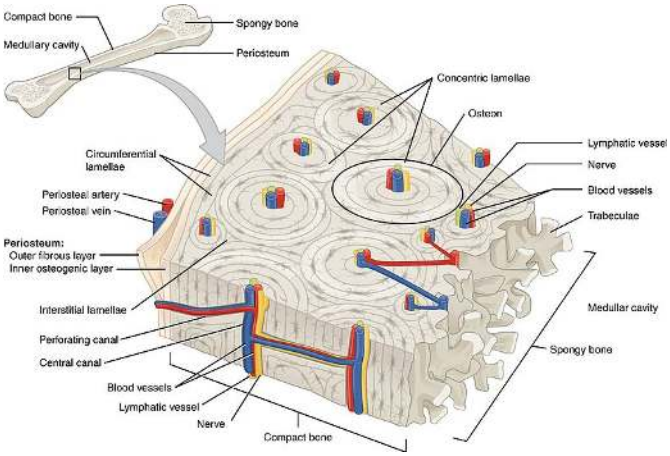


Figure **4.4.4**: Macroscopic and microscopic structures of the compact bone tissue.

The basic microscopic unit of bone is an osteon (or Haversian system). Osteons are roughly cylindrical structures that can measure several millimeters long and around 0.2 mm in diameter. Each osteon consists of lamellae of compact bone tissue that surround a central canal (Haversian canal). The Haversian canal contains the bone's blood supplies. The boundary of an osteon is called the cement line. Osteons can be arranged into woven bone or lamellar bone. Osteoblasts make the matrix of bone which calcifies hardens. This entraps the mature bone cells, osteocytes, in a little chamber called lacunae. The osteocytes receive their nutrition from the central (Haversian) canal via little canals called canaliculi. All of these structures plus more are visible in Figure **4.4.4**.

TYPES OF BONES

There are six types of bones in the human body based on their shape or location: long, short, flat, sesamoid, sutural, and irregular bones. You can see an example of each type of bone in Figure **4.4.5**.

- Long bones are characterized by a shaft that is much longer than it is wide and by a rounded head at each end of the shaft. Long bones are made mostly of compact bone, with lesser amounts of spongy bone and marrow. Most bones of the limbs, including those of the fingers and toes, are long bones.
- Short bones are roughly cube-shaped and have only a thin layer of cortical bone surrounding a spongy bone interior. The bones of the wrists and ankles are short bones.
- Flat bones are thin and generally curved, with two parallel layers of compact bone sandwiching a layer of spongy bone. Most of the bones of the skull are flat bones, as is the sternum (breast bone).
- Sesamoid bones are embedded in tendons, the connective tissues that bind muscles to bones. Sesamoid bones hold tendons farther away from joints so the angle of the tendons is increased, thus increasing the leverage of muscles. The patella (knee cap) is an example of a sesamoid bone.
- Sutural bones are very small bones that are located between the major bones of the skull, within the joints (sutures) between the larger bones. They are not always present.
- Irregular bones are those that do not fit into any of the above categories. They generally consist of thin layers of cortical bone surrounding a spongy bone interior. Their shapes are irregular and complicated. Examples of irregular bones include the vertebrae and the bones of the pelvis.

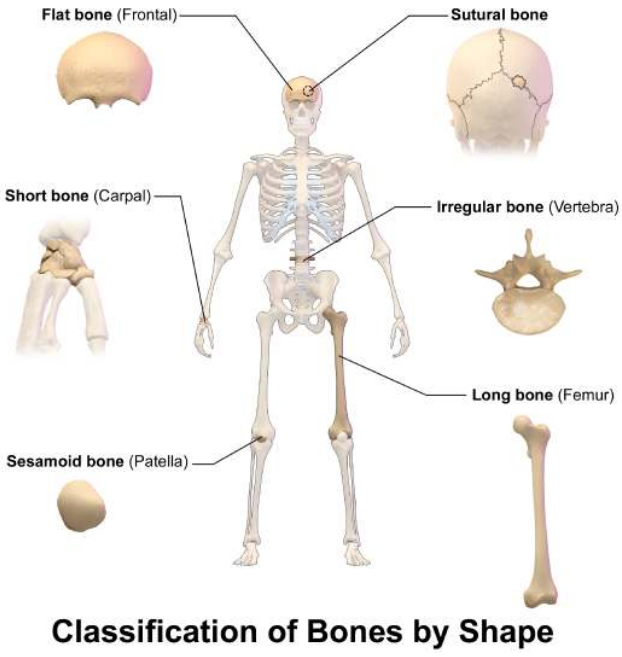


Figure **4.4.5**: six types of bones classified by shape or location.

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FEATURE: RELIABLE SOURCES

Diseased or damaged bone marrow can be replaced by donated bone marrow cells, which help treat and often cure many life-threatening conditions, including leukemia, lymphoma, sickle cell anemia, and thalassemia. If a bone marrow transplant is successful, the new bone marrow will start making healthy blood cells and improve the patient's condition.

Learn more about bone marrow donation, and consider whether you might want to do it yourself. Find reliable sources to answer the following questions:

1. How does one become a potential bone marrow donor?
2. Who can and who cannot donate bone marrow?
3. How is a bone marrow donation made?
4. What risks are there in donating bone marrow?

REVIEW

1. Describe osseous tissue.
2. Why are bones hard but not brittle?
3. Compare and contrast the two main types of osseous tissue.
4. What non-osseous tissues are found in bones?
5. List four types of bone cells and their functions.
6. Identify six types of bones, and give an example of each type.
7. *True or False.* Spongy bone tissue is another name for bone marrow.
8. *True or False.* Periosteum covers osseous tissue.
9. Compare and contrast yellow bone marrow and red bone marrow.
10. Which bone is mostly made of cortical bone tissue?

    A. Pelvis

    B. Vertebrae

    C. Femur

    D. Carpal
11. a. Which type of bone cell divides to produce new bone cells?

    b. Where is this cell type located?
12. Where do osteoblasts and osteocytes come from, and how are they related to each other?
13. Which type of bone is embedded in tendons?
14. *True or False.* Calcium is the only mineral in bones.

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4.5: BONE GROWTH, REMODELING, AND REPAIR

BREAK A LEG

Did you ever break a leg or other bone, like the man looking longingly at the water in this swimming pool? Having a broken bone can really restrict your activity. Bones are very hard, but they will break, or fracture if enough force is applied to them. Fortunately, bones are highly active organs that can repair themselves if they break. Bones can also remodel themselves and grow. You'll learn how bones can do all of these things in this concept.



Figure 4.5.1: Broken leg

BONE GROWTH

Early in the development of a human fetus, the skeleton is made almost entirely of cartilage. The relatively soft cartilage gradually turns into hard bone through ossification. **Ossification** is a process in which bone tissue is created from cartilage. The steps in which bones of the skeleton form from cartilage are illustrated in Figure 4.5.2. The steps include the following:

1. Cartilage "model" of bone forms; this model continues to grow as ossification takes place.
2. Ossification begins at a primary ossification center in the middle of the bone.
3. Ossification then starts to occur at secondary ossification centers at the ends of the bone.
4. The medullary cavity forms and will contain red bone marrow.
5. Areas of ossification meet at epiphyseal plates, and articular cartilage forms. Bone growth ends.

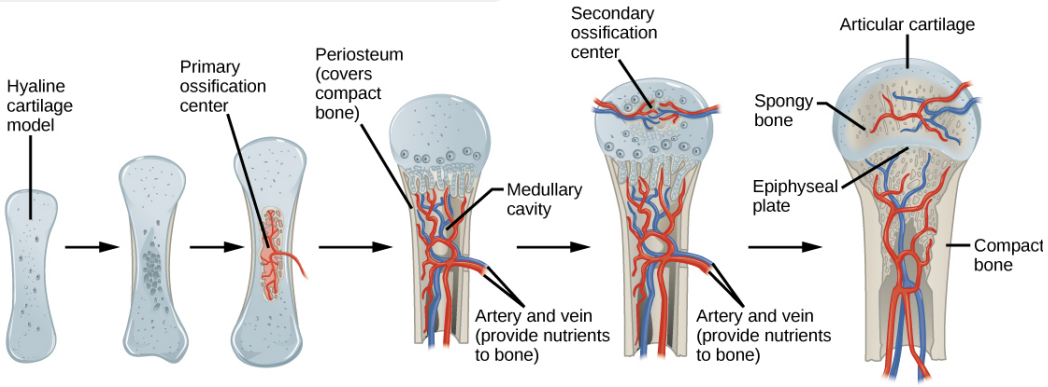


Figure 4.5.2: The ossification of cartilage in the human skeleton is a process that lasts throughout childhood in some bones.

PRIMARY AND SECONDARY OSSIFICATION CENTERS

When bone forms from cartilage, ossification begins with a point in the cartilage called the primary ossification center. This generally appears during fetal development, although a few short bones begin their primary ossification after birth. Ossification occurs toward both ends of the bone from the primary ossification center, and it eventually forms the shaft of the bone in the case of long bones.

Secondary ossification centers form after birth. Ossification from secondary centers eventually forms the ends of the bones. The shaft and ends of the bone are separated by a growing zone of cartilage until the individual reaches skeletal maturity.

SKELETAL MATURITY

Throughout childhood, the cartilage remaining in the skeleton keeps growing and allows for bones to grow in size. However, once all of the cartilage has been replaced by bone and fusion has taken place at epiphyseal plates, bones can no longer keep growing in length. This is the point at which skeletal maturity has been reached. It generally takes place by age 18 to 25.

The use of anabolic steroids by teens can speed up the process of skeletal maturity, resulting in a shorter period of cartilage growth before fusion takes place. This means that teens who use steroids are likely to end up shorter as adults than they would otherwise have been.

BONE REMODELING

Even after skeletal maturity has been attained, bone is constantly being resorbed and replaced with new bone in a process known as **bone remodeling**. In this lifelong process, mature bone tissue is continually turned over, with about 10 percent of the skeletal mass of an adult being remodeled each year. Bone remodeling is carried

out through the work of osteoclasts, which are bone cells that resorb bone and dissolve its minerals; and osteoblasts, which are bone cells that make the new bone matrix.

Bones remodeling serves several functions. It shapes the bones of the skeleton as a child grows, and it repairs tiny flaws in the bone that result from everyday movements. Remodeling also makes bones thicker at points where muscles place the most stress on them. In addition, remodeling helps regulate mineral homeostasis because it either releases minerals from bones into the blood or absorbs minerals from the blood into bones. The figure below shows how osteoclasts in bones are involved in calcium regulation.

The action of osteoblasts and osteoclasts in bone remodeling and calcium homeostasis is controlled by a number of enzymes, hormones, and other substances that either promote or inhibit the activity of the cells. In this way, these substances control the rate at which bone is made, destroyed, and changed in shape. For example, the rate at which osteoclasts resorb bone and release calcium into the blood is promoted by parathyroid hormone (PTH) and inhibited by calcitonin, which is produced by the thyroid gland (Figure **4.5.3**). The rate at which osteoblasts create new bone is stimulated by growth hormone, which is produced by the anterior lobe of the pituitary gland. Thyroid hormone and sex hormones (estrogens and androgens) also stimulate osteoblasts to create new bone.

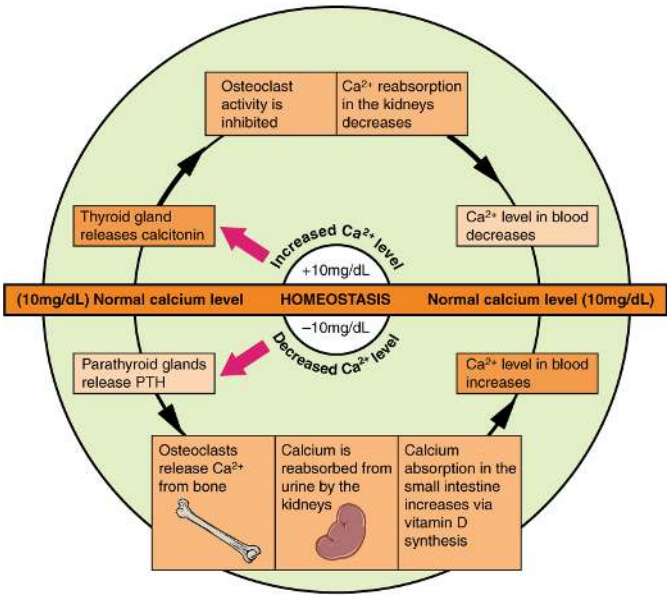


Figure **4.5.3**: Keeping the calcium level in homeostasis includes the work of osteoclasts, the bone cells that resorb bone and release calcium into the blood. If calcium levels increase, the thyroid releases calcitonin which inhibits osteoclast activity. This results in less calcium be reabsorbed in the kidneys which results in the lowering of calcium in the blood. If calcium levels decrease below homeostasis, the parathyroid gland releases PTH. This causes osteoclasts to release calcium from bones and increases calcium absorption in the kidney and small intestines. This brings calcium back to homeostasis.

BONE REPAIR

Bone repair, or healing, is the process in which a bone repairs itself following a bone fracture. You can see an X-ray of bone fracture in Figure **4.5.4**. In this fracture, the humerus in the upper arm has been completely broken through its shaft. Before this fracture heals, a physician must push the displaced bone parts back into their correct positions. Then the bone must be stabilized — for example, with a cast and/or pins surgically inserted into the bone — until the bone's natural healing process is completed. This process may take several weeks.

The process of bone repair is mainly determined by the periosteum, which is the connective tissue membrane covering the bone. The periosteum is the primary source of precursor cells that develop into osteoblasts, which are essential to the healing process. Bones heal as osteoblasts form new bone tissue.

Although bone repair is a natural physiological process, it may be promoted or inhibited by several factors. For example, fracture repair is likely to be more successful with adequate nutrient intake. Age, bone type, drug therapy, and pre-existing bone disease are additional factors that may affect healing. Bones that are weakened by diseases, such as osteoporosis or bone cancer, are not only likely to heal more slowly but are also more likely to fracture in the first place.



Figure **4.5.4**: A bone fracture does not always involve a complete break in the bone, as in this X-ray. Sometimes a fracture is just a crack in the bone. In other cases, the bone not only breaks all the way through, as here but also breaks through the soft tissues around it so it protrudes from the skin. This is called an open fracture.

FEATURE: MYTH VS. REALITY

Bone fractures are fairly common, and there are many myths about them. Knowing the facts is important because fractures generally require emergency medical treatment.

Myth: A bone fracture is a milder injury than a broken bone.

Reality: A bone fracture is the same thing as a broken bone.

Myth: If you still have a full range of motion in a limb, then it must not be fractured.

Reality: Even if a bone is fractured, the muscles and tendons attached to it may still be able to move the bone normally. This

is especially likely if the bone is cracked but not broken into two pieces. Even if a bone is broken all the way through, the range of motion may not be much affected if the bones on either side of the fracture remain properly aligned.

Myth: A fracture always produces a bruise.

Reality: Many but not all fractures produce a bruise. If a fracture does produce a bruise, it may take several hours or even a day or more for the bruise to appear.

Myth: Fractures are so painful that you will immediately know if you break a bone.

Reality: Ligament sprains and muscle strains are also very painful, sometimes more painful than fractures. Additionally, every person has a different pain tolerance. People with high pain tolerance may continue using a broken bone in spite of the pain.

Myth: You can tell when a bone is fractured because there will be very localized pain over the break.

Reality: A broken bone is often accompanied by injuries to surrounding muscles or ligaments. As a result, the pain may extend far beyond the location of the fracture. The pain may be greater directly over the fracture, but the intensity of the pain may make it difficult to pinpoint exactly where the pain originates.

REVIEW

1. Outline how bone develops from early in the fetal stage through the age of skeletal maturity.
2. Describe the process of bone remodeling. When does it occur?
3. What purposes does bone remodeling serve?
4. Define bone repair. How long does this process take?
5. Explain how bone repair occurs.
6. Identify factors that may affect bone repair.
7. Parts of bone that have not yet become ossified are made of _____.
8. If there is a large region between the primary and secondary ossification centers in a bone, is the person young or old? Explain your answer.
9. The region where the primary and secondary ossification centers meet is called the _____.
10. *True or False.* Most bones are made entirely of cartilage at birth.
11. *True or False.* A broken bone is the same as a bone fracture.
12. If bones can repair themselves, why are casts and pins sometimes needed?
13. Which bone cell type causes the release of calcium to the bloodstream when calcium levels are low?
14. Which tissue and bone cell type are mainly involved in bone repair after a fracture?
15. Describe one way in which hormones are involved in bone remodeling.

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4.6: JOINTS

DOUBLE JOINTED?

Is this person double jointed? No; there is no such thing, at least as far as humans are concerned. However, some people, like the individual pictured here, are much more flexible than others, generally because they have looser ligaments. Physicians call the condition joint hypermobility. Regardless of what it's called, the feats of people with highly mobile joints can be quite impressive.



Figure **4.6.1**: Yoga

WHAT ARE JOINTS?

Joints are locations at which bones of the skeleton connect with one another. A joint is also called an articulation. The majority of joints are structured in such a way that they allow movement. However, not all joints allow movement. Of joints that do allow movement, the extent, and direction of the movements they allow also vary.

CLASSIFICATION OF JOINTS

Joints can be classified as structurally or functionally. The structural classification of joints depends on the manner in which the bones connect to each other. The functional classification of joints depends on the nature of the movement the joints allow. There is significant overlap between the two types of classifications because function depends largely on the structure.

STRUCTURAL CLASSIFICATION OF JOINTS

The structural classification of joints is based on the type of tissue that binds the bones to each other at the joint. There are three types of joints in the structural classification: fibrous, cartilaginous, and synovial joints.

1. **Fibrous joints** are joints in which bones are joined by dense connective tissue that is rich in collagen fibers. These joints are also called sutures. The joints between bones of the cranium are fibrous joints.
2. **Cartilaginous joints** are joints in which bones are joined by cartilage. The joints between most of the vertebrae in the spine are cartilaginous joints.
3. **Synovial joints** are characterized by a fluid-filled space, called a synovial cavity, between the bones of the joints. You can see a drawing of a typical synovial joint in Figure **4.6.2**. The cavity is enclosed by a membrane and filled with a fluid, called the synovial fluid, which provides extra cushioning to the ends of the bones. Cartilage covers the articulating surfaces of the two bones, but the bones are actually held together by ligaments. The knee is a synovial joint.

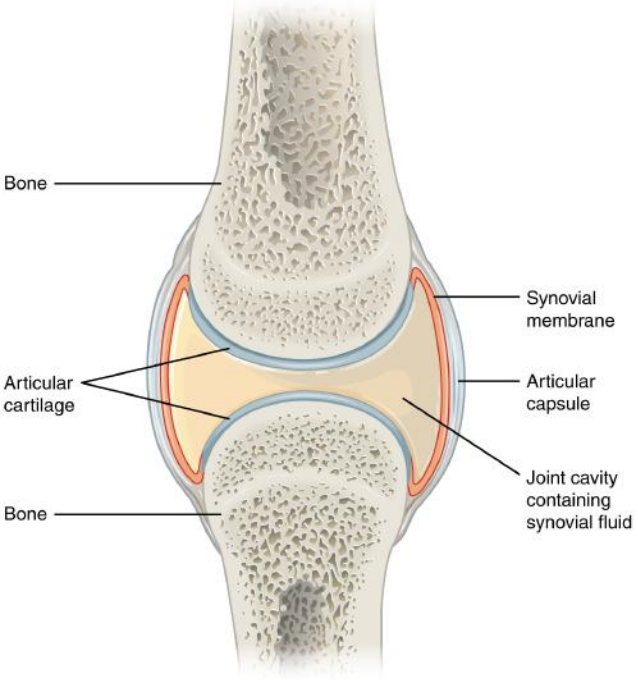


Figure **4.6.2**: The synovial membrane, articular capsule, joint cavity with synovial fluid, articular cartilage, and bone ends are the main components of a typical synovial joint.

FUNCTIONAL CLASSIFICATION OF JOINTS

The functional classification of joints is based on the type and degree of movement that they allow. There are three types of joints in the functional classification: immovable, partly movable, and movable joints.

1. Immovable joints allow little or no movement at the joint. Most immovable joints are fibrous joints. Besides the bones of the cranium, immovable joints include joints between the tibia and fibula in the lower leg and between the radius and ulna in the lower arm.
2. Partly movable joints permit slight movement. Most partly movable joints are cartilaginous joints. Besides the joints between vertebrae, they include the joints between the ribs and sternum (breast bone).
3. Movable joints allow bones to move freely. All movable joints are synovial joints. Besides the knee, they include the shoulder, hip, and elbow. Movable joints are the most common type of joints in the body.

TYPES OF MOVABLE JOINTS

Movable joints can be classified further according to the type of movement they allow. There are six classes of movable joints: pivot, hinge, saddle, plane, condyloid, and ball-and-socket joints. An example of each class, as well as the type of movement it allows, is shown in Figure **4.6.3**.

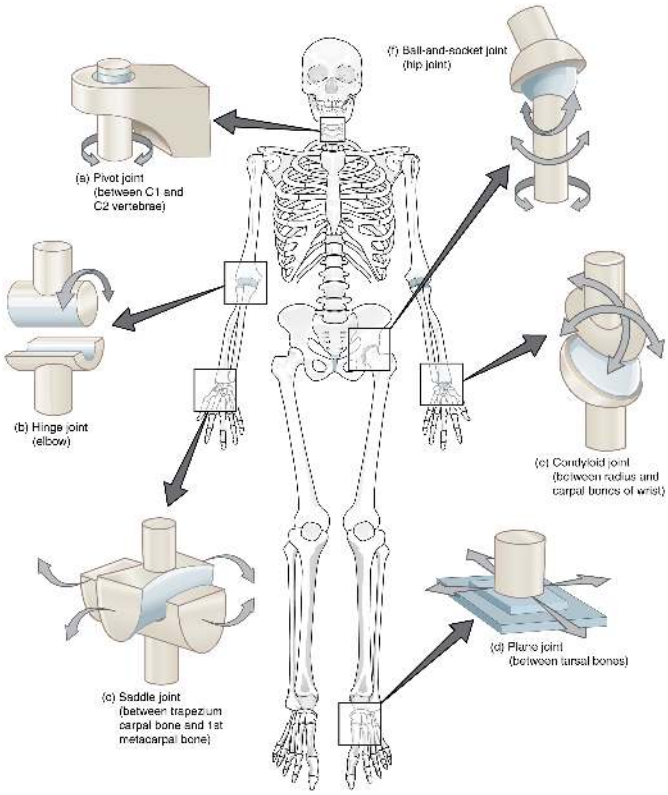


Figure **4.6.3**: This diagram shows the six classes of movable joints in the human body. All of these joints are synovial joints.

- A pivot joint allows one bone to rotate around another. An example of a pivot joint is the joint between the first two vertebrae in the spine. This joint allows the head to rotate from left to right and back again.
- A hinge joint allows back and forth movement like the hinge of a door. An example of a hinge joint is the elbow. This joint allows the arm to bend back and forth.
- A saddle joint allows two different types of movement. An example of a saddle joint is the joint between the first metacarpal bone in the hand and one of the carpal bones in the wrist. This joint allows the thumb to move toward and away from the index finger and also to cross over the palm toward the little finger.
- A plane joint also called a gliding joint, allows two bones that glide over one another. The joints between the tarsals in the ankles and between the carpals in the wrists are mainly gliding joints. In the wrist, this type of joint allows the hand to bend upward at the wrist and also to wave from side to side while the lower arm is held steady.
- A condyloid joint is one in which an oval-shaped head on one bone moves in an elliptical cavity in another bone, allowing movement in all directions except rotation around an axis. The joint between the radius in the lower arm and carpal bones of the wrist is a condyloid joint as is the joint at the base of the index finger.
- A ball-and-socket joint allows the greatest range of movement of any movable joint. It allows forward and backward as well as upward and downward motions. It also allows rotation in a circle. The hip and shoulder are the only two ball-and-socket joints in the human body.

FEATURE: MY HUMAN BODY

Of all the parts of the skeletal system, the joints are generally the most fragile and subject to damage. If the cartilage that cushions bones at joints wears away, it does not grow back. Eventually, all of the cartilage may wear away. This is the cause of osteoarthritis, which can be both painful and debilitating. In serious cases, people may lose the ability to climb stairs, walk long distances, perform routine daily activities, or participate in activities they love such as gardening or playing sports. If you protect your joints, you can reduce your chances of joint damage, pain, and disability. If you already have joint damage, it is equally important to protect your joints and limit further damage. Follow these five tips:

1. Maintain a normal, healthy weight. The higher your weight is, the more force you exert on your joints. When you walk, each knee has to bear a force equal to as much as six times your body weight. If a person weighs 200 pounds, each knee bears more than half a ton of weight with every step. Seven in ten knee replacement surgeries for osteoarthritis can be attributed to obesity.
2. Avoid too much high-impact exercise. Examples of high-impact activities include volleyball, basketball, and tennis. These activities generally involve running or jumping on hard surfaces, which puts tremendous stress on weight-bearing joints, especially the knees. Replace some or all of your high-impact activities with low-impact activities, such as biking, swimming, yoga, or lifting light weights.
3. Reduce your risk of injury. Don't be a weekend warrior, sitting at a desk all week and then crowding all your physical activity into two days. Get involved in a regular, daily exercise routine that keeps your body fit and your muscles toned. Building up muscles will make your joints more stable and spread stress across them. Be sure to do some stretching every day to keep the muscles around joints flexible and less prone to injury.
4. Distribute work over your body, and use your largest, strongest joints. Use your shoulder, elbow, and wrist to lift heavy objects, not just your fingers. Hold small items in the palm of your hand, rather than by the fingers. Carry heavy items in a backpack rather than in your hands. Hold weighty objects close to your body rather than at arms' length. Lift with your hips and knees, not your back.
5. Respect pain. If it hurts, stop doing it. Take a break from the activity at least until the pain stops. Try to use joints only to the point of mild fatigue, not pain.

REVIEW

1. What are the joints?
2. What are the two ways that joints are commonly classified?

3. How are joints classified structurally?
4. Describe the functional classification of joints.
5. How are movable joints classified?
6. Name the six classes of movable joints, and describe how they move.
7. Give an example of a joint in each of the classes of movable joints.
8. *True or False.* The skull is one smooth bone and has no joints.
9. *True or False.* A plane joint is a type of synovial joint.
10. Which specific type of moveable joint do you think your knee joint is? Explain your reasoning.
11. Explain the difference between cartilage in a cartilaginous joint and cartilage in a synovial joint.
12. Why are fibrous joints immovable?
13. Which type of joint has ligaments?

    A. Ball-and-socket
    B. Fibrous
    C. Cartilaginous
    D. None of the above

14. Which type of joint allows for the greatest range of motion?
15. What is the function of synovial fluid?

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4.7: DISORDERS OF THE SKELETAL SYSTEM

DOWAGER'S HUMP

The individual on the right in Figure **4.7.1** has a deformity in her back commonly called dowager's hump because it occurs most often in elderly women. Its medical name is kyphosis, and it is defined as excessive curvature of the spinal column in the thoracic region. The curvature generally results from fractures of thoracic vertebrae. As the inset drawings suggest, these fractures may occur due to a significant decrease in bone mass, which is called osteoporosis. Osteoporosis is one of the most prevalent disorders of the skeletal system.



Figure **4.7.1**: Kyphosis

COMMON SKELETAL SYSTEM DISORDERS

A number of disorders affect the skeletal system, including bone fractures and bone cancers. However, the two most common disorders of the skeletal system are osteoporosis and osteoarthritis. At least ten million people in the United States have osteoporosis, and more than 8 million of them are women. Osteoarthritis is even more common, affecting almost 30 million people in the United States. Because osteoporosis and osteoarthritis are so common, they are the focus of this concept. These two disorders are also good examples to illustrate the structure and function of the skeletal system.

OSTEOPOROSIS

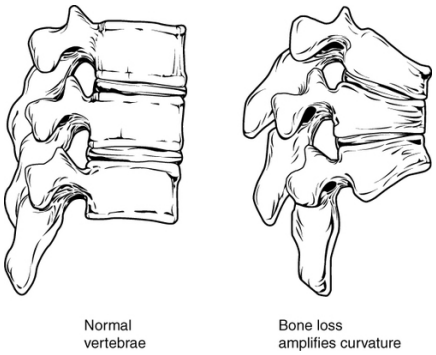


Figure **4.7.2**: Compression fractures of thoracic vertebrae are relatively common in people with osteoporosis.

Osteoporosis is an age-related disorder in which bones lose mass, weaken, and break more easily than normal bones. Bones may weaken so much that a fracture can occur with minor stress — or even spontaneously, without any stress at all. Osteoporosis is the most common cause of broken bones in the elderly, but until a bone fracture occurs, it typically causes no symptoms. The bones that break most often include those in the wrist, hip, shoulder, and spine. When the thoracic vertebrae are affected, there can be a gradual collapse of the vertebrae due to compression fractures, as shown in Figure **4.7.2**. This is what causes kyphosis, as pictured in Figure **4.7.1**.

CHANGES IN BONE MASS WITH AGE

As shown in the graph below, bone mass in both males and females generally peaks when people are in their thirties. Bone mass usually decreases after that, and this tends to occur more rapidly in individuals with XX chromosomes, especially after menopause. This is generally attributable to low levels of estrogen in the post-menopausal years.

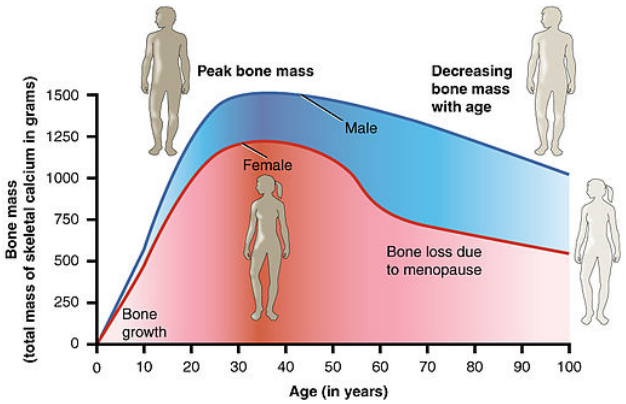


Figure **4.7.3**: Bone mass is a measure of the total mass of calcium in the bones of the skeleton. The chart shows that the bone mass peaks around age 30 in males and females. Then it starts to decrease.

WHAT CAUSES OSTEOPOROSIS?

Osteoporosis is due to an imbalance between bone formation by osteoblasts and bone resorption by osteoclasts. Normally, bones are constantly being remodeled by these two processes, with up to ten percent of all bone mass undergoing remodeling at any point in time. If these two processes are in balance, no net loss of bone occurs. There are three main ways that an imbalance between bone formation and bone resorption can occur and lead to a net loss of bone.

1. **An individual never develops normal peak bone mass during the young adult years:** If the peak level is lower than normal, then there is less bone mass, to begin with, making osteoporosis more likely to develop.
2. **There is greater than normal bone resorption:** Bone resorption normally increases after peak bone mass is reached, but age-related bone resorption may be greater than normal for a variety of reasons. One possible reason is calcium or vitamin D

deficiency, which causes the parathyroid gland to release PTH, the hormone that promotes resorption by osteoclasts.

3. **There is the inadequate formation of new bone by osteoblasts during remodeling:** Lack of estrogen may decrease the normal deposition of new bone. Inadequate levels of calcium and vitamin D also lead to the impaired bone formation by osteoblasts.

An imbalance between bone building and bone destruction leading to bone loss may also occur as a side effect of other disorders. For example, people with alcoholism, anorexia nervosa, or hyperthyroidism have an increased rate of bone loss. Some medications — including anti-seizure medications, chemotherapy drugs, steroid medications, and some antidepressants — also increase the rate of bone loss.

OSTEOPOROTIC FRACTURES

Fractures are the most dangerous aspect of osteoporosis, and osteoporosis is responsible for millions of fractures annually. Debilitating pain among the elderly is often caused by fractures from osteoporosis, and it can lead to further disability and early mortality. Fractures of the long bones (such as the femur) can impair mobility and may require surgery. A hip fracture usually requires immediate surgery, as well. The immobility associated with fractures — especially of the hip — increases the risk of deep vein thrombosis, pulmonary embolism, and pneumonia. Osteoporosis is rarely fatal, but these complications of fractures often are. Older people tend to have more falls than younger people, due to such factors as poor eyesight and balance problems, increasing their risk of fractures even more. The likelihood of falls can be reduced by removing obstacles and loose carpets or rugs in the living environment.

RISK FACTORS FOR OSTEOPOROSIS

There are a number of factors that increase the risk of osteoporosis. Eleven of them are listed below. The first five factors cannot be controlled, but the remaining factors generally can be controlled by changing behaviors.

1. older age
2. XX chromosome
3. European or Asian ancestry
4. family history of osteoporosis
5. short stature and small bones
6. smoking
7. alcohol consumption
8. lack of exercise
9. vitamin D deficiency
10. poor nutrition
11. consumption of soft drinks

TREATMENT AND PREVENTION OF OSTEOPOROSIS

Osteoporosis is often treated with medications that may slow or even reverse bone loss. Medications called bisphosphonates, for example, are commonly prescribed. Bisphosphonates slow down the breakdown of bone, allowing bone rebuilding during remodeling to keep pace. This helps maintain bone density and decreases the risk of fractures. The medications may be more effective in patients who have already broken bones than in those who have not, significantly reducing their risk of another fracture. Generally, patients are not recommended to stay on bisphosphonates for more than three or four years. There is no evidence for continued benefit after this time — in fact, there is a potential for adverse side effects.



Figure **4.7.4**: Hiking is an enjoyable way to help keep bones strong and reduce the risk of osteoporosis.

Preventing osteoporosis includes eliminating any risk factors that can be controlled through changes of behavior. If you smoke, stop. If you drink, reduce your alcohol consumption — or cut it out altogether. Eat a nutritious diet and make sure you are getting adequate amounts of vitamin D. You should also avoid drinking carbonated beverages.

If you're a couch potato, get involved in regular exercise. Aerobic, weight-bearing and resistance exercises can all help maintain or increase bone mineral density. Exercise puts stress on bones, which stimulates bone building. Good weight-bearing exercises for bone-building include weight training, dancing, stair climbing, running, and hiking (Figure **4.7.4**). Biking and swimming are less beneficial because they don't stress the bones. Ideally, you should exercise for at least 30 minutes a day on most days of the week.

OSTEOARTHRITIS

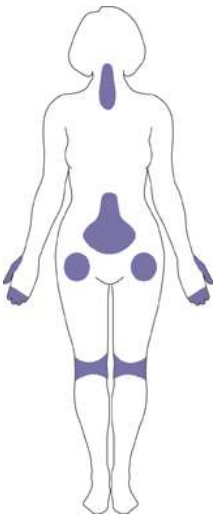


Figure **4.7.5**: The areas shaded in blue indicate the joints most commonly affected by OA.

Osteoarthritis (OA) is a joint disease that results from the breakdown of joint cartilage and bone. The most common symptoms are joint pain and stiffness. Other symptoms may include joint swelling and decreased range of motion. Initially, symptoms may

occur only after exercise or prolonged activity, but over time, they may become constant, negatively affecting work and normal daily activities. As shown in Figure **4.7.5**, the most commonly involved joints are those near the ends of the fingers, at the bases of the thumbs, and in the neck, lower back, hips, and knees. Often, joints on one side of the body are affected more than those on the other side.

WHAT CAUSES OSTEOARTHRITIS?

OA is thought to be caused by mechanical stress on the joints with insufficient self-repair of cartilage. The stress may be exacerbated by low-grade inflammation of the joints, as cells lining the joint attempt to remove breakdown products from cartilage in the synovial space. OA develops over decades as stress and inflammation cause an increasing loss of articular cartilage. Eventually, bones may have no cartilage to separate them, so bones rub against one another at joints. This damages the articular surfaces of the bones and contributes to the pain and other symptoms of OA. Because of the pain, movement may be curtailed, leading to loss of muscle, as well.

DIAGNOSING OSTEOARTHRITIS

Diagnosis of OA is typically made on the basis of signs and symptoms. Signs include joint deformities, such as bony nodules on the finger joints or bunions on the feet (Figure **4.7.6**). Symptoms include joint pain and stiffness. The pain is usually described as a sharp ache or burning sensation, which may be in the muscles and tendons around the affected joints, as well as in the joints themselves. The pain is usually made worse by prolonged activity, and it typically improves with rest. Stiffness is most common when first arising in the morning, and it usually improves quickly as daily activities are undertaken.



Figure **4.7.6**. A bunion is a common sign of osteoarthritis. It is typically located at the base of the big toe.

X-rays or other tests are sometimes used to either support the diagnosis of OA or to rule out other disorders. Blood tests might be done, for example, to look for factors that indicate rheumatoid arthritis (RA), an autoimmune disease in which the immune system attacks the body's joints. If these factors are not present in the blood, then RA is unlikely, and a diagnosis of OA is more likely to be correct.

RISK FACTORS FOR OSTEOARTHRITIS

Age is the chief risk factor for osteoarthritis. By age 65, as many as 80 percent of all people have evidence of osteoarthritis. However, people are more likely to develop OA — especially at younger ages — if they have had a joint injury. A high school football player might have a bad knee injury that damages the joint, leading to OA in the knee by the time he is in his thirties. If people have joints that are misaligned due to congenital malformations or disease, they are also more likely to develop OA. Excess body weight is another factor that increases the risk of OA, because of the added stress it places on weight-bearing joints.

Researchers have found that people with a family history of OA have a heightened risk of developing the disorder, which suggests that genetic factors are also involved in OA. It is likely that many different genes are needed for normal cartilage and cartilage repair. If such genes are defective and cartilage is abnormal or not normally repaired, OA is more likely to result.

TREATMENT AND PREVENTION OF OSTEOARTHRITIS

OA cannot be cured, but the symptoms — especially the pain — can often be treated successfully to maintain a good quality of life for people with OA. Treatments include exercise, efforts to decrease stress on joints, pain medications, and surgery.

DESTRESSING JOINTS

Efforts to decrease stress on joints include resting and using mobility devices such as canes, which reduce the weight placed on weight-bearing joints and also improve stability. In people who are overweight, losing weight may also reduce joint stress.

EXERCISE

Exercise helps maintain joint mobility and also increases muscle strength. Stronger muscles may help keep the bones in joints correctly aligned, and this can reduce joint stress. Good exercises for OA include swimming, water aerobics (see Figure **4.7.7**), and biking. These activities are recommended for OA because they put relatively little stress on the joints.



Figure **4.7.7**: Exercising in water provides buoyancy that places less stress on joints than the same exercises would on the ground or other hard surfaces.

PAIN MEDICATIONS

The first type of pain medication likely to be prescribed for OA is acetaminophen (e.g., Tylenol). When taken as prescribed, it has a relatively low risk of serious side effects. If this medication is inadequate to relieve the pain, non-steroidal anti-inflammatory drugs (NSAIDs, such as ibuprofen) may be prescribed. NSAIDs, however, are more likely to cause serious side effects, such as gastrointestinal bleeding, elevated blood pressure, and increased risk of stroke. Opioids usually are reserved for patients who have suffered serious side effects or for whom other medications have failed to relieve pain. Due to the risk of addiction, the short-term use of opioids is generally recommended.

SURGERY

Joint replacement surgery is the most common treatment for serious OA in the knee or hip. In fact, knee and hip replacement surgeries are among the most common of all surgeries. Although they require a long period of healing and physical rehabilitation, the results are usually worth it. The replacement "parts" are usually pain-free and fully functional for at least a couple of decades. Quality, durability, and customization of artificial joints are constantly improving.

FEATURE: MYTH VS. REALITY

About one out of every two Americans will develop osteoarthritis in his or her lifetime. The more you know about this disease, the more you can do to avoid it or slow its progression. That means knowing the facts, rather than believing the myths about osteoarthritis.

Myth: Cracking my knuckles will cause osteoarthritis.

Reality: Cracking your knuckles may lead to inflammation of your tendons, but it will not cause osteoarthritis.

Myth: My diet has no effect on my joints.

Reality: What and how much you eat *does* affect your body weight, and every pound you gain translates into an additional four pounds (or more!) of stress on your knees. Being overweight, therefore, increases the chances of developing osteoarthritis — and also the rate at which it progresses.

Myth: Exercise causes osteoarthritis or makes it worse, so I should avoid it.

Reality: This is one of the biggest myths about osteoarthritis. Low-impact exercise can actually lessen the pain and improve other symptoms of osteoarthritis. If you don't have osteoarthritis, exercise can reduce your risk of developing it. Low-impact exercise helps keep the muscles around joints strong and flexible, so they can help stabilize and protect the joints.

Myth: If my mom or dad has osteoarthritis, I will also develop it.

Reality: It is true that you are more likely to develop osteoarthritis if a parent has it, but it isn't a sure thing. There are several things you can do to decrease your risk, such as getting regular exercise and maintaining a healthy weight.

Myth: Bad weather causes osteoarthritis.

Reality: Weather conditions do not cause osteoarthritis, although, in some people who already have osteoarthritis, bad weather seems to make the symptoms worse. It is primarily low barometric pressure that increases osteoarthritis pain, probably because it leads to greater pressure inside the joints relative to the outside air pressure. Some people think their osteoarthritis pain is worse in cold weather, but systematic studies have not found convincing evidence for this.

Myth: Joint pain is unavoidable as you get older, so there is no need to see a doctor for it.

Reality: Many people with osteoarthritis think there is nothing that can be done for the pain of osteoarthritis, or that surgery is the only treatment option. In reality, osteoarthritis symptoms often can be improved with a combination of exercise, weight loss, pain management techniques, and pain medications. If osteoarthritis pain interferes with daily life and lasts more than a few days, you should see your doctor.

Myth: Osteoarthritis is inevitable in seniors.

Reality: Although many people over 65 develop osteoarthritis, there are many people who never develop it, no matter how old they live to be. You can reduce your risk of developing osteoarthritis in later life by protecting your joints throughout life.

REVIEW

1. Name the two most common disorders of the skeletal system.
2. What is osteoporosis? What causes it?
3. How is osteoporosis diagnosed?
4. Why is osteoporosis dangerous?
5. Identify risk factors for osteoporosis.
6. How is osteoporosis treated? What can be done to prevent it?
7. What is OA? What are its chief symptoms?
8. What causes OA?
9. Describe how OA is diagnosed.
10. Identify risk factors for OA.
11. How is OA treated?
12. Why is it important to build sufficient bone mass in your young adult years?
13. Explain the difference in the cause of rheumatoid arthritis and osteoarthritis.
14. *True or False:* Osteoarthritis is caused by physical activity, so people who are equally active are equally susceptible to it.
15. *True or False:* Estrogen generally promotes the production of new bone.

EXPLORE MORE

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ATTRIBUTIONS

1. Osteoporosis by Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. licensed CC BY 3.0 via Wikimedia Commons
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4.8: CASE STUDY CONCLUSION- HEELS AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: A PAIN IN THE FOOT

You may have seen signs such as the one in Figure **4.8.1** indicating that high-heeled shoes are not allowed on certain walking surfaces because of the risk of injury. High heels affect a person's balance, and wearers can easily twist their ankle on uneven or slippery surfaces, causing a sprain or even a fracture. Besides twisting an ankle, wearing high heels on a regular basis can cause a variety of other negative health consequences—some of which may be long-lasting.



Figure **4.8.1**: No heels

As Amari discovered at the beginning of the chapter, wearing high heels can result in a condition called metatarsalgia. Metatarsalgia is named for the metatarsal bones, which are the five bones that run through the ball of the foot just behind the toes (highlighted in Figure **4.8.2**) Wearing high heels causes excessive pressure on the ball of the foot, as described at the beginning of this chapter. Additionally, the toes are forced to pull upwards in high heels, which moves the fleshy padding away from the ball of the foot, adding to the overall pressure placed on this region. Over time, this can cause inflammation and direct stress on the bones, resulting in pain in the ball of the foot known as metatarsalgia. The pain particularly occurs in weight-bearing positions such as standing, walking, or running—which is what Amari was experiencing. There may also be pain, numbness, or tingling in the toes associated with metatarsalgia.

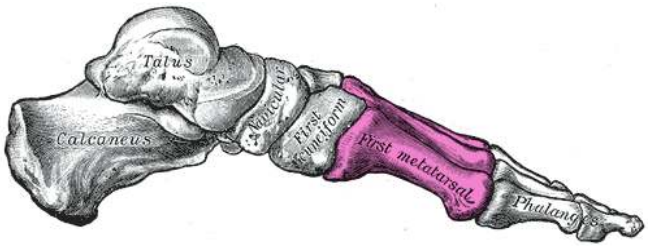


Figure **4.8.2**: Illustration of the bones of the foot, with the metatarsal bones highlighted in pink.

Wearing high heels can also cause stress fractures in the feet, which are tiny breaks in the bone that occur due to repeated mechanical stress. This is due to the excessive pressure that high heels put on some of the bones of the feet. These fractures are somewhat similar to what occurs in osteoporosis when the bone mass decreases to the point where bones can fracture easily as people go about their daily activities. In both cases, a major, noticeable injury is not necessary to create tiny fractures. As you have learned, tiny fractures that accrue over time are the cause of dowager's hump, or kyphosis, which is often seen in women with osteoporosis.

Don't think you are immune to stress fractures just because you don't wear high heels! This injury also commonly occurs in people who participate in sports that involve repetitive striking of the foot on the ground, such as running, tennis, basketball, or gymnastics. Stress fractures may be avoided by taking preventative measures such as ramping up any increase in activity slowly, cross-training by engaging in a variety of different sports or activities, resting if you experience pain, and wearing well-cushioned and supportive running shoes.

Amari learned through their online research that wearing high heels can also lead to foot deformities such as bunions and hammertoes. As you saw in the section *Disorders of the Skeletal System*, a bunion is a protrusion on the side of the foot, most often at the base of the big toe. It can be caused by wearing shoes with a narrow, pointed toe box — a common shape for high heels (see Figure **4.8.3**). The pressure of the shoes on the side of the foot causes an enlargement of bone or inflammation of other tissues in the region, which pushes the big toe towards the other toes.



Figure **4.8.3**: High heels with a narrow, pointed toe box and thin stiletto heels.

Hammertoes are abnormal bend in the middle joint of the second, third, or fourth toe (with the big toe being the first toe), causing the toe to be shaped similar to a hammer as seen in Figure **4.8.4**. The narrow, pointed toe box of many high heels, combined with the way the toes are squished into the front of the shoe as a result of the height of the heel, can cause the toes to become deformed in this manner. Treatments for bunions and hammertoe include wearing shoes with a roomy toe box, padding or taping the toes, and toe exercises and stretches. If the bunion or hammertoe does not respond to these treatments, surgery may be necessary to correct the deformity.



Figure **4.8.4**: X-ray of a hammer toe.

Because the bones of the skeleton are connected and work together with other systems to support the body, wearing high heels can also cause physical problems in areas other than the feet. Wearing high heels shifts a person's posture and alignment and can put a strain on tendons, muscles, and other joints in the body. For instance, research from a team at Stanford University published in 2014 suggests that wearing high heels, particularly if the person is overweight or the heels are very high, may increase the risk of osteoarthritis (OA) in the knee due to added stress on the knee joint as the person walks. As you have learned, OA results from the breakdown of cartilage and bone at the joint. Because it can only be treated to minimize symptoms, not cured, OA could be an unfortunate long-term consequence of wearing high heels.

Amari has decided that wearing high heels regularly is not worth the pain and potential long-term damage to their body. After consulting with their doctor, who confirmed they have metatarsalgia, Amari was able to successfully treat it with ice, rest, and wearing comfortable, supportive shoes instead of heels.

High heels are not the only kind of shoes that can cause problems. Flip-flops, worn-out sneakers, and shoes that are too tight can all cause foot issues. To prevent future problems from shoe choices, Amari is following guidelines recommended by medical experts, which include:

- Wearing shoes that fit well, have plenty of room in the toe box, are supportive, and are comfortable right away. There should be no "break-in" period needed for shoes.
- Avoiding shoes that have high heels, especially ones over two inches in height; narrow, pointed toe boxes; or very thin heels. The shoes in Figure **4.8.3** are an example of a type that should be avoided!
- If high heels must be worn, they should be worn for only a limited period of time.

As you have learned in this chapter, your skeletal system carries out a variety of important functions in your body, including physical support. But even though it is strong, your skeletal system can become damaged and deformed—even through such a seemingly innocuous act as wearing a certain type of shoe. Taking good care of your skeletal system is necessary to help it continue to take good care of the rest of you.

CHAPTER SUMMARY

In this chapter, you learned about the skeletal system. Specifically, you learned that:

- The skeletal system is the organ system that provides an internal framework for the human body. In adults, the skeletal system contains 206 bones.
- Bones are organs made of dense connective tissues, mainly the tough protein collagen. Bones also contain blood vessels, nerves, and other tissues. Bones are hard and rigid due to deposits of calcium and other mineral salts within their living tissues. Besides bones, the skeletal system includes cartilage and ligaments.
- The skeletal system has many different functions, including supporting the body and giving it shape, protecting internal organs, providing attachment surfaces for skeletal muscles, allowing body movements, producing blood cells, storing minerals, helping to maintain mineral homeostasis, and producing endocrine hormones.
- The skeleton is traditionally divided into two major parts: the axial skeleton and the appendicular skeleton.
- The axial skeleton consists of a total of 80 bones. It includes the skull, vertebral column, and rib cage. It also includes the three tiny ossicles in the middle ear and the hyoid bone in the throat.
    - The skull provides a bony framework for the head. It consists of 22 different bones: eight in the cranium, which encloses the brain, and 14 in the face, which includes the upper and lower jaw.
    - The vertebral column is a flexible, S-shaped column of 33 vertebrae that connects the trunk with the skull and encloses the spinal cord. The vertebrae are divided into five regions: cervical, thoracic, lumbar, sacral, and coccygeal regions. The S shape of the vertebral column allows it to absorb shocks and distribute the weight of the body.
    - The rib cage holds and protects the organs of the upper part of the trunk, including the heart and lungs. It includes the 12 thoracic vertebrae, the sternum, and 12 pairs of ribs.
- The appendicular skeleton consists of a total of 126 bones. It includes the bones of the four limbs, shoulder girdle, and pelvic girdle. The girdles attach the appendages to the axial skeleton.
    - Each upper limb consists of 30 bones. There is one bone, called the humerus, in the upper arm, and two bones, called the ulna and radius, in the lower arm. The wrist contains eight carpal bones, the hand contains five metacarpals, and the fingers consist of 14 phalanges. The thumb is opposable to the palm and fingers of the same hand.
    - Each lower limb also consists of 30 bones. There is one bone, called the femur, in the upper leg, and two bones, called the tibia and fibula, in the lower leg. The patella covers the knee joint. The ankle contains seven tarsal bones, and the foot contains five metatarsals. The tarsals and metatarsals form the heel and arch of the foot. The bones in the toes consist of 14 phalanges.

- The shoulder girdle attaches the upper limbs to the trunk of the body. It is connected to the axial skeleton only by muscles, allowing mobility of the upper limbs. Bones of the shoulder girdle include a right and left clavicle and a right and left scapula.
- The pelvic girdle attaches the legs to the trunk of the body and supports the organs of the abdomen. It is connected to the axial skeleton by ligaments. The pelvic girdle consists of two halves that are fused together in adults. Each half consists of three bones: the ilium, pubis, and ischium.

- Bones are organs that consist mainly of bone, or osseous, tissue. Osseous tissue is a type of connective tissue consisting of a collagen matrix that is mineralized with calcium and phosphorus crystals. The combination of flexible collagen and minerals makes bone hard without making it brittle.
  - There are two types of osseous tissues: cortical bone tissue and spongy bone tissue. Cortical bone tissue is smooth and dense. It forms the outer layer of bones. Spongy bone tissue is porous and light. It is found inside many bones.
- Besides osseous tissues, bones also contain nerves, blood vessels, bone marrow, and periosteum.
- Bone tissue is composed of four different types of bone cells: osteoblasts, osteocytes, osteoclasts, and osteogenic cells. Osteoblasts form new collagen matrix and mineralize it, osteoclasts break down bone, osteocytes regulate the formation and breakdown of bone, and osteogenic cells divide and differentiate to form new osteoblasts. Bone is a very active tissue, constantly being remodeled by the work of osteoblasts and osteoclasts.
- There are six types of bones in the human body: long bones such as the limb bones, short bones such as the wrist bones, sesamoid bones such as the patella, sutural bones in the skull, and irregular bones such as the vertebrae.
- Early in the development of a human fetus, the skeleton is made almost entirely of cartilage. The relatively soft cartilage gradually turns into hard bone. This is called ossification. It begins at a primary ossification center in the middle of the bone and later also occurs at secondary ossification centers in the ends of the bone. The bone can no longer grow in length after the areas of ossification meet and fuse at the time of skeletal maturity.
- Throughout life, bone is constantly being replaced in the process of bone remodeling. In this process, osteoclasts resorb bone and osteoblasts make new bone to replace it. Bone remodeling shapes the skeleton, repairs tiny flaws in bones, and helps maintain mineral homeostasis in the blood.
- Bone repair is the natural process in which a bone repairs itself following a bone fracture. This process may take several weeks. In the process, periosteum produces cells that develop into osteoblasts, and the osteoblasts form a new bone matrix to heal the fracture. Bone repair may be affected by diet, age, pre-existing bone disease, or other factors.
- Joints are locations at which bones of the skeleton connect with one another.
- Joints can be classified structurally or functionally, and there is significant overlap between the two types of classifications.
- The structural classification of joints depends on the type of tissue that binds the bones to each other at the joint. There are three types of joints in the structural classification: fibrous, cartilaginous, and synovial joints.
- The functional classification of joints is based on the type and degree of movement that they allow. There are three types of joints in the functional classification: immovable, partly movable, and movable joints.
  - Movable joints can be classified further according to the type of movement they allow. There are six classes of movable joints: pivot, hinge, saddle, plane, condyloid, and ball-and-socket joints.
- A number of disorders affect the skeletal system, including bone fractures and bone cancers. The two most common disorders of the skeletal system are osteoporosis and osteoarthritis.
- Osteoporosis is an age-related disorder in which bones lose mass, weaken, and break more easily than normal bones. The underlying mechanism in all cases of osteoporosis is an imbalance between bone formation and bone resorption in bone remodeling. Osteoporosis may also occur as a side effect of other disorders or certain medications.
  - Osteoporosis is diagnosed by measuring a patient's bone density and comparing it with the normal level of peak bone density. Fractures are the most dangerous aspect of osteoporosis. Osteoporosis is rarely fatal, but complications of fractures often are.
  - Risk factors for osteoporosis include older age, female sex, European or Asian ancestry, family history of osteoporosis, short stature and small bones, smoking, alcohol consumption, lack of exercise, vitamin D deficiency, poor nutrition, and consumption of soft drinks.
  - Osteoporosis is often treated with medications such as bisphosphonates that may slow or even reverse bone loss. Preventing osteoporosis includes eliminating any risk factors that can be controlled through changes of behavior, such as undertaking weight-bearing exercise.
- Osteoarthritis (OA) is a joint disease that results from the breakdown of joint cartilage and bone. The most common symptoms are joint pain and stiffness. OA is thought to be caused by mechanical stress on the joints with insufficient self-repair of cartilage, coupled with low-grade inflammation of the joints.
  - Diagnosis of OA is typically made on the basis of signs and symptoms, such as joint deformities, pain, and stiffness. X-rays or other tests are sometimes used to either support the diagnosis or rule out other disorders. Age is the chief risk factor for OA. Other risk factors include joint injury, excess body weight, and a family history of OA.

- OA cannot be cured, but the symptoms can often be treated successfully. Treatments may include exercise, efforts to decrease stress on joints, pain medications, and surgery to replace affected hip or knee joints.

As you have learned in this chapter, one of the important functions of the skeletal system is to allow movement of the body. But it doesn't do it alone. Movement is caused by the contraction of muscles, which pull on the bones, causing them to move. Read the next chapter to learn about this and other important functions of the muscular system.

CHAPTER SUMMARY REVIEW

1. Hematopoiesis is carried out by:
   A. spongy bone tissue
   B. periosteum
   C. yellow bone marrow
   D. red bone marrow
2. *True or False.* Osteocalcin is a hormone produced by bone cells.
3. *True or False.* Vertebrae make up part of the rib cage.
4. For each of the following bones, indicate whether they are part of the axial or appendicular skeleton.
   A. The ossicles of the middle ear
   B. The femur
   C. The phalanges
   D. The bones of the cranium
   E. The ilium
5. Why does the rib cage need to be flexible and why is it able to be flexible?
6. In general, what do "girdles" in the skeletal system do?
7. Which protein does bone mainly consist of?
   A. Keratin
   B. Collagen
   C. Cellulose
   D. Elastin
8. For each of the descriptions below, identify which process best fits the description. Use each process only once. Processes: bone growth; bone repair; bone remodeling
   A. New osteoblasts form from the periosteum and produce new bone tissue.
   B. Cartilage grows, and the primary and secondary ossification centers move towards each other.
   C. Osteoclasts break down bone tissue and osteoblasts build new bone tissue.
9. For each of the following processes, describe when it occurs.
   A. Bone growth
   B. Bone repair
   C. Bone remodeling
10. Would swimming likely be more effective as an exercise for preventing osteoporosis or as a treatment for osteoarthritis? Explain your answer.
11. *True or False.* Use of anabolic steroids in the teenage years generally makes people taller.
12. *True or False.* The largest joint in the human body is the knee joint.
13. How much of an adult's skeletal mass is broken down and rebuilt each year?
    A. None
    B. 5 percent
    C. 10 percent
    D. 30 percent
14. Explain why some of the vertebrae become misshapen in the condition called dowager's hump, or kyphosis.
15. Explain why osteoarthritis often involves inflammation in the joints.
16. Osteoporosis can involve both excess bone resorption as well as insufficient production of new bone tissue. What are the two main bone cell types that carry out these processes, respectively?
17. *True or False.* Bone mass does not decrease as men age.
18. *True or False.* Ideally, a person's spine would be perfectly straight and rigid.
19. Compare and contrast a tendon and a ligament.
20. Describe two roles that calcium plays in the bones of the body.
21. How many bones are in the adult human skeleton?
    A. 80
    B. 126
    C. 206
    D. 270

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CHAPTER OVERVIEW

5: MUSCULAR SYSTEM

This chapter describes the structure and functions of the muscular system. It compares and contrasts the three major types of muscle tissue and explains in detail how muscles contract according to the sliding filament theory. The chapter also relates physical exercise to fitness and health and describes several musculoskeletal and neuromuscular disorders.

5.1: Case Study- Muscles and Movement

5.2: Introduction to the Muscular System

5.3: Types of Muscle Tissue

5.4: Naming Skeletal Muscle

5.5: Skeletal Muscle Functions and Structures

5.6: Muscle Contraction

5.7: Physical Exercise

5.8: Disorders of the Muscular System

5.9: Case Study Conclusion- Needing to Relax and Chapter Summary

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5.1: CASE STUDY- MUSCLES AND MOVEMENT

CASE STUDY: NEEDING TO RELAX

The dog in Figure **5.1.3** is expressing his interest in something—perhaps a piece of food—by using the neck muscles to tilt its head in an adorable fashion. Humans also sometimes tilt their heads to express interest. But imagine how disturbing and painful it would be if your neck tilted involuntarily, without you being able to control it! Forty-three-year-old Nasir, unfortunately, knows just how debilitating this can be. Nasir uses they, them, and their pronouns.



Figure **5.1.1**: Curious dog

Nasir has a rare condition called cervical dystonia, which is also called spasmodic torticollis. In this condition, the muscles in the neck contract involuntarily, often causing the person's head to twist to one side. The illustration in Figure **5.1.2** shows one type of abnormal head positioning that can be caused by cervical dystonia. The muscles may contract in a sustained fashion, holding the head and neck in one position, or they may spasm repeatedly, causing jerky movements of the head and neck.

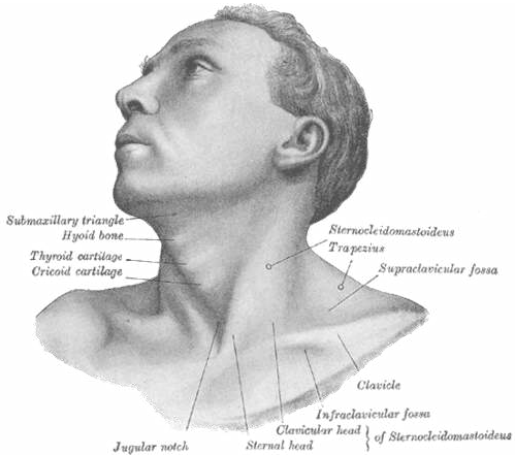


Figure **5.1.2**: Illustration from a medical book written around 1910, showing a person identified as having spasmodic torticollis. The person's neck is permanently tilted to the side.

Cervical dystonia is painful and can significantly interfere with individuals' ability to carry out their usual daily activities. In Nasir's case, they can no longer drive a car, because their uncontrollable head and neck movements and abnormal head positioning prevent them from navigating the road safely. Nasir also has severe neck and shoulder pain much of the time.

Although it can be caused by an injury, there is no known cause of cervical dystonia—and there is also no cure. Fortunately for Nasir and other cervical dystonia sufferers, though, there is a treatment that can significantly reduce symptoms in many people. You may be surprised to learn that this treatment is the same substance that, when injected into the face, is used for cosmetic purposes to reduce wrinkles!

The substance is botulinum toxin, one preparation of which may be familiar to you by its brand name: Botox. It is a neurotoxin produced by the bacterium *Clostridium botulinum*, and can cause a life-threatening illness called botulism. However, when injected in very small amounts by a skilled medical professional, botulinum toxins have some safe and effective uses. In addition to cervical dystonia, botulinum toxins can be used to treat other disorders involving the muscular system, such as strabismus (misalignment of the eyes), eye twitches, excessive muscle contraction due to neurological conditions like cerebral palsy; and even overactive bladder.

Botulinum toxin has its effect on the muscular system by inhibiting muscle contractions. When used to treat wrinkles, it relaxes the muscles of the face, lessening the appearance of wrinkles. When used to treat cervical dystonia and other disorders involving excessive muscle contraction, it reduces abnormal contractions.

In this chapter, you will learn about the muscles of the body, how they contract to produce movements and carry out their functions, and some disorders that affect the muscular system. At the end of the chapter, you will find out if botulinum toxin helped relieve Nasir's cervical dystonia, and how this toxin works to inhibit muscle contraction.

CHAPTER OVERVIEW: MUSCULAR SYSTEM

In this chapter, you will learn about the muscular system, which carries out both voluntary body movements and involuntary contractions of internal organs and structures. Specifically, you will learn about:

- The different types of muscle tissue—skeletal, cardiac, and smooth muscle—and their different characteristics and functions
- How muscle cells are specialized to contract and cause voluntary and involuntary movements
- The ways in which muscle contraction is controlled
- How skeletal muscles can grow or shrink, causing changes in strength
- The structure and organization of skeletal muscles (including the different types of muscle fibers) and how actin and myosin

filaments move across each other, according to the sliding filament theory, to cause muscle contraction
- How cardiac muscle tissue in the heart contracts to pump blood through the body
- Smooth muscle tissue that makes up internal organs and structures, such as the digestive system, blood vessels, and uterus
- The physical and mental health benefits of aerobic and anaerobic exercise, such as running and weight lifting
- How individuals vary in their response to exercise
- Disorders of the muscular system, including musculoskeletal disorders (such as strains and carpal tunnel syndrome) and neuromuscular disorders (such as muscular dystrophy, myasthenia gravis, and Parkinson's disease)

As you read the chapter, think about the following questions:

1. How is the contraction of skeletal muscles controlled?
2. Botulinum toxin works on the cellular and molecular levels to inhibit muscle contraction. Based on what you learn about how muscle contraction works, can you think of some ways it could potentially be inhibited?
3. What is one disorder involving a lack of sufficient muscle contraction? Why does it occur?

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5.2: INTRODUCTION TO THE MUSCULAR SYSTEM

MARVELOUS MUSCLES

Does the word *muscle* make you think of the well-developed muscles of a weightlifter, like a woman in Figure **5.2.1**? Her name is Natalia Zabolotnaya, and she's a Russian Olympian. The muscles that are used to lift weights are easy to feel and see, but they aren't the only muscles in the human body. Many muscles are deep within the body, where they form the walls of internal organs and other structures. You can flex your biceps at will, but you can't control internal muscles like these. It's a good thing that these internal muscles work without any conscious effort on your part because the movement of these muscles is essential for survival. Muscles are the organs of the muscular system.



Figure **5.2.1**: weightlifter lifting weight over her head.

WHAT IS THE MUSCULAR SYSTEM?



Figure **5.2.2**: Many of the skeletal muscles in the human muscular system are shown in this drawing of the human body.

The **muscular system** consists of all the muscles of the body. The largest percentage of muscles in the muscular system consists of skeletal muscles, which are attached to bones and enable voluntary body movements. There are almost 650 skeletal muscles in the human body, many of them shown in Figure **5.2.2**. Besides skeletal muscles, the muscular system also includes cardiac muscle — which makes up the walls of the heart — and smooth muscles, which control movement in other internal organs and structures.

MUSCLE STRUCTURE AND FUNCTION

Muscles are organs composed mainly of muscle cells, which are also called **muscle fibers** (mainly in skeletal and cardiac muscle) or **myocytes** (mainly in smooth muscle). Muscle cells are long and thin cells that are specialized for the function of contracting. They contain protein filaments that slide over one another using energy in ATP. The sliding filaments increase the tension in — or shorten the length of — muscle cells, causing a contraction. Muscle contractions are responsible for virtually *all* the movements of the body, both inside and out.

Skeletal muscles are attached to the bones of the skeleton. When these muscles contract, they move the body. They allow us to use our limbs in a variety of ways, from walking to turning cartwheels. Skeletal muscles also maintain posture and help keep balance.

Smooth muscles in the walls of blood vessels contract to cause vasoconstriction, which may help conserve body heat. Relaxation of these muscles causes vasodilation, which may help the body lose heat. In the organs of the digestive system, smooth muscles squeeze food through the gastrointestinal tract by contracting in sequence to form a wave of muscle contractions called **peristalsis.** Think of squirting toothpaste through a tube by applying pressure in sequence from the bottom of the tube to the top, and you have a good idea of how food is moved by muscles through the digestive system. Peristalsis of smooth muscles also moves urine through the urinary tract.

Cardiac muscle tissue is found only in the walls of the heart. When cardiac muscle contracts, it makes the heartbeat. The pumping action of the beating heart keeps blood flowing through the cardiovascular system.

MUSCLE HYPERTROPHY AND ATROPHY

Muscles can grow larger, or **hypertrophy.** This generally occurs through increased use, although hormonal or other influences can also play a role. The increase in testosterone during puberty, for example, causes a significant increase in muscle size. Physical exercise that involves weight-bearing or resistance training can increase the size of skeletal muscles in virtually everyone. Exercises (such as running) that increase the heart rate may also increase the size and strength of cardiac muscle. The size of a muscle, in turn, is the main determinant of muscle strength, which may be measured by the amount of force a muscle can exert.

Muscles can also grow smaller, or **atrophy**, which can occur through lack of physical activity or from starvation. People who are immobilized for any length of time — for example, because of a broken bone or surgery — lose muscle mass relatively quickly. People in concentration or famine camps may be so malnourished

that they lose much of their muscle mass, becoming almost literally just “skin and bones.” Astronauts on the International Space Station may also lose significant muscle mass because of weightlessness in space (Figure 5.2.3).

Many diseases, including cancer and AIDS, are often associated with muscle atrophy. Atrophy of muscles also happens with age. As people grow older, there is a gradual decrease in the ability to maintain skeletal muscle mass, known as **sarcopenia.** The exact cause of sarcopenia is not known, but one possible cause is a decrease in sensitivity to growth factors that are needed to maintain muscle mass. Because muscle size determines the strength, muscle atrophy causes a corresponding decline in muscle strength.

In both hypertrophy and atrophy, the number of muscle fibers does not change. What changes the size of the muscle fibers? When muscle hypertrophy happens, the individual fibers become wider. When muscle atrophy happens, the fibers become narrower.

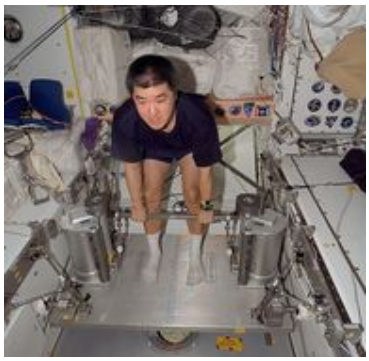


Figure 5.2.3: An astronaut exercising in space. It is important for astronauts to exercise onboard the International Space Station to help counter the loss of muscle mass that occurs because they are weightless without Earth’s gravity.

INTERACTIONS WITH OTHER BODY SYSTEMS

Muscles cannot contract on their own. Skeletal muscles need stimulation from motor neurons in order to contract. The point where a motor neuron attaches to a muscle is called a **neuromuscular junction**. Let’s say you decide to raise your hand in class. Your brain sends electrical messages through motor neurons to your arm and shoulder. The motor neurons, in turn, stimulate muscle fibers in your arm and shoulder to contract, causing your arm to rise.

Involuntary contractions of smooth and cardiac muscles are also controlled by electrical impulses, but in the case of these muscles, the impulses come from the autonomic nervous system (smooth muscle) or specialized cells in the heart (cardiac muscle). Hormones and some other factors also influence involuntary contractions of cardiac and smooth muscles. For example, the fight-or-flight hormone adrenaline increases the rate at which cardiac muscle contracts, thereby speeding up the heartbeat.

Muscles cannot move the body on their own. They need the skeletal system to act upon. The two systems together are often referred to as the **musculoskeletal system**. Skeletal muscles are attached to the skeleton by tough connective tissues called **tendons**. Many skeletal muscles are attached to the ends of bones that meet at a joint. The muscles span the joint and connect the bones. When the muscles contract, they pull on the bones, causing them to move. The skeletal system provides a system of levers that allow body movement. The muscular system provides the force that moves the levers.

REVIEW

1. What is the muscular system?
2. Describe muscle cells and their function.
3. Identify three types of muscle tissue and where each type is found.
4. Define muscle hypertrophy and muscle atrophy.
5. What are the possible causes of muscle hypertrophy?
6. Give three reasons that muscle atrophy may occur.
7. How do muscles change when they increase or decrease in size?
8. How do changes in muscle size affect strength?
9. Explain why astronauts can easily lose muscle mass in space.
10. Describe how the terms *muscle cells*, *muscle fibers*, and *myocytes* relate to each other.
11. Muscle tissue in the stomach is considered _____.

A. cardiac muscle

B. skeletal muscle

C. smooth muscle

D. voluntary muscle

12. Muscle contraction is the _____ of muscle fibers.

A. hypertrophy

B. atrophy

C. lengthening

D. shortening

13. *True or False:* Smooth muscle does not contract.
14. Name two systems in the body that work together with the muscular system to carry out movements.
15. Describe one way in which the muscular system is involved in regulating body temperature.

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5.3: TYPES OF MUSCLE TISSUE

WHAT IS MUSCLE TISSUE?

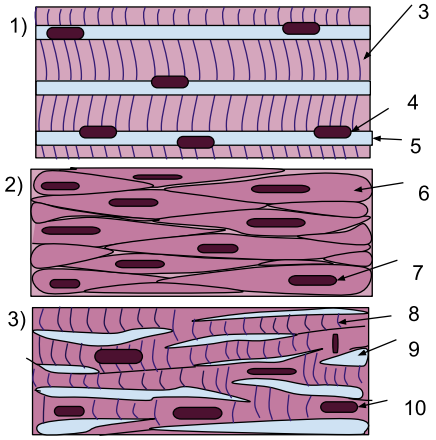


Figure **5.3.2**: Muscle type 1) Skeletal muscle cells are long tubular cells with striations (3) and multiple nuclei (4). The nuclei are embedded in the cell membrane (5) to be just inside the cell. This type of tissue occurs in the muscles that are attached to the skeleton. Skeletal muscles function for the voluntary movements of the body. Muscle type 2) Smooth muscle cells are spindle-shaped (6), and each cell has a single nucleus (7). Unlike skeletal muscle, there are no striations. The smooth muscle acts involuntarily and functions in the movement of substances in the lumens. They are primarily found in blood vessel walls and walls along the digestive tract. Muscle type 3) Cardiac muscle cells branch off from each other, rather than remaining, like the cells in the skeletal and smooth muscle tissues. Because of this, there are junctions between adjacent cells (9). The cells have striations (8), and each cell has a single nucleus (10). This type of tissue occurs in the heart wall, and its primary function is for pumping blood. This is an involuntary action.

Muscle tissue is a soft tissue that makes up most of the tissues in the muscles of the human muscular system. Other tissues in muscles are connective tissues, such as tendons that attach skeletal muscles to bones and sheaths of connective tissues that cover or line muscle tissues. Only muscle tissue per se, however, has cells with the ability to contract.

There are three major types of muscle tissues in the human body: skeletal, smooth, and cardiac muscle tissues. Figure **5.3.2** shows how the three types of muscle tissues appear under a microscope. When you read about each type below, you will learn why the three types appear as they do.

All three muscle tissues have some properties in common; they all exhibit a quality called excitability as their plasma membranes can change their electrical states (from polarized to depolarized) and send an electrical wave called an action potential along the entire length of the membrane. While the nervous system can influence the excitability of cardiac and smooth muscle to some degree, skeletal muscle completely depends on signaling from the nervous system to work properly. On the other hand, both cardiac muscle and smooth muscle can respond to other stimuli, such as hormones and local stimuli.

Differences among the three muscle types include the microscopic organization of their contractile proteins—actin and myosin. The actin and myosin proteins are arranged very regularly in the cytoplasm of individual muscle cells (referred to as fibers) in both skeletal muscle and cardiac muscle, which creates a pattern, or stripes, called striations. The striations are visible with a light microscope under high magnification

SKELETAL MUSCLE

Skeletal muscle has a distinctive striped pattern, called striations. The striations result form actin and myosin proteins arranged very regularly in the cytoplasm of individual muscle cells (fibers), and are visible with a light microscope under high magnification. Skeletal muscle fibers (cells) are multinucleated structures that compose the skeletal muscle.

The next sections of this chapter will go into more detail about the structure and function of skeletal muscle tissue and skeletal muscles.

SMOOTH MUSCLE

Smooth muscle is muscle tissue in the walls of internal organs and other internal structures such as blood vessels. When smooth muscles contract, they help the organs and vessels carry out their functions. When smooth muscles in the stomach wall contract, they squeeze the food inside the stomach, helping to mix and churn the food and break it into smaller pieces. This is an important part of digestion. Contractions of smooth muscles are involuntary, so they are not under conscious control. Instead, they are controlled by the autonomic nervous system, hormones, neurotransmitters, and other physiological factors.

STRUCTURE OF SMOOTH MUSCLE

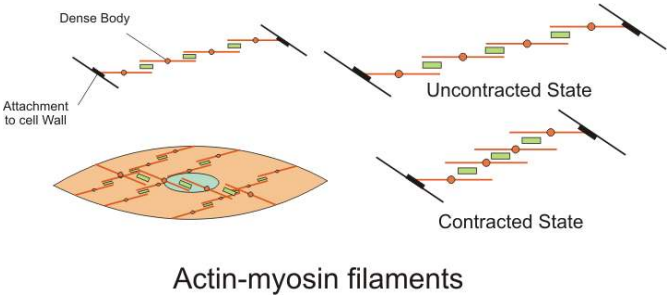


Figure **5.3.8**: The smooth muscle cell is composed of actin and myosin filaments, but they are not arranged in the sarcomere. The arrangement of these filaments is alternate and staggered.

The cells that make up smooth muscle are generally called **myocytes.** Unlike the muscle fibers of striated muscle tissue, the myocytes of smooth muscle tissue do not have their filaments arranged in sarcomeres. Therefore, smooth tissue is not striated. However, the myocytes of smooth muscle contain myofibrils, which contain bundles of myosin and actin filaments. The filaments cause contractions when they slide over each other, as shown in Figure **5.3.8**.

FUNCTIONS OF SMOOTH MUSCLE

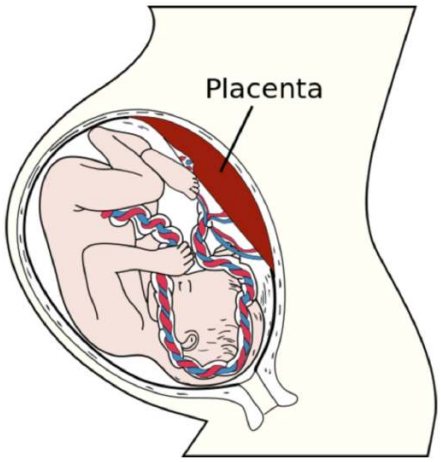


Figure **5.3.9**: The muscular uterine wall stretches to a great extent to accommodate a growing fetus, yet it can still contract with great force during the labor that precedes childbirth. At that time, it can exert up to 100 pounds of force.

Unlike striated muscle, smooth muscle can sustain very long-term contractions. Smooth muscle can also stretch and still maintain its contractile function, which striated muscle cannot. An extracellular matrix secreted by myocytes enhances the elasticity of smooth muscle. The matrix consists of elastin, collagen, and other stretchy fibers. The ability to stretch and still contract is an important attribute of smooth muscle in organs such as the stomach and uterus (Figure **5.3.9**), both of which must stretch considerably as they perform their normal functions.

The following list indicates where many smooth muscles are found, along with some of their specific functions.

- Walls of the gastrointestinal tract (such as the esophagus, stomach, and intestines), moving food through the tract by peristalsis.
- Walls of air passages of the respiratory tract (such as the bronchi), controlling the diameter of the passages and the volume of air that can pass through them
- Walls of organs of the male and female reproductive tracts; in the uterus, for example, pushing a baby out of the uterus and into the birth canal
- Walls of the urinary system structures, including the urinary bladder, allow the bladder to expand so it can hold more urine and then contract as urine is released.
- Walls of blood vessels, controlling the diameter of the vessels and thereby affecting blood flow and blood pressure
- Walls of lymphatic vessels, squeezing the fluid called lymph through the vessels.
- Iris of the eyes, controlling the size of the pupils and thereby the amount of light entering the eyes
- Arrector pili in the skin, raising hairs in hair follicles in the dermis.

CARDIAC MUSCLE

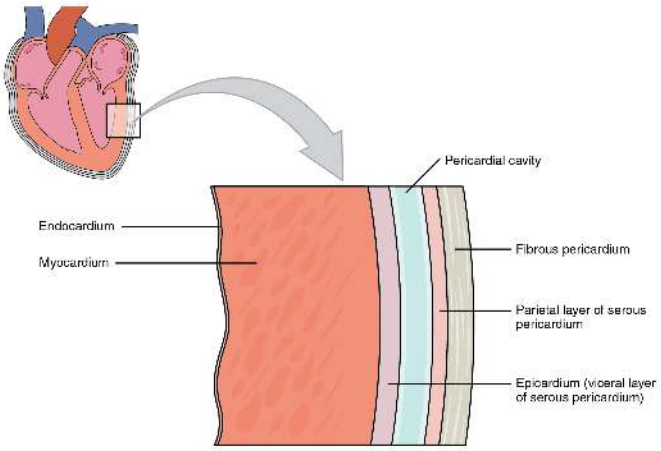


Figure **5.3.10**: The thick wall of the heart consists mainly of cardiac muscle tissue called myocardium. The thin epithelial tissue endocardium covers the chambers of the heart and the epicardium covers the myocardium. The heart is located in the pericardial cavity of the chest. The covering of the pericardial cavity is composed of fibrous and serous layers.

Cardiac muscle is found only in the wall of the heart. It is also called myocardium. As shown in Figure **5.3.10**, the myocardium is enclosed within connective tissues, including the endocardium on the inside of the heart and pericardium on the outside of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Contractions of cardiac muscle are involuntary, like those of smooth muscles. They are controlled by electrical impulses from specialized cardiac muscle cells in the heart muscle area called the sinoatrial node.

Like skeletal muscle, cardiac muscle is striated because its filaments are arranged in sarcomeres inside the muscle fibers. However, in cardiac muscle, the myofibrils are branched at irregular angles rather than arranged in parallel rows (as they are in skeletal muscle). This explains why cardiac and skeletal muscle tissues look different from one another.

The cells of cardiac muscle tissue are arranged in interconnected networks. This arrangement allows rapid transmission of electrical impulses, which stimulate virtually simultaneous contractions of the cells. This enables the cells to coordinate contractions of the heart muscle.

The heart is the muscle that performs the greatest amount of physical work in a lifetime. Although the heart's power output is much less than the maximum power output of some other muscles in the human body, the heart does its work continuously over an entire lifetime without rest. The cardiac muscle contains many mitochondria, which produce ATP for energy and help the heart resist fatigue.

REVIEW

1. What is muscle tissue?

2. Where is the skeletal muscle found, and what is its general function?

3. Why is skeletal muscle tissue striated?

4. Where is the smooth muscle found? What controls the contraction of smooth muscle?

5. Compare and contrast smooth muscle and striated muscle (such as skeletal muscle).

6. Where is the cardiac muscle found? What controls its contractions?

7. Both cardiac and skeletal muscle tissues are striated, but they look different from one another. Why?

8. The heart muscle is smaller and less powerful than some other muscles in the body. Why is the heart the muscle that performs the greatest amount of physical work in a lifetime? How does the heart resist fatigue?

9. *True or False:* skeletal muscle fibers are cells with multiple nuclei.

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5.4: Naming Skeletal Muscle

Learning Objectives

By the end of this section, you will be able to:

- Describe the criteria used to name skeletal muscles
- Explain how understanding the muscle names helps describe shapes, location, and actions of various muscles

Understanding Root Words

The Greeks and Romans conducted the first studies done on the human body in Western culture. The educated class of subsequent societies studied Latin and Greek, and therefore the early pioneers of anatomy continued to apply Latin and Greek terminology or roots when they named the skeletal muscles. The large number of muscles in the body and unfamiliar words can make learning the names of the muscles in the body seem daunting, but understanding the etymology can help. Etymology is the study of how the root of a particular word entered a language and how the use of the word evolved over time. Taking the time to learn the root of the words is crucial to understanding the vocabulary of anatomy and physiology. When you understand the names of muscles it will help you remember where the muscles are located and what they do (Figure 5.4.1, Figure 5.4.2, and Table 5.4.1). Pronunciation of words and terms will take a bit of time to master, but after you have some basic information; the correct names and pronunciations will become easier.

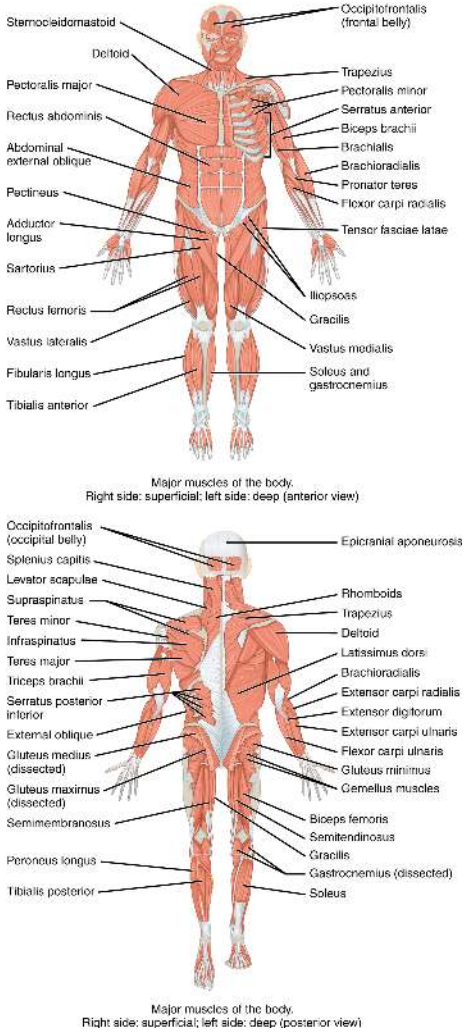


Figure 5.4.1: Overview of the Muscular System On the anterior and posterior views of the muscular system above, superficial muscles (those at the surface) are shown on the right side of the body while deep muscles (those underneath the superficial

muscles) are shown on the left half of the body. For the legs, superficial muscles are shown in the anterior view while the posterior view shows both superficial and deep muscles.

Example	Word	Latin Root 1	Latin Root 2	Meaning	Translation
abductor digiti minimi	abductor	ab = away from	duct = to move	a muscle that moves away from	A muscle that moves the little finger or toe away
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	
adductor digiti minimi	adductor	ad = to, toward	duct = to move	a muscle that moves towards	A muscle that moves the little finger or toe toward
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	

Figure 5.4.2: Understanding a Muscle Name from the Latin

Mnemonic Device for Latin Roots

Example	Latin or Greek Translation	Mnemonic Device
ad	to; toward	ADvance toward your goal
ab	away from	n/a
sub	under	SUBmarines move under water.
ductor	something that moves	A conDUCTOR makes a train move.
anti	against	If you are antisocial, you are against engaging in social activities.
epi	on top of	n/a
apo	to the side of	n/a
longissimus	longest	“Longissimus” is longer than the word “long.”
longus	long	long
brevis	short	brief
maximus	large	max
medius	medium	“Medius” and “medium” both begin with “med.”
minimus	tiny; little	mini
rectus	straight	To RECTify a situation is to straighten it out.
multi	many	If something is MULTIcolored, it has many colors.
uni	one	A UNIcorn has one horn.
bi/di	two	If a ring is DIcast, it is made of two metals.
tri	three	TRIple the amount of money is three times as much.
quad	four	QUADruplets are four children born at one birth.
externus	outside	EXternal
internus	inside	INternal

Table 5.4.1: Examples of using root words and mnemonics to help understand and remember terms

Understanding Skeletal Muscle Naming

Anatomists name the skeletal muscles according to a number of criteria, each of which describes the muscle in some way. These include naming the muscle after its shape, its size compared to other muscles in the area, its location in the body or the location of its attachments to the skeleton, how many origins it has, or its action.

The skeletal muscle's anatomical location or its relationship to a particular bone often determines its name. For example, the frontalis muscle is located on top of the frontal bone of the skull. Similarly, the shapes of some muscles are very distinctive and the names, such as orbicularis, reflect the shape. For the buttocks, the size of the muscles influences the names: gluteus maximus (largest), gluteus medius (medium), and the gluteus minimus (smallest). Names were given to indicate length—brevis (short), longus (long)—and to identify position relative to the midline: lateralis (to the outside away from the midline), and medialis (toward the midline). The direction of the muscle fibers and fascicles are used to describe muscles relative to the midline, such as the rectus (straight) abdominis, or the oblique (at an angle) muscles of the abdomen.

Some muscle names indicate the number of muscles in a group. One example of this is the quadriceps, a group of four muscles located on the anterior (front) thigh. Other muscle names can provide information as to how many origins a particular muscle has, such as the biceps brachii. The prefix bi indicates that the muscle has two origins and tri indicates three origins.

The location of a muscle's attachment can also appear in its name. When the name of a muscle is based on the attachments, the origin is always named first. For instance, the sternocleidomastoid muscle of the neck has a dual origin on the sternum (sterno) and clavicle (cleido), and it inserts on the mastoid process of the temporal bone. The last feature by which to name a muscle is its action. When muscles are named for the movement they produce, one can find action words in their name. Some examples are flexor (decreases the angle at the joint), extensor (increases the angle at the joint), abductor (moves the bone away from the midline), or adductor (moves the bone toward the midline).

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5.5: Skeletal Muscle Functions and Structures

Turn your eyes—a tiny movement, considering the conspicuously large and strong external eye muscles that control eyeball movements. These muscles have been called the strongest muscles in the human body relative to the work they do. However, the external eye muscles actually do a surprising amount of work. Eye movements occur almost constantly during waking hours, especially when we are scanning faces or reading. Eye muscles are also exercised nightly during the phase of sleep called rapid eye movement sleep. External eye muscles can move the eyes because they are made mainly of muscle tissue.



Figure 5.5.1: Eyes

Skeletal Muscle Functions

The best-known feature of skeletal muscle is its ability to contract and cause movement. Skeletal muscles act not only to produce movement but also to stop movement, such as resisting gravity to maintain posture. Small, constant adjustments of the skeletal muscles are needed to hold a body upright or balanced in any position. Muscles also prevent excess movement of the bones and joints, maintaining skeletal stability and preventing skeletal structure damage or deformation. Joints can become misaligned or dislocated entirely by pulling on the associated bones; muscles work to keep joints stable. Skeletal muscles are located throughout the body at the openings of internal tracts to control the movement of various substances. These muscles allow functions, such as swallowing, urination, and defecation, to be under voluntary control. Skeletal muscles also protect internal organs (particularly abdominal and pelvic organs) by acting as an external barrier or shield to external trauma and by supporting the weight of the organs.

Skeletal muscles contribute to the maintenance of homeostasis in the body by generating heat. Muscle contraction requires energy, and when ATP is broken down, heat is produced. This heat is very noticeable during exercise, when sustained muscle movement causes body temperature to rise, and in cases of extreme cold, when shivering produces random skeletal muscle contractions to generate heat.

Major Skeletal Muscles

Skeletal muscle is muscle tissue attached to bones by **tendons**, which are bundles of collagen fibers. Whether you are moving your eyes or running a marathon, you are using skeletal muscles. Contractions of skeletal muscles are voluntary or under the conscious control of the central nervous system via the somatic nervous system. Skeletal muscle tissue is the most common type of muscle tissue in the human body. By weight, an average adult male is about 42 percent skeletal muscles, and the average adult female is about 36 percent skeletal muscles.

Some of the major skeletal muscles in the human body are labeled in Figures 5.5.3 and Figure 5.5.4 and listed in Table 5.5.1.

Table 5.5.1: Skeletal muscles. Some muscles are visible from both anterior and posterior views.

Muscles visible in Figure 5.5.3	Muscles visible in Figure 5.5.4
rotator cuff (multiple muscles are part of this group)	levator scapulae
biceps brachii	rhomboids
brachialis	rotator cuff
pronator teres	triceps brachii
brachioradialis	gluteus maximus
adductor muscles	tibialis posterior
tibialis anterior	peroneus longus
deltoid	peroneus brevis
pectoralis major	trapezius
rectus abdominis	deltoid
abdominal external oblique	brachioradialis
iliopsoas	latissimus dorsi
quadriceps femoris	biceps femoris
peroneus longus	semitendinosus
peroneus bravis	semimembranousus
	gastrocnemius
	soleus

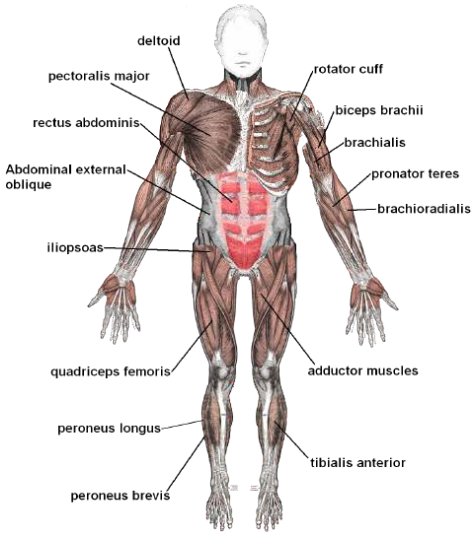


Figure 5.5.3: This figure shows major skeletal muscles in the front (anterior) of the body.

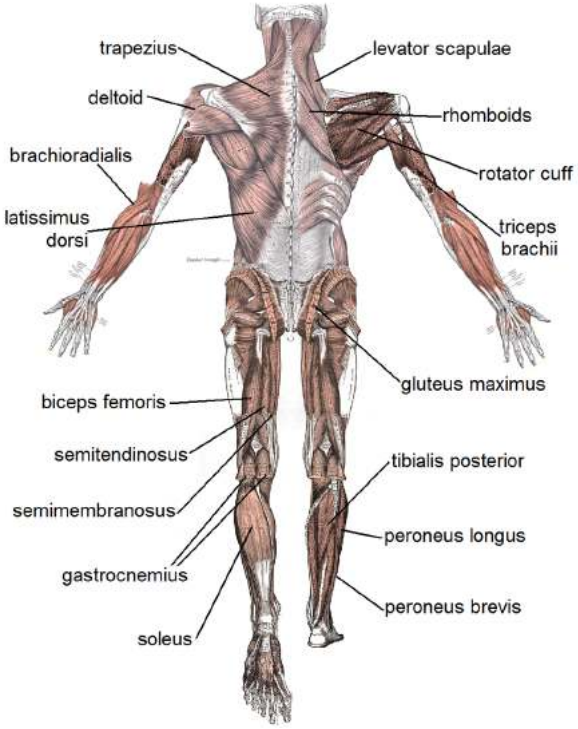


Figure 5.5.4: This figure shows major skeletal muscles in the back (posterior) of the body.

Skeletal Muscle Pairs

To move bones in opposite directions, skeletal muscles often consist of muscle pairs that work in opposition to one another. For example, when the biceps muscle (on the anterior of the upper arm) contracts, it can cause the elbow joint to flex or bend the arm (flexion), as shown in Figure 5.5.5. When the triceps muscle (on the posterior of the upper arm) contracts, it can cause the elbow to extend or straighten the arm (extension). The biceps and triceps muscles are examples of a muscle pair where the muscles work in opposition to each other.

In another example, to flex the knee joint a set of muscles called the hamstrings (n the posterior of the thigh) is activated. However, to extend the knee a group of four muscles called the quadriceps femoris (on the anterior of the thigh) are activated.

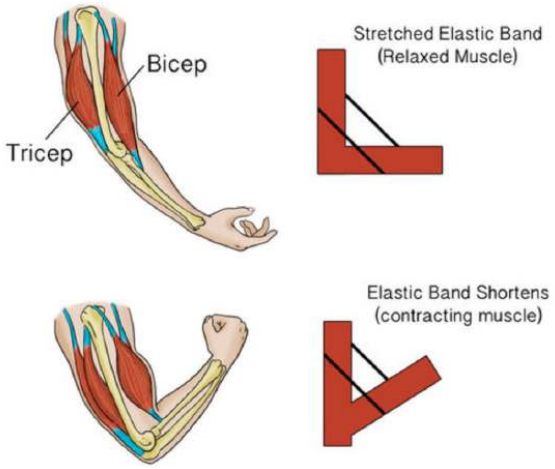


Figure 5.5.5: Triceps and biceps muscles in the upper arm are opposing muscles that move the arm at the elbow in opposite directions.

Skeletal Muscle Structure

Each skeletal muscle is an organ that consists of various integrated tissues. These tissues include the skeletal muscle fibers, blood vessels, nerve fibers, and connective tissue. Each skeletal muscle has three layers of connective tissue that enclose it and provide

structure to the muscle as a whole, and also compartmentalize the muscle fibers within the muscle. Each muscle is wrapped in a sheath of dense, irregular connective tissue called the epimysium, which allows a muscle to contract and move powerfully while maintaining its structural integrity. The epimysium also separates muscle from other tissues and organs in the area, allowing the muscle to move independently.

Each skeletal muscle consists of hundreds — or even *thousands* — of skeletal muscle fibers, which are long, string-like cells. As shown in Figure 5.5.6, skeletal muscle fibers are individually wrapped in connective tissue called **endomysium**. The skeletal muscle fibers are bundled together in units called **muscle fascicles**, surrounded by sheaths of connective tissue called **perimysium**. Each fascicle contains between ten and 100 (or even more!) skeletal muscle fibers. Fascicles, in turn, are bundled together to form individual skeletal muscles, which are wrapped in connective tissue called **epimysium**. The connective tissues in skeletal muscles have a variety of functions. They support and protect muscle fibers, allowing them to withstand contraction forces by distributing the forces applied to the muscle. They also provide pathways for nerves and blood vessels to reach the muscles. Also, the epimysium anchors the muscles to tendons.

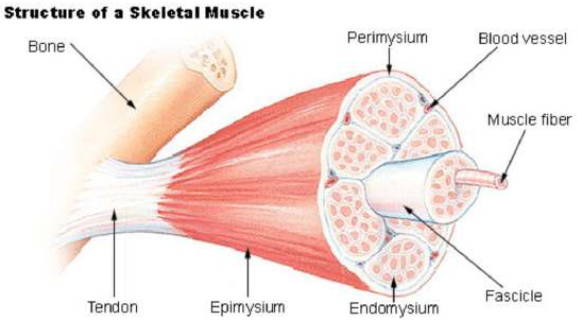


Figure 5.5.6: Each skeletal muscle has a structure of bundles within bundles. Bundles of muscle fibers make up a muscle fascicle, and fascicles' bundles make up a skeletal muscle. At each level of bundling, a connective tissue membrane surrounds the bundle. The muscle cells, fascicle, and the whole muscle are surrounded by Endomysium, perimysium, and epimysium, respectively. All connective tissues merge together to make a tendon that attaches the muscle to bones.

The same bundles-within-bundles structure is replicated within each muscle fiber. As shown in Figure 5.5.7, a muscle fiber consists of a bundle of myofibrils, which are themselves bundles of protein filaments. These protein filaments consist of thin filaments of the protein actin, anchored to structures called Z discs — and thick filaments of the protein myosin. The filaments are arranged together within a myofibril in repeating units called **sarcomeres,** which run from one Z disc to the next. The sarcomere is the basic functional unit of skeletal (and cardiac) muscles. It contracts as actin and myosin filaments slide over one another. Skeletal muscle tissue is said to be striated because it appears striped. It has this appearance because of the regular, alternating A (dark) and I (light) bands of filaments arranged in sarcomeres inside the muscle fibers. Other components of a skeletal muscle fiber include multiple nuclei and mitochondria.

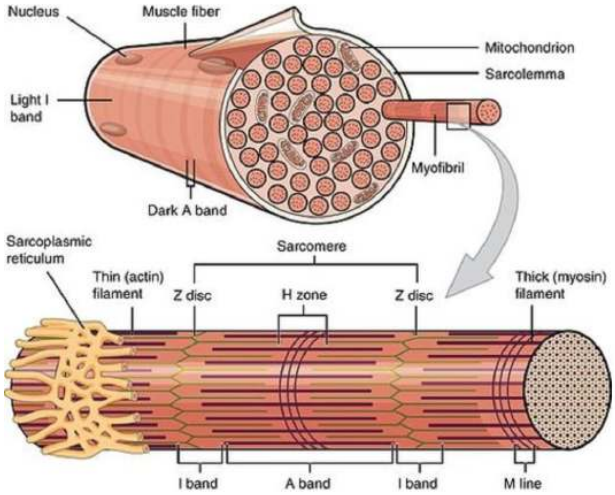


Figure 5.5.7: Bundles of protein filaments form a myofibril, and bundles of myofibrils make up a single muscle fiber. I and A bands refer to the positioning of myosin and actin fibers in a myofibril. Sarcoplasmic reticulum is a specialized type of endoplasmic reticulum that forms a network around each myofibril. It serves as a reservoir for calcium ions, which are needed for muscle contractions. H zones and Z discs are also involved in muscle contractions, which you can read about in the concept of Muscle Contraction.

Slow- and Fast-Twitch Skeletal Muscle Fibers

Skeletal muscle fibers can be divided into two types, called slow-twitch (or type I) muscle fibers and fast-twitch (or type II) muscle fibers.

- **Slow-twitch muscle fibers** are dense with capillaries and rich in mitochondria and myoglobin, a protein that stores oxygen until needed for muscle activity. Relative to fast-twitch fibers, slow-twitch fibers can carry more oxygen and sustain aerobic (oxygen-using) activity. Slow-twitch fibers can contract for long periods of time, but not with very much force. They are relied upon primarily in endurance events, such as distance running or cycling.
- **Fast-twitch muscle fibers** contain fewer capillaries and mitochondria and less myoglobin. This type of muscle fiber can contract rapidly and powerfully, but it fatigues very quickly. Fast-twitch fibers can sustain only short, anaerobic (non-oxygen-using) bursts of activity. Relative to slow-twitch fibers, fast-twitch fibers contribute more to muscle strength and have a greater potential for increasing mass. They are relied upon primarily in short, strenuous events, such as sprinting or weight lifting.

Proportions of fiber types vary considerably from muscle to muscle and from person to person. Individuals may be genetically predisposed to have a larger percentage of one type of muscle fiber than the other. Generally, an individual who has more slow-twitch fibers is better suited for activities requiring endurance. In contrast, an individual who has more fast-twitch fibers is better suited for activities requiring short bursts of power.

Review

1. Where is the skeletal muscle found, and what is its general function?

2. Why do many skeletal muscles work in pairs?

3. Describe the structure of a skeletal muscle.

4. Relate muscle fiber structure to the functional units of muscles.

5. Why is skeletal muscle tissue striated?

6. Compare and contrast slow-twitch and fast-twitch skeletal muscle fibers.

7. Arrange the following units within a skeletal muscle in order, from smallest to largest: *fascicle; sarcomere; muscle fiber; myofibril*

8. Give one example of connective tissue that is found in muscles. Describe one of its functions.

9. *True or False:* skeletal muscle fibers are cells with multiple nuclei.

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5.6: MUSCLE CONTRACTION

ARM WRESTLING

A sport like arm-wrestling depends on muscle contractions. Arm wrestlers must contract muscles in their hands and arms and *keep* them contracted to resist their opponent's opposing force. The wrestler whose muscles can contract with greater force wins the match.



Figure **5.6.1**: Arm wrestling

MUSCLE CONTRACTION

HOW A SKELETAL MUSCLE CONTRACTION BEGINS

Excluding reflexes, all skeletal muscle contractions occur as a result of conscious effort originating in the brain. The brain sends electrochemical signals through the somatic nervous system to motor neurons that innervate muscle fibers (to review how the brain and neurons function, see the chapter *Nervous System*). A single motor neuron with multiple axon terminals can innervate multiple muscle fibers, thereby causing them to contract at the same time. The connection between a motor neuron axon terminal and a muscle fiber occurs at a neuromuscular junction site**.** This is a chemical synapse where a motor neuron transmits a signal to muscle fiber to initiate a muscle contraction.

The process by which a signal is transmitted at a neuromuscular junction is illustrated in Figure **5.6.2**. The sequence of events begins when an action potential is initiated in the cell body of a motor neuron, and the action potential is propagated along the neuron's axon to the neuromuscular junction. Once the action potential reaches the end of the axon terminal, it causes the neurotransmitter acetylcholine (ACh) from synaptic vesicles in the axon terminal. The ACh molecules diffuse across the synaptic cleft and bind to the muscle fiber receptors, thereby initiating a muscle contraction. Muscle contraction is initiated with the depolarization of the sarcolemma caused by the sodium ions' entrance through the sodium channels associated with the ACh receptors.

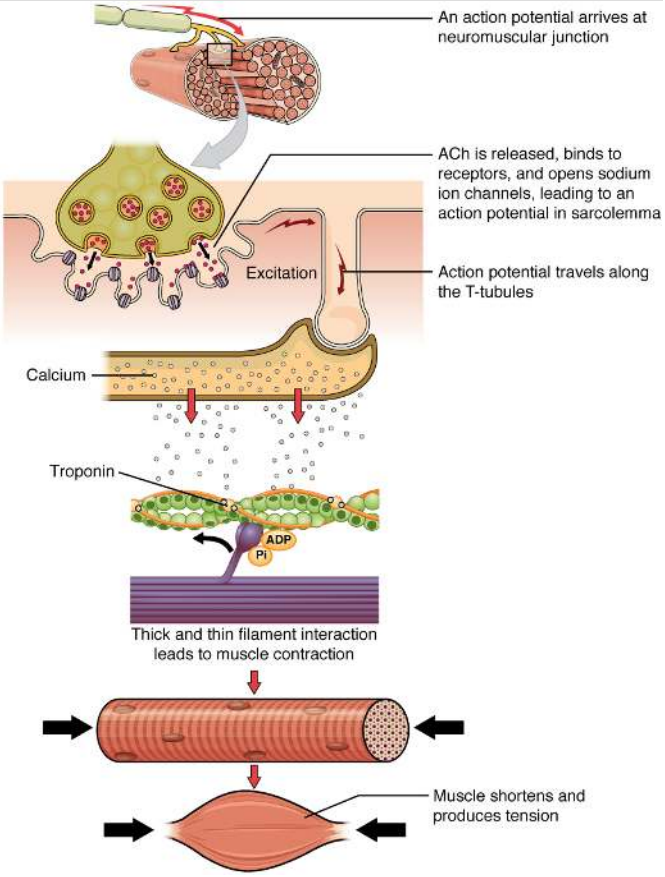


Figure **5.6.2**: This diagram represents the sequence of events that occurs when a motor neuron stimulates a muscle fiber to contract. The action potential travels down the t-tubules and excites the sarcoplasmic reticulum which releases calcium. Calcium when bound to troponin causes conformational changes in the sarcomere. Consequently, the interaction of thick and thin filaments of the sarcomere leads to muscle contraction.

Things happen very quickly in the world of excitable membranes (think about how quickly you can snap your fingers as soon as you decide to do it). Immediately following depolarization of the membrane, it repolarizes, re-establishing the negative membrane potential. Meanwhile, the ACh in the synaptic cleft is degraded by the enzyme acetylcholinesterase (AChE). The ACh cannot rebind to a receptor and reopen its channel, which would cause unwanted extended muscle excitation and contraction.

Propagation of an action potential along the sarcolemma enters the **T-tubules**. For the action potential to reach the membrane of the Sarcoplasmic Reticulum (SR), there are periodic invaginations in the sarcolemma, called **T-tubules** ("T" stands for "transverse"). The arrangement of a T-tubule with the membranes of SR on either side is called a **triad** (Figure **5.6.3**). The triad surrounds the cylindrical structure called a **myofibril**, which contains actin and myosin. The T-tubules carry the action potential into the interior of the cell, which triggers the opening of calcium channels in the membrane of the adjacent SR, causing Ca^{++} to diffuse out of the SR and into the sarcoplasm. It is the arrival of Ca^{++} in the sarcoplasm that initiates

contraction of the muscle fiber by its contractile units, or sarcomeres.

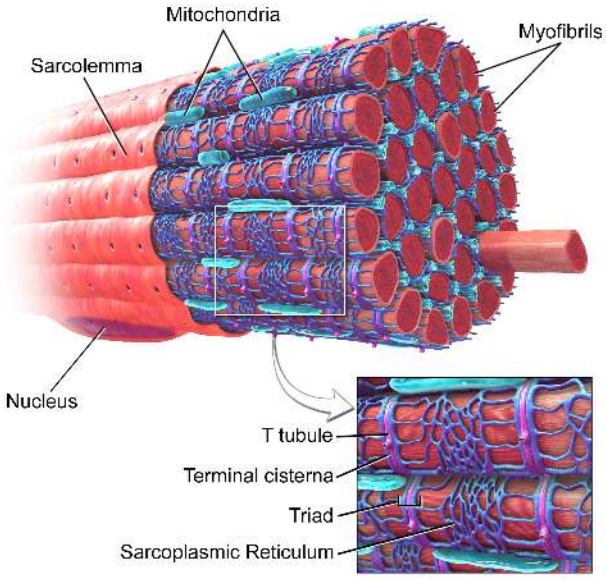


Figure 5.6.3: Narrow T-tubules permit the conduction of electrical impulses. The SR functions to regulate intracellular levels of calcium. Two terminal cisternae (where enlarged SR connects to the T-tubule) and one T-tubule comprise a triad—a "threesome" of membranes, with those of SR on two sides and the T-tubule sandwiched between them.

EXCITATION-CONTRACTION COUPLING

Although the term **excitation-contraction coupling** confuses or scares some students, it comes down to this: for a skeletal muscle fiber to contract, its membrane must first be "excited"—in other words, it must be stimulated to fire an action potential. The muscle fiber action potential, which sweeps along the sarcolemma as a wave, is "coupled" to the actual contraction through the release of calcium ions (Ca^{++}) from the SR. Once released, the Ca^{++} interacts with the shielding proteins, troponin and tropomyosin complex, forcing them to move aside so that the actin-binding sites are available for attachment by myosin heads. The myosin then pulls the actin filaments toward the center, shortening the muscle fiber.

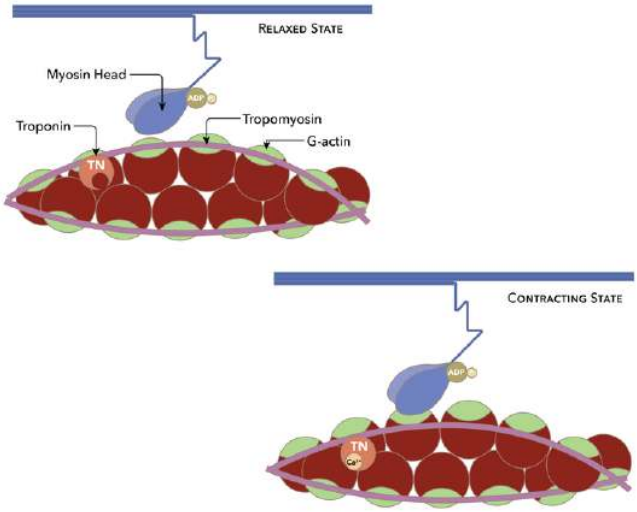


Figure 5.6.4: Tropomyosin Troponin complex shields the cross-bridge sites on actin. Myosin can only bind with actin when this complex is removed with the help of Calcium ions.

In skeletal muscle, this sequence begins with signals from the somatic motor division of the nervous system. In other words, the "excitation" step in skeletal muscles is always triggered by signaling from the nervous system.

SLIDING FILAMENT THEORY OF MUSCLE CONTRACTION

Once the muscle fiber is stimulated by the motor neuron, actin, and myosin protein filaments within the skeletal muscle fiber slide past each other to produce a contraction. The **sliding filament theory** is the most widely accepted explanation for how this occurs. According to this theory, muscle contraction is a cycle of molecular events in which thick myosin filaments repeatedly attach to and pull on thin actin filaments, so they slide over one another. The actin filaments are attached to Z discs, each of which marks the end of a sarcomere. The sliding of the filaments pulls the Z discs of a sarcomere closer together, thus shortening the sarcomere. As this occurs, the muscle contracts.

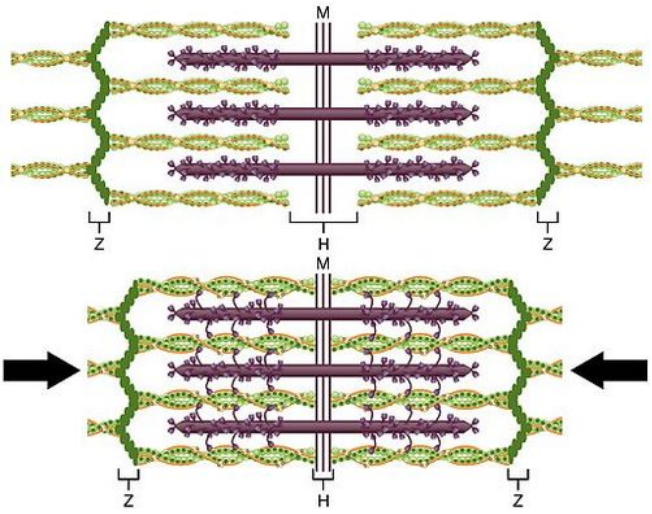


Figure **5.6.5**: The top diagram shows a relaxed sarcomere, and the bottom diagram shows a contracted sarcomere. Please note the z discs, h zone, and M line. In a contracted sarcomere the H zone reduces as compared to relaxed sarcomere because actin fibers (greenish-yellow double helix) move towards the M line.

CROSSBRIDGE CYCLING

Crossbridge cycling is a sequence of molecular events that underlies the sliding filament theory. There are many projections from the thick myosin filaments, each of which consists of two myosin heads (you can see the projections and heads in Figures **5.6.5** and **5.6.3**). Each myosin head has binding sites for ATP (or ATP hydrolysis products: ADP and P_i) and actin. The thin actin filaments also have binding sites for the myosin heads—a cross-bridge forms when a myosin head binds with an actin filament.

The process of cross-bridge cycling is shown in Figure **5.6.6**. A cross-bridge cycle begins when the myosin head binds to an actin filament. ADP and P_i are also bound to the myosin head at this stage. Next, a power stroke moves the actin filament inward toward the sarcomere center, thereby shortening the sarcomere. At the end of the power stroke, ADP and P_i are released from the myosin head, leaving the myosin head attached to the thin filament until another ATP binds to the myosin head. When ATP binds to the myosin head, it causes the myosin head to detach from the actin filament. ATP is again split into ADP and P_i and the energy released is used to move the myosin head into a "cocked" position. Once in this position, the myosin head can bind to the actin filament again, and another cross-bridge cycle begins.

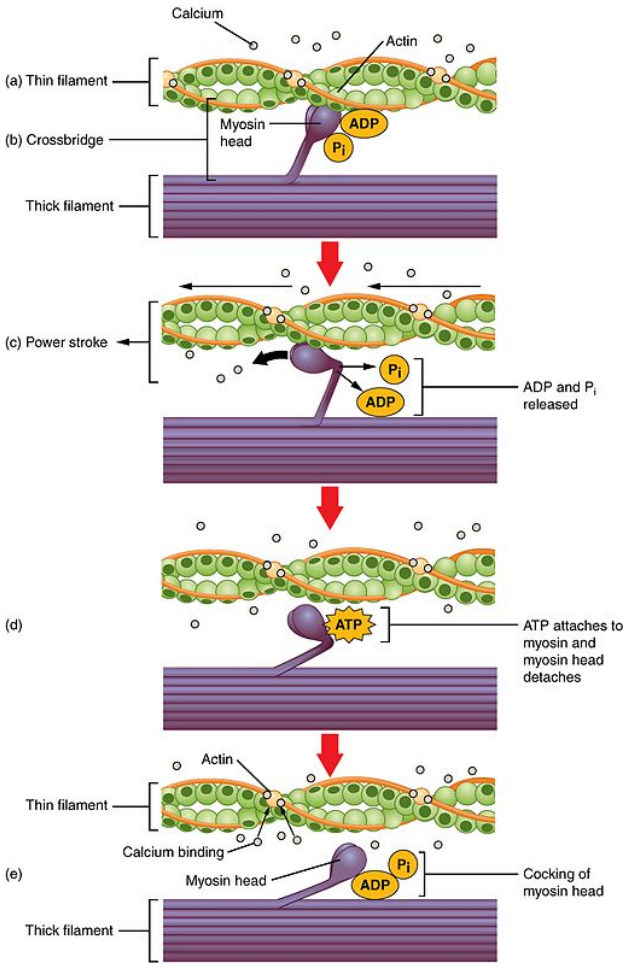


Figure **5.6.6**: Crossbridge cycling

FEATURE: HUMAN BIOLOGY IN THE NEWS

Interesting and hopeful basic research on muscle contraction is often in the news because muscle contractions are involved in so many different body processes and disorders, including heart failure and stroke.

- **Heart failure** is a chronic condition in which cardiac muscle cells cannot contract forcefully enough to keep body cells adequately supplied with oxygen. In 2016, researchers at the University of Texas Southwestern Medical Center identified a potential new target for developing drugs to increase the strength of cardiac muscle contractions in patients with heart failure. The UT researchers found a previously unidentified protein involved in muscle contraction. The minimal protein turns off the “brake” on the heart, so it pumps blood more vigorously. At the molecular level, the protein affects the calcium-ion pump that controls muscle contraction. This result is likely to lead to searches for additional such proteins.
- A **stroke** occurs when a blood clot lodges in an artery in the brain and cuts off blood flow to part of the brain. Damage from the clot would be reduced if the smooth muscles lining brain arteries relaxed following a stroke because the arteries

would dilate and allow greater blood flow to the brain. In a recent study undertaken at the Yale University School of Medicine, researchers determined that the muscles lining blood vessels in the brain actually contract after a stroke. This constricts the vessels, reduces blood flow to the brain, and appears to contribute to permanent brain damage. The hopeful takeaway of this finding is that it suggests a new target for stroke therapy.

REVIEW

1. What is skeletal muscle contraction?
2. Distinguish between isometric and isotonic contractions of skeletal muscle.
3. How does a motor neuron stimulate a skeletal muscle contraction?
4. What is the sliding filament theory?
5. Describe cross-bridge cycling.
6. Where does the ATP needed for a muscle contraction come from?
7. Explain why an action potential in a single motor neuron can cause multiple muscle fibers to contract.
8. The name of the synapse between a motor neuron and a muscle fiber is the _____ _____.
9. If a drug blocks the acetylcholine receptors on muscle fibers, what do you think this would do to muscle contraction? Explain your answer.
10. *True or False:* According to the sliding filament theory, actin filaments actively attach to and pull on myosin filaments.
11. *True or False:* When a motor neuron produces an action potential, the sarcomeres in the muscle fiber that it innervates become shorter as a result.
12. Explain how cross-bridge cycling and sliding filament theory are related to each other.
13. When does anaerobic respiration typically occur in human muscle cells?
14. If there were no ATP available in a muscle, how would this affect cross-bridge cycling? What would this do to muscle contraction?

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5.7: PHYSICAL EXERCISE

STROLLERS

These caregivers are setting a great example for their children by engaging in physical exercise. Adopting a regular physical exercise habit is one of the most important ways to maintain fitness and good health. From higher self-esteem to a healthier heart, physical exercise can positively affect virtually all aspects of health, including physical, mental, and emotional health.



Figure **5.7.1**: Jogging with strollers

WHAT IS PHYSICAL EXERCISE?

Physical exercise is any bodily activity that enhances or maintains physical fitness and overall health and wellness. We generally think of physical exercise as activities that are undertaken for the main purpose of improving physical fitness and health. However, physical activities that are undertaken for other purposes may also count as physical exercise. Scrubbing a floor, raking a lawn, or playing active games with young children or a dog are all activities that can have fitness and health benefits, even though they generally are not done mainly for this purpose.

How much physical exercise should people get? In the United States, both the Centers for Disease Control and Prevention and the Surgeon General have recommended that every adult participates in moderate exercise for a minimum of 30 minutes a day. This might include walking, swimming, and/or household or yard work.

TYPES OF PHYSICAL EXERCISE

Physical exercise can be classified into three types, depending on the effects it has on the body: aerobic exercise, anaerobic exercise, and flexibility exercise. Many specific physical exercise examples (including playing soccer and rock climbing) can be classified as more than one type.

AEROBIC EXERCISE

Aerobic exercise is any physical activity in which muscles are used below their maximum contraction strength, but for long periods of time. Aerobic exercise uses a relatively high percentage of slow-twitch muscle fibers that consume a large amount of oxygen. The main goal of aerobic exercise is to increase cardiovascular endurance, although it can have many other benefits, including muscle toning. Examples of aerobic exercise include cycling, swimming, brisk walking, jumping rope, rowing, hiking, and tennis.

ANAEROBIC EXERCISE

Anaerobic exercise is any physical activity in which muscles are used close to their maximum contraction strength but for relatively short periods of time. Anaerobic exercise uses a relatively high percentage of fast-twitch muscle fibers that consume a small amount of oxygen. The goals of anaerobic exercise include building and strengthening muscles and improving bone strength, balance, and coordination. Examples of anaerobic exercise include push-ups, lunges, sprinting, interval training, resistance training, and weight training (such as biceps curls with a dumbbell, as pictured Figure **5.7.2**).



Figure **5.7.2**: Pitting the biceps muscle in the upper arm against a heavyweight helps build and strengthen this muscle.

FLEXIBILITY EXERCISE

Flexibility exercise is any physical activity that stretches and lengthens muscles. The goals of flexibility exercise include increasing joint flexibility, keeping muscles limber, and improving the range of motion, all of which can reduce the risk of injury. Examples of flexibility exercises include stretching, yoga, and tai chi.

HEALTH BENEFITS OF PHYSICAL EXERCISE

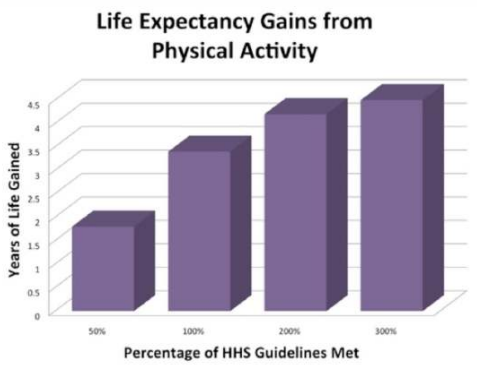


Figure 5.7.3: The U.S. Department of Health and Human Services (HHS) recommends that adults aged 18 to 64 engage in regular aerobic physical activity for 2.5 hours at moderate intensity (1.25 hours at vigorous intensity) each week. Moderate activities are those during which a person could talk but not sing. Vigorous activities are those during which a person could say only a few words without stopping to breathe. When people exercise at 50 percent of the HHS guidelines, they gain an average of 1.5 years of life. Exercising at 100 percent of the HHS guidelines results in a gain of almost four years of life. The gain in life expectancy starts to level off at about 300 percent of the HHS guidelines.

Many studies have shown that physical exercise is positively correlated with a diversity of health benefits. Some of these benefits include maintaining physical fitness, losing weight and maintaining a healthy weight, regulating digestive health, building and maintaining healthy bone density, increasing muscle strength, improving joint mobility, strengthening the immune system, boosting cognitive ability, and promoting psychological well-being. Some studies have also found a significant positive correlation between exercise and quality of life and life expectancy. People who participate in moderate to high levels of physical activity have been shown to have lower mortality rates than people of the same ages who are not physically active. The years of life gained with different amounts of physical activity are shown in the graph in Figure 5.7.3.

The underlying physiological mechanisms explaining why exercise has these positive health benefits are not completely understood. However, developing research suggests that many of the benefits of exercise may come about because of skeletal muscles' role as endocrine organs. Contracting muscles release hormones called **myokines**, which promote tissue repair and the growth of new tissue. Myokines also have anti-inflammatory effects, which, in turn, reduce the risk of developing inflammatory diseases. Exercise also reduces cortisol levels, the adrenal cortex stress hormone that may cause many health problems — both physical and mental — at sustained high levels.

CARDIOVASCULAR BENEFITS OF PHYSICAL EXERCISE

The beneficial effects of exercise on the cardiovascular system are well documented. Physical inactivity has been identified as a risk factor for the development of coronary artery disease. There is also a direct correlation between physical inactivity and cardiovascular disease mortality. Physical exercise, in contrast, has been demonstrated to reduce several risk factors for cardiovascular disease, including hypertension (high blood pressure), "bad" cholesterol (low-density lipoproteins), high total cholesterol, and excess body weight. Physical exercise has also been shown to increase "good" cholesterol (high-density lipoproteins), insulin sensitivity, the mechanical efficiency of the heart, and exercise tolerance, which can perform physical activity without undue stress and fatigue.

COGNITIVE BENEFITS OF PHYSICAL EXERCISE

Physical exercise has been shown to help protect people from developing neurodegenerative disorders, such as dementia. A 30-year study of almost 2,400 men found that those who exercised regularly had a 59 percent reduction in dementia when compared with those who did not exercise. Similarly, a review of cognitive enrichment therapies for the elderly found that physical activity — in particular, aerobic exercise — can enhance the cognitive function of older adults. Anecdotal evidence suggests that frequent exercise may even help reverse alcohol-induced brain damage. There are several possible reasons why exercise is so beneficial for the brain. Physical exercise:

- increases blood flow and oxygen availability to the brain
- increases growth factors that promote new brain cells and new neuronal pathways in the brain
- increases levels of neurotransmitters (such as serotonin), which increase memory retention, information processing, and cognition

MENTAL HEALTH BENEFITS OF PHYSICAL EXERCISE

Numerous studies suggest that regular aerobic exercise works as well as pharmaceutical antidepressants in treating mild-to-moderate depression. A possible reason for this effect is that exercise increases the biosynthesis of at least three neurochemicals that may act as euphoriants. The euphoric effect of exercise is well known. Distance runners may refer to it as "runner's high," and people who participate in the crew (Figure 5.7.4) may refer to it as "rower's high." Because of these effects, health care providers often promote aerobic exercise as a treatment for depression.



Figure 5.7.4: This crew team is competing for the U.S. Army in the lightweight division of the world championships in 2003. They are clearly exerting themselves — and no doubt increasing their euphoriant neurochemicals in the process.

Additional mental health benefits of physical exercise include reducing stress, improving body image, and promoting positive self-esteem. Conversely, there is evidence to suggest that being sedentary is associated with an increased risk of anxiety.

SLEEP BENEFITS OF PHYSICAL EXERCISE

A recent review of published scientific research suggests that exercise generally improves sleep for most people and helps sleep disorders, such as insomnia. Exercise is the most recommended alternative to sleeping pills for people with insomnia. For sleep benefits, the optimum time to exercise is four to eight hours before bedtime, although exercise at any time of day seems to be beneficial. The only possible exception is a heavy exercise undertaken shortly before bedtime, which may actually interfere with sleep.

OTHER BENEFITS OF PHYSICAL EXERCISE

Some studies suggest that physical activity may benefit the immune system. For example, moderate excise is associated with a decreased incidence of upper respiratory tract infections. Evidence from many studies has found a correlation between physical exercise and reduced death rates from cancer, specifically breast cancer and colon cancer. Physical exercise has also been shown to reduce the risk of type 2 diabetes and obesity.

VARIATION IN RESPONSES TO PHYSICAL EXERCISE

Not everyone benefits equally from physical exercise. When participating in aerobic exercise, most people will have a moderate increase in their endurance, but some will double their endurance. On the other hand, some people will show little or no increase in endurance from aerobic exercise. Genetic differences in slow-twitch and fast-twitch skeletal muscle fibers may play a role in these different results. People with more slow-twitch fibers may develop greater endurance because these muscle fibers have more capillaries, mitochondria, and myoglobin than fast-twitch fibers. As a result, slow-twitch fibers can carry more oxygen and sustain aerobic activity for a longer period of time than fast-twitch fibers. Studies show that endurance athletes (like the marathoner in Figure **5.7.5**) generally tend to have a higher proportion of slow-twitch fibers than other people.



Figure **5.7.5**: This winning marathoner is likely to have a relatively high proportion of slow-twitch muscle fibers that increase his endurance.

There is also great variation in individual responses to muscle building as a result of anaerobic exercise. Some people have a much greater capacity to increase muscle size and strength, whereas other people never develop large muscles, no matter how much they exercise them. People who have more fast-twitch than slow-twitch muscle fibers may develop bigger, stronger muscles because fast-twitch muscle fibers contribute more to muscle strength and have greater potential to increase in mass. Evidence suggests that athletes who excel at power activities (such as throwing and jumping) tend to have a higher proportion of fast-twitch fibers than endurance athletes.

CAN YOU "OVERDOSE" ON PHYSICAL EXERCISE?



Figure **5.7.6**: New military recruits may suffer muscle damage from overexertion of unconditioned muscles. The drill instructor pictured here (in an orange shirt) is doing his best to encourage these marine recruits to expend their maximum effort.

Is it possible to exercise too much? Can too much exercise be harmful? Evidence suggests that some adverse effects may occur if exercise is extremely intense and the body is not given proper rest between exercise sessions. Athletes who train for multiple marathons have been shown to develop scarring of the heart and heart rhythm abnormalities. Doing too much exercise without prior conditioning also increases the risk of injuries to muscles and joints. Damage to muscles due to overexertion is often seen in new military recruits (Figure **5.7.6**). Too much exercise in females may cause amenorrhea, which is a cessation of menstrual periods. When this occurs, it generally indicates that a woman is pushing her body too hard.

Many people develop delayed onset muscle soreness (DOMS), which is pain or discomfort in muscles felt one to three days after exercising and generally subsides two or three days later. DOMS was once thought to be caused by the buildup of lactic acid in the muscles. Lactic acid is a product of anaerobic respiration in muscle tissues. However, lactic acid disperses fairly rapidly, so it is unlikely to explain pain experienced several days after exercise. The current theory is that DOMS is caused by tiny tears in muscle fibers, which occur when muscles are used at too high a level of intensity.

FEATURE: MY HUMAN BODY

Most people know that exercise is important for good health, and it's easy to find endless advice about exercise programs and fitness plans. What is not so easy to find is the motivation to start exercising and stick with it. This is the main reason why so many people fail to get regular exercise. Practical concerns like a busy schedule and bad weather can certainly make exercising more of a challenge, but the biggest barriers to adopting a

regular exercise routine are mental. If you want to exercise but find yourself making excuses or getting discouraged and giving up, here are some tips that may help you get started and stay moving:

- **Avoid an all-or-nothing point of view.** Don't think you need to spend hours sweating at the gym or training for a marathon to get healthy. Even a little bit of exercise is better than nothing at all. Start with ten or 15 minutes of moderate activity each day. Taking a walk around your neighborhood is a great way to begin! From there, gradually increase the amount of time until you exercise to at least 30 minutes a day, five days a week.
- **Be kind to yourself, and reinforce positive behaviors with rewards.** Don't be down on yourself because you are overweight or out of shape. Don't beat yourself up because of a supposed lack of willpower. Instead, look at any past failures as opportunities to learn and do better. When you do achieve even small exercise goals, treat yourself to something special. Did you complete your first workout? Reward yourself with a relaxing bath or other treats.
- **Don't make excuses for not exercising.** Common complaints include being too busy or tired or not athletic enough. Such excuses are not valid reasons to avoid exercising, and they will sabotage any plans to improve your fitness. If you can't find a 30-minute period to work out, try to find ten minutes, three times a day. If you're feeling tired, know that exercise can actually reduce fatigue and boost your energy level. If you feel clumsy and uncoordinated, remind yourself that you don't need to be athletic to take a walk or engage in vigorous house or yard work.
- **Find an activity that you truly enjoy doing.** Don't think you have to lift weights or run on a treadmill to exercise your muscles. If you find such activities boring or unpleasant, you won't stick with them. Any activity that increases your heart rate and uses large muscles can provide a workout, especially if you're not in the habit of exercising, so find something you like to do. Do you like to dance? Put on some music and dance up a sweat! Do you enjoy gardening? Get out in the yard and dig up some dirt! Still not interested? Try an activity-based video game, such as Wii or Kinect. You may find it so much fun that it doesn't seem like exercise until you realize you've worked up a sweat.
- **Make yourself accountable.** Tell friends and family members that you're going to start exercising. You'll be letting them — as well as yourself — down if you don't follow through. Some people find that keeping an exercise log to track their progress is a good way to be accountable and stick to an exercise program. Perhaps the best way to keep at it is to find an exercise partner. If you've got someone waiting to exercise with you, you will be less likely to make excuses for not exercising.
- **Add more physical activity to your daily life.** You don't need to follow a structured exercise program to increase your activity level. Do your house or yard work briskly for a workout. Park your car further than necessary from work or the mall, and walk the extra distance. If you live close enough, leave the car at home and walk to and from your destination. Rather than taking elevators or escalators, walk up and downstairs. When you take breaks at work, take a walk instead of sitting. Every time a commercial comes on while you're watching TV, take a quick exercise break — run in place or do some curls with hand weights.

REVIEW

1. How is physical exercise defined?
2. What are the current recommendations for physical exercise for adults?
3. Describe aerobic exercise, and give examples of aerobic exercises.
4. How does anaerobic exercise differ from aerobic exercise, and what are some examples of anaerobic exercises?
5. Define flexibility exercise, and state its benefits. What are two examples of flexibility exercises?
6. In general, how does physical exercise affect health, quality of life, and longevity?
7. What mechanism may underlie many of the general health benefits of physical exercise?
8. Relate physical exercise to cardiovascular disease risk.
9. What may explain the positive benefits of physical exercise on cognition?
10. How does physical exercise compare with antidepressant drugs in the treatment of depression?
11. Identify several other health benefits of physical exercise.
12. Explain how genetics may influence the way individuals respond to physical exercise.
13. Can too much physical exercise be harmful?
14. Lifting hefty weights for a short period of time is likely to:

    A. use a relatively high percentage of fast-twitch muscle fibers

    B. use a relatively high percentage of slow-twitch muscle fibers

    C. be an aerobic exercise

    D. use a large amount of oxygen

15. Walking quickly for an extended period of time is likely to:

    A. use a relatively high percentage of fast-twitch muscle fibers

    B. use a relatively high percentage of slow-twitch muscle fibers

    C. use muscles at close to their maximum contraction

    D. cause the muscles to use only a small amount of oxygen

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5.8: DISORDERS OF THE MUSCULAR SYSTEM

PAIN IN THE NECK

Spending hours each day looking down at hand-held devices is a pain in the neck — literally. The weight of the head bending forward can put a lot of strain on neck muscles, and muscle injuries can be excruciating. Neck pain is one of the most common complaints that bring people to the doctor's office. In any given year, about one in five adults will suffer from neck pain. That's a lot of pain in the neck! Not all of them are due to muscular disorders, but many of them are. Muscular disorders, in turn, generally fall into two general categories: musculoskeletal disorders and neuromuscular disorders.



Figure **5.8.1**: On the phone

MUSCULOSKELETAL DISORDERS

Musculoskeletal disorders are injuries in muscles or associated tissues (such as tendons) because of biomechanical stresses. They may be caused by sudden exertion, over-exertion, repetitive motions, or long periods of maintaining awkward positions. Musculoskeletal disorders often work- or sports-related, and generally, just one or a few muscles are affected. They can often be treated successfully, and full recovery can be very likely. The disorders include muscle strains, tendonitis, and carpal tunnel syndrome.

MUSCLE STRAIN

A **muscle strain** is an injury in which muscle fibers tear as a result of overstretching. A muscle strain is also commonly called a pulled muscle or torn muscle. (Strains are often confused with sprains, which are similar injuries to ligaments.) Depending on the degree of injury to muscle fibers, a muscle strain can range from mildly to extremely painful. Besides pain, typical symptoms include stiffness and bruising in the area of the strained muscle. Figure **5.8.2** shows a large bruise caused by a hamstring muscle strain. Hamstring strains are prevalent in track and field athletes. In sprinters, for example, about one-third of injuries are hamstring injuries. Having a previous hamstring injury puts an athlete at increased risk of having another one.



Figure **5.8.2**: Bleeding in muscle tissue may cause a muscle strain to produce a bruise over the affected muscle, as in this hamstring bruise. The photos show two images of the same leg, both taken four days after the injury occurred.

Proper first aid for a muscle strain includes five steps, which are represented by the acronym PRICE. The PRICE steps should be followed for several days after the injury. The five steps are:

1. **Protection:** Apply soft padding to the strained muscle to minimize impact with objects that might cause further damage.
2. **Rest:** Rest the muscle to accelerate healing and reduce the potential for re-injury.
3. **Ice:** Apply ice for 20 minutes at a time every two hours to reduce swelling and pain.
4. **Compression:** Apply a stretchy bandage to the strained muscle to reduce swelling.
5. **Elevation:** Keep the strained muscle elevated to reduce the chance of blood pooling in the muscle.

Non-steroidal anti-inflammatory drugs (NSAIDs, such as ibuprofen) can help reduce inflammation and relieve pain. However, because such drugs interfere with blood clotting, they should be taken only after bleeding in the muscle has stopped — not immediately after the injury occurs. For severe muscle strains, professional medical care may be needed.

TENDINITIS

Tendinitis is inflammation of a tendon that occurs when it is over-extended or worked too hard without rest. Tendons that are commonly affected include those in the ankle, knee, shoulder, and elbow. The affected tendon depends on the type of use that causes inflammation. Rock climbers tend to develop tendinitis in their fingers, while basketball players are more likely to develop tendonitis in the knees, to name a few examples.

Symptoms of tendinitis may include aching, sharp pain, a burning sensation, or joint stiffness. In some cases, swelling occurs around the inflamed tendon, and the area feels hot and looks red. Treatment includes the PRICE guidelines listed above and the use of NSAIDs to reduce inflammation and pain further. Although symptoms should show improvement within a few days of treatment, full recovery may take several months. A gradual return to exercise or other use of the affected tendon is recommended. Physical or occupational therapy may speed the return to normal activity levels.

CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome is a common biomechanical problem in the wrist when the median nerve becomes compressed between carpal bones (Figure **5.8.3**). This may occur due to repetitive use of the wrist, a tumor, or trauma to the wrist. Two-thirds of the cases are work-related. Computer work, work with vibrating tools and work requiring a strong grip all increase one's risk of developing this problem. Carpal tunnel syndrome occurs more often in women than in men. Other risk factors include obesity, pregnancy, and arthritis. Genetics may also play a role.

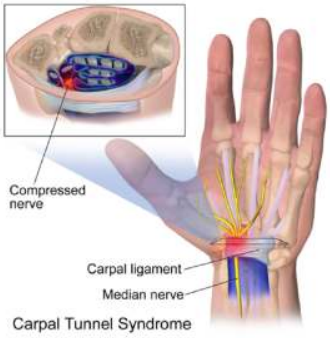


Figure **5.8.3**: Carpal tunnel syndrome occurs when the median nerve in the wrist becomes compressed.

Compression of the median nerve results in the muscles' inadequate nervous stimulation in the thumb and first two fingers of the hand. The main symptoms are pain, numbness, and tingling in these digits. Sometimes, symptoms can be improved by wearing a wrist splint or receiving corticosteroid injections. Surgery to cut the carpal ligament reduces pressure on the median nerve and is generally more effective than nonsurgical treatment. Recurrence of carpal tunnel syndrome after surgery is rare. On the other hand, without treatment, the lack of nervous stimulation by the median nerve may eventually cause the affected muscles of the hand to weaken and waste away.

NEUROMUSCULAR DISORDERS

Neuromuscular disorders are systemic disorders that occur because of problems with the nervous control of muscle contractions or muscle cells themselves. These disorders are often due to faulty genes and not due to biomechanical stresses. Other system-wide problems, such as abnormal immune system responses, may also be involved in neuromuscular disorders.

Unlike musculoskeletal disorders, neuromuscular disorders generally affect most or all of the muscles in the body. The disorders also tend to be progressive and incurable. However, in most cases, treatment is available to slow the disease progression or lessen symptoms. Examples of neuromuscular disorders include muscular dystrophy, myasthenia gravis, and Parkinson's disease.

MUSCULAR DYSTROPHY

Muscular dystrophy is a genetic disorder caused by defective proteins in muscle cells. It is characterized by progressive skeletal muscle weakness and death of muscle cells and tissues. Muscles become increasingly unable to contract in response to nervous stimulation.

There are at least nine major types of muscular dystrophy caused by different gene mutations. Some of the mutations cause autosomal recessive or autosomal dominant disorders, and some cause X-linked disorders. The most common type of childhood muscular dystrophy is Duchenne muscular dystrophy (DMD) due to a mutation in a recessive gene on the X chromosome. As an X-linked recessive disorder, Duchenne muscular dystrophy occurs almost exclusively in males.

Different types of muscular dystrophy affect different major muscle groups. In Duchenne muscular dystrophy, the lower limbs are affected. Signs of the disorder usually first become apparent when a child starts walking. Difficulty walking becomes progressively worse through childhood. By the time a child is ten, braces may be needed for walking — and walking may no longer even be possible by age 12. The lifespan of someone with muscular dystrophy is likely to be shorter than normal because of the disease, ranging from 15 to 45 years.

Duchenne muscular dystrophy (DMD) is a progressive weakening of the skeletal muscles. It is one of several diseases collectively referred to as "muscular dystrophy." DMD is caused by a lack of the protein dystrophin, which helps the thin filaments of myofibrils bind to the sarcolemma. Without sufficient dystrophin, muscle contractions cause the sarcolemma to tear, causing an influx of Ca++, leading to cellular damage and muscle fiber degradation. Over time, as muscle damage accumulates, muscle mass is lost, and greater functional impairments develop.

In some cases, physical therapy, drug therapy, or orthopedic surgery may improve muscular dystrophy signs and symptoms. However, at present, there is no known cure for the disorder. Research is ongoing to find a cure, with financial support from such sources as the Muscular Dystrophy Association (MDA) (see photo below). MDA is a non-profit organization dedicated to curing muscular dystrophy by funding worldwide research.



Figure **5.8.4**: A firefighters from Camp Pendleton, California, who collected donations during their off hours for the Muscular Dystrophy Association (MDA) in 2010.

MYASTHENIA GRAVIS

Myasthenia gravis is an autoimmune disorder in which circulating antibodies block the nicotinic acetylcholine receptors on the neuromuscular junction's motor endplate. This blockage of acetylcholine receptors causes muscle weakness, often first exhibiting drooping eyelids and expanding to include overall muscle

weakness and fatigue. It occurs more commonly in women and generally begins between the ages of 20 and 40. The initial symptom of myasthenia gravis is painless muscle weakness, generally in muscles around the eye (Figure 5.8.5). The disease then progresses to muscles elsewhere in the body, eventually involving most of the muscles. Swallowing and chewing may become difficult as the disease progresses, and speech may become slow and slur. In more advanced cases, myasthenia crises may occur, during which the muscles that control breathing may be affected. Emergency medical care to provide assisted ventilation is required to sustain life. A myasthenia gravis crisis may be triggered by various stressors, such as infection, fever, or stress. Treatment of myasthenia gravis may include medications to counter the mutant gene's effects or suppress the immune system.



Figure 5.8.5: The photograph on the left shows a myasthenia gravis patient with a drooping eyelid. The photo on the right shows the same patient after administering a drug that blocks the breakdown of acetylcholine.

PARKINSON'S DISEASE



Figure 5.8.6: The awkward, stooped gait of this person is typical of people with advanced Parkinson's disease.

Parkinson's disease is a degenerative disorder of the central nervous system that mainly affects the muscular system and movement. Four motor signs and symptoms are considered defining Parkinson's disease: muscle tremor (shaking), muscle rigidity, slowness of movement, and postural instability. Tremor is the most common and obvious symptom, and it most often occurs in a limb at rest, so it disappears during sleep or when the patient moves the limb voluntarily. Difficulty walking eventually develops, and dementia is common in the advanced stages of the disease. Depression is common, as well.

Parkinson's disease is more common in older people, with most cases being diagnosed after 50. Often, the disease occurs for no known reason. Cases like this are called primary Parkinson's disease. Sometimes, the disease has a known or suspected cause, such as exposure to toxins in pesticides or repeated head trauma. In this case, it is called secondary Parkinson's disease. Regardless of the cause, the disease's motor symptoms result from the death of neurons in the midbrain. The cause of cell death is not fully understood, but it appears to involve the buildup in the brain of protein structures called Lewy bodies. Early in the course of the illness, medications can be prescribed to help reduce the motor disturbances. As the disease progresses, however, the medications become ineffective. They also cause a negative side effect of involuntary writhing movements.

FEATURE: HUMAN BIOLOGY IN THE NEWS

On June 3, 2016, media worldwide exploded with news of the death of Muhammad Ali at the age of 74. The world champion boxer and Olympic gold medalist died that day of a respiratory infection complication, but the underlying cause was Parkinson's disease. Ali was diagnosed with Parkinson's in 1984 when he was only 42 years old. Doctors attributed his disease to repeated head trauma from boxing.

In the days following Ali's death, the news was full of stories and images from milestones in the athlete's life, both before and after his diagnosis with Parkinson's disease. Sadly, the news coverage also provided an overview of his gradual decline as the disease progressed. Ali was pictured in 1996, lighting the flame at the Summer Olympics in Atlanta. In 2012, Ali had to be helped to his feet by his wife to stand before the flag he was supposed to carry into the stadium. He was unable to carry it because of the ravages of Parkinson's disease.

Muhammad Ali retired from boxing in 1981 at 39, but he didn't retire from fighting. Until the final year of his life, Ali was a passionate activist for peace and justice and against war and racism. In 1998, he joined Michael J. Fox, who also has Parkinson's disease, to raise awareness and fund research on Parkinson's disease. In 2002, Fox and Ali made a joint appearance before Congress to present their case. In 2005, Ali received the Presidential Medal of Freedom from George W. Bush (Figure 5.8.7) for the many achievements and contributions he made throughout his amazing life, despite Parkinson's disease.



Figure 5.8.7: President George W. Bush gives a congratulatory hug to Muhammad Ali after awarding him a Presidential Medal of Freedom in 2005 as Ali's wife, Lonnie Ali, looks on.

REVIEW

1. What are musculoskeletal disorders? What causes them?
2. How does a muscle strain occur?
3. Define tendinitis. Why does it occur?
4. Identify first-aid steps for treating musculoskeletal disorders such as muscle strains and tendinitis.
5. Describe carpal tunnel syndrome and how it may be treated.
6. Define neuromuscular disorders.
7. Identify the cause and symptoms of muscular dystrophy.

8. Outline the cause and progression of myasthenia gravis.
9. What is Parkinson's disease? List four characteristic signs of the disorder.
10. What are the main differences between musculoskeletal disorders and neuromuscular disorders?
11. Why is the padding of a strained muscle part of the typical treatment?
12. Which disorder would be the most likely to be caused by repeated use of a jackhammer?

    A. Parkinson's disease

    B. Muscular dystrophy

    C. Carpal tunnel syndrome

    D. A neuromuscular disorder

13. *True or False.* Participation in some sports may cause Parkinson's disease.
14. *True or False.* Myasthenia gravis occurs because the body stops making acetylcholine.
15. What are two tissues, other than muscle tissue, that can experience problems that result in muscular system disorders?

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5.9: CASE STUDY CONCLUSION- NEEDING TO RELAX AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: NEEDING TO RELAX

As you learned at the beginning of this chapter, botulinum toxin—one form sold under the brand name Botox—does much more than smooth out wrinkles. It can be used to treat several disorders involving excessive muscle contraction, including cervical dystonia. You also learned that cervical dystonia, from which Nasir suffers, causes abnormal, involuntary muscle contractions of the neck. This results in the head and neck's jerky movements and/or a sustained abnormal tilt to the head. It is often painful and can significantly interfere with a person's life.

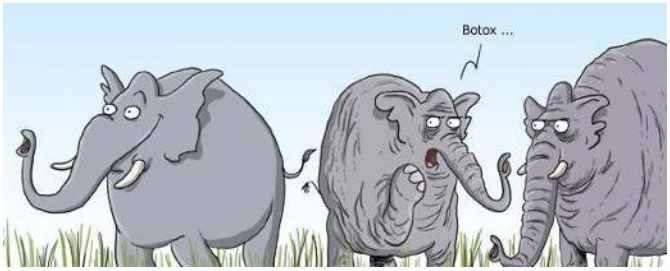


Figure 5.9.1: Botox, he whispered.

How could a toxin actually *help* treat a muscular disorder? The soil bacterium *Clostridium botulinum* produces the botulinum toxin, and it is the cause of the potentially deadly disease called botulism. Botulism is often a foodborne illness, commonly caused by improperly canned foods. Other forms of botulism are caused by wound infections or occur when infants consume the bacteria's spores from soil or honey.

Botulism can be life-threatening because it paralyzes muscles throughout the body, including those involved in breathing. When a minimal amount of botulinum toxin is injected carefully into specific muscles by a trained medical professional, however, it can inhibit unwanted muscle contractions.



Figure 5.9.2: These pickles are jokingly labeled "botulism," but actual botulism is really no joke.

For cosmetic purposes, botulinum toxin injected into the facial muscles relaxes them to reduce wrinkles' appearance. When used to treat cervical dystonia, it is injected into the neck muscles to inhibit excessive muscle contractions. For many patients, this helps relieve the abnormal positioning, movements, and pain associated with the disorder. The effect is temporary, so the injections must be repeated every three to four months to keep the symptoms under control.

How does botulinum toxin inhibit muscle contraction? First, recall how skeletal muscle contraction works. A motor neuron instructs skeletal muscle fibers to contract at a synapse between them called the neuromuscular junction. A nerve impulse called an action potential travels down to the motor neuron's axon terminal, where it causes the release of the neurotransmitter acetylcholine (ACh) from synaptic vesicles. The ACh travels across the synaptic cleft and binds to ACh receptors on the muscle fiber, signaling the muscle fiber to contract. According to the sliding filament theory, muscle fibers' contraction occurs due to the sliding of myosin and actin filaments across each other. This causes the Z discs of the sarcomeres to close together, shortening the sarcomeres and causing the muscle fiber to contract.

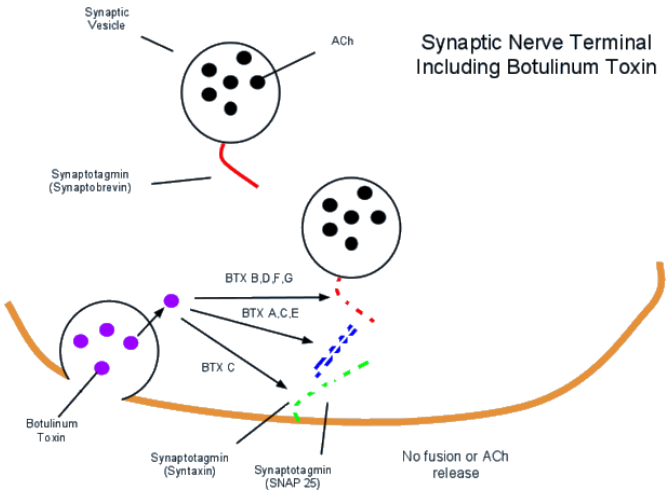


Figure 5.9.3: Botulinum toxins cleave (break down) proteins (depicted here as red, blue, and green lines) that normally allow synaptic vesicles to bind to the membrane of the motor neuron's axon terminal to release the neurotransmitter ACh. Cleavage of these proteins prevents the synaptic vesicles from fusing to the membrane, and therefore ACh release is inhibited. In this illustration, BTX A-G refers to different subtypes of botulinum toxins.

If you wanted to inhibit muscle contraction, at what points could you theoretically interfere with this process? Inhibiting the action potential in the motor neuron, the release of ACh, the activity of ACh receptors, or the sliding filament process in the muscle fiber would all theoretically impair this process and inhibit muscle contraction. For example, in the disease myasthenia gravis, the ACh receptors' function is impaired, causing a lack of sufficient muscle contraction. As you have learned, this results in muscle weakness that can eventually become life-threatening. Botulinum toxin works by inhibiting the release of ACh from the motor neurons, thereby removing the signal instructing the muscles to contract (Figure 5.9.3).

Fortunately, Nasir's excessive muscle contractions and associated pain improved significantly, thanks to botulinum toxin injections.

Although cervical dystonia cannot currently be cured, botulinum toxin injections have improved many patients' quality of life with this and other disorders involving excessive involuntary muscle contractions.

As you have learned in this chapter, our muscular system allows us to make voluntary movements, digest our food, and pump blood through our bodies. Whether in your arm, heart, stomach, or blood vessels, muscle tissue works by contracting. But as you have seen here, too much contraction can be a terrible thing. Fortunately, scientists and physicians have found a way to put a potentially deadly toxin—and wrinkle-reducing treatment—to excellent use as a medical treatment for some muscular system disorders.

CHAPTER SUMMARY

In this chapter, you learned about the muscular system. Specifically, you learned that:

- The muscular system consists of all the muscles of the body. There are three types of muscle: skeletal muscle (which is attached to bones by tendons and enables voluntary body movements), cardiac muscle (which makes up the walls of the heart and makes it beat), and smooth muscle (which is found in the walls of internal organs and other internal structures and controls their movements).
- Muscles are organs composed mainly of muscle cells, which may also be called muscle fibers or myocytes. Muscle cells are specialized for contracting, which occurs when protein filaments inside the cells slide over one another using energy from ATP. Muscle tissue is the only type of tissue that has cells with the ability to contract.
- Muscles can grow larger or hypertrophy. This generally occurs through increased use, although hormonal or other influences can also play a role. Muscles can also grow smaller or atrophy. This may occur through lack of use, starvation, certain diseases, or aging. In both hypertrophy and atrophy, the size—but not the number—of muscle fibers changes. The size of the muscles is the main determinant of muscle strength.
- Skeletal muscles need the stimulus of motor neurons to contract and to move the body; they need the skeletal system to act upon.
- Skeletal muscle is the most common type of muscle tissue in the human body. To move bones in opposite directions, skeletal muscles often consist of pairs of muscles that work in opposition to move bones in different directions at joints.
- Skeletal muscle fibers are bundled together in muscle fascicles, which are bundled together to form individual skeletal muscles. Skeletal muscles also have connective tissue supporting and protecting the muscle tissue.
    - Each skeletal muscle fiber consists of a bundle of myofibrils, which are bundles of protein filaments. The filaments are arranged in repeating units called sarcomeres, which are the skeletal muscles' basic functional units. Skeletal muscle tissue is striated because of the pattern of sarcomeres in its fibers.
    - Skeletal muscle fibers can be divided into two types, called slow-twitch and fast-twitch fibers. Slow-twitch fibers are used mainly in aerobic endurance activities (such as long-distance running). Fast-twitch fibers are used mainly for non-aerobic, strenuous activities (such as sprinting). Proportions of the two types of fibers vary from muscle to muscle and person to person.
- Smooth muscle tissue is found in the walls of internal organs and vessels. When smooth muscles contract, they help the organs and vessels carry out their functions. Contractions of smooth muscles are involuntary and controlled by the autonomic nervous system, hormones, and other substances.
    - Cells of smooth muscle tissue are not striated because they lack sarcomeres, but the cells contract in the same basic way as striated muscle cells. Unlike striated muscle, smooth muscle can sustain very long-term contractions and maintain its contractile function, even when stretched.
- Cardiac muscle tissue is found only in the wall of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Contractions of cardiac muscle are involuntary, like those of smooth muscles. Electrical impulses from specialized cardiac cells control them.
    - Like skeletal muscle, cardiac muscle is striated because its filaments are arranged in sarcomeres. However, the exact arrangement differs, making cardiac and skeletal muscle tissues look different from one another.
    - The heart is the muscle that performs the greatest amount of physical work in a lifetime. Its cells contain many mitochondria to produce ATP for energy and help the heart resist fatigue.
- A muscle contraction is an increase in tension or a decrease in the length of a muscle. A muscle contraction is isometric if muscle tension changes, but muscle length remains the same. It is isotonic if muscle length changes, but muscle tension remains the same.
    - A skeletal muscle contraction begins with the electrochemical stimulation of a muscle fiber by a motor neuron. This occurs at a chemical synapse called a neuromuscular junction. The neurotransmitter acetylcholine diffuses across the synaptic cleft and binds to receptors on the muscle fiber. This initiates a muscle contraction.
    - Once stimulated, the skeletal muscle fibers' protein filaments slide past each other to produce a contraction. The sliding filament theory is the most widely accepted explanation for how this occurs. According to this theory, thick myosin filaments repeatedly attach to and pull on thin actin filaments, thus shortening sarcomeres.
    - Crossbridge cycling is a cycle of molecular events that underlies the sliding filament theory. Using energy in ATP, myosin heads repeatedly bind with and pull on actin filaments. This moves the actin filaments toward the center of

a sarcomere, shortening the sarcomere and causing a muscle contraction.
    - The ATP needed for a muscle contraction comes first from ATP already available in the cell, and more is generated from creatine phosphate. These sources are quickly used up. Glucose and glycogen can be broken down to form ATP and pyruvate. Pyruvate can then be used to produce ATP in aerobic respiration if oxygen is available or used in anaerobic respiration if oxygen is not available.
- Physical exercise is defined as any bodily activity that enhances or maintains physical fitness and overall health. Activities such as household chores may even count as physical exercise! Current recommendations for adults are 30 minutes of moderate exercise a day.
- Aerobic exercise is any physical activity that uses muscles at less than their maximum contraction strength but for long periods of time. This type of exercise uses a relatively high percentage of slow-twitch muscle fibers that consume large amounts of oxygen. Aerobic exercises increase cardiovascular endurance and include cycling and brisk walking.
- Anaerobic exercise is any physical activity that uses muscles at close to their maximum contraction strength, but for short periods of time. This type of exercise uses a relatively high percentage of fast-twitch muscle fibers that consume small amounts of oxygen. Anaerobic exercises increase muscle and bone mass and strength, and they include push-ups and sprinting.
- Flexibility exercise is any physical activity that stretches and lengthens muscles, thereby improving the range of motion and reducing injury risk. Examples include stretching and yoga.
- Many studies have shown that physical exercise is positively correlated with a diversity of physical, mental, and emotional health benefits. Physical exercise also increases the quality of life and life expectancy.
    - Many of the exercise benefits may come about because contracting muscles release hormones called myokines, which promote tissue repair and growth and have anti-inflammatory effects.
    - Physical exercise can reduce risk factors for cardiovascular disease, including hypertension and excess body weight. Physical exercise can also increase cardiovascular health factors, such as the mechanical efficiency of the heart.
    - Physical exercise has been shown to offer protection from dementia and other cognitive problems, perhaps because it increases blood flow or neurotransmitters in the brain, among other potential effects.
    - Numerous studies suggest that regular aerobic exercise works and pharmaceutical antidepressants in treating mild-to-moderate depression, possibly because it increases the synthesis of natural euphoriants in the brain.
    - Research shows that physical exercise generally improves sleep for most people and helps sleep disorders, such as insomnia. Other health benefits of physical exercise include better immune system function and reduced risk of type 2 diabetes and obesity.
- There is great variation in individual responses to exercise, partly due to genetic differences in proportions of slow-twitch and fast-twitch muscle fibers. People with more slow-twitch fibers may be able to develop greater endurance from aerobic exercise. In contrast, people with more fast-twitch fibers may develop greater muscle size and strength from anaerobic exercise.
- Some adverse effects may occur if exercise is extremely intense, and the body is not given proper rest between exercise sessions. Many people who overwork their muscles develop delayed onset muscle soreness (DOMS), caused by tiny tears in muscle fibers.
- Musculoskeletal disorders are injuries in muscles or associated tissues (such as tendons) because of biomechanical stresses. The disorders may be caused by sudden exertion, over-exertion, repetitive motions, and similar stresses.
    - A muscle strain is an injury in which muscle fibers tear as a result of overstretching. First aid for a muscle strain includes the five steps represented by the acronym PRICE (protection, rest, ice, compression, and elevation). Medications for inflammation and pain (such as NSAIDs) may also be used.
    - Tendinitis is inflammation of a tendon that occurs when it is over-extended or worked too hard without rest. Tendinitis may also be treated with PRICE and NSAIDs.
    - Carpal tunnel syndrome is a biomechanical problem in the wrist when the median nerve becomes compressed between carpal bones. It may occur with repetitive use, a tumor, or trauma to the wrist. It may cause pain, numbness, and eventually—if untreated—muscle wasting in the thumb and first two fingers of the hand.
- Neuromuscular disorders are systemic disorders that occur because of problems with the nervous control of muscle contractions or muscle cells themselves.
    - Muscular dystrophy is a genetic disorder caused by defective proteins in muscle cells. It is characterized by progressive skeletal muscle weakness and death of muscle tissues.
    - Myasthenia gravis is a genetic neuromuscular disorder characterized by fluctuating muscle weakness and fatigue. More muscles are affected, and muscles become increasingly weakened, as the disorder progresses. Myasthenia gravis most often occurs because immune system antibodies block acetylcholine receptors on muscle cells because of the actual loss of acetylcholine receptors.
    - Parkinson's disease is a degenerative disorder of the central nervous system that mainly affects the muscular system and movement. It occurs because of the death of neurons in the midbrain. Characteristic signs of the disorder are muscle tremor, muscle rigidity, slowness of movement, and postural instability. Dementia and depression also often characterize advanced stages of the disease.

As you saw in this chapter, muscles need oxygen to provide enough ATP for most of their activities. In fact, all of the body's systems

require oxygen and remove waste products, such as carbon dioxide. In the next chapter, you will learn about how the respiratory system obtains and distributes oxygen throughout the body and how it removes wastes, such as carbon dioxide.

CHAPTER SUMMARY REVIEW

1. *True or False.* Each motor neuron controls one muscle fiber.
2. *True or False.* Peristalsis is a pattern of muscle contraction in smooth muscle tissue.
3. When muscles atrophy:
   A. muscle fibers become narrower
   B. muscle fibers turn into fat cells
   C. muscle fibers are lost
   D. muscle fibers become shorter
4. What are tendons?
5. What is a muscular system disorder involving tendons?
6. Which of the main types of muscle tissue is used when you make a voluntary movement of one of your limbs?
7. Which main types of muscle tissue function independently of conscious control by the brain?
8. Describe the relationship between muscles, muscle fibers, and fascicles.
9. *Choose one.* The (autonomic; somatic) nervous system controls the skeletal muscles.
10. *True or False.* Sarcomeres are the cells of the muscular system.
11. *True or False.* Muscles contain connective tissue as well as muscle tissue.
12. The biceps and triceps muscles are shown in Figure **5.9.4**. Answer the following questions about these arm muscles.
    A. When the biceps contract and become shorter, as in the illustration, what kind of motion does this produce in the arm?
    B. Is the situation described in part more likely to be an isometric or isotonic contraction? Explain your answer.
    C. If the triceps were to then contract, which way would help the arm move?

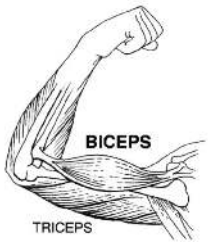


Figure **5.9.4**: biceps

13. Put the following events in order of when they occur during the process of skeletal muscle contraction, from earliest to latest:
    A. Acetylcholine binds to receptors on the muscle fiber
    B. Actin filaments slide, shortening the sarcomere
    C. An action potential is initiated in a motor neuron
    D. Acetylcholine is released from synaptic vesicles
14. What are Z discs, and what happens to them during muscle contraction?
15. *True or False.* Synapses only exist between neurons.
16. *True or False.* Muscles can produce hormones.
17. Which have been called the strongest muscles in the human body, relative to their work?
    A. The heart muscles
    B. The hamstring muscles
    C. The external eye muscles
    D. The stomach muscles
18. What is the function of mitochondria in muscle cells? Which type of muscle fiber has more mitochondria—slow-twitch or fast-twitch?
19. Fast-twitch and slow-twitch are types of which kind of muscle fibers?
    A. skeletal
    B. smooth
    C. cardiac
    D. B and C
20. Myoglobin:
    A. Stores oxygen for anaerobic respiration
    B. Stores oxygen for aerobic respiration
    C. Is present in higher amounts in fast-twitch fibers than slow-twitch fibers
    D. Is where ATP is produced
21. *True or False.* All people have the same proportion of slow-twitch to fast-twitch muscle fibers.
22. *True or False.* A sprain is a tear in the muscle fibers.
23. Which condition directly damages neurons, not muscles?
    A. Myasthenia gravis
    B. Muscular dystrophy
    C. Musculoskeletal disorder
    D. Parkinson's disease
24. What is the difference between primary and secondary Parkinson's disease?
25. Why can carpal tunnel syndrome cause muscle weakness in the hands?
26. *True or False.* The heart consists of smooth muscle tissue.
27. *True or False.* Sprinting is considered an anaerobic exercise

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CHAPTER OVERVIEW

6: NERVOUS SYSTEM

This chapter describes neurons and other cells of the nervous system and compares and contrasts divisions of the nervous system, including central, peripheral, somatic, and autonomic divisions. The chapter explains how nerve impulses occur and how we sense stimuli. It also describes disorders of the nervous system and the effects of psychoactive drugs on the nervous system.

6.1: Case Study- The Control Center of Your Body

6.2: Introduction to the Nervous System

6.3: Neurons

6.4: Nerve Impulses

6.5: Central Nervous System

6.6: Peripheral Nervous System

6.7: Psychoactive Drugs

6.8: Case Study Conclusion- Memory and Chapter Summary

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6.1: CASE STUDY- THE CONTROL CENTER OF YOUR BODY

CASE STUDY: FADING MEMORY

Each of these brightly colored sticky notes represents a piece of information that someone doesn't want to forget. Although we are all forgetful sometimes, most people do not have trouble remembering things that are important or routine to us, such as our friend's name or how to get to class. Our brain, the control center of the nervous system and the rest of the body, normally allows us to retain and recall information. But if the brain becomes damaged, a person may need to rely excessively on external reminders — like this wall of sticky notes — rather than being able to trust their own memory. That is if they are able to remember to write things down in the first place.

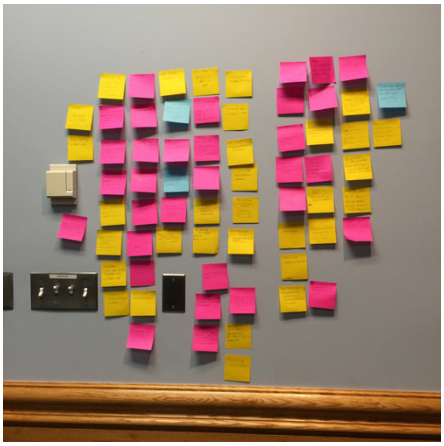


Figure **6.1.1**: Stickies

One person having trouble with their memory is Rosa, who is 68 years old. Rosa has been having difficulty remembering where she has set down objects in her house and forgot about a few doctor's appointments and lunches she planned with friends. Her family began to notice that she would sometimes not recall recent conversations, requiring them to repeat things to her. Rosa would also sometimes struggle to find the right word in a conversation and would put objects in unusual places, such as the milk in a cabinet instead of the refrigerator. While most people do things like this occasionally, it seemed to Rosa and her family that it was happening to her more often recently.

She also had some other symptoms that were impacting her life, such as having trouble paying her bills on time and managing her budget, which she had previously done well. Rosa ascribed these lapses in memory and mental functioning to the normal effects of aging, but her family was concerned. They noticed that she was also more irritable than usual and would sometimes verbally lash out at them, which was not like her. When she became disoriented on a walk around her neighborhood and a neighbor had to escort her home, her family convinced her to see a doctor.

Besides a complete physical exam and lab tests, Rosa's doctor interviewed Rosa and her family about her memory, ability to carry out daily tasks, and mood changes. He also administered a variety of tests to assess her memory and cognitive functioning, such as her ability to solve problems and use numbers and language correctly. Finally, he ordered a scan of her brain to investigate whether a tumor or some other observable cause was causing changes in the functioning of her brain.

Based on the results of these tests, Rosa's doctor came to the conclusion that she most likely has mild Alzheimer's disease (AD). AD results from abnormal changes in the molecules and cells of the brain, characterized by clumps of proteins called amyloid plaques between brain cells and tangled bundles of protein fibers called neurofibrillary tangles within certain brain cells. The affected brain cells stop functioning properly, lose their connections to other brain cells, and eventually will die. The picture below shows part of a cross-section of a brain from a patient who had severe AD compared to a similar section of a healthy brain. You can see how severely shrunken the brain with AD is, due to the death of many brain cells.

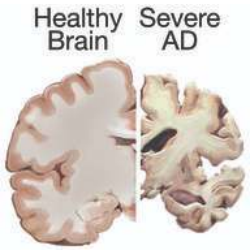


Figure **6.1.2**: The healthy brain is much larger than the brain with AD.

AD is a progressive disease, which means the damage and associated symptoms get worse over time. Clinicians have categorized the progression into three main stages — mild, moderate, and severe AD. Typically, AD cannot be definitively diagnosed until after death when the brain tissue can be directly examined for plaques and tangles. However, based on Rosa's symptoms and the results of her tests, her doctor thinks she most likely has mild AD, when the brain changes and resulting symptoms are not yet severe.

Although there is currently no cure for AD, and Rosa will eventually get worse, her doctor says that medications and behavioral therapies may improve and prolong her functioning and quality of life over the next few years. He prescribes a medication that improves communication between brain cells, which has been shown to help some people with AD.

As you read this chapter, you will learn much more about how the brain and the rest of the nervous system work, and the multitude of functions they control in the body. By the end of the chapter, you will have enough knowledge about the nervous system to learn more about why AD causes the symptoms that it does, how Rosa's medication works, and some promising new approaches that may help physicians diagnose and treat AD patients at earlier stages.

CHAPTER OVERVIEW: NERVOUS SYSTEM

In this chapter, you will learn about the human nervous system, which includes the brain, spinal cord, and nerves. Specifically, you will learn about:

- The organization of the nervous system, including the central and peripheral nervous systems and their organs and subdivisions.
- The cells of the nervous system — neurons and glia — their parts, and their functions.
- How messages are sent by neurons through the nervous system and to and from the rest of the body.
- How these messages, or nerve impulses, are transmitted by electrical changes within neurons, and through chemical molecules to other cells.
- The structure and functions of different parts of the central nervous system, which includes the brain and spinal cord, and some of the things that can go wrong when they are damaged.
- The structure and functions of the peripheral nervous system, which includes the nerves that carry motor and sensory information to and from the body to control voluntary and involuntary activities.
- The human senses and how visual information, sounds, smells, tastes, touch, and balance are detected by sensory receptor cells and then sent to the brain for interpretation.
- How legal and illegal drugs can have psychoactive effects on the brain-altering mood, perceptions, thinking, and behavior — which can sometimes lead to addiction.

As you read the chapter, think about the following questions:

1. Based on Rosa's symptoms, which parts of her brain may have been affected by Alzheimer's disease?
2. How are messages sent between cells in the nervous system? What molecules are involved in this process? What are the ways in which drugs can alter this process?
3. Why can't Rosa's brain just grow new cells to replace the ones that have died?

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6.2: INTRODUCTION TO THE NERVOUS SYSTEM

IN THE BLINK OF AN EYE

As you drive into a parking lot, a skateboarder suddenly flies in front of your car across your field of vision. You see the skateboarder in the nick of time and react immediately. You slam on the brakes and steer sharply to the right — all in the blink of an eye. You avoid a collision, but just barely. You're shaken up but thankful that no one was hurt. How did you respond so quickly? Such rapid responses are controlled by your nervous system.



Figure **6.2.1**: Skateboarder

OVERVIEW OF THE NERVOUS SYSTEM

The **nervous system**, illustrated in Figure **6.2.2**, is the human organ system that coordinates all of the body's voluntary and involuntary actions by transmitting electrical signals to and from different parts of the body. Specifically, the nervous system extracts information from the internal and external environments using sensory receptors. It then usually sends signals encoding this information to the brain, which processes the information to determine an appropriate response. Finally, the brain sends signals to muscles, organs, or glands to bring about the response. In the example above, your eyes detected the skateboarder, the information traveled to your brain, and your brain instructed your body to act so as to avoid a collision.

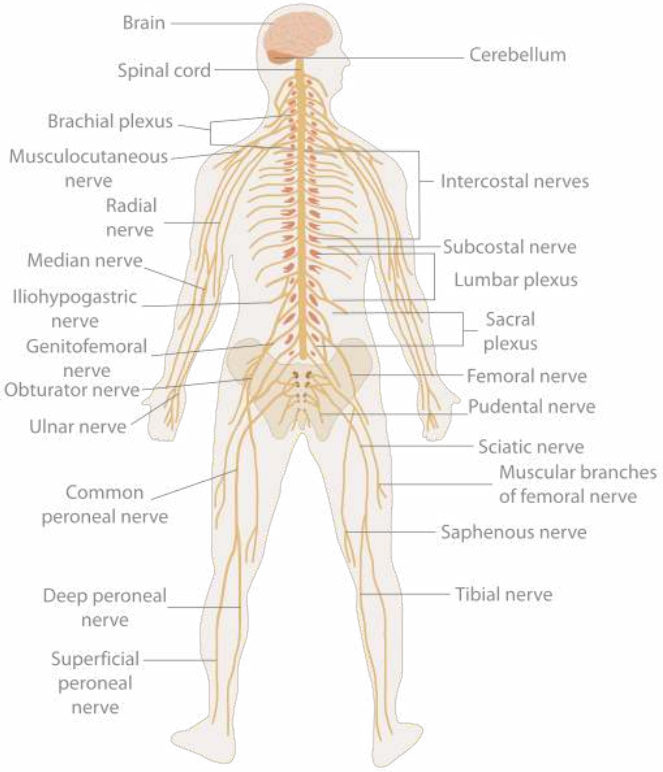


Figure **6.2.2**: The human nervous system consists of the brain and spinal cord (central nervous system) and a network of branching nerves that travel throughout the body (peripheral nervous system). Some of the major nerves in the peripheral system are identified in this drawing.

SIGNALS OF THE NERVOUS SYSTEM

The signals sent by the nervous system are electrical signals called nerve impulses, and they are transmitted by special nervous system cells named neurons, or nerve cells, like the one in Figure **6.2.3** (all the parts of a neuron are explained in the next section). Dendrites of a neuron receive nerve impulses from other cells. Long projection (called axons) from neurons carries nerve impulses directly to specific target cells. Schwann cells wrapped around the axon are called **glial cells**. They create a myelin sheath which allows the nerve impulse to travel very rapidly through the axons. A cell that receives nerve impulses from a neuron may be excited to perform a function, inhibited from carrying out an action, or otherwise controlled. In this way, the information transmitted by the nervous system is specific to particular cells and is transmitted very rapidly.

In fact, the fastest nerve impulses travel at speeds greater than 100 meters per second! Compare this to the chemical messages carried by the hormones that are secreted into the blood by endocrine glands. These hormonal messages are "broadcast" to all the cells of the body, and they can travel only as quickly as the blood flows through the cardiovascular system.

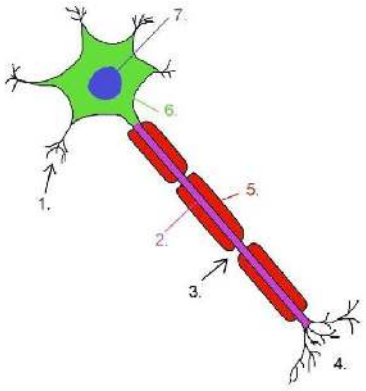


Figure 6.2.3: This simple model of a neuron shows 1 Dendrite, 2 Axon, 3 Nodes of Ranvier, 4 Axon Terminals, 5 Schwann cell (Myelin Sheath), 6 Cell body, and 7 Nucleus

ORGANIZATION OF THE NERVOUS SYSTEM

As you might predict, the human nervous system is very complex. It has multiple divisions, beginning with its two main parts, the central nervous system (CNS) and the peripheral nervous system (PNS), as shown in Figure 6.2.4. The CNS includes the brain and spinal cord, and the PNS consists mainly of nerves, which are bundles of axons from neurons. The nerves of the PNS connect the CNS to the rest of the body. You can learn much more about the CNS by reading the concept *Central Nervous System*.

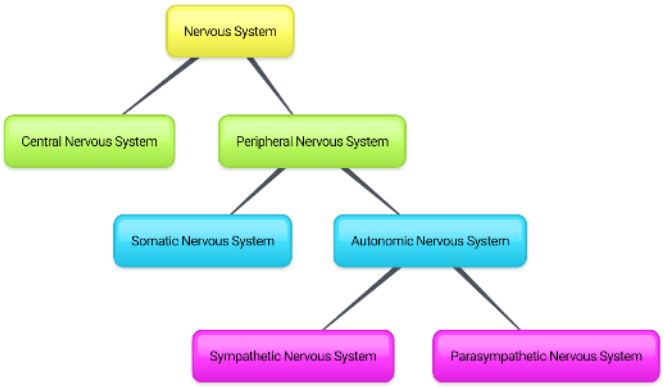


Figure 6.2.4: The concept map illustrates that the nervous system is divided into the peripheral and central systems. The peripheral nervous system is divided into the autonomic and somatic systems. The autonomic nervous system is divided into the sympathetic and parasympathetic systems.

The PNS is divided into two major parts, called the autonomic and somatic nervous systems. The somatic nervous system controls activities that are under voluntary control, such as turning a steering wheel. The autonomic nervous system controls activities that are not under voluntary control, such as digesting a meal. The autonomic nervous system has two divisions: the sympathetic division, which controls the fight-or-flight response during emergencies, and the parasympathetic division, which controls the routine "housekeeping" functions of the body at other times. You can learn more about the PNS and its subdivisions by reading the concept *Peripheral Nervous System*.

REVIEW

1. List the general steps by which the nervous system generates an appropriate response to information from the internal and external environments.
2. What are neurons?
3. Compare and contrast the central and peripheral nervous systems.
4. Which major division of the peripheral nervous system allows you to walk to class? Which major division of the peripheral nervous system controls your heart rate?
5. Identify the functions of the three divisions of the autonomic nervous system.
6. What is an axon and what is its function?
7. *True or False*. A nerve impulse always causes the target cell to perform an action.
8. *True or False*. The spinal cord is not considered part of the peripheral nervous system.
9. Define nerve impulses.
10. Explain why signals in the nervous system are generally more targeted and specific than signals in the endocrine system.
11. Explain generally how the brain and spinal cord can interact with and control the rest of the body.
12. _____ actions are performed without the person thinking about them.
13. The fight-or-flight response is controlled by the:
    A. autonomic nervous system
    B. somatic nervous system
    C. central nervous system
    D. parasympathetic nervous system
14. How are nerves and neurons related?
15. What type of information from the outside environment do you think is detected by sensory receptors in your ears?

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6.3: NEURONS

LIFE AS ART

This colorful picture could be an abstract work of modern art. You might imagine it hanging in an art museum or art gallery. In fact, the picture illustrates real life rather than an artistic creation. It is a micrograph of human nervous tissue. The neon green structures in the picture are neurons. The neuron is one of two basic types of cells in the nervous system, the other type being the glial cell.

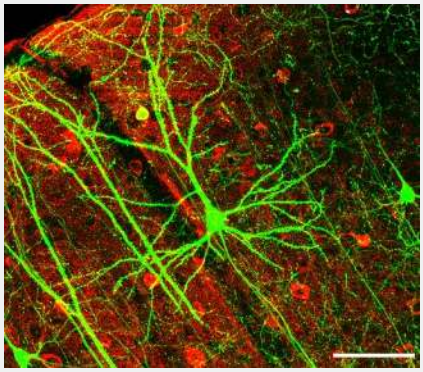


Figure **6.3.1**: Interneurons of Adult Visual Cortex

Neurons, also called nerve cells, are electrically excitable cells that are the main functional units of the nervous system. Their function is to transmit nerve impulses. They are the only type of human cells that can carry out this function.

NEURON STRUCTURE

Figure **6.3.2** shows the structure of a typical neuron. The main parts of a neuron are labeled in the figure and described below.

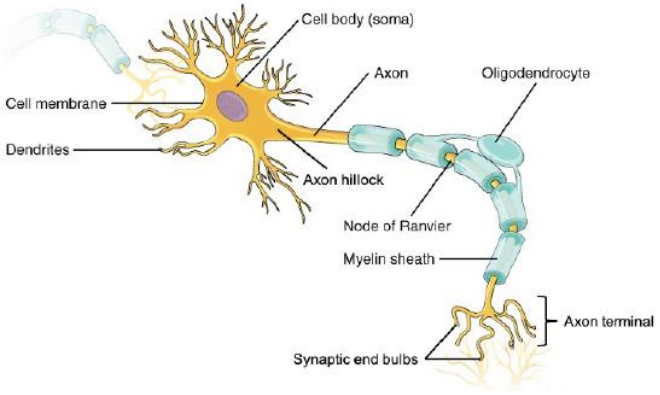


Figure **6.3.2**: Somatic Motor Neuron with cell body, axon, axon, myelin sheath, nodes of Ranvier, axon terminal, dendrites, synaptic end of the bulbs, and other associated structures.

- The **cell body** is the part of a neuron that contains the cell nucleus and other cell organelles. It is usually quite compact, and may not be much wider than the nucleus.
- **Dendrites** are thin structures that are extensions of the cell body. Their function is to receive nerve impulses from other cells and carry them to the cell body. A neuron may have many dendrites, and each dendrite may branch repeatedly to form a dendrite "tree" with more than 1,000 "branches." The end of each branch can receive nerve impulses from another cell, allowing a given neuron to communicate with tens of thousands of other cells.
- The **axon** is a long, thin extension of the cell body. It transmits nerve impulses away from the cell body and toward other cells. The axon branches at the end, forming multiple axon terminals. These are the points where nerve impulses are transmitted to other cells, often to the dendrites of other neurons. An area called a synapse occurs at each axon terminal. Synapses are complex membrane junctions that transmit signals to other cells. An axon may branch hundreds of times, but there is never more than one axon per neuron.
- Spread out along axons, especially the long axons of nerves, are many sections of the **myelin sheath.** These are lipid layers that cover sections of the axon. The myelin sheath is a very good electrical insulator, similar to the plastic or rubber that encases an electrical cord.
- Regularly spaced gaps between sections of myelin sheath occur along the axon. These gaps are called **nodes of Ranvier**, and they allow the transmission of nerve impulses along the axon. Nerve impulses skip from node to node, allowing nerve impulses to travel along the axon very rapidly.
- A Schwann cell (also on an axon) is a type of glial cell. Its function is to produce the myelin sheath that insulates axons in the peripheral nervous system. In the central nervous system, a different type of glial cell, called an oligodendrocyte, produces the myelin sheath.

NEUROGENESIS

Fully differentiated neurons, with all their special structures, cannot divide and form new daughter neurons. Until recently, scientists thought that new neurons could no longer be formed after the brain developed prenatally. In other words, they thought that people were born with all the brain neurons they would ever have, and as neurons died, they would not be replaced. However, new evidence shows that additional neurons can form in the brain, even in adults, from the division of undifferentiated neural stem cells that are found throughout the brain. The production of new neurons is called **neurogenesis.** The extent to which it can occur is not known, but it is not likely to be very great in humans.

NEURONS IN NERVOUS TISSUES

The nervous tissue in the brain and spinal cord consists of gray matter and white matter. Gray matter contains mainly the cell bodies of neurons. It is gray only in cadavers; living gray matter is actually more pink than gray (see image below). White matter consists mainly of axons covered with myelin sheath, which gives them their white color. White matter also makes up nerves of the peripheral nervous system. Nerves consist of long bundles of myelinated axons that extend to muscles, organs, or glands throughout the body. The axons in each nerve are bundled together like wires in a cable.

Axons in nerves may be more than a meter long in an adult. The longest nerve runs from the base of the spine to the toes.

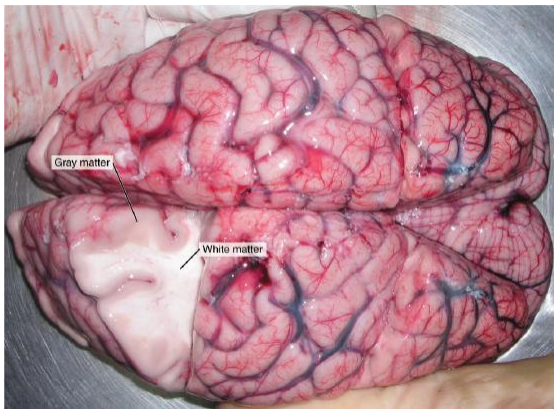


Figure **6.3.3**: You can see the layers of (pinkish) gray matter and white matter in this photo of a brain from a recently deceased human patient

TYPES OF NEURONS

There are hundreds of different types of neurons in the human nervous system. These types exhibit a variety of structures and functions. Nonetheless, many neurons can be classified functionally based on the direction in which they carry nerve impulses.

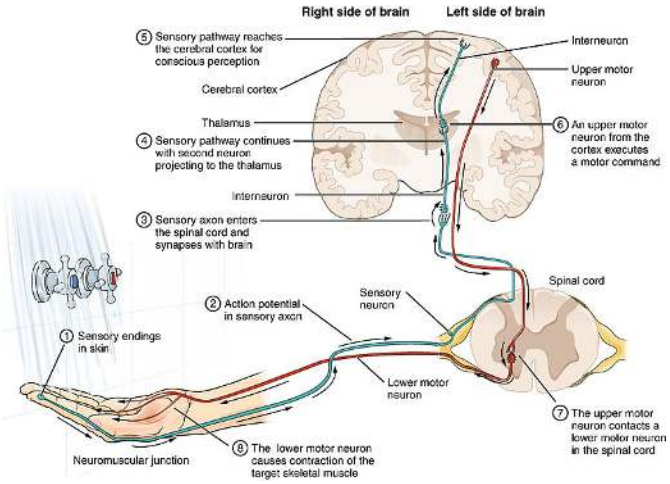


Figure **6.3.4**: Sensory neurons carry information towards the CNS. Motor neurons carry information from the CNS. Interneurons carry information between sensory and motor neurons.

- **Sensory** (also called afferent) **neurons** carry nerve impulses from sensory receptors in tissues and organs to the central nervous system. They change physical stimuli such as touch, light, and sound into nerve impulses.
- **Motor** (also called efferent) **neurons,** like the one in figure **6.3.2**, carry nerve impulses from the central nervous system to muscles and glands. They change nerve signals into the activation of these structures.
- **Interneurons** carry nerve impulses back and forth often between sensory and motor neurons within the spinal cord or brain.

GLIAL CELLS

Besides neurons, nervous tissues also consist of **glial cells** (also called neuroglia). They make up about 90% of the cells in our nervous tissue and are now known to play many vital roles in the nervous system. There are several different types of glial cells, each with a different function. Schwann cells and Oligodendrocytes are glial cells that produce myelin sheath.

FEATURE: MY HUMAN BODY

Would you like your brain to make new neurons that could help you become a better learner? What college student wouldn't want a little more brainpower when it comes to learning new things? If research on rats applies to humans, then sustained aerobic exercise such as running can increase neurogenesis in the adult brain, and specifically in the hippocampus, a brain structure important for learning temporally and/or spatially complex tasks as well as memory. Although the research is still at the beginning stages, it suggests that exercise may actually lead to a "smarter" brain. However, even if the research results are not confirmed in the future for humans, it can't hurt to get more aerobic exercise, because it is certainly beneficial for your body if not for your brain.

REVIEW

1. Identify the three main parts of a neuron and their functions.
2. Describe the myelin sheath and nodes of Ranvier. How does their arrangement allow nerve impulses to travel very rapidly along axons?
3. What is a synapse?
4. Define neurogenesis. What is the potential for neurogenesis in the human brain?
5. Relate neurons to different types of nervous tissues.
6. Compare and contrast sensory and motor neurons.
7. Identify the role of interneurons.
8. For each type of neuron below, identify whether it is a sensory neuron, motor neuron, or interneuron.
   A. A neuron in the spinal cord receives touch information and then transmits that information to another spinal cord neuron that controls the movement of an arm muscle.
   B. A neuron that takes taste information from your tongue and sends it to your brain.
   C. A spinal cord neuron stimulates a muscle to contract.
9. The myelin sheath is made by:
   A. Sensory neurons
   B. White neurons
   C. Peripheral nervous system neurons
   D. Glial cells
10. *True or False.* Synapses often exist where a dendrite and an axon terminal meet.
11. *True or False.* There is only one axon terminal per neuron.

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6.4: NERVE IMPULSES

WHEN LIGHTNING STRIKES

This amazing cloud-to-surface lightning occurred when a difference in electrical charge built up in a cloud relative to the ground. When the buildup of charge was great enough, a sudden discharge of electricity occurred. A nerve impulse is similar to a lightning strike. Both a nerve impulse and a lightning strike occur because of differences in electrical charge, and both result in an electric current.



Figure **6.4.1**: Lightning

GENERATING NERVE IMPULSES

A **nerve impulse**, like a lightning strike, is an electrical phenomenon. A nerve impulse occurs because of a difference in electrical charge across the plasma membrane of a neuron. How does this difference in electrical charge come about? The answer involves ions, which are electrically charged atoms or molecules.

RESTING POTENTIAL

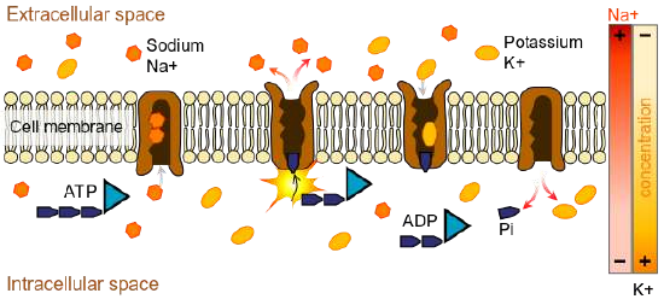


Figure **6.4.2**: The sodium-potassium pump maintains the resting potential of a neuron. There is more negative charge inside than outside the cell membrane. ATP is used to pump sodium out and potassium into the cell. There is more concentration of sodium outside the membrane and more concentration of potassium inside the cell due to the unequal movement of these ions by the pump

When a neuron is not actively transmitting a nerve impulse, it is in a resting state, ready to transmit a nerve impulse. During the resting state, the sodium-potassium pump maintains a difference in charge across the cell membrane of the neuron. The sodium-potassium pump is a mechanism of active transport that moves sodium ions out of cells and potassium ions into cells. The sodium-potassium pump moves both ions from areas of lower to higher concentration, using energy in ATP and carrier proteins in the cell membrane. Figure **6.4.3** shows in greater detail how the sodium-potassium pump works. Sodium is the principal ion in the fluid outside of cells, and potassium is the principal ion in the fluid inside of cells. These differences in concentration create an electrical gradient across the cell membrane, called **resting potential**. Tightly controlling membrane resting potential is critical for the transmission of nerve impulses.

ACTION POTENTIAL

An **action potential**, also called a nerve impulse, is an electrical charge that travels along the membrane of a neuron. It can be generated when a neuron's membrane potential is changed by chemical signals from a nearby cell. In an action potential, the cell membrane potential changes quickly from negative to positive as sodium ions flow into the cell through ion channels, while potassium ions flow out of the cell, as shown in Figure **6.4.3**.

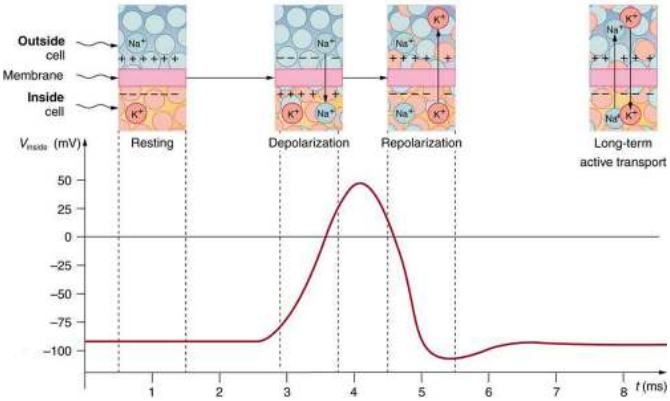


Figure **6.4.3**: An action potential speeds along an axon in milliseconds. Sodium ions flow in and cause the action potential, and then potassium ions flow out to reset the resting potential.

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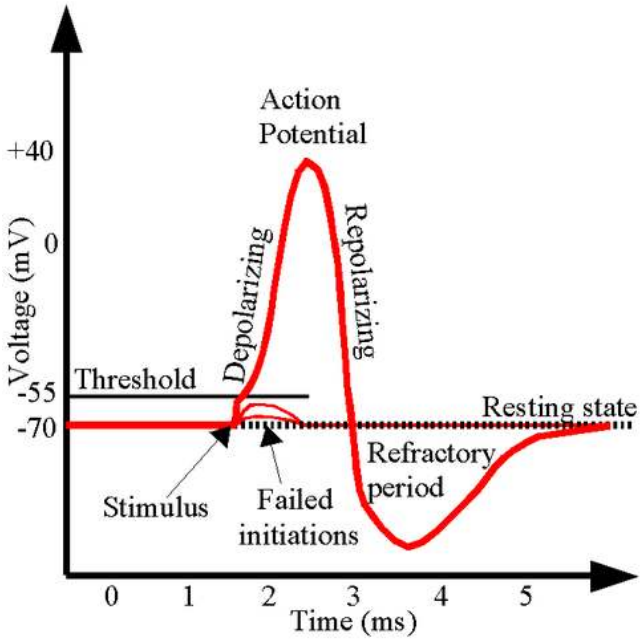


Figure **6.4.4**: An action potential graph of membrane potential over time. A neuron must reach a certain threshold in order to begin the depolarization step of reaching the action potential. The figure also shows the change in potential during the repolarization and refractory periods of the axon.

The change in membrane potential results in the cell becoming depolarized. An action potential works on an all-or-nothing basis. That is, the membrane potential has to reach a certain level of depolarization, called the threshold, otherwise, an action potential will not start. This threshold potential varies but is generally about 15 millivolts (mV) more positive than the cell's resting membrane potential. If a membrane depolarization does not reach the threshold level, an action potential will not happen. You can see in Figure **6.4.4** that two depolarizations did not reach the threshold level of -55mV.

The first channels to open are the sodium ion channels, which allow sodium ions to enter the cell. The resulting increase in positive charge inside the cell (up to about +40 mV) starts the action potential. This is called the depolarization of the membrane. Potassium ion channels then open, allowing potassium ions to flow out of the cell, which ends the action potential. The inside of the membrane becomes negative again. This is called repolarization of the membrane. Both of the ion channels then close, and the sodium-potassium pump restores the resting potential of -70 mV. The action potential will move down the axon toward the synapse like a wave would move along the surface of the water. Figure **6.4.4** shows the change in potential of the axon membrane during an action potential. The nerve goes through a brief refractory period before racing resting potential. During the refractory period, another action potential cannot be generated

In myelinated neurons, ion flows occur only at the nodes of Ranvier. As a result, the action potential signal "jumps" along the axon membrane from node to node rather than spreading smoothly along the membrane, as they do in axons that do not have a myelin sheath. This is due to a clustering of Na+ and K+ ion channels at the Nodes of Ranvier. Unmyelinated axons do not have nodes of Ranvier, and ion channels in these axons are spread over the entire membrane surface.

TRANSMITTING NERVE IMPULSES

The place where an axon terminal meets another cell is called a **synapse.** This is where the transmission of a nerve impulse to another cell occurs. The cell that sends the nerve impulse is called the presynaptic cell, and the cell that receives the nerve impulse is called the postsynaptic cell.

Some synapses are purely electrical and make direct electrical connections between neurons. However, most synapses are chemical synapses. The transmission of nerve impulses across chemical synapses is more complex.

CHEMICAL SYNAPSES

At a chemical synapse, both the presynaptic and postsynaptic areas of the cells are full of the molecular machinery that is involved in the transmission of nerve impulses. As shown in Figure **6.4.5**, the presynaptic area contains many tiny spherical vessels called synaptic vesicles that are packed with chemicals called **neurotransmitters**. When an action potential reaches the axon terminal of the presynaptic cell, it opens channels that allow calcium to enter the terminal. Calcium causes synaptic vesicles to fuse with the membrane, releasing their contents into the narrow space between the presynaptic and postsynaptic membranes. This area is called the synaptic cleft. The neurotransmitter molecules travel across the synaptic cleft and bind to **receptors**, which are proteins that are embedded in the membrane of the postsynaptic cell.

The effect of a neurotransmitter on a postsynaptic cell depends mainly on the type of receptors that it activates, making it possible for a particular neurotransmitter to have different effects on various target cells. A neurotransmitter might excite one set of target cells, inhibit others, and have complex modulatory effects on still others, depending on the type of receptors. However, some neurotransmitters have relatively consistent effects on other cells.

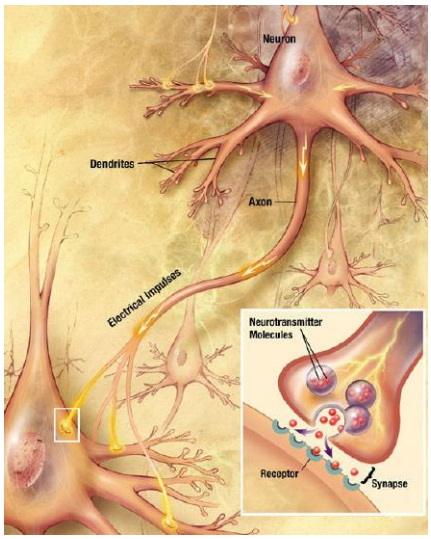


Figure 6.4.5: This diagram shows how an action potential transmits a signal across a synapse to another cell by neurotransmitter molecules. The inset diagram shows the axon terminal, synapse, and receptor of the postsynaptic cell. The neurotransmitters are released from the axon terminal, travel in the synaptic cleft, and attach to the receptors.

REVIEW

1. Define nerve impulse.
2. What is the resting potential of a neuron, and how is it maintained?
3. Explain how and why an action potential occurs.
4. Outline how a signal is transmitted from a presynaptic cell to a postsynaptic cell at a chemical synapse.
5. What generally determines the effects of a neurotransmitter on a postsynaptic cell?
6. Identify three general types of effects neurotransmitters may have on postsynaptic cells.
7. Explain how an electrical signal in a presynaptic neuron causes the transmission of a chemical signal at the synapse.
8. The flow of which type of ion into the neuron results in an action potential?
   A. How do these ions get into the cell?
   B. What does this flow of ions do to the relative charge inside the neuron compared to the outside?
9. The sodium-potassium pump:
   A. is activated by an action potential
   B. requires energy
   C. does not require energy
   D. pumps potassium ions out of cells
10. *True or False.* Some action potentials are larger than others, depending on the amount of stimulation.
11. *True or False.* Synaptic vesicles from the presynaptic cell enter the postsynaptic cell.
12. *True or False.* An action potential in a presynaptic cell can ultimately cause the postsynaptic cell to become inhibited.
13. Name three neurotransmitters.

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6.5: CENTRAL NERVOUS SYSTEM

HOMUNCULUS

Figure **6.5.1** is a very odd-looking drawing and is called a homunculus. The mass represents a cross-sectional wedge of the human brain. The drawing shows some areas of the brain associated with different parts of the body. As you can see, larger areas of the brain in this region are associated with the hands, face, and tongue than the legs and feet. Given the importance of speech, manual dexterity, and face-to-face social interactions in human beings, it is not surprising that relatively large areas of the brain are needed to control these body parts. The brain is the most complex organ in the human body and part of the central nervous system.

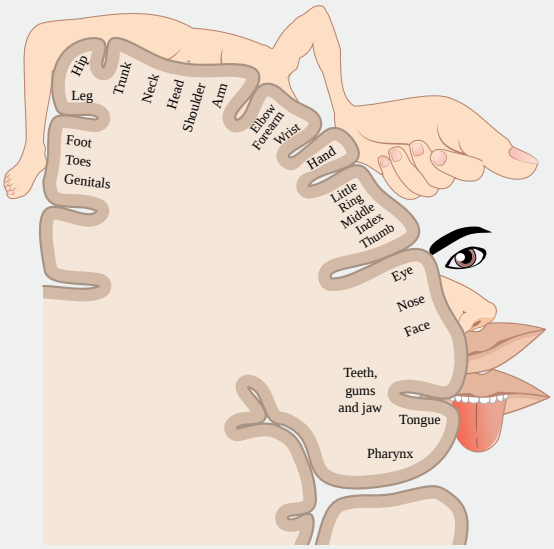


Figure **6.5.1**: Brain-Body Map. There's a map of your body on your brain's cortex, but the map is not proportional to actual space. Sensitive parts like the face and fingers are represented by more areas than less sensitive parts like the legs or back

WHAT IS THE CENTRAL NERVOUS SYSTEM?

The central nervous system (CNS) is the part of the nervous system that includes the brain and spinal cord. Figure **6.5.2** shows the central nervous system as one of the two main divisions of the total nervous system. The other main division is the peripheral nervous system (PNS). The CNS and PNS work together to control virtually all body functions. You can read much more about the PNS in the concept *Peripheral Nervous System*.

The delicate nervous tissues of the central nervous system are protected by major physical and chemical barriers. Physically, the brain and spinal cord are surrounded by tough meninges, a three-layer protective sheath that also contains cushioning cerebrospinal fluid. The bones of the skull and spinal vertebrae also contribute to physically protecting the brain and spinal cord. Chemically, the brain and spinal cord are isolated from the circulation — and most toxins or pathogens in the blood — by the **blood-brain barrier.** The blood-brain barrier is a highly selective membrane formed of endothelial cells (a type of glial cells) that separates the circulating blood from the extracellular fluid in the CNS. The barrier allows water, certain gases, glucose, and some other molecules needed by the brain and spinal cord to cross from the blood into the CNS while keeping out potentially harmful substances. These physical and chemical barriers make the CNS less susceptible to injury. However, damage to the CNS is likely to have more serious consequences.

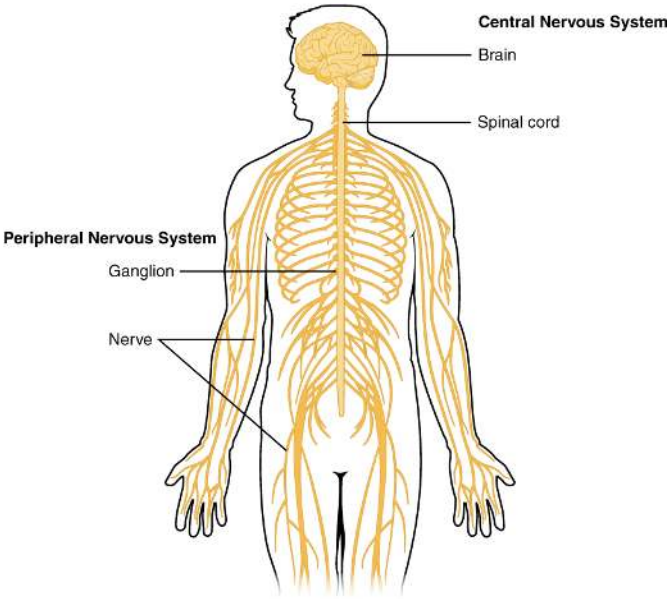


Figure **6.5.2**: The two main parts of the central nervous system are the brain and the spinal cord. Ganglions and nerves are part of the peripheral nerve system.

THE BRAIN

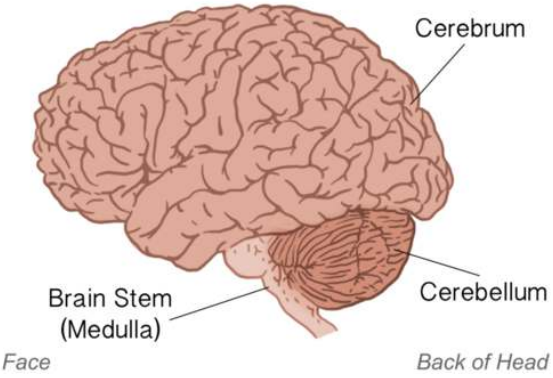


Figure **6.5.3**: Cerebrum, Cerebellum, and Brain Stem are the major parts of the brain. the medulla is part of the brain stem.

The **brain** is the control center not only of the rest of the nervous system but of the entire organism. The adult brain makes up only about 2 percent of the body's weight, but it uses about 20 percent of the body's total energy. The brain contains an estimated one hundred billion neurons, and each neuron has thousands of synaptic connections to other neurons. The brain also has about the same number of glial cells as neurons. No wonder the brain uses so much

energy! In addition, the brain uses mostly glucose for energy. As a result, if the brain is deprived of glucose, it can lead to unconsciousness. The brain is able to store some glucose in the form of glycogen, but in much smaller amounts than are found in the liver and skeletal muscles.

The brain controls such mental processes as reasoning, imagination, memory, and language. It also interprets information from the senses and commands the body how to respond. It controls basic physical processes such as breathing and heartbeat as well as voluntary activities such as walking and writing. The brain has three major parts: the cerebrum, cerebellum, and brain stem (Figure **6.5.3**). The figure shows the brain from the left side of the head. It shows how the brain would appear if the skull and meninges were removed. The brain stem via its medulla links to the spinal cord. The cerebellum is a small section at the back of the brain. The largest part of the brain is the cerebrum.

CEREBRUM

The **cerebrum** is the largest part of the brain. It controls conscious, intellectual functions. For example, it controls reasoning, language, memory, sight, touch, and hearing. When you read a book, play a video game, or recognize a classmate, you are using your cerebrum.

HEMISPHERES AND LATERALIZATION OF THE CEREBRUM

The cerebrum is divided from front to back into two halves called the left and right **hemispheres.** The two hemispheres are connected by a thick bundle of axons, known as the corpus callosum, which lies deep within the brain. The corpus callosum is the main avenue of communication between the two hemispheres. It connects each point in the cerebrum to the mirror-image point in the opposite hemisphere.

The right and left hemispheres of the cerebrum are similar in shape, and most areas of the cerebrum are found in both hemispheres. Some areas, however, show **lateralization,** or a concentration in one hemisphere or the other. For example, in most people, language functions are more concentrated in the left hemisphere, whereas abstract reasoning and visual-spatial abilities are more concentrated in the right hemisphere.

For reasons that are not yet clear, each hemisphere of the brain interacts primarily with the opposite side of the body. The left side of the brain receives messages from and sends commands to the right side of the body, and the right side of the brain receives messages from and sends commands to the left side of the body. Sensory nerves from the spinal cord to the brain and motor nerves from the brain to the spinal cord both cross the midline of the body at the level of the brain stem.

CEREBRAL CORTEX

Most of the information processing in the brain actually takes place in the **cerebral cortex.** This is a rind of gray matter and other tissues just a few millimeters thick that makes up the outer surface of the cerebrum in both hemispheres of the brain. The cerebral cortex has many folds in it that greatly increase the amount of surface area of the brain that can fit within the skull. Because of all the folds in the human cerebral cortex, it has a surface area of about 2,500 cm^2(2.5 ft^2). The size and importance of the cerebral cortex are far greater in the human brain than the brains of any other vertebrates including nonhuman primates.

LOBES OF THE CEREBRAL CORTEX

Each hemisphere of the cerebrum is further divided into the four lobes shown in Figure **6.5.4** and described below.

1. The **frontal lobes** are located at the front of the brain behind the forehead. The frontal lobes are associated with executive functions such as attention, self-control, planning, problem-solving, reasoning, abstract thought, language, and personality.

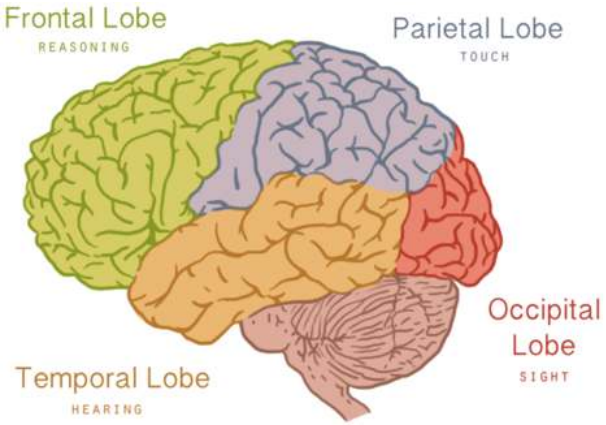


Figure **6.5.4**: Each hemisphere of the cerebrum consists of four parts, called lobes. The lobes are associated with multiple functions. The image shows one function of each lobe. Frontal, Parietal, Occipital, and Temporal lobes are associated with reasoning, touch, sight, and hearing, respectively.

2. The **parietal lobes** are located behind the frontal lobes at the top of the head. The parietal lobes are involved in sensation, including temperature, touch, and taste. Reading and arithmetic are also functions of the parietal lobes.

3. The **temporal lobes** are located at the sides of the head below the frontal and parietal lobes. The temporal lobes enable hearing, the formation and retrieval of memories, and the integration of memories and sensations.

4. The **occipital lobes** are located at the back of the head below the parietal lobes. The occipital lobes are the smallest of the four pairs of lobes. They are dedicated almost solely to vision.

INNER STRUCTURES OF THE BRAIN

Several structures are located deep within the brain and are important for communication between the brain and spinal cord or the rest of the body. These structures include the hypothalamus and thalamus. Figure **6.5.5** shows where these structures are located in the brain. The cerebrum, hypothalamus, and thalamus exist in two halves, one in each hemisphere.

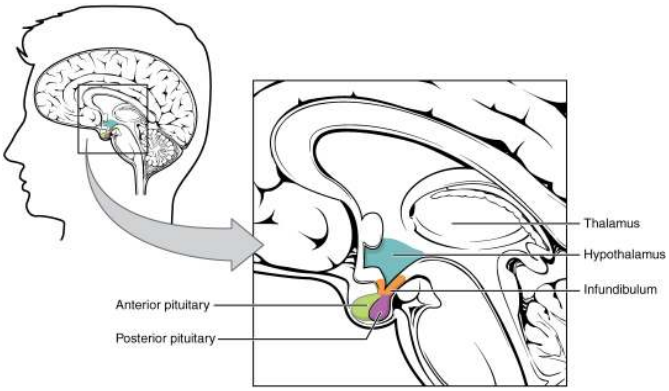


Figure **6.5.5**: Just below the cerebrum is the thalamus. Hypothalamus is located below the thalamus and a little to the anterior. The pituitary gland is attached to the hypothalamus via a tube called the infundibulum.

HYPOTHALAMUS

The **hypothalamus** is located just above the brain stem and is about the size of an almond. The hypothalamus is responsible for certain metabolic processes and other activities of the autonomic nervous system, including body temperature, heart rate, hunger, thirst, fatigue, sleep, wakefulness, and circadian (24-hour) rhythms. The hypothalamus is also an important emotional center of the brain. The hypothalamus can regulate so many body functions because it responds to many different internal and external signals, including messages from the brain, light, steroid hormones, stress, and invading pathogens, among others.

One way the hypothalamus influences body functions is by synthesizing hormones that directly influence body processes. For example, it synthesizes the hormone oxytocin, which stimulates uterine contractions during childbirth and the letdown of milk during lactation. It also synthesizes the hormone vasopressin (also called antidiuretic hormone), which stimulates the kidneys to reabsorb more water and excrete more concentrated urine. These two hormones are sent from the hypothalamus via a stalk-like structure called the infundibulum (see diagram above) directly to the posterior (back) portion of the pituitary gland, which secretes them into the blood.

The main way the hypothalamus influences body functions is by controlling the pituitary gland, known as the master gland of the endocrine system. The hypothalamus synthesizes neurohormones called releasing factors that travel through the infundibulum directly to the anterior (front) part of the pituitary gland. The releasing factors generally either stimulate or inhibit the secretion of anterior pituitary hormones, most of which control other glands of the endocrine system.

THALAMUS

The **thalamus,** which is located near the hypothalamus (Figure **6.5.5**), is a major hub for information traveling back and forth between the spinal cord and cerebrum. It filters sensory information traveling to the cerebrum. It relays sensory signals to the cerebral cortex and motor signals to the spinal cord. It is also involved in the regulation of consciousness, sleep, and alertness.

CEREBELLUM

The **cerebellum** is just below the cerebrum and at the back of the brain behind the brain stem (Figure **6.5.3**). It coordinates body movements and is involved in movements that are learned with repeated practice. For example, when you hit a softball with a bat or touch type on a keyboard you are using the cerebellum. Many nerve pathways link the cerebellum with motor neurons throughout the body.

BRAIN STEM

Sometimes called the “lower brain,” the **brain stem** is the lower part of the brain that is joined to the spinal cord. There are three parts to the brainstem: the midbrain, the pons, and the medulla oblongata, which are shown in Figure **6.5.6** below. The brain stem is primarily involved in the unconscious autonomic functions as well as several types of sensory information. It also helps coordinate large body movements such as walking and running. The **midbrain** deals with sight and sound information and translates these inputs before sending them to the forebrain. The **pons** relays messages to other parts of the brain (primarily the cerebrum and cerebellum) and helps regulate breathing. Some researchers have hypothesized that the pons plays a role in dreaming. Some of the functions of the Pons are shared by the **medulla oblongata,** also called the medulla. The medulla controls several subconscious homeostatic functions such as breathing, heart and blood vessel activity, swallowing, and digestion.

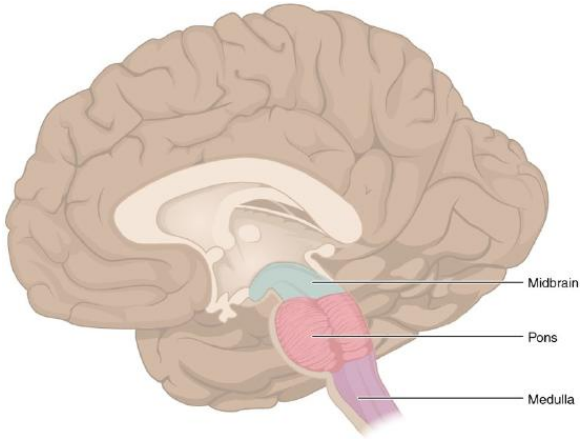


Figure **6.5.6**: Brain stem includes the midbrain, pons, and medulla oblongata

One of the brain stem’s most important roles is that of an “information highway.” That is, all of the information coming from the body to the brain and the information from the cerebrum to the body go through the brain stem. Sensory pathways for such things as pain, temperature, touch, and pressure sensation go upward to the cerebrum, and motor pathways for movement and other body processes go downward to the spinal cord. Most of the axons in the motor pathways cross from one side of the CNS to the other as they pass through the medulla oblongata. As a result, the right side of the brain controls much of the movement on the left side of the body,

and the left side of the brain controls much of the movement on the right side of the body.

SPINAL CORD



Figure **6.5.7**: The spinal cord (yellow) runs from the bottom of the brain to the lower back

The **spinal cord** is a long, thin, tubular bundle of nervous tissues that extends from the brain stem and continues down the center of the back to the pelvis. It is highlighted in yellow in Figure **6.5.7**. The spinal cord is enclosed within but is shorter than, the vertebral column.

STRUCTURE OF THE SPINAL CORD

The center of the spinal cord consists of gray matter, which is made up mainly of cell bodies of neurons, including interneurons and motor neurons. The gray matter is surrounded by white matter that consists mainly of myelinated axons of motor and sensory neurons. Spinal nerves, which connect the spinal cord to the PNS, exit from the spinal cord between vertebrae (Figure **6.5.8**).

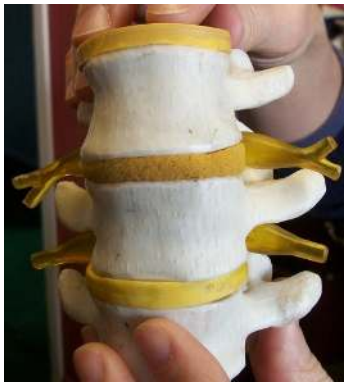


Figure **6.5.8**: This model shows three vertebrae (white) with branching spinal nerves (yellow) emerging from either side of the spinal cord between vertebrae

FUNCTIONS OF THE SPINAL CORD

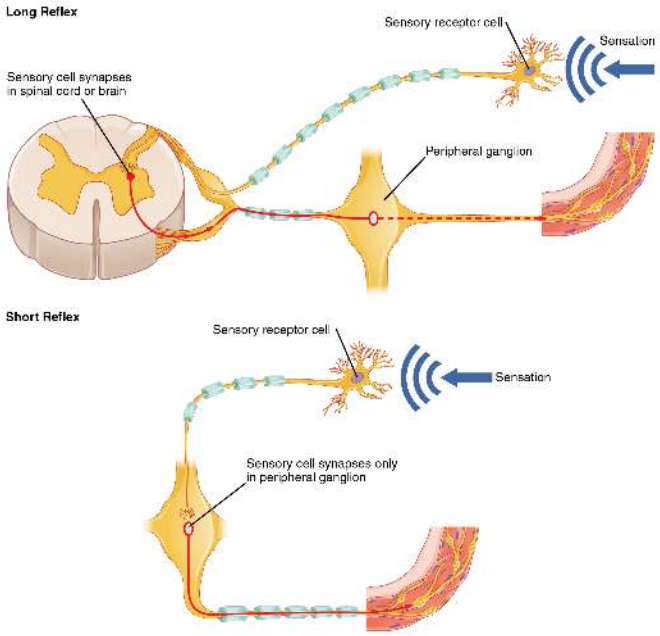


Figure **6.5.9**: This diagram shows what happens in a long reflex (top), in which sensory nerves carry the message all the way to the spinal cord; and in a short reflex (bottom), in which sensory nerves travel only to a ganglion outside the spinal cord. Note that interneurons are involved in reflexes, connecting sensory and motor neurons, but they are not actually shown in the diagram.

The spinal cord serves as an information superhighway. It passes messages from the body to the brain and from the brain to the body. Sensory (afferent) nerves carry nerve impulses to the brain from sensory receptor cells everywhere in and on the body. Motor (efferent) nerves carry nerve impulses away from the brain to glands, organs, or muscles throughout the body.

The spinal cord also independently controls certain rapid responses called **reflexes** without any input from the brain. You can see how this may happen in Figure **6.5.9**. A sensory receptor responds to a sensation and sends a nerve impulse along a sensory nerve to the spinal cord. In the spinal cord, the message passes to an interneuron and from the interneuron to a motor nerve, which carries the impulse to a muscle. The muscle contracts in response. These neuron connections form a reflex arc, which requires no input from the brain. No doubt you have experienced such reflex actions yourself. For example, you may have reached out to touch a pot on the stove, not realizing that it was very hot. Virtually at the same moment that you feel the burning heat, you jerk your arm back and remove your hand from the pot.

INJURIES TO THE SPINAL CORD

Physical damage to the spinal cord may result in **paralysis,** which is a loss of sensation and movement in part of the body. Paralysis generally affects all the areas of the body below the level of the injury because nerve impulses are interrupted and can no longer travel back and forth between the brain and body beyond that point. If an injury to the spinal cord produces nothing more than swelling, the symptoms may be transient. However, if nerve fibers (axons) in

the spinal cord are badly damaged, the loss of function may be permanent. Experimental studies have shown that spinal nerve fibers attempt to regrow, but tissue destruction usually produces scar tissue that cannot be penetrated by the regrowing nerves, as well as other factors that inhibit nerve fiber regrowth in the central nervous system.

FEATURE: MY HUMAN BODY

Each year, many millions of people have a stroke, and stroke is the second leading cause of death in adults. **Stroke,** also known as cerebrovascular accident, occurs when poor blood flow to the brain results in the death of brain cells. There are two main types of strokes:

- Ischemic strokes occur due to a lack of blood flow because of a blood clot in an artery going to the brain.
- Hemorrhagic strokes occur due to bleeding from a broken blood vessel in the brain.

Either type of stroke may result in paralysis, loss of the ability to speak or comprehend speech, loss of bladder control, personality changes, and many other potential effects, depending on the part of the brain that is injured. The effects of a stroke may be mild and transient or more severe and permanent. A stroke may even be fatal. It generally depends on the type of stroke and how extensive it is.

Are you at risk of stroke? The main risk factor for stroke is age: about two-thirds of strokes occur in people over the age of 65. There is nothing you can do about your age, but most other stroke risk factors can be reduced with lifestyle changes or medications. The risk factors include high blood pressure, tobacco smoking, obesity, high blood cholesterol, diabetes mellitus, and atrial fibrillation.

Chances are good that you or someone you know is at risk of a stroke, so it is important to recognize a stroke if one occurs. Stoke is a medical emergency, and the more quickly treatment is given, the better the outcome is likely to be. In the case of ischemic strokes, the use of clot-busting drugs may prevent permanent brain damage if administered within 3 or 4 hours of the stroke. Remembering the signs of a stroke is easy.

They are summed up by the acronym FAST, as explained in the chart below.



Figure **6.5.10**: The signs of stroke are abbreviated as FAST. Where F, A, S, and T stand for droopy face, arm weakness, slurry speech, and time to call 911, respectively.

REVIEW

1. What is the central nervous system?
2. How is the central nervous system protected?
3. What is the overall function of the brain?
4. Identify the three main parts of the brain and one function of each part.
5. Describe the hemispheres of the brain.
6. Explain and give examples of lateralization of the brain.
7. Identify one function of each of the four lobes of the cerebrum.
8. Summarize the structure and function of the cerebral cortex.
9. Explain how the hypothalamus controls the endocrine system.
10. Describe the spinal cord.
11. What is the main function of the spinal cord?
12. Explain how reflex actions occur.
13. Why do severe spinal cord injuries usually cause paralysis?
14. What do you think are some possible consequences of severe damage to the brain stem? How might this compare to the consequences of severe damage to the frontal lobe? Explain your answer.
15. Information travels very quickly in the nervous system, but generally, the longer the path between areas, the longer it takes. Based on this, explain why you think reflexes often occur at the spinal cord level and do not require input from the brain.

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6.6: PERIPHERAL NERVOUS SYSTEM

ONE PIANO, FOUR HANDS

Did you ever see two people play the same piano? How do they coordinate all the movements of their own fingers, let alone synchronize them with those of their partner? The peripheral nervous system plays an important part in this challenge.



Figure **6.6.1**: Two people playing piano together

WHAT IS THE PERIPHERAL NERVOUS SYSTEM?

The *peripheral nervous system (PNS)* consists of all the nervous tissue that lies outside of the central nervous system (CNS). The main function of the PNS is to connect the CNS to the rest of the organism. It serves as a communication relay, going back and forth between the CNS and muscles, organs, and glands throughout the body.

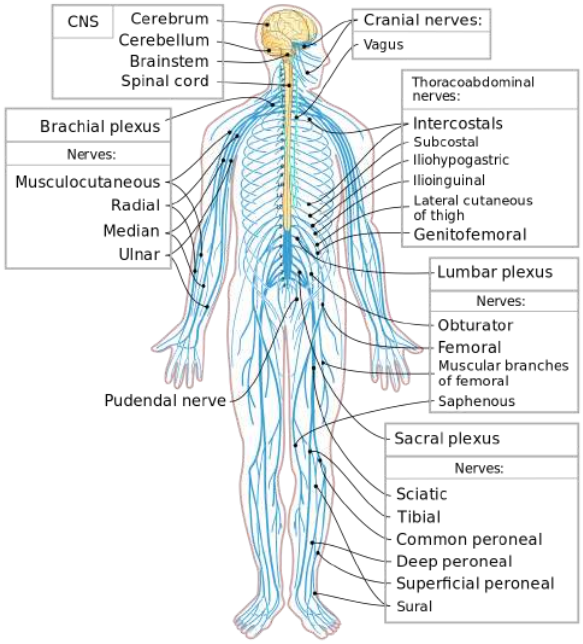


Figure **6.6.2**: The nerves of the peripheral nervous system are shown in blue in this figure.

TISSUES OF THE PERIPHERAL NERVOUS SYSTEM

The tissues that make up the PNS are nerves and ganglia. Ganglia are nervous tissues that act as relay points for messages transmitted through nerves of the PNS. Nerves are cable-like bundles of axons that make up the majority of PNS tissues. Nerves are generally classified on the basis of the direction in which they carry nerve impulses as sensory, motor, or mixed nerves. See examples of sensory and motor never in Figure **6.6.3**.

- **Sensory nerves** transmit information from sensory receptors in the body to the CNS. Sensory nerves are also called afferent nerves.
- **Motor nerves** transmit information from the CNS to muscles, organs, and glands. Motor nerves are also called efferent nerves.
- **Mixed nerves** contain both sensory and motor neurons, so they can transmit information in both directions. They have both afferent and efferent functions.

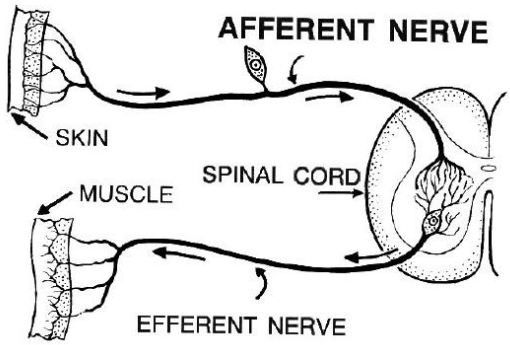


Figure **6.6.3**: An afferent nerve is a sensory nerve. The one pictured here sends nerve impulses from sensory cells in the skin to the CNS. An efferent nerve is a motor nerve. This one sends nerve impulses from the CNS to a muscle.

DIVISIONS OF THE PERIPHERAL NERVOUS SYSTEM

The PNS is divided into two major systems, called the autonomic nervous system and the somatic (or sensory-somatic) nervous system. Both systems of the PNS interact with the CNS and include sensory and motor neurons, but they use different circuits of nerves and ganglia.

SOMATIC NERVOUS SYSTEM

The **somatic nervous system** primarily senses the external environment and controls voluntary activities in which decisions and commands come from the cerebral cortex of the brain. For example, when you feel too warm, decide to turn on the air conditioner, and walk across the room to the thermostat, you are using your somatic nervous system. In general, the somatic nervous system is responsible for all of your conscious perceptions of the outside world and all of the voluntary motor activities you perform in response. Whether it's playing piano, driving a car, or playing basketball, you can thank your somatic nervous system for making it possible.

Structurally, the somatic nervous system consists of 12 pairs of cranial nerves and 31 pairs of spinal nerves (Figure **6.6.2**). Cranial nerves are in the head and neck and connect directly to the brain. Sensory cranial nerves sense smells, tastes, light, sounds, and body position. Motor cranial nerves control muscles of the face, tongue, eyeballs, throat, head, and shoulders. The motor nerves also control the salivary glands and swallowing. Four of the 12 cranial nerves participate in both sensory and motor functions as mixed nerves, having both sensory and motor neurons.

Spinal nerves of the somatic nervous system emanate from the spinal column between vertebrae. All of the spinal nerves are mixed nerves, containing both sensory and motor neurons. Spinal nerves also include motor nerves that stimulate skeletal muscle contraction, allowing for voluntary body movements.

AUTONOMIC NERVOUS SYSTEM

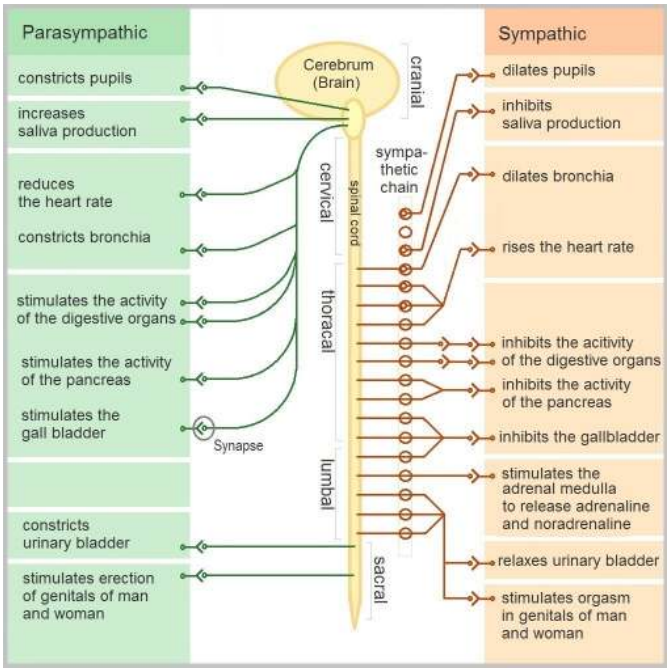


Figure **6.6.4**: This diagram summarizes the structures and functions controlled by the parasympathetic and sympathetic divisions of the autonomic nervous system. The images explained how eyes, salivary gland, bronchi, heart rate, digestive system, bladder, and genitalia are affected in opposite ways by the two systems.

The **autonomic nervous system** primarily senses the internal environment and controls involuntary activities. It is responsible for monitoring conditions in the internal environment and bringing about appropriate changes in them. In general, the autonomic nervous system is responsible for all the activities that go on inside your body without your conscious awareness or voluntary participation.

Structurally, the autonomic nervous system consists of sensory and motor nerves that run between the CNS (especially the hypothalamus in the brain) and internal organs (such as the heart, lungs, and digestive organs) and glands (such as the pancreas and sweat glands). Sensory neurons in the autonomic system detect internal body conditions and send messages to the brain. Motor nerves in the autonomic system function by controlling the contractions of smooth or cardiac muscle or glandular tissue. For example, when sensory nerves of the autonomic system detect a rise in body temperature, motor nerves signal smooth muscles in blood vessels near the body surface to undergo vasodilation, and the sweat glands in the skin secrete more sweat to cool the body.

The autonomic nervous system, in turn, has two subdivisions: the sympathetic division and parasympathetic division. The two subdivisions of the autonomic system are summarized in Figure **6.6.4**. Both affect the same organs and glands, but they generally do so in opposite ways.

- The **sympathetic division** controls the fight-or-flight response. Changes occur in organs and glands throughout the body that prepare the body to fight or flee in response to a perceived danger. For example, the heart rate speeds up, air passages in the

lungs become wider, more blood flows to the skeletal muscles, and the digestive system temporarily shuts down.

- The **parasympathetic division** returns the body to normal after the fight-or-flight response has occurred. For example, it slows down the heart rate, narrows air passages in the lungs, reduces blood flow to the skeletal muscles, and stimulates the digestive system to start working again. The parasympathetic division also maintains the internal homeostasis of the body at other times.

DISORDERS OF THE PERIPHERAL NERVOUS SYSTEM

Unlike the CNS, which is protected by bones, meninges, and cerebrospinal fluid, the PNS has no such protections. The PNS also has no blood-brain barrier to protect it from toxins and pathogens in the blood. Therefore, the PNS is more subject to injury and disease than is the CNS. Causes of nerve injury include diabetes, infectious diseases such as shingles, and poisoning by toxins such as heavy metals. Disorders of the PNS often have symptoms such as loss of feeling, tingling, burning sensations, or muscle weakness. If a traumatic injury results in a nerve being transacted (cut all the way through), it may regenerate, but this is a very slow process and may take many months.

REVIEW

1. Describe the general structure of the peripheral nervous system, and state its primary function.
2. What are ganglia?
3. Identify three types of nerves based on the direction in which they carry nerve impulses.
4. Outline all of the divisions of the peripheral nervous system.
5. Compare and contrast the somatic and autonomic nervous systems.
6. When and how does the sympathetic division of the autonomic nervous system affect the body?
7. What is the function of the parasympathetic division of the autonomic nervous system? What specific effects does it have on the body?
8. Name and describe two disorders of the peripheral nervous system.
9. Give one example of how the CNS interacts with the PNS to control a function in the body.
10. For each of the following types of information, identify whether the neuron carrying it is sensory or motor and whether it is most likely in the somatic or autonomic nervous system.
    A. Visual information
    B. Blood pressure information
    C. Information that causes muscle contraction in digestive organs after eating
    D. Information that causes muscle contraction in skeletal muscles based on the person's decision to make a movement
11. The cranial nerves:
    A. Carry sensory information
    B. Carry motor information
    C. Are part of the somatic nervous system
    D. All of the above
12. *True or False.* All of the spinal nerves carry both sensory and motor information.
13. *True or False.* The sympathetic nervous system enhances digestion to provide more energy for the body.

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6.7: PSYCHOACTIVE DRUGS

ART IN A CUP

Who knew that a cup of coffee could also be a work of art? A talented barista can make coffee look as good as it tastes. If you are a coffee drinker, you probably know that coffee can also affect your mental state. It can make you more alert and may improve your concentration. That's because the caffeine in coffee is a psychoactive drug. In fact, caffeine is the most widely consumed psychoactive substance in the world. In North America, for example, 90 percent of adults consume caffeine daily.



Figure **6.7.1**: Murano Coffee with decoration on the surface.

Psychoactive drugs are substances that change the function of the brain and result in alterations of mood, thinking, perception, and/or behavior. Psychoactive drugs may be used for many purposes, including therapeutic, ritual, or recreational purposes. Besides caffeine, other examples of psychoactive drugs include cocaine, LSD, alcohol, tobacco, codeine, and morphine. Psychoactive drugs may be legal prescription medications (e.g., codeine and morphine), legal nonprescription drugs (e.g., alcohol and tobacco), or illegal drugs (cocaine and LSD).



Figure **6.7.2**: Advertising for legal psychoactive drugs is ubiquitous.

Cannabis (or marijuana) is also a psychoactive drug, but its status is in flux, at least in the United States. Depending on the jurisdiction, cannabis may be used recreationally and/or medically, and it may be either legal or illegal. Legal prescription medications such as opioids are also used illegally by increasingly large numbers of people. Some legal drugs, such as alcohol and nicotine, are readily available almost everywhere, as illustrated by the sign pictured in Figure **6.7.2**.

CLASSES OF PSYCHOACTIVE DRUGS

Psychoactive drugs are divided into different classes according to their pharmacological effects. Several classes are listed below, along with examples of commonly used drugs in each class.

- Stimulants are drugs that stimulate the brain and increase alertness and wakefulness. Examples of stimulants include caffeine, nicotine, cocaine, and amphetamines such as Adderall.
- Depressants are drugs that calm the brain, reduce anxious feelings, and induce sleepiness. Examples of depressants include ethanol (in alcoholic beverages) and opioids such as codeine and heroin.
- Anxiolytics are drugs that have a tranquilizing effect and inhibit anxiety. Examples of anxiolytic drugs include benzodiazepines such as diazepam (Valium), barbiturates such as phenobarbital, opioids, and antidepressant drugs such as sertraline (Zoloft).
- Euphoriants are drugs that bring about a state of euphoria, or intense feelings of well-being and happiness. Examples of euphoriants include the so-called club drug MDMA (ecstasy), amphetamines, ethanol, and opioids such as morphine.
- Hallucinogens are drugs that can cause hallucinations and other perceptual anomalies. They also cause subjective changes in thoughts, emotions, and consciousness. Examples of hallucinogens include LSD, mescaline, nitrous oxide, and psilocybin.
- Empathogens are drugs that produce feelings of empathy, or sympathy with other people. Examples of empathogens include amphetamines and MDMA.



Figure **6.7.3**: Ecstasy (MDMA) is most commonly taken in tablet form, like the colorful and decorated tablets shown here.

Many psychoactive drugs have multiple effects so they may be placed in more than one class. An example is MDMA, pictured below, which may act both as a euphoriant and as an empathogen. In some people, MDMA may also have stimulant or hallucinogenic effects. As of 2016, MDMA had no accepted medical uses, but it was undergoing testing for use in the treatment of post-traumatic stress disorder and certain other types of anxiety disorders.

MECHANISMS OF ACTION

Psychoactive drugs generally produce their effects by affecting brain chemistry, which in turn may cause changes in a person's mood,

thinking, perception, and/or behavior. Each drug tends to have a specific action on one or more neurotransmitters or neurotransmitter receptors in the brain. Generally, they act as either agonists or antagonists.

- **Agonists** are drugs that increase the activity of particular neurotransmitters. They might act by promoting the synthesis of the neurotransmitters, reducing their reuptake from synapses, or mimicking their action by binding to receptors for the neurotransmitters.
- **Antagonists** are drugs that decrease the activity of particular neurotransmitters. They might act by interfering with the synthesis of the neurotransmitters or by blocking their receptors so the neurotransmitters cannot bind to them.

Consider the example of the neurotransmitter GABA. This is one of the most common neurotransmitters in the brain, and it normally has an inhibitory effect on cells. GABA agonists, which increase its activity, include ethanol, barbiturates, and benzodiazepines, among other psychoactive drugs. All of these drugs work by promoting the activity of GABA receptors in the brain.

USES OF PSYCHOACTIVE DRUGS

You may have been prescribed psychoactive drugs by your doctor. For example, you may have been prescribed an opioid drug such as codeine for pain (most likely in the form of Tylenol with added codeine). Chances are you also use nonprescription psychoactive drugs, such as caffeine for mental alertness. These are just two of the many possible uses of psychoactive drugs.

MEDICAL USES



Figure **6.7.4**: This child is being prepared to receive a general anesthetic prior to surgery

Medical uses of psychoactive drugs include general anesthesia, in which pain is blocked and unconsciousness is induced. General anesthetics are most often used during surgical procedures and may be administered in gaseous form, as in the photo below. General anesthetics include the drugs halothane and ketamine. Other psychoactive drugs are used to manage pain without affecting consciousness. They may be prescribed either for acute pain in cases of trauma such as broken bones; or for chronic pain such as pain caused by arthritis, cancer, or fibromyalgia. Most often, the drugs used for pain control are opioids, such as morphine and codeine.

Many psychiatric disorders are also managed with psychoactive drugs. For example, antidepressants such as sertraline are used to treat depression, anxiety, and eating disorders. Anxiety disorders may also be treated with anxiolytics, such as buspirone and diazepam. Stimulants such as amphetamines are used to treat attention deficit disorder. Antipsychotics such as clozapine and risperidone, as well as mood stabilizers such as lithium, are used to treat schizophrenia and bipolar disorder.

RITUAL USES

Certain psychoactive drugs, particularly hallucinogens, have been used for ritual purposes since prehistoric times. For example, Native Americans have used the mescaline-containing peyote cactus (pictured below) for religious ceremonies for as long as 5,700 years. In prehistoric Europe, the mushroom *Amanita muscaria*, which contains a hallucinogenic drug called muscimol, was used for similar purposes. Various other psychoactive drugs — including jimsonweed, psilocybin mushrooms, and cannabis — have also been used by various peoples for ritual purposes for millennia.



Figure **6.7.5**: The peyote cactus contains a hallucinogenic drug that is still used by some Native Americans for religious rituals.

RECREATIONAL USES

The recreational use of psychoactive drugs generally has the purpose of altering one's consciousness and creating a feeling of euphoria commonly called a "high." Some of the drugs used most commonly for recreational purposes include cannabis, ethanol, opioids, and stimulants such as nicotine. Hallucinogens are also used recreationally, primarily for the alterations in thinking and perception that they cause.

Some investigators have suggested that the urge to alter one's state of consciousness is a universal human drive, similar to the drive to satiate thirst, hunger, or sexual desire. They think that the drive to alter one's state of mind is even present in children, who may attain an altered state by repetitive motions such as spinning or swinging. Some nonhuman animals also exhibit a drive to experience altered states. For example, they may consume fermented berries or fruit and become intoxicated. The way cats respond to catnip (Figure **6.7.6**) is another example.



Figure **6.7.6**: This cat is holding a catnip toy and apparently enjoying its psychoactive effects.

ADDICTION, DEPENDENCE, AND REHABILITATION

Psychoactive substances often bring about subjective changes that the user may find pleasant (for example, euphoria) or advantageous (for example, increased alertness). These changes are rewarding and positively reinforcing, so they have the potential for misuse, addiction, and dependence. **Addiction** refers to the compulsive use of a drug despite the negative consequences that such use may entail. Sustained use of an addictive drug may produce dependence on the drug. **Dependence** may be physical and/or psychological. It occurs when cessation of drug use produces withdrawal symptoms. Physical dependence produces physical withdrawal symptoms, which may include tremors, pain, seizures, or insomnia. Psychological dependence produces psychological withdrawal symptoms, such as anxiety, depression, paranoia, or hallucinations.

Rehabilitation for drug dependence and addiction typically involves psychotherapy, which may include both individual and group therapy. Organizations such as Alcoholics Anonymous (AA) and Narcotics Anonymous (NA) may also be helpful for people trying to recover from addiction. These groups are self-described as international mutual aid fellowships with the primary purpose of helping addicts achieve and maintain sobriety. In some cases, rehabilitation is aided by the temporary use of psychoactive substances that reduce cravings and withdrawal symptoms without creating addiction themselves. For example, the drug methadone is commonly used in the treatment of heroin addiction.

FEATURE: HUMAN BIOLOGY IN THE NEWS

Currently, in the United States, a lot of media attention is being given to a rising tide of opioid addiction and overdose deaths. **Opioids** are drugs derived from the opium poppy or synthetic versions of such drugs. They include illegal drug heroin and prescription painkillers such as codeine, morphine, hydrocodone, oxycodone, and fentanyl. In 2016, fentanyl received wide media attention when it was announced that an accidental fentanyl overdose was responsible for the death of rock-music icon Prince. Fentanyl is an extremely strong and dangerous drug, said to be 50 to 100 times stronger than morphine, making the risk of overdose death from fentanyl very high.

The dramatic increase in opioid addiction and overdose deaths has been called an opioid epidemic. It is considered to be the worst drug crisis in American history. Consider the following facts:

- In 1999, there were more than twice as many accidental deaths from motor vehicle crashes than from drug overdoses. By 2014, these causes of accidental death were reversed, with close to 40 percent more accidental deaths from drug overdoses than car crashes. The majority of these drug overdose deaths were from heroin and opioid painkillers.
- In 1999, the stimulant drug cocaine killed about twice as many people as did heroin. By 2014, deaths from heroin were up by 439 percent. During the same interval, deaths from cocaine also rose slightly but were a much smaller proportion of all drug deaths than those caused by heroin.

The opioid epidemic in the United States has occurred in all demographic groups, including every ethnic, age, gender, and socioeconomic category. What has caused this epidemic? The answer appears to be an equally dramatic increase in the medical use of prescription painkillers. In 1991, about 76 million prescriptions were written for painkillers. In 2011, the number of prescriptions for these drugs had risen to 219 million, an almost three-fold increase. During these same two decades, Mexican drug cartels began shipping huge amounts of heroin to the United States. Heroin became cheaper and easier to buy than prescription painkillers. Many people who became addicted to prescription opioids switched to heroin. About 80 percent of new heroin users in 2014 reported started out misusing prescription painkillers.

Doctors, public health professionals, and politicians have all called for new policies, funding, programs, and laws to address the opioid epidemic. Changes that have already been made include a shift from criminalizing to medicalizing the problem, an increase in treatment programs, and more widespread distribution and use of the opioid-overdose antidote naloxone (Narcan). Opioids can slow or stop a person's breathing, which is what usually causes overdose deaths. Naloxone helps the person wake up and keeps them breathing until emergency medical treatment can be provided.

REVIEW

1. What are psychoactive drugs?
2. Identify six classes of psychoactive drugs and an example of a drug in each class.
3. Compare and contrast psychoactive drugs that are agonists and psychoactive drugs that are antagonists.
4. Describe two medical uses of psychoactive drugs.
5. Give an example of a ritual use of a psychoactive drug.
6. Why do people generally use psychoactive drugs recreationally?

7. Define addiction.
8. Identify possible withdrawal symptoms associated with physical dependence on a psychoactive drug.
9. Why might a person with a heroin addiction be prescribed the psychoactive drug methadone?
10. The prescription drug Prozac inhibits the reuptake of the neurotransmitter serotonin, causing more serotonin to be present in the synapse. Prozac can elevate mood, which is why it is sometimes used to treat depression. Answer the following questions about Prozac.
    A. Is Prozac an agonist or an antagonist for serotonin? Explain your answer.
    B. Is Prozac a psychoactive drug? Explain your answer.
11. Name 3 classes of psychoactive drugs that include opioids.
12. *True or False.* All psychoactive drugs are either illegal or available by prescription only.
13. *True or False.* Anxiolytics might be prescribed by a physician.
14. Name two drugs that activate receptors for the neurotransmitter GABA. Why do you think these drugs generally have a depressant effect?

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6.8: CASE STUDY CONCLUSION- MEMORY AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: FADING MEMORY

Figure 6.8.1 illustrates some of the molecular and cellular changes that occur in **Alzheimer's disease** (AD), which Rosa was diagnosed with at the beginning of this chapter, after experiencing memory problems and other changes in her cognitive functioning, mood, and personality. These abnormal changes in the brain include the development of amyloid plaques between brain cells and neurofibrillary tangles inside of neurons. These hallmark characteristics of AD are associated with the loss of synapses between neurons, and ultimately the death of neurons.

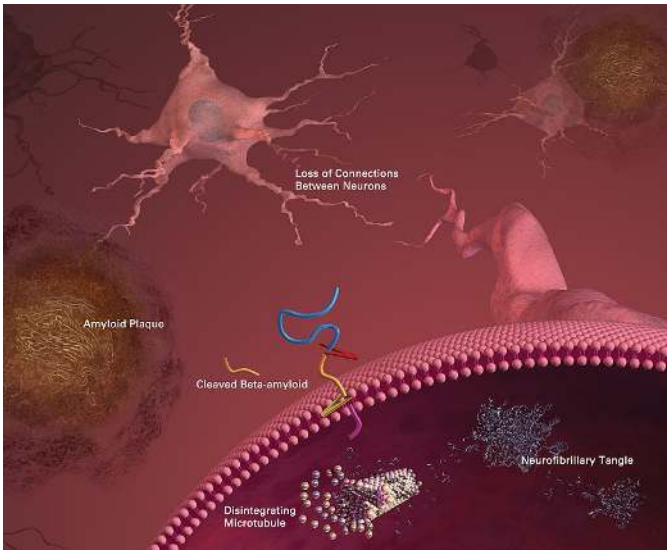


Figure 6.8.1: Characteristics of Alzheimer's disease. On a microscopic level, some of the changes that happen are depicted above. For example, the neurons lose connections, plaque accumulates, microtubes disintegrate, and much more.

After reading this chapter, you should have a good appreciation for the importance of keeping neurons alive and communicating with each other at synapses. The nervous system coordinates all of the body's voluntary and involuntary activities. It interprets information from the outside world through sensory systems and makes appropriate responses through the motor system, through communication between the PNS and CNS. The brain directs the rest of the nervous system and controls everything from basic vital functions such as heart rate and breathing to high-level functions such as problem-solving and abstract thought. The nervous system is able to perform these important functions by generating action potentials in neurons in response to stimulation and sending messages between cells at synapses, typically using chemical neurotransmitter molecules. When neurons are not functioning properly, lose their synapses, or die, they cannot carry out the signaling that is essential for the proper functioning of the nervous system.

AD is a progressive neurodegenerative disease, meaning that the damage to the brain becomes more extensive as time goes on. Figure 6.8.2 illustrates how the damage progresses from before AD is diagnosed (preclinical AD), to mild and moderate AD, and finally to severe AD.

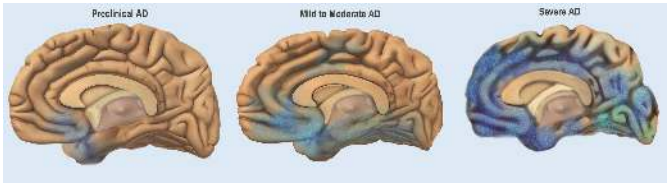


Figure 6.8.2: Illustration showing the areas of the brain that become damaged as Alzheimer's disease (AD) progresses. This is a side view along the middle of the brain, with the front of the brain shown to the left. Damaged are (blue shade) is widespread in severe AD.

You can see that the damage starts in a relatively small location towards the bottom of the brain. One of the earliest brain areas to be affected by AD is the hippocampus. The hippocampus is important for learning and memory. This explains why many of Rosa's symptoms of mild AD involve deficits in memory, such as trouble remembering where she placed objects, recent conversations, and appointments.

As AD progresses, more of the brain is affected, including areas involved in emotional regulation, social behavior, planning, language, spatial navigation, and higher-level thought. Rosa is beginning to show signs of problems in these areas, including irritability, lashing out at family members, getting lost in her neighborhood, problems finding the right words, putting objects in unusual locations, and difficulty in managing her finances. You can see that as AD progresses, damage spreads further across the cerebrum, which you now know controls conscious functions such as reasoning, language, and interpretation of sensory stimuli. You can also see how the frontal lobe, which controls executive functions such as planning, self-control, and abstract thought, becomes increasingly damaged.

Increasing damage to the brain causes corresponding deficits in functioning. In moderate AD, patients have increased memory, language, and cognitive deficits compared to mild AD. They may not recognize their own family members, and may wander and get lost, engage in inappropriate behaviors, become easily agitated, and have trouble carrying out daily activities such as dressing. In severe AD, much of the brain is affected. Patients usually cannot recognize family members or communicate and are fully dependent on others for their care. They begin to lose the ability to control their basic functions, such as bladder and bowel control and proper swallowing. Eventually, AD causes death, usually as a result of this loss of basic functions.

For now, Rosa only has mild AD is still able to function relatively well with care from her family. The medication her doctor gave her has helped improve some of her symptoms. It is a cholinesterase inhibitor, which blocks an enzyme that normally degrades the neurotransmitter acetylcholine. With more of the neurotransmitter available, more of it can bind to neurotransmitter receptors on postsynaptic cells. Therefore, this drug acts as an agonist for

acetylcholine, which enhances communication between neurons in Rosa's brain. This increase in neuronal communication can help restore some of the functions lost in early Alzheimer's disease and may slow the progression of symptoms.

But medication such as this is only a short-term measure and does not halt the progression of the underlying disease. Ideally, the damaged or dead neurons would be replaced by new, functioning neurons. Why does this not happen automatically in the body? As you have learned, neurogenesis is very limited in adult humans, so once neurons in the brain die, they are not normally replaced to any significant extent. However, scientists are studying the ways in which neurogenesis might be able to be increased in cases of disease or injury to the brain. Also, they are investigating the possibility of using stem cell transplants to replace damaged or dead neurons with new neurons. But this research is in very early stages and is not currently a treatment for AD.

One promising area of research is in the development of methods to allow earlier detection and treatment of AD, given that the changes in the brain may actually start 10 to 20 years before the diagnosis of AD. For example, a radiolabeled chemical called Pittsburgh Compound B (PiB) binds to amyloid plaques in the brain and in the future may be used in conjunction with brain imaging techniques to detect early signs of AD. Scientists are also looking for biomarkers in bodily fluids such as blood and cerebrospinal fluid that might indicate the presence of AD before symptoms appear. Finally, researchers are also investigating possible early and subtle symptoms, such as changes in how people move or a loss of smell, to see whether they can be used to identify people who will go on to develop AD. This research is in the early stages, but the hope is that patients can be identified earlier to provide earlier and possibly more effective treatment and to allow families more time to plan.

Scientists are also still trying to fully understand the causes of AD, which affects more than 5 million Americans. Some genetic mutations have been identified that play a role, but environmental factors also appear to be important. With more research into the causes and mechanisms of AD, hopefully, a cure can be found, and people like Rosa can live a longer and better life.

CHAPTER SUMMARY

In this chapter, you learned about the human nervous system. Specifically, you learned that:

- The nervous system is the organ system that coordinates all of the body's voluntary and involuntary actions by transmitting signals to and from different parts of the body. It has two major divisions, the central nervous system (CNS) and the peripheral nervous system (PNS).
- The CNS includes the brain and spinal cord.
- The PNS consists mainly of nerves that connect the CNS with the rest of the body. It has two major divisions: the somatic nervous system and the autonomic nervous system. The somatic system controls activities that are under voluntary control. The autonomic system controls activities that are involuntary.
- The autonomic nervous system is further divided into the sympathetic division, which controls the fight-or-flight response; the parasympathetic division, which controls most routine involuntary responses; and the enteric division, which provides local control for digestive processes.
- Signals sent by the nervous system are electrical signals called nerve impulses. They are transmitted by special, electrically excitable cells called neurons, which are one of two major types of cells in the nervous system.
- Glial cells are the other major type of nervous system cells. There are many types of glial cells, and they have many specific functions. In general, glial cells function to support, protect, and nourish neurons.
- The main parts of a neuron include the cell body, dendrites, and axon. The cell body contains the nucleus. Dendrites receive nerve impulses from other cells, and the axon transmits nerve impulses to other cells at axon terminals. A synapse is a complex membrane junction at the end of an axon terminal that transmits signals to another cell.
- Axons are often wrapped in an electrically-insulating myelin sheath, which is produced by glial cells. Electrical impulses called action potentials occur at gaps in the myelin sheath, called nodes of Ranvier, which speeds the conduction of nerve impulses down the axon.
- Neurogenesis, or the formation of new neurons by cell division, may occur in a mature human brain but only to a limited extent.
- The nervous tissue in the brain and spinal cord consists of gray matter, which contains mainly the cell bodies of neurons; and white matter, which contains mainly myelinated axons of neurons. Nerves of the peripheral nervous system consist of long bundles of myelinated axons that extend throughout the body.
- There are hundreds of types of neurons in the human nervous system, but many can be classified on the basis of the direction in which they carry nerve impulses. Sensory neurons carry nerve impulses away from the body and toward the central nervous system, motor neurons carry them away from the central nervous system and toward the body, and interneurons often carry them between sensory and motor neurons.
- A nerve impulse is an electrical phenomenon that occurs because of a difference in electrical charge across the plasma membrane of a neuron.
- The sodium-potassium pump maintains an electrical gradient across the plasma membrane of a neuron when it is not actively transmitting a nerve impulse. This gradient is called the resting potential of the neuron.
- An action potential is a sudden reversal of the electrical gradient across the plasma membrane of a resting neuron. It begins when the neuron receives a chemical signal from another cell or some other type of stimulus. The action potential travels rapidly down the neuron's axon as an electric current.
- A nerve impulse is transmitted to another cell at either an electrical or a chemical synapse. At a chemical synapse, neurotransmitter chemicals are released from the presynaptic cell

into the synaptic cleft between cells. The chemicals travel across the cleft to the postsynaptic cell and bind to receptors embedded in its membrane.

- There are many different types of neurotransmitters. Their effects on the postsynaptic cell generally depend on the type of receptor they bind to. The effects may be excitatory, inhibitory, or modulatory in more complex ways. Both physical and mental disorders may occur if there are problems with neurotransmitters or their receptors.
- The CNS includes the brain and spinal cord. It is physically protected by bones, meninges, and cerebrospinal fluid. It is chemically protected by the blood-brain barrier.
- The brain is the control center of the nervous system and of the entire organism. The brain uses a relatively large proportion of the body's energy, primarily in the form of glucose.
- The brain is divided into three major parts, each with different functions: brain stem, cerebellum, and cerebrum. The cerebrum is further divided into left and right hemispheres. Each hemisphere has four lobes: frontal, parietal, temporal, and occipital. Each lobe is associated with specific senses or other functions.
- The cerebrum has a thin outer layer called the cerebral cortex. Its many folds give it a large surface area. This is where most information processing takes place.
- Inner structures of the brain include the hypothalamus, which controls the endocrine system via the pituitary gland; and the thalamus, which has several involuntary functions.
- The spinal cord is a tubular bundle of nervous tissues that extends from the head down the middle of the back to the pelvis. It functions mainly to connect the brain with the PNS. It also controls certain rapid responses called reflexes without input from the brain.
- A spinal cord injury may lead to paralysis (loss of sensation and movement) of the body below the level of the injury because nerve impulses can no longer travel up and down the spinal cord beyond that point.
- The PNS consists of all the nervous tissue that lies outside of the CNS. Its main function is to connect the CNS to the rest of the organism.
- The tissues that make up the PNS are nerves and ganglia. Ganglia act as relay points for messages that are transmitted through nerves. Nerves are classified as sensory, motor, or a mix of the two.
- The PNS is not as well protected physically or chemically as the CNS, so it is more prone to injury and disease. PNS problems include injury from diabetes, shingles, and heavy metal poisoning. Two disorders of the PNS are Guillain-Barre syndrome and Charcot-Marie-Tooth disease.
- The human body has two major types of senses, special senses, and general senses. Special senses have specialized sense organs and include vision (eyes), hearing (ears), balance (ears), taste (tongue), and smell (nasal passages). General senses are all associated with touch and lack special sense organs. Touch receptors are found throughout the body but particularly in the skin.
- All senses depend on sensory receptor cells to detect sensory stimuli and transform them into nerve impulses. Types of sensory receptors include mechanoreceptors (mechanical forces), thermoreceptors (temperature), nociceptors (pain), photoreceptors (light), and chemoreceptors (chemicals).
- Touch includes the ability to sense pressure, vibration, temperature, pain, and other tactile stimuli. The skin includes several different types of touch receptor cells.
- Vision is the ability to sense light and see. The eye is the special sensory organ that collects and focuses light, forms images, and changes them to nerve impulses. Optic nerves send information from the eyes to the brain, which processes the visual information and "tells" us what we are seeing.
- Common vision problems include myopia (nearsightedness), hyperopia (farsightedness), and presbyopia (age-related decline in close vision).
- Hearing is the ability to sense sound waves, and the ear is the organ that senses sound. It changes sound waves to vibrations that trigger nerve impulses, which travel to the brain through the auditory nerve. The brain processes the information and "tells" us what we are hearing.
- The ear is also the organ that is responsible for the sense of balance, which is the ability to sense and maintain an appropriate body position. The ears send impulses on head position to the brain, which sends messages to skeletal muscle via the peripheral nervous system. The muscles respond by contracting to maintain balance.
- Taste and smell are both abilities to sense chemicals. Taste receptors in taste buds on the tongue sense chemicals in food and olfactory receptors in the nasal passages sense chemicals in the air. The sense of smell contributes significantly to the sense of taste.
- Psychoactive drugs are substances that change the function of the brain and result in alterations of mood, thinking, perception, and/or behavior. They include prescription medications such as opioid painkillers, legal substances such as nicotine and alcohol, and illegal drugs such as LSD and heroin.
- Psychoactive drugs are divided into different classes according to their pharmacological effects. They include stimulants, depressants, anxiolytics, euphoriants, hallucinogens, and empathogens. Many psychoactive drugs have multiple effects so they may be placed in more than one class.
- Psychoactive drugs generally produce their effects by affecting brain chemistry. Generally, they act either as agonists, which enhance the activity of particular neurotransmitters; or as antagonists, which decrease the activity of particular neurotransmitters.
- Psychoactive drugs are used for various purposes, including medical, ritual, and recreational purposes.
- Misuse of psychoactive drugs may lead to addiction, which is the compulsive use of a drug despite negative consequences.

Sustained use of an addictive drug may produce physical or psychological dependence on the drug. Rehabilitation typically involves psychotherapy and sometimes the temporary use of other psychoactive drugs.

In addition to the nervous system, there is another system of the body that is important for coordinating and regulating many different functions – the endocrine system. You will learn about the endocrine system in the next chapter.

CHAPTER SUMMARY REVIEW

1. Imagine that you decide to make a movement. To carry out this decision, a neuron in the cerebral cortex of your brain (neuron A) fires a nerve impulse that is sent to a neuron in your spinal cord (neuron B). Neuron B then sends the signal to a muscle cell, causing it to contract, resulting in movement. Answer the following questions about this pathway.
    a. Which part of the brain is neuron A located in — the cerebellum, cerebrum, or brain stem? Explain how you know.
    b. The cell body of neuron A is located in a lobe of the brain that is involved in abstract thought, problem-solving and planning. Which lobe is this?
    c. Part of neuron A travels all the way down to the spinal cord to meet neuron B. Which part of neuron A travels to the spinal cord?
    d. Neuron A forms a chemical synapse with neuron B in the spinal cord. How is the signal from neuron A transmitted to neuron B?
    e. Is neuron A in the central nervous system (CNS) or peripheral nervous system (PNS)?
    f. The axon of neuron B travels in a nerve to a skeletal muscle cell. Is the nerve part of the CNS or PNS? Is this an afferent nerve or an efferent nerve?
    g. What part of the PNS is involved in this pathway — the autonomic nervous system or the somatic nervous system? Explain your answer.
2. What are the differences between a neurotransmitter receptor and a sensory receptor?
3. Which part of a postsynaptic neuron typically receives the signals from a presynaptic neuron?
    A. The axon terminal
    B. The nodes of Ranvier
    C. The dendrites
    D. The cell body
4. *True or False.* Glial cells produce action potentials.
5. *True or False.* The spinal cord consists of white matter only.
6. *True or False.* Axons may be more than a meter long in adult humans.
7. If a person has a stroke and as a result has trouble using language correctly, which hemisphere of their brain was most likely damaged? Explain your answer.
8. The right side of the brain generally controls the which side of the body?
    A. right side
    B. left side
    C. head region
    D. trunk and leg regions
9. Electrical gradients are responsible for the resting potential and action potential in neurons. Answer the following questions about the electrical characteristics of neurons.
    a. Define what an electrical gradient is, in the context of a cell.
    b. What is responsible for maintaining the electrical gradient that results in the resting potential?
    c. Compare and contrast the resting potential and the action potential.
    d. Where along a myelinated axon does the action potential occur? Why does it happen here?
10. What does it mean that the action potential is “all-or-none?”
11. What determines whether a neurotransmitter has an excitatory or inhibitory effect? Choose the best answer.
    A. The neurotransmitter itself
    B. The specific receptor for the neurotransmitter on the postsynaptic cell
    C. The number of synaptic vesicles in the axon terminal
    D. Whether it is in a sensory neuron or a motor neuron
12. Compare and contrast Schwann cells and oligodendrocytes.
13. *True or False.* The cerebellum makes up most of the brain and is divided into four lobes.
14. *True or False.* The hypothalamus is part of the brain.
15. Which lobe of the brain processes touch information?
    A. Parietal
    B. Occipital
    C. Cochlea
    D. Temporal
16. Information about sounds is mainly sent to which lobe of the brain?
    A. Parietal
    B. Occipital
    C. Cochlea
    D. Temporal
17. Rods and cones in the retina are:
    A. Mechanoreceptors
    B. Nociceptors
    C. Photoreceptors
    D. Chemoreceptors
18. For the senses of smell and hearing, name their respective sensory receptor cells, what type of receptor cells they are, and what stimuli they detect.
19. *True or False.* Sensory information such as smell, taste, and sound, are carried to the CNS by cranial nerves.
20. *True or False.* The parasympathetic nervous system is a division of the central nervous system.

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CHAPTER OVERVIEW

7: Senses

7.1: Introduction to the Senses

7.2: Vision

7.3: Hearing and Balance

7.4: Taste and Smell

7.5: Touch

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7.1: Introduction to the Senses



Figure 7.1.1: This shark uses its senses of sight and smell to hunt, but it also relies on its ability to sense the electric fields of prey, a sense not present in most land animals. (credit: modification of work by Hermanus Backpackers Hostel, South Africa)

In more advanced animals, the senses are constantly at work, making the animal aware of stimuli—such as light, or sound, or the presence of a chemical substance in the external environment—and monitoring information about the organism's internal environment. All bilaterally symmetric animals have a sensory system, and the development of any species' sensory system has been driven by natural selection; thus, sensory systems differ among species according to the demands of their environments. The shark, unlike most fish predators, is electrosensitive—that is, sensitive to electrical fields produced by other animals in its environment. While it is helpful to this underwater predator, electrosensitivity is a sense not found in most land animals. in this chapter, information about smell, taste, hearing, and vision is presented.

Special and General Senses

The human body has two basic types of senses, called special senses and general senses. **Special senses** have specialized sense organs that gather sensory information and change it into nerve impulses. Special senses include the vision for which the eyes are the specialized sense organs, hearing (ears), balance (ears), taste (tongue), and smell (nasal passages). **General senses,** in contrast, are all associated with the sense of touch and lack special sense organs. Instead, sensory information about touch is gathered by the skin and other body tissues, all of which have important functions besides gathering sensory information. Whether the senses are special or general, however, all of them depend on cells called sensory receptors.

Sensory Receptors

A **sensory receptor** is a specialized nerve cell that responds to a stimulus in the internal or external environment by generating a nerve impulse. The nerve impulse then travels along with the sensory (afferent) nerve to the central nervous system for processing and to form a response.

A major role of sensory receptors is to help us learn about the environment around us, or about the state of our internal environment. Stimuli from varying sources, and of different types, are received and changed into the electrochemical signals of the nervous system. This occurs when a stimulus changes the cell membrane potential of a sensory neuron. The stimulus causes the sensory cell to produce an action potential that is relayed into the central nervous system (CNS), where it is integrated with other sensory information—or sometimes higher cognitive functions—to become a conscious perception of that stimulus. The central integration may then lead to a motor response.

Describing sensory function with the term sensation or perception is a deliberate distinction. Sensation is the activation of sensory receptor cells at the level of the stimulus. Perception is the central processing of sensory stimuli into a meaningful pattern. Perception is dependent on sensation, but not all sensations are perceived. Receptors are the cells or structures that detect sensations. A receptor cell is changed directly by a stimulus. A transmembrane protein receptor is a protein in the cell membrane that mediates a physiological change in a neuron, most often through the opening of ion channels or changes in the cell signaling processes. Transmembrane receptors are activated by chemicals called ligands. For example, a molecule in food can serve as a ligand for taste receptors. Other transmembrane proteins, which are not accurately called receptors, are sensitive to mechanical or

thermal changes. Physical changes in these proteins increase ion flow across the membrane, and can generate an action potential or a graded potential in the sensory neurons.

There are several different types of sensory receptors that respond to different kinds of stimuli:

- **Mechanoreceptors** respond to mechanical forces such as pressure, roughness, vibration, and stretching. Most mechanoreceptors are found in the skin and are needed for the sense of touch. Mechanoreceptors are also found in the inner ear where they are needed for the senses of hearing and balance.
- **Thermoreceptors** respond to variations in temperature. They are found mostly in the skin and detect temperatures that are above or below body temperature.
- **Nociceptors** respond to potentially damaging stimuli, which are generally perceived as pain. They are found in internal organs as well as on the surface of the body. Different nociceptors are activated depending on the particular stimulus. For example, some detect damaging heat or cold, others detect excessive pressure, and still, others detect painful chemicals such as very hot spices in food.
- **Photoreceptors** detect and respond to light. Most photoreceptors are found in the eyes and are needed for the sense of vision.
- **Chemoreceptors** respond to certain chemicals. They are found mainly in taste buds on the tongue, where they are needed for the sense of taste; and in nasal passages, where they are needed for the sense of smell.

Review

1. Compare and contrast special senses and general senses.
2. What are sensory receptors?
3. List five types of sensory receptors and the type of stimulus each detects.

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7.2: Vision

Figure 7.2.1 appears at first glance to be just a pattern of colored leaves, but hidden within it is the three-dimensional shape of an ant. Can you see the ant among the leaves? This figure is an example of a stereogram, which is a two-dimensional picture that reveals a three-dimensional object when viewed correctly. If you can't see the hidden image, it doesn't mean that there is anything wrong with your eyes. It's all in how your brain interprets what your eyes are sensing. The eyes are special sensory organs, and vision is one of our special senses.

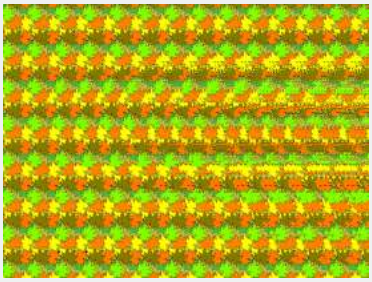


Figure 7.2.1: Stereogram

Vision

Vision is the ability to detect light patterns from the outside environment and interpret them into images. Basically vision, or sight, is the ability to sense light and see. The **eye** is the special sensory organ that collects and focuses light and forms images. However, the eye is not sufficient for us to see. The brain also plays a necessary role in vision.

Humans are bombarded with sensory information, and the sheer volume of visual information can be problematic. Fortunately, our visual system is able to attend to the most-important stimuli. The importance of vision to humans is further substantiated by the fact that about one-third of the human cerebral cortex is dedicated to analyzing and perceiving visual information.

Anatomy of the Eye

The photoreceptive (light receiving) cells of the eye, where conversion of light to nervous impulses occurs, are located in the **retina** (shown in Figure 7.2.2: (a)) on the inner surface of the back of the eye. Light passes through several layers of the eye that process it so that it can be interpreted by the retina (Figure 7.2.2: (b)). The **cornea** (Figures 7.2.2 and 7.2.3), the front transparent layer of the eye, and the crystalline **lens**, a transparent convex structure behind the cornea, both refract (bend) light to focus the image on the retina. The **iris**, which is conspicuous as the colored part of the eye, is a circular muscular ring lying between the lens and cornea that regulates the amount of light entering the eye. In conditions of high light, the iris contracts, reducing the size of the pupil at its center. In conditions of low light, the iris relaxes and the pupil enlarges.

The main function of the lens is to focus light on the retina and fovea. The lens is dynamic, focusing and re-focusing light as the eye rests on near and far objects in the visual field. The lens is operated by muscles that stretch it flat or allow it to thicken, changing the focal length of light coming through it to focus it sharply on the retina.

The eyelids, with lashes at their leading edges, help to protect the eye from abrasions by blocking particles that may land on the surface of the eye. The inner surface of each lid is a thin membrane known as the **palpebral conjunctiva**. The conjunctiva extends over the white areas of the eye (the sclera), connecting the eyelids to the eyeball. Tears are produced by the **lacrimal gland**, located beneath the lateral edges of the nose. Tears produced by this gland flow through the **lacrimal duct** to the medial corner of the eye, where the tears flow over the conjunctiva, washing away foreign particles.

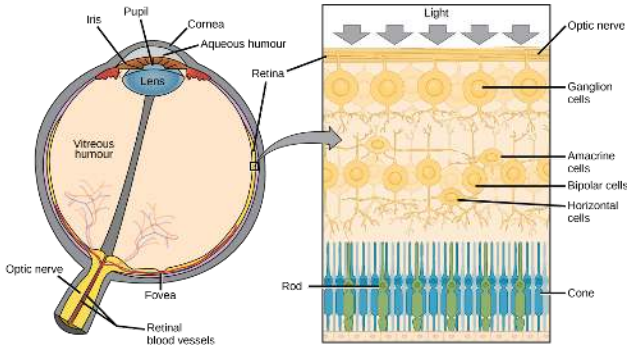


Figure 7.2.2: (a) The human eye is shown in cross section. (b) A blowup shows the layers of the retina.

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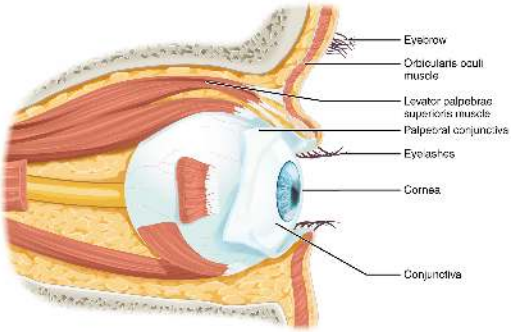


Figure 7.2.3: The Eye in the Orbit The eye is located within the orbit and surrounded by soft tissues that protect and support its function. The orbit is surrounded by cranial bones of the skull.

There are two types of photoreceptor cells in the retina: **rods** and **cones**, named for their general appearance as illustrated in Figure 7.2.4: . Rods are strongly photosensitive and are located in the outer edges of the retina; Rods detect dim light and are used primarily for peripheral and nighttime vision. Cones are weakly photosensitive and are located near the center of the retina; Cones respond to bright light, and their primary role is in daytime, color vision.

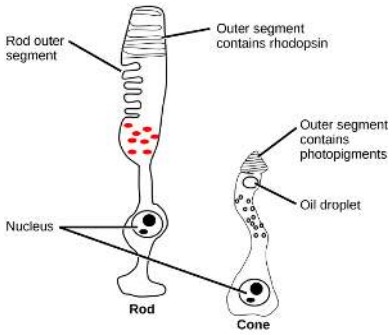


Figure 7.2.4: Rods and cones are photoreceptors in the retina. Rods respond in low light and can detect only shades of gray. Cones respond in intense light and are responsible for color vision. (credit: modification of work by Piotr Sliwa)

The **fovea** is the region in the center back of the eye that is responsible for acute vision. The fovea has a high density of just cones. When you bring your gaze to an object to examine it intently in bright light, the eyes orient so that the object's image falls on the fovea. This is the area of the retina that gives us high clarity of vision. However, when looking at a star in the night sky or other object in dim light, the object can be better viewed by the peripheral vision because it is the rods in higher concentrations in the other regions of the retina, rather than the cones at the center, that operate better in low light. In low-light conditions, the rods allow us to see in shades of gray because cones require bright light to be stimulated and don't respond in low light conditions.

LINK TO LEARNING

Review the anatomical structure of the eye, clicking on each part to practice identification.

How the Eye Works

Figure 7.2.5 shows the anatomy of the human eye in cross-section. The eye gathers and focuses light to form an image and then changes the image to nerve impulses that travel to the brain. How the eye performs these functions is summarized in the following steps.

1. Light passes first through the **cornea**, which is a clear outer layer that protects the eye and helps to focus the light by refracting, or bending, it.
2. Light next enters the interior of the eye through an opening called the **pupil**. The size of this opening is controlled by the colored part of the eye, called the **iris**, which adjusts the size based on the brightness of the light. The iris causes the pupil to narrow in bright light and widen in dim light.
3. The light then passes through the **lens**, which refracts the light even more and focuses it on the retina at the back of the eye as an inverted image.
4. The **retina** contains photoreceptor cells of two types, called rods and cones. Rods, which are found mainly in all areas of the retina other than the very center, are particularly sensitive to low levels of light. Cones, which are found mainly in the center of the retina, are sensitive to light of different colors and allow color vision. The rods and cones convert the light that strikes them to nerve impulses.
5. The nerve impulses from the rods and cones travel to the **optic nerve** via the **optic disc**, which is a circular area at the back of the eye where the optic nerve connects to the retina.

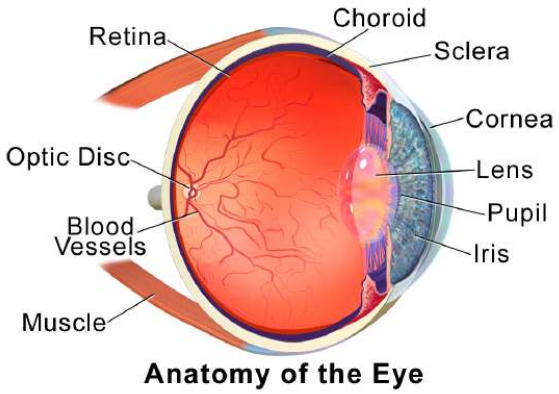


Figure 7.2.5: In this image, you can see the three layers of the eyeball, the sclera (cornea at the front), choroid, and retina. Lens, pupil, Irish, optic disc, option nerve (not labeled), blood vessels, and eye muscles are also visible. Trace the path of light through the eye as you read about in the five steps described in the text

Role of the Brain in Vision

The optic nerves from both eyes meet and cross just below the bottom of the hypothalamus in the brain. The information from both eyes is sent to the visual cortex in the **occipital lobe** of the cerebrum, which is part of the cerebral cortex. The visual cortex is the largest system in the human brain and is responsible for processing visual images. It interprets messages from both eyes and "tells" us what we are seeing.

Processing Visual Input

Light

Light travels in electromagnetic waves. Figure 7.2.6 of the electromagnetic spectrum shows that visible light for humans is just a small slice of the entire spectrum, which includes radiation that we cannot see as light because it is below the frequency of visible red light or above the frequency of visible violet light. The wavelength of light is expressed in nanometers (nm); one nanometer is one billionth of a meter.

Humans can see light that ranges between approximately 380 nanometers (nm) and 740 nm wavelengths (called visible light). We perceive different wavelengths within this range as different colors. Some other animals, though, can detect wavelengths outside of the human range. For example, bees see near-ultraviolet light in order to locate nectar guides on flowers, and some non-avian reptiles sense infrared light (heat that prey gives off).

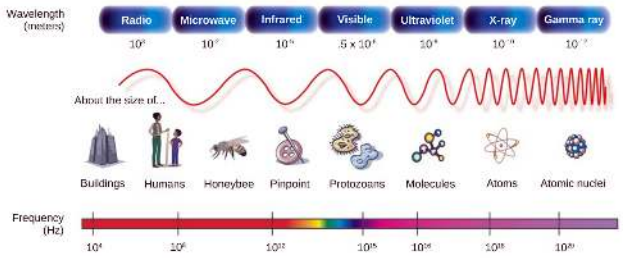


Figure 7.2.6: In the electromagnetic spectrum, visible light lies between 380 nm and 740 nm. (credit: modification of work by NASA)

Color Vision (Trichromatic Coding)

There are three types of cones, each with different photoreceptive proteins (photopsins). By being sensitive to different wavelengths of light, provide us with color vision (Figure 7.2.7). By comparing the activity of the three different cones, the brain can extract color information from visual stimuli. For example, a bright blue light that has a wavelength of approximately 450 nm would activate the “red” cones minimally, the “green” cones marginally, and the “blue” cones predominantly. The relative activation of the three different cones is calculated by the brain, which perceives the color as blue. However, cones cannot react to low-intensity light, and rods do not sense the color of light. Therefore, our low-light vision is—in essence—in grayscale. In other words, in a dark room, everything appears as a shade of gray. If you think that you can see colors in the dark, it is most likely because your brain knows what color something is and is relying on that memory.

With only one type of cone, color vision would not be possible, and a two-cone (dichromatic) system has limitations. Primates, including humans, use a three-cone (trichromatic) system, resulting in full color vision. The color we perceive is a result of the ratio of activity of our three types of cones. Humans have very sensitive perception of color and can distinguish about 500 levels of brightness, 200 different hues, and 20 steps of saturation, or about 2 million distinct colors.

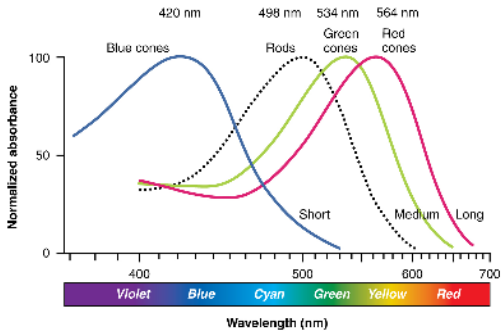


Figure 7.2.7: Human rod cells and the different types of cone cells each have an optimal wavelength. However, there is considerable overlap in the wavelengths of light detected.

Retinal Processing

Visual signals leave the cones and rods, travel to the bipolar cells, and then to ganglion cells. A large degree of processing of visual information occurs in the retina itself, before visual information is sent to the brain.

Higher Processing

The myelinated axons of ganglion cells make up the optic nerves. Within the nerves, different axons carry different qualities of the visual signal. Some axons constitute the magnocellular (big cell) pathway, which carries information about form, movement, depth, and differences in brightness. Other axons constitute the parvocellular (small cell) pathway, which carries information on color and fine detail. Some visual information projects directly back into the brain, while other information crosses to the opposite side of the brain. This crossing of optical pathways produces the distinctive optic chiasma (Greek, for “crossing”) found at the base of the brain and allows us to coordinate information from both eyes.

Once in the brain, visual information is processed in several places, and its routes reflect the complexity and importance of visual information to humans and other animals.

Vision Problems

Vision problems are very common. Two of the most common are myopia and hyperopia, and they often start in childhood or adolescence. Another common problem, called presbyopia, occurs in most people beginning in middle adulthood. All three problems result in blurred vision due to the failure of the eyes to focus images correctly on the retina.

Myopia

Myopia, or nearsightedness, occurs when the light that comes into the eye does not directly focus on the retina but in front of it, as shown in Figure 7.2.8. This causes the image of distant objects to be out of focus but does not affect the focus of close objects. Myopia may occur because the eyeball is elongated from front to back or because the cornea is too curved. Myopia can be corrected through the use of corrective lenses, either eyeglasses or contact lenses. Myopia can also be corrected by refractive surgery performed with a laser.

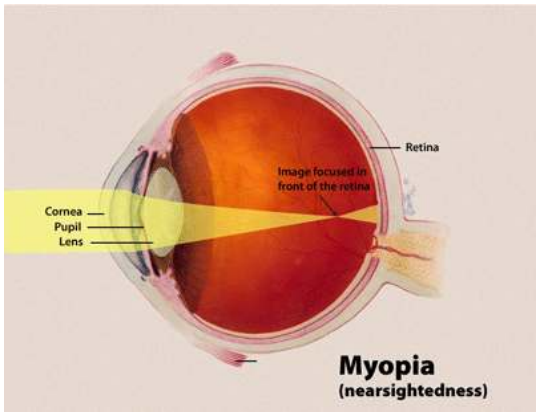


Figure 7.2.8: In myopia, the focal point of images is in front of the retina because the eyeball is elongated.

Hyperopia

Hyperopia, or farsightedness, occurs when the light that comes into the eye does not directly focus on the retina but behind it, as shown in Figure 7.2.9. This causes the image of close objects to be out of focus but does not affect the focus of distant objects. Hyperopia may occur because the eyeball is too short from front to back or because the lens is not curved enough. Hyperopia can be corrected through the use of corrective lenses or laser surgery.

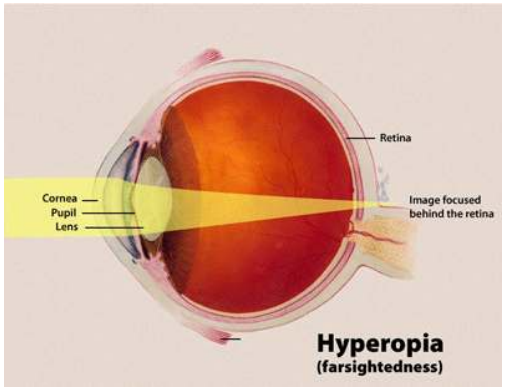


Figure 7.2.9: In hyperopia, the focal point of images is behind the retina because the eyeball is too short.

Presbyopia

Presbyopia is a vision problem associated with aging in which the eye gradually loses its ability to focus on close objects. Presbyopia occurs because the image focuses behind the retina. The precise cause of presbyopia is not known for certain, but evidence suggests that the lens may become less elastic with age, and the muscles that control the lens may lose power as people grow older. The first signs of presbyopia – eyestrain, difficulty seeing in dim light, problems focusing on small objects, and fine print – are usually first noticed between the ages of 40 and 50. Most older people with this problem use corrective lenses to focus on close objects because surgical procedures to correct presbyopia have not been as successful as those for myopia and hyperopia.

Feature: Human Biology in the News

The most common cause of blindness in the Western hemisphere is **age-related macular degeneration (AMD).** About 15 million people in the United States have this type of blindness, and 30 million people are affected worldwide. At present, there is no cure for AMD. The disease occurs with the death of a layer of cells called retinal pigment epithelium, which normally provides nutrients and other support to the macula of the eye. The macula is an oval-shaped pigmented area near the center of the retina that is specialized for high visual acuity and has the retina's greatest concentration of cones. When the epithelial cells die and the macula is no longer supported or nourished, the macula also starts to die. Patients experience a black spot in the center of their vision, and as the disease progresses, the black spot grows outward. Patients eventually lose the ability to read and even to recognize familiar faces before developing total blindness.

In 2016, a landmark surgery was performed as a trial on a patient with severe AMD. In the first-ever operation of its kind, Dr. Pete Coffey of the University of London implanted a tiny patch of cells behind the retina in each of the patient's eyes. The cells were retinal pigmented epithelial cells that had been grown in a lab from **stem cells,** which are undifferentiated cells that have the ability to develop into other cell types. By six months out from the operation, the new cells were still surviving, and the doctor was hopeful that the patient's vision loss would stop and even be reversed. At that point, several other operations had already been planned to test the new procedure. If these cases are a success, Dr. Coffey predicts that the surgery will become as routine as cataract surgery and prevent millions of patients from losing their vision.

Section Summary

Vision is the only photo responsive sense. Visible light travels in waves and is a very small slice of the electromagnetic radiation spectrum. Light waves differ based on their frequency (wavelength = hue) and amplitude (intensity = brightness).

In the retina there are two types of light receptors (photoreceptors): cones and rods. Cones, which are the source of color vision, exist in three forms—L, M, and S—and they are differentially sensitive to different wavelengths. Cones are located in the retina, along with the dim-light, achromatic receptors (rods). Cones are found in the fovea, the central region of the retina, whereas rods are found everywhere else throughout the retina.

Visual signals travel from the eye over the axons of retinal ganglion cells, which make up the optic nerves. Ganglion cells come in several versions. Some ganglion cell axons carry information on form, movement, depth, and brightness, while other axons carry information on color and fine detail.

Questions

1. Explain how the eye collects and focuses light to form an image and converts it to nerve impulses.
2. Identify two common vision problems, including both their causes and their effects on vision.
3. If a person is blind but their retina is functioning properly, where do you think the damage might be? Explain your answer.
4. When you see colors, what receptor cells are activated? Where are these receptors located? What lobe of the brain is primarily used to process visual information?

5. Why do people over 55 often need reading glasses?

a. Their cornea no longer focuses correctly.
b. Their lens no longer focuses correctly.
c. Their eyeball has elongated with age, causing images to focus in front of their retina.
d. Their retina has thinned with age, making vision more difficult.

6. Why is it easier to see images at night using peripheral, rather than the central, vision?

a. Cones are denser in the periphery of the retina.
b. Bipolar cells are denser in the periphery of the retina.
c. Rods are denser in the periphery of the retina.
d. The optic nerve exits at the periphery of the retina.

Explore More

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7.3: Hearing and Balance

Hearing

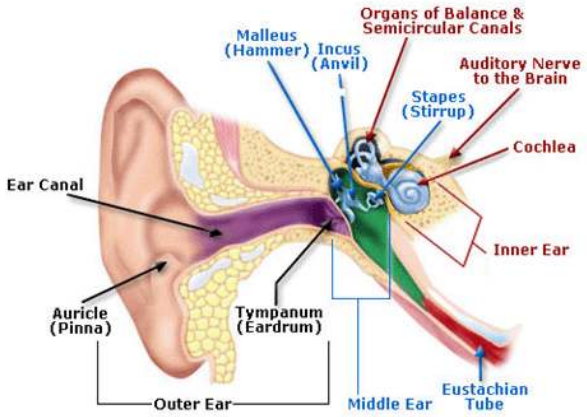


Figure 7.3.1: The image shows structures of the outer, middle and inner ear. The outer ear has an auricle and an ear canal in it. The eardrum is in the middle of the outer and middle ear. The middle ear contains a hammer, anvil, and stirrup, and the inner ear has a cochlea, vestibule (not labeled), semicircular canal, and Eustachian tube. Most of the structures of the ear are involved in hearing. Only the semicircular canals are not involved in hearing. Instead, they sense head position, which is used to monitor balance.

Hearing (audition) is the ability to sense sound waves, and the **ear** is the organ that senses sound. The large, fleshy structure on the lateral aspect of the head is known as the auricle. Some sources will also refer to this structure as the pinna, though that term is more appropriate for a structure that can be moved, such as the external ear of a cat. The C-shaped curves of the auricle direct sound waves toward the auditory canal. Sound waves enter the ear through the auditory (ear) canal and travel to the tympanum (tympanic membrane, sometimes referred to as the eardrum) (see the diagram of the ear in Figure 7.3.1). The sound waves strike the tympanum and make it vibrate. The auricle, ear canal, and tympanic membrane are often referred to as the external ear. The vibrations then travel through the three tiny bones (hammer, anvil, and stirrup) of the middle ear, which amplify the vibrations. The middle ear is connected to the pharynx through the Eustachian tube, which helps equilibrate air pressure across the tympanic membrane. The tube is normally closed but will pop open when the muscles of the pharynx contract during swallowing or yawning. From the middle ear, the vibrations pass to the cochlea in the inner ear. The cochlea is a coiled tube filled with liquid. The liquid moves in response to the vibrations, causing tiny hair cells (which are mechanoreceptors) lining the cochlea to bend. In response, the hair cells send nerve impulses to the auditory nerve, which carries the impulses to the brain. The brain interprets the impulses and “tells” us what we are hearing.

Hearing is important to humans and to other animals for many different interactions. It enables an organism to detect and receive information about danger, such as an approaching predator, and to participate in communal exchanges like those concerning territories or mating. On the other hand, although it is physically linked to the auditory system, the vestibular system of the ear is not involved in hearing. Instead, an animal’s vestibular system detects its own movement, both linear and angular acceleration and deceleration, and balance.

Sound

Auditory stimuli are sound waves, which are mechanical pressure waves that move through a medium, such as air or water. As is true for all waves, there are four main characteristics of a sound wave: frequency, wavelength, period, and amplitude. Frequency is the number of waves per unit of time, and in sound is heard as pitch. High-frequency (≥15.000Hz) sounds are higher-pitched (short wavelength) than low-frequency (long wavelengths; ≤100Hz) sounds. Frequency is measured in cycles per second, and for sound, the most commonly used unit is hertz (Hz), or cycles per second. Most humans can perceive sounds with frequencies between 30 and 20,000 Hz. Women are typically better at hearing high frequencies, but everyone’s ability to hear high frequencies decreases with age. Dogs detect up to about 40,000 Hz; cats, 60,000 Hz; bats, 100,000 Hz; and dolphins 150,000 Hz, and American shad (*Alosa sapidissima*), a fish, can hear 180,000 Hz. Those frequencies above the human range are called ultrasound.

Amplitude, or the dimension of a wave from peak to trough, in sound is heard as volume and is illustrated in Figure 7.3.2. The sound waves of louder sounds have greater amplitude than those of softer sounds. For sound, volume is measured in decibels (dB). The softest sound that a human can hear is the zero point. Humans speak normally at 60 decibels.

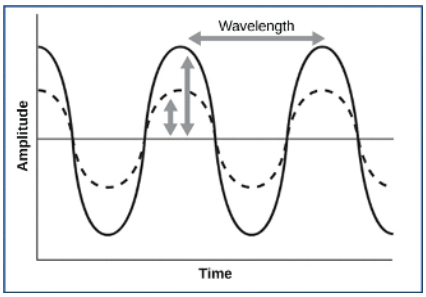


Figure 7.3.2: For sound waves, wavelength corresponds to pitch. Amplitude of the wave corresponds to volume. The sound wave shown with a dashed line is softer in volume than the sound wave shown with a solid line. (credit: NIH)

The Ear and Hearing

Reception of Sound

In humans and other mammals, sound waves are collected by the external, cartilaginous part of the ear called the **auricle** (or pinna), then travel through the auditory (ear) canal and cause vibration of the thin diaphragm called the **tympanum** (tympanic membrane) or eardrum, the innermost part of the **outer ear** (illustrated in Figures 7.3.1 and 7.3.3). Interior to the tympanum is the **middle ear**. The middle ear holds three small bones called the **ossicles**, which transfer energy from the moving tympanum to the inner ear. The three ossicles are the **malleus** (also known as the hammer), the **incus** (the anvil), and **stapes** (the stirrup). The aptly named stapes looks very much like a stirrup. The three ossicles are unique to mammals, and each plays a role in hearing. The malleus attaches at three points to the interior surface of the tympanic membrane. The incus attaches the malleus to the stapes. In humans, the stapes is not long enough to reach the tympanum. If we did not have the malleus and the incus, then the vibrations of the tympanum would never reach the inner ear. These bones also function to collect force and amplify sounds.

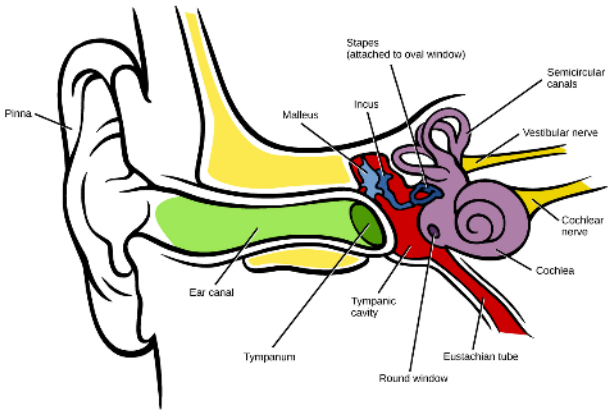


Figure 7.3.3: Sound travels through the outer ear to the middle ear, which is bounded on its exterior by the tympanic membrane. The middle ear contains three bones called ossicles that transfer the sound wave to the oval window, the exterior boundary of the inner ear. The organ of Corti, which is the organ of sound transduction, lies inside the cochlea. (credit: modification of work by Lars Chittka, Axel Brockmann)

Processing of Sound

Vibrating objects, such as vocal cords, create sound waves or pressure waves in the air. When these pressure waves reach the ear, the ear converts this mechanical stimulus (pressure wave) into a nerve impulse (electrical signal) that the brain perceives as sound. The pressure waves strike the tympanum, causing it to vibrate. The mechanical energy from the moving tympanum transmits the vibrations to the three bones of the middle ear. The stapes transmits the vibrations to a thin diaphragm called the **oval window**, which is the outermost structure of the **inner ear**. The structures of the inner ear are found in the bony **labyrinth**, a bony, hollow

structure that is the most interior portion of the ear. Here, the energy from the sound wave is transferred from the stapes through the flexible oval window and to the fluid of the cochlea. The vibrations of the oval window create pressure waves in the fluid (perilymph) inside the cochlea. The **cochlea** is a whorled structure, like the shell of a snail, and it contains receptors for transduction of the mechanical wave into an electrical signal (as illustrated in 7.3.4). Inside the cochlea, the basilar membrane is a mechanical analyzer that runs the length of the cochlea, curling toward the cochlea's center.

The mechanical properties of the basilar membrane change along its length, such that it is thicker, tauter, and narrower at the outside of the whorl (where the cochlea is largest), and thinner, floppier, and broader toward the apex, or center, of the whorl (where the cochlea is smallest). Different regions of the basilar membrane vibrate according to the frequency of the sound wave conducted through the fluid in the cochlea. For these reasons, the fluid-filled cochlea detects different wave frequencies (pitches) at different regions of the membrane. When the sound waves in the cochlear fluid contact the basilar membrane, it flexes back and forth in a wave-like fashion. Above the basilar membrane is the tectorial membrane.

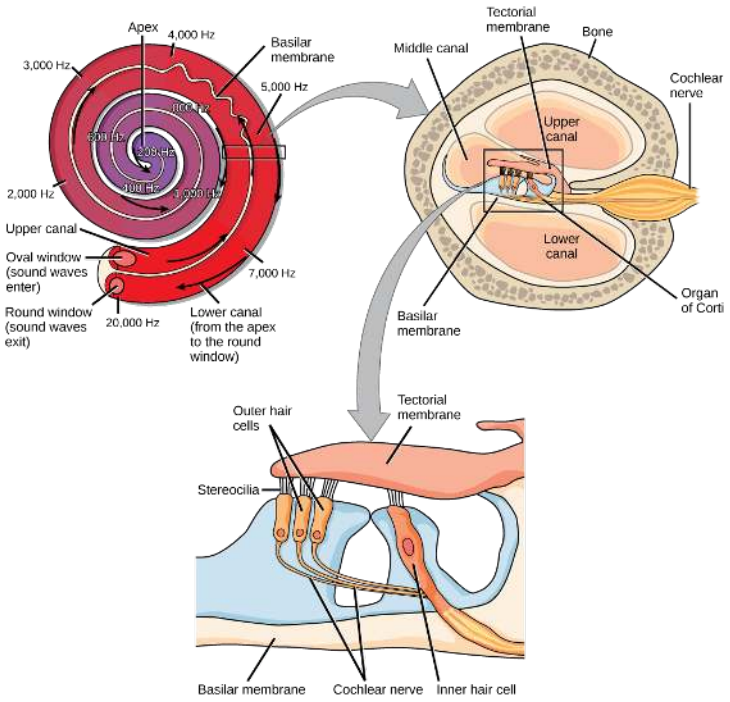


Figure 7.3.4: In the human ear, sound waves cause the stapes to press against the oval window. Vibrations travel up the fluid-filled interior of the cochlea. The basilar membrane that lines the cochlea gets continuously thinner toward the apex of the cochlea. Different thicknesses of membrane vibrate in response to different frequencies of sound. Sound waves then exit through the round window. In the cross section of the cochlea (top right figure), note that in addition to the upper canal and lower canal, the cochlea also has a middle canal. The organ of Corti (bottom image) is the site of sound transduction. Movement of stereocilia on hair cells results in an action potential that travels along the auditory nerve.

The site of transduction of sound from a mechanical wave to a nerve impulse is in the **organ of Corti** (spiral organ). It is composed of hair cells held in place above the basilar membrane like flowers projecting up from soil, with their exposed short, hair-like stereocilia contacting or embedded in the tectorial membrane above them. The inner hair cells are the primary auditory receptors and exist in a single row, numbering approximately 3,500. The stereocilia from inner hair cells extend into small dimples on the tectorial membrane's lower surface. The outer hair cells are arranged in three or four rows. They number approximately 12,000, and they function to fine tune incoming sound waves. The longer stereocilia that project from the outer hair cells actually attach to the tectorial membrane. All of the stereocilia are mechanoreceptors, and when bent by vibrations they respond by opening a gated ion channel. As a result, the hair cell membrane is depolarized, and a signal is transmitted to the cochlear nerve. Intensity (volume) of sound is determined by how many hair cells at a particular location are stimulated.

The hair cells are arranged on the basilar membrane in an orderly way. The basilar membrane vibrates in different regions, according to the frequency of the sound waves impinging on it. Likewise, the hair cells that lay above it are most sensitive to a specific frequency of sound waves. Hair cells can respond to a small range of similar frequencies, but they require stimulation of

greater intensity to fire at frequencies outside of their optimal range. The difference in response frequency between adjacent inner hair cells is about 0.2 percent. Compare that to adjacent piano strings, which are about six percent different. Place theory, which is the model for how biologists think pitch detection works in the human ear, states that high frequency sounds selectively vibrate the basilar membrane of the inner ear near the entrance port (the oval window). Lower frequencies travel farther along the membrane before causing appreciable excitation of the membrane. The basic pitch-determining mechanism is based on the location along the membrane where the hair cells are stimulated. The place theory is the first step toward an understanding of pitch perception. Considering the extreme pitch sensitivity of the human ear, it is thought that there must be some auditory "sharpening" mechanism to enhance the pitch resolution.

When sound waves produce fluid waves inside the cochlea, the basilar membrane flexes, bending the stereocilia that attach to the tectorial membrane. Their bending results in action potentials in the hair cells, and auditory information travels along the neural endings of the bipolar neurons of the hair cells (collectively, the auditory nerve) to the brain. When the hairs bend, they release an excitatory neurotransmitter at a synapse with a sensory neuron, which then conducts action potentials to the central nervous system. The cochlear branch of the vestibulocochlear cranial nerve sends information on hearing. The auditory system is very refined, and there is some modulation or "sharpening" built in. The brain can send signals back to the cochlea, resulting in a change of length in the outer hair cells, sharpening or dampening the hair cells' response to certain frequencies.

Higher Processing of Sound

The inner hair cells are most important for conveying auditory information to the brain. About 90 percent of the afferent neurons carry information from inner hair cells, with each hair cell synapsing with 10 or so neurons. Outer hair cells connect to only 10 percent of the afferent neurons, and each afferent neuron innervates many hair cells. The afferent, bipolar neurons that convey auditory information travel from the cochlea to the medulla, through the pons and midbrain in the brainstem, finally reaching the primary auditory cortex in the temporal lobe.

The Ear and Balance (Equilibrium)

Vestibular Information

Equilibrium, the vestibular sense, also known as the movement, gravity and/or balance sense, allows us to move smoothly, maintain a sense of balance, and sit and stand upright. We are able to maintain our balance while engaged in activities because of this sense. While the vestibular sense helps us with balance while we walk and run, it also helps us stay upright when we sit and stand. Our sense of balance comes from our inner ear communicating with the brain. Together, they help us to have a sense of balance and orient to the space around us. This helps keep you standing up straight and remaining in place.

The vestibular system detects its own movement. The stimuli associated with the vestibular system are linear acceleration (gravity), angular acceleration and deceleration, and balance. Gravity, acceleration, and deceleration are detected by evaluating the inertia on receptive cells in the vestibular system. Gravity is detected through head position. Angular acceleration and deceleration are expressed through turning or tilting of the head.

The vestibular system has some similarities with the auditory system. It utilizes hair cells just like the auditory system, but it excites them in different ways. There are five vestibular receptor organs in the inner ear: the utricle, the saccule, and three semicircular canals. Together, they make up what's known as the **vestibular labyrinth** that is shown in Figure 7.3.5. The utricle and saccule respond to acceleration in a straight line, such as gravity. The roughly 30,000 hair cells in the utricle and 16,000 hair cells in the saccule lie below a gelatinous layer, with their stereocilia projecting into the gelatin. Embedded in this gelatin are calcium carbonate crystals—like tiny rocks. When the head is tilted, the crystals continue to be pulled straight down by gravity, but the new angle of the head causes the gelatin to shift, thereby bending the stereocilia. The bending of the stereocilia stimulates the neurons, and they signal to the brain that the head is tilted, allowing the maintenance of balance. It is the vestibular branch of the vestibulocochlear cranial nerve that deals with balance.

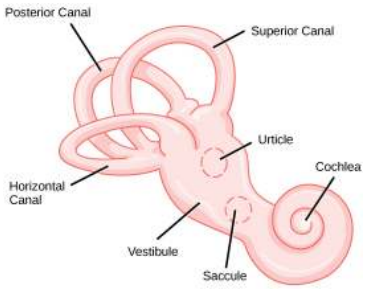


Figure 7.3.5: The structure of the vestibular labyrinth is shown. (credit: modification of work by NIH)

The fluid-filled **semicircular canals** are tubular loops set at oblique angles. They are arranged in three spatial planes. The base of each canal has a swelling that contains a cluster of hair cells. The hairs project into a gelatinous cap called the cupula and monitor angular acceleration and deceleration from rotation. They would be stimulated by driving your car around a corner, turning your head, or falling forward. One canal lies horizontally, while the other two lie at about 45 degree angles to the horizontal axis, as illustrated in Figure 7.3.5. When the brain processes input from all three canals together, it can detect angular acceleration or deceleration in three dimensions. When the head turns, the fluid in the canals shifts, thereby bending stereocilia and sending signals to the brain. Upon cessation accelerating or decelerating—or just moving—the movement of the fluid within the canals slows or stops. For example, imagine holding a glass of water. When moving forward, water may splash backwards onto the hand, and when motion has stopped, water may splash forward onto the fingers. While in motion, the water settles in the glass and does not splash. Note that the canals are not sensitive to velocity itself, but to changes in velocity, so moving forward at 60mph with your eyes closed would not give the sensation of movement, but suddenly accelerating or braking would stimulate the receptors.

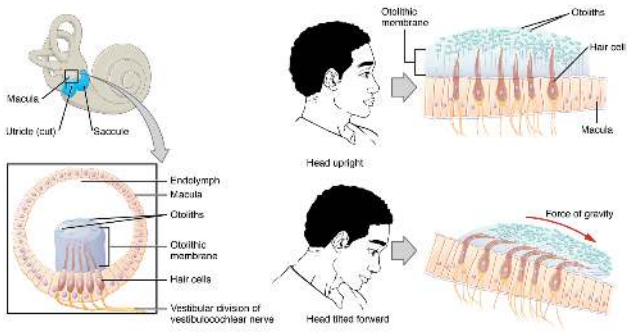


Figure 7.3.6: Linear Acceleration Coding by Maculae The maculae are specialized for sensing linear acceleration, such as when gravity acts on the tilting head, or if the head starts moving in a straight line. The difference in inertia between the hair cell stereocilia and the otolithic membrane in which they are embedded leads to a shearing force that causes the stereocilia to bend in the direction of that linear acceleration.

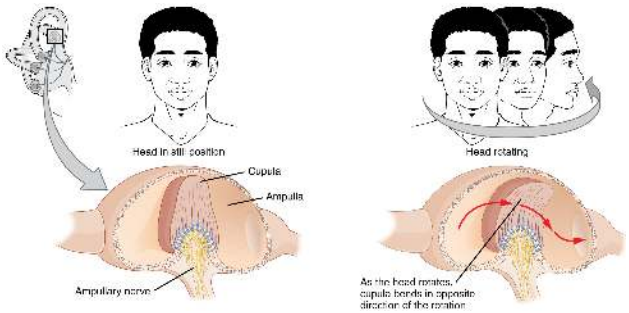


Figure 7.3.7: Rotational Coding by Semicircular Canals Rotational movement of the head is encoded by the hair cells in the base of the semicircular canals. As one of the canals moves in an arc with the head, the internal fluid moves in the opposite direction, causing the cupula and stereocilia to bend. The movement of two canals within a plane results in information about the direction in which the head is moving, and activation of all six canals can give a very precise indication of head movement in three dimensions.

Higher Processing of Vestibular Information

Hair cells from the utricle, saccule, and semicircular canals also communicate through bipolar neurons to the cochlear nucleus in the medulla. Cochlear neurons send descending projections to the spinal cord and ascending projections to the pons, thalamus, and cerebellum. Connections to the cerebellum are important for coordinated movements. There are also projections to the temporal cortex, which account for feelings of dizziness; projections to autonomic nervous system areas in the brainstem, which account for motion sickness; and projections to the primary somatosensory cortex, which monitors subjective measurements of the external world and self-movement. People with lesions in the vestibular area of the somatosensory cortex see vertical objects in the world as being tilted. Finally, the vestibular signals project to certain optic muscles to coordinate eye and head movements.

LINK TO LEARNING

This animation illustrates how the human cochlea, a structure in the inner ear involved in hearing, receives sound in the form of vibrations.

Section Summary

Audition is important in animals for territory defense, predation, predator defense, and communal exchanges. The vestibular system, which is not auditory, detects linear acceleration and angular acceleration and deceleration. Both the auditory system and vestibular system use hair cells as their receptors.

Auditory stimuli are sound waves. The sound wave energy reaches the outer ear (pinna, canal, tympanum), and vibrations of the tympanum send the energy to the middle ear. The middle ear bones shift and the stapes transfers mechanical energy to the oval window of the fluid-filled inner ear cochlea. Once in the cochlea, the energy causes the basilar membrane to flex, thereby bending the stereocilia on receptor hair cells. This activates the receptors, which send their auditory neural signals to the brain.

The vestibular system has five parts that work together to provide the sense of direction, thus helping to maintain balance. The utricle and saccule measure head orientation: their calcium carbonate crystals shift when the head is tilted, thereby activating hair cells. The semicircular canals work similarly, such that when the head is turned, the fluid in the canals bends stereocilia on hair cells. The vestibular hair cells also send signals to the thalamus and to somatosensory cortex, but also to the cerebellum, the structure above the brainstem that plays a large role in timing and coordination of movement.

Review

1. Explain how the structures of the ear collect and amplify sound waves and transform them into nerve impulses.
2. What role does the ear play in balance? Which structures of the ear are involved in balance?
3. How might being in a place with less gravity than Earth has (such as Earth's moon) affect vestibular sensation, and why?
4. The auditory nerve carries:
   A. Smell information
   B. Taste information
   C. Balance information
   D. Sound information
5. Cochlear implants can restore hearing in people who have a nonfunctional cochlea. The implant consists of a microphone that picks up sound. A speech processor selects sounds in the range of human speech, and a transmitter converts these sounds to electrical impulses, which are then sent to the auditory nerve. Which of the following types of hearing loss would not be restored by a cochlear implant?
   a. Hearing loss resulting from absence or loss of hair cells in the organ of Corti.
   b. Hearing loss resulting from an abnormal auditory nerve.
   c. Hearing loss resulting from fracture of the cochlea.
   d. Hearing loss resulting from damage to bones of the middle ear.
6. Auditory hair cells are indirectly anchored to the _____.
   a. basilar membrane
   b. oval window
   c. tectorial membrane
   d. ossicles
7. Which of the following are found both in the auditory system and the vestibular system?
   a. basilar membrane
   b. hair cells
   c. semicircular canals
   d. ossicles

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7.4: Taste and Smell

Taste and Smell

Both taste and odor stimuli are molecules taken in from the environment. Taste and smell are both abilities to sense chemicals, so taste and olfactory (odor) receptors are chemoreceptors. Both types of chemoreceptors send nerve impulses to the brain along sensory nerves, and the brain “tells” us what we are tasting or smelling. A distinction between the two is that taste chemoreceptors detect chemicals in fluid (saliva and the liquids in the food and beverages we consume) whereas olfactory chemoreceptors detect chemicals in the air. Smell is an important part of what we perceive as the flavor of the food and drink we consume, and we have many more different types of olfactory chemoreceptors than smell chemoreceptors.

Taste, also called **gustation**, and smell, also called **olfaction**, are the most interconnected senses in that both involve molecules of the stimulus entering the body and bonding to receptors. Smell lets an animal sense the presence of food other chemicals in the environment that can impact their survival. Similarly, the sense of taste allows animals to discriminate between types of foods. While the value of a sense of smell is obvious, what is the value of a sense of taste? Different tasting foods have different attributes, both helpful and harmful. For example, sweet-tasting substances tend to be highly caloric, which could be necessary for survival in lean times. Bitterness is associated with toxicity, and sourness is associated with spoiled food. Salty foods are valuable in maintaining homeostasis by helping the body retain water and by providing ions necessary for cells to function.

Both tasting abilities and sense of smell change with age. In humans, the senses decline dramatically by age 50 and continue to decline. A child may find a food to be too spicy, whereas an elderly person may find the same food to be bland and unappetizing.

Taste (Gustation)

The primary tastes detected by humans are sweet, sour, bitter, salty and umami. The first four tastes need little explanation. The identification of **umami** as a fundamental taste occurred fairly recently—it was identified in 1908 by Japanese scientist Kikunae Ikeda while he worked with seaweed broth, but it was not widely accepted as a taste that could be physiologically distinguished until many years later. Umami is a Japanese word that means “delicious taste,” and is often translated to mean savory. The taste of umami, also known as savoriness, is attributable to the taste of the amino acid L-glutamate. In fact, monosodium glutamate, or MSG, is often used in cooking to enhance the savory taste of certain foods. What is the adaptive value of being able to distinguish umami? Savory substances tend to be high in protein. Very recent research has suggested that there may also be a sixth taste for fats, or lipids.

Gustation is the special sense associated with the tongue. A **taste bud** is a cluster of gustatory receptors (taste cells) that are located within the bumps on the tongue called **papillae** (singular = papilla) (illustrated in Figures 7.4.2 - Figure 7.4.4). The surface of the tongue, along with the rest of the oral cavity, is lined by a stratified squamous epithelium. The papillae contain the structures for gustatory transduction. There are several structurally distinct papillae. Filiform papillae, which are located across the tongue, are tactile, providing friction that helps the tongue move substances, and contain no taste cells. In contrast, fungiform papillae, which are located mainly on the anterior two-thirds of the tongue, each contain one to eight taste buds and also have receptors for pressure and temperature. The large circumvallate papillae contain up to 100 taste buds and form a V near the posterior margin of the tongue. Within the structure of the papillae are taste buds that contain specialized gustatory receptor cells for the transduction of taste stimuli. Taste receptor cells make contact with chemicals in food through tiny openings called taste pores. When certain chemicals bind with taste receptor cells, it generates nerve impulses that travel through afferent nerves to the CNS. There are separate taste receptors for sweet, salty, sour, bitter, and umami (savory or meaty) tastes. These receptor cells are sensitive to the chemicals contained within foods that are ingested, and they release neurotransmitters based on the amount of the chemical in the food. Neurotransmitters from the gustatory cells can activate sensory neurons in the facial, glossopharyngeal, and vagus cranial nerves. You can see a diagram of a taste receptor cell and related structures in Figure 7.4.3.

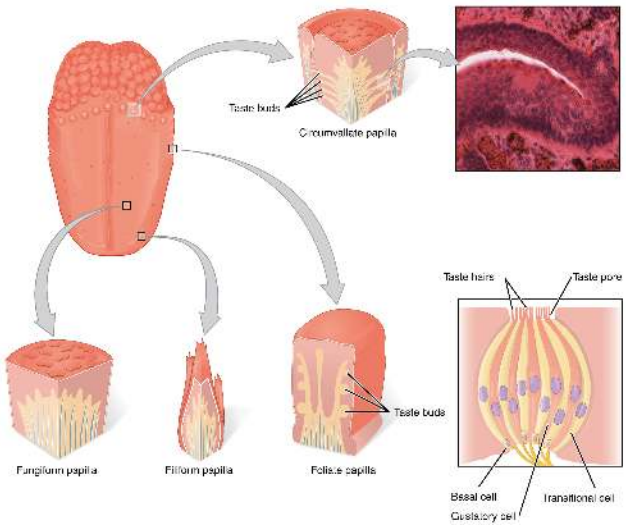


Figure 7.4.2: The Tongue The tongue is covered with small bumps, called papillae, which contain taste buds that are sensitive to chemicals in ingested food or drink. Different types of papillae are found in different regions of the tongue. The taste buds contain specialized gustatory receptor cells that respond to chemical stimuli dissolved in the saliva. These receptor cells activate sensory neurons that are part of the facial and glossopharyngeal nerves. LM × 1600. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

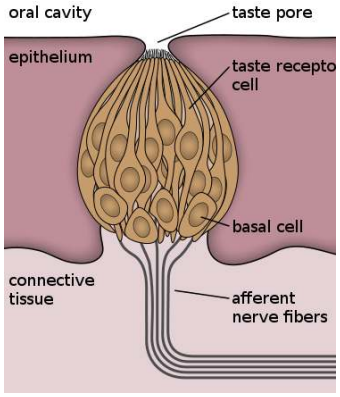


Figure 7.4.3: Taste receptor cells are in taste buds on the tongue. Taste pore exposes these cells into the oral cavity. Basal cells are not involved in tasting but differentiate into taste receptor cells.

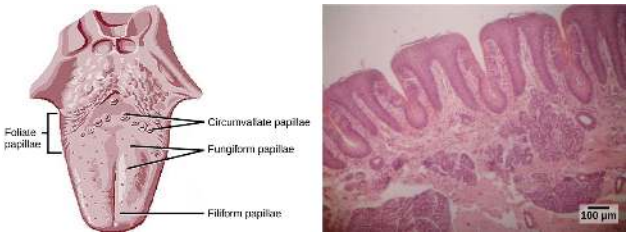


Figure 7.4.4: (a) Foliate, circumvallate, and fungiform papillae are located on different regions of the tongue. (b) Foliate papillae are prominent protrusions on this light micrograph. (credit a: modification of work by NCI; scale-bar data from Matt Russell)

In addition to those two types of chemically and mechanically sensitive papillae are foliate papillae—leaf-like papillae located in parallel folds along the edges and toward the back of the tongue, as seen in the Figure 7.4.4 micrograph. Foliate papillae contain about 1,300 taste buds within their folds. Finally, there are circumvallate papillae, which are wall-like papillae in the shape of an inverted “V” at the back of the tongue. Each of these papillae is surrounded by a groove and contains about 250 taste buds.

Each taste bud's taste cells are replaced every 10 to 14 days. These are elongated cells with hair-like processes called microvilli at the tips that extend into the taste bud pore (illustrate in Figure 12.2.4). Food molecules (tastants) are dissolved in saliva, and they bind with and stimulate the receptors on the microvilli. The receptors for tastants are located across the outer portion and front of the tongue, outside of the middle area where the filiform papillae are most prominent.

The Five Tastes

Salty taste is simply the perception of sodium ions (Na^+) in the saliva. When you eat something salty, the salt crystals dissociate into the component ions Na^+ and $Cl^–$, which dissolve into the saliva in your mouth. The Na^+ concentration becomes high outside the gustatory cells, creating a strong concentration gradient that drives the diffusion of the ion into the cells. The entry of Na^+ into these cells results in the depolarization of the cell membrane and the generation of a receptor potential.

Sour taste is the perception of H^+ concentration (acidity). Just as with sodium ions in salty flavors, these hydrogen ions enter the cell and trigger depolarization. Sour flavors are, essentially, the perception of acids in our food. Increasing hydrogen ion concentrations in the saliva (lowering saliva pH) triggers progressively stronger graded potentials in the gustatory cells. For example, orange juice—which contains citric acid—will taste sour because it has a pH value of approximately 3. Of course, it is often sweetened so that the sour taste is masked.

The first two tastes (salty and sour) are triggered by the cations Na^+ and H^+. The other tastes result from food molecules binding to a G protein–coupled receptor. A G protein signal transduction system ultimately leads to depolarization of the gustatory cell. The **sweet** taste is the sensitivity of gustatory cells to the presence of glucose dissolved in the saliva. Other monosaccharides such as fructose, or artificial sweeteners such as aspartame (NutraSweet™), saccharine, or sucralose (Splenda™) also activate the sweet receptors. The affinity for each of these molecules varies, and some will taste sweeter than glucose because they bind to the G protein–coupled receptor differently.

Bitter taste is similar to sweet in that food molecules bind to G protein–coupled receptors. However, there are a number of different ways in which this can happen because there are a large diversity of bitter-tasting molecules. Some bitter molecules depolarize gustatory cells, whereas others hyperpolarize gustatory cells. Likewise, some bitter molecules increase G protein activation within the gustatory cells, whereas other bitter molecules decrease G protein activation. The specific response depends on which molecule is binding to the receptor.

One major group of bitter-tasting molecules are alkaloids. Alkaloids are nitrogen containing molecules that are commonly found in bitter-tasting plant products, such as coffee, hops (in beer), tannins (in wine), tea, and aspirin. By containing toxic alkaloids, the plant is less susceptible to microbe infection and less attractive to herbivores.

Therefore, the function of bitter taste may primarily be related to stimulating the gag reflex to avoid ingesting poisons. Because of this, many bitter foods that are normally ingested are often combined with a sweet component to make them more palatable (cream and sugar in coffee, for example). The highest concentration of bitter receptors appear to be in the posterior tongue, where a gag reflex could still spit out poisonous food.

The taste known as **umami** is often referred to as the savory taste. Like sweet and bitter, it is based on the activation of G protein–coupled receptors by a specific molecule. The molecule that activates this receptor is the amino acid L-glutamate. Therefore, the umami flavor is often perceived while eating protein-rich foods. Not surprisingly, dishes that contain meat are often described as savory.

Once the gustatory cells are activated by the taste molecules, they release neurotransmitters onto the dendrites of sensory neurons. These neurons are part of the facial and glossopharyngeal cranial nerves, as well as a component within the vagus nerve dedicated to the gag reflex. The facial nerve connects to taste buds in the anterior third of the tongue. The glossopharyngeal nerve connects to taste buds in the posterior two thirds of the tongue. The vagus nerve connects to taste buds in the extreme posterior of the tongue, verging on the pharynx, which are more sensitive to noxious stimuli such as bitterness.

Smell (Olfaction)

Like taste, the sense of smell, or olfaction, is also responsive to chemical stimuli. All odors that we perceive are molecules in the air we breathe. If a substance does not release molecules into the air from its surface, it has no smell. And if a human or other animal does not have a receptor that recognizes a specific molecule, then that molecule has no smell. Humans have about 350 olfactory receptor subtypes that work in various combinations to allow us to sense about 10,000 different odors. Compare that to mice, for example, which have about 1,300 olfactory receptor types, and therefore probably sense more odors. Both odors and tastes involve molecules that stimulate specific chemoreceptors. Although humans commonly distinguish taste as one sense and smell as another, they work together to create the perception of flavor. A person's perception of flavor is reduced if he or she has congested nasal passages.

The olfactory receptor neurons are located in a small region within the superior nasal cavity (Figure 7.4.5). This region is referred to as the olfactory epithelium and contains bipolar sensory neurons. Each olfactory sensory neuron has dendrites that extend from the apical surface of the epithelium into the mucus lining the cavity. As airborne molecules are inhaled through the nose, they pass over the olfactory epithelial region and dissolve into the mucus. These odorant molecules bind to proteins that keep them dissolved in the mucus and help transport them to the olfactory dendrites. The odorant–protein complex binds to a receptor protein within the cell membrane of an olfactory dendrite. These receptors are G protein–coupled, and will produce a graded membrane potential in the olfactory neurons. There are millions of olfactory receptors, which sense chemicals in the air. Unlike taste receptors, which can sense only five different tastes, olfactory receptors can sense hundreds of different odors and send signals to the olfactory bulb of the brain. Did you ever notice that food seems to have less taste when you have a stuffy nose? This occurs because the sense of smell contributes to the sense of taste, and a stuffy nose interferes with the ability to smell.

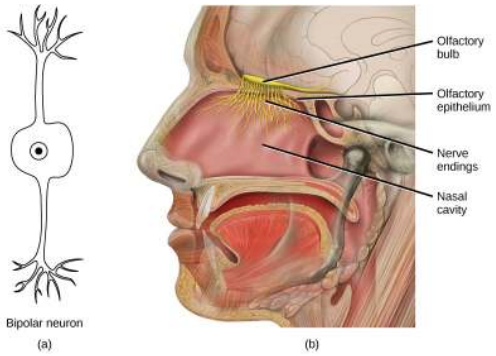


Figure 7.4.5: The yellow structures inside this drawing of the nasal passages are an olfactory nerve with many nerve endings. The nerve endings are located at the roof of the nasal cavity. The nerve endings sense chemicals in the air as it passes through the nasal cavities. (a) bipolar olfactory neurons extend from (b) the olfactory epithelium, where olfactory receptors are located, to the olfactory bulb. (credit: modification of work by Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist)

The axon of an olfactory neuron extends from the basal surface of the epithelium, through an olfactory foramen in the cribriform plate of the ethmoid bone, and into the brain. The group of axons called the olfactory tract connect to the olfactory bulb on the ventral surface of the frontal lobe. From there, the axons split to travel to several brain regions. Some travel to the cerebrum, specifically to the primary olfactory cortex that is located in the inferior and medial areas of the temporal lobe. Others project to structures within the limbic system and hypothalamus, where smells become associated with long-term memory and emotional responses. This is how certain smells trigger emotional memories, such as the smell of food associated with one's birthplace. Smell is the one sensory modality that does not synapse in the thalamus before connecting to the cerebral cortex. This intimate connection between the olfactory system and the cerebral cortex is one reason why smell can be a potent trigger of memories and emotion.The nasal epithelium, including the olfactory cells, can be harmed by airborne toxic chemicals. Therefore, the olfactory neurons are regularly replaced within the nasal epithelium, after which the axons of the new neurons must find their appropriate connections in the olfactory bulb. These new axons grow along the axons that are already in place in the cranial nerve.

Reception and Transduction

Odorants (odor molecules) enter the nose and dissolve in the olfactory epithelium, the mucosa at the back of the nasal cavity (as illustrated in Figure 7.4.6). The **olfactory epithelium** is a collection of specialized olfactory receptors in the back of the nasal cavity

that spans an area about 5 cm^2 in humans. Recall that sensory cells are neurons. An **olfactory receptor**, which is a dendrite of a specialized neuron, responds when it binds certain molecules inhaled from the environment by sending impulses directly to the olfactory bulb of the brain. Humans have about 12 million olfactory receptors, distributed among hundreds of different receptor types that respond to different odors. Twelve million seems like a large number of receptors, but compare that to other animals: rabbits have about 100 million, most dogs have about 1 billion, and bloodhounds—dogs selectively bred for their sense of smell—have about 4 billion. The overall size of the olfactory epithelium also differs between species, with that of bloodhounds, for example, being many times larger than that of humans.

Olfactory neurons are bipolar neurons (neurons with two processes from the cell body). Each neuron has a single dendrite buried in the olfactory epithelium, and extending from this dendrite are 5 to 20 receptor-laden, hair-like cilia that trap odorant molecules. The sensory receptors on the cilia are proteins, and it is the variations in their amino acid chains that make the receptors sensitive to different odorants. Each olfactory sensory neuron has only one type of receptor on its cilia, and the receptors are specialized to detect specific odorants, so the bipolar neurons themselves are specialized. When an odorant binds with a receptor that recognizes it, the sensory neuron associated with the receptor is stimulated. Olfactory stimulation is the only sensory information that directly reaches the cerebral cortex, whereas other sensations are relayed through the thalamus.

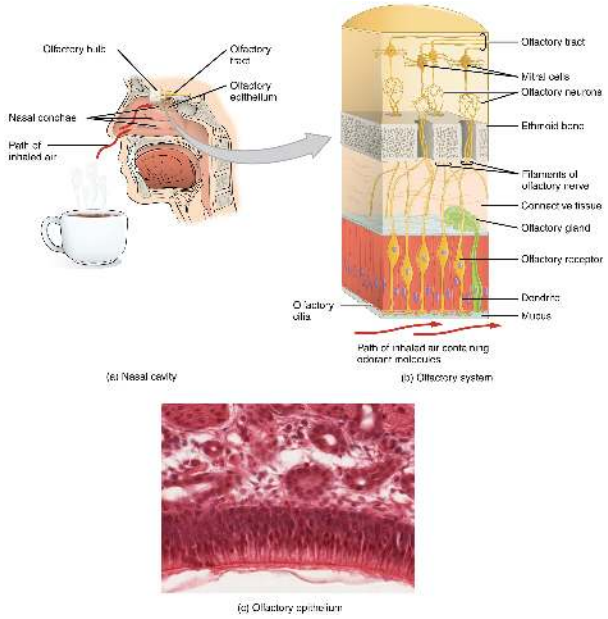


Figure 7.4.6: The Olfactory System (a) The olfactory system begins in the peripheral structures of the nasal cavity. (b) The olfactory receptor neurons are within the olfactory epithelium. (c) Axons of the olfactory receptor neurons project through the cribriform plate of the ethmoid bone and synapse with the neurons of the olfactory bulb (tissue source: simian). LM × 812. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Disorders of the...

Olfactory System: Anosmia

Blunt force trauma to the face, such as that common in many car accidents, can lead to the loss of the olfactory nerve, and subsequently, loss of the sense of smell. This condition is known as anosmia. When the frontal lobe of the brain moves relative to the ethmoid bone, the olfactory tract axons may be sheared apart. Professional fighters often experience anosmia because of repeated trauma to face and head. In addition, certain pharmaceuticals, such as antibiotics, can cause anosmia by killing all the olfactory neurons at once. If no axons are in place within the olfactory nerve, then the axons from newly formed olfactory neurons have no guide to lead them to their connections within the olfactory bulb. There are temporary causes of anosmia, as well, such as those caused by inflammatory responses related to respiratory infections or allergies.

Loss of the sense of smell can result in food tasting bland. A person with an impaired sense of smell may require additional spice and seasoning levels for food to be tasted. Anosmia may also be related to some presentations of mild depression, because the loss of enjoyment of food may lead to a general sense of despair.

The ability of olfactory neurons to replace themselves decreases with age, leading to age-related anosmia. This explains why some elderly people salt their food more than younger people do. However, this increased sodium intake can increase blood volume and blood pressure, increasing the risk of cardiovascular diseases in the elderly.

Section Summary

There are five primary tastes in humans: sweet, sour, bitter, salty, and umami. Each taste has its own receptor type that responds only to that taste. Tastants enter the body and are dissolved in saliva. Taste cells are located within taste buds, which are found on three of the four types of papillae in the mouth.

Regarding olfaction, there are many thousands of odorants, but humans detect only about 10,000. Like taste receptors, olfactory receptors are each responsive to only one odorant. Odorants dissolve in nasal mucosa, where they excite their corresponding olfactory sensory cells. When these cells detect an odorant, they send their signals to other structures which ultimately are conveyed to the CNS.

Questions

1. Describe the range of tactile stimuli that are detected in the sense of touch.
2. Explain why your skin can detect different types of stimuli, such as pressure and temperature.
3. Describe two ways that the body senses chemicals and the special sense organs that are involved in these senses.
4. What might be the effect on a person of not being able to perceive taste?
5. *Choose one.* Sensory information is sent to the central nervous system via (efferent/afferent) nerves.
6. Identify a mechanoreceptor used in two different human senses, and describe the type of mechanical stimuli that each one detects.

How many different taste molecules do taste cells each detect?

a. one
b. five
c. ten
d. It depends on the spot on the tongue

Salty foods activate the taste cells by _____.

a. exciting the taste cell directly
b. causing hydrogen ions to enter the cell
c. causing sodium channels to close
d. binding directly to the receptors

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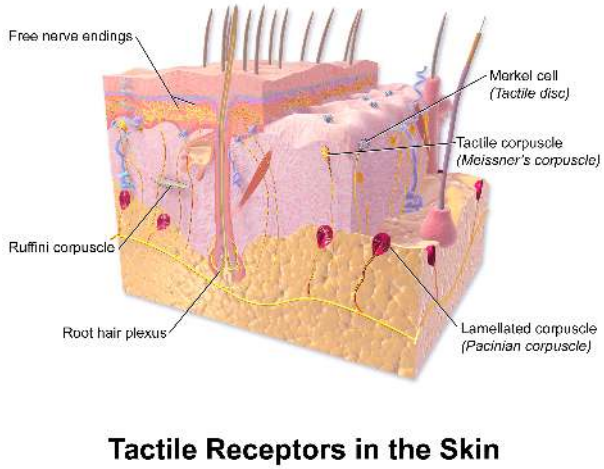
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7.5: Touch

Touch

In contrast to the special senses (such as vision, hearing, balance, taste and smell), which have specialized sense organs that gather sensory information and change it into nerve impulses, **touch** is a general sense. General senses are all associated with the sense of touch and lack special sense organs. Instead, sensory information about touch is gathered by the skin and other body tissues, all of which have important functions besides gathering sensory information. Whether the senses are special or general, however, all of them depend on cells called sensory receptors.

Touch is the ability to sense pressure, vibration, temperature, pain, and other tactile stimuli. These types of stimuli are detected by mechanoreceptors, thermoreceptors, and nociceptors all over the body, but most noticeably in the skin. These receptors are especially concentrated on the tongue, lips, face, palms of the hands, and soles of the feet. Various types of tactile receptors in the skin are shown in Figure 7.5.1.



Tactile Receptors in the Skin

Figure 7.5.1: Tactile receptors in the skin include free nerve endings, Merkel cells, Meissner's corpuscles, Pacinian corpuscles, root hair plexuses, and Ruffini corpuscles. Each type of sensory receptor responds to a different kind of tactile stimulus. For example, free nerve endings generally respond to pain and temperature variations, whereas Merkel cells are associated with the sense of light touch and the discrimination of shapes and textures.

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CHAPTER OVERVIEW

8: ENDOCRINE SYSTEM

This chapter describes the endocrine system and its vital roles in communication, control, and homeostasis within the human body. The focus is on the pituitary gland, as the master gland of the endocrine system, and three other endocrine glands: the thyroid gland, adrenal glands, and pancreas. The chapter also explains the differing mechanisms of steroid and non-steroid endocrine hormones.

8.1: Case Study- Hormones and Health

8.2: Introduction to the Endocrine System

8.3: Endocrine Hormones

8.4: Pituitary Gland and Hypothalamus

8.5: Thyroid Gland

8.6: Parathyroid Glands

8.7: Adrenal Glands

8.8: Pancreas

8.9: Case Study Conclusion- Hormonal and Chapter Summary

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8.1: CASE STUDY- HORMONES AND HEALTH

CASE STUDY: HORMONAL HAVOC

18-year-old Gabrielle checks her calendar. It has been 42 days since her last menstrual period, two weeks later than the length of the average woman's menstrual cycle. Although many women would suspect pregnancy if their period was late, Gabrielle has not been sexually active. She is not even sure she is "late" because her period has never been regular. Ever since her first period at 13 years of age, her cycle lengths have varied greatly, and there are months where she does not get a period at all. Her mother told her that a girl's period is often irregular when it first starts, but Gabrielle's still has not become regular five years later. She decides to go to the student health center on her college campus to get it checked out.



Figure **8.1.1**: Calendar

The doctor asks her about the timing of her menstrual periods and performs a pelvic exam. She also notices that Gabrielle is overweight, has acne, and excess facial hair. As she explains to Gabrielle, while these physical characteristics can be perfectly normal, in combination with an irregular period they can be signs of a disorder of the endocrine, or hormonal, system called polycystic ovary syndrome (PCOS).

In order to check for PCOS, the doctor refers Gabrielle for a pelvic ultrasound and sends her to the lab to get blood work done. When her lab results come back, Gabrielle learns that her levels of androgens (a group of hormones) are high, and so is her blood glucose (sugar). The ultrasound showed that she has multiple fluid-filled sacs known as cysts in her ovaries. Based on Gabrielle's symptoms and test results, the doctor tells her that she does indeed have PCOS.

PCOS is common in young women. It is estimated that between 1 in 10 to 20 women of childbearing age have PCOS — as many as five million women in the United States. You may know someone with PCOS or may have it yourself.

Read the rest of this chapter to learn about the glands and hormones of the endocrine system, their functions, how they are regulated, and the disorders — such as PCOS — that can arise when hormones are not regulated properly. At the end of the chapter, you will learn more about PCOS, its possible long-term consequences including fertility problems and diabetes, and how these negative outcomes can sometimes be prevented with lifestyle changes and medications.

CHAPTER OVERVIEW: ENDOCRINE SYSTEM

In this chapter, you will learn about the endocrine system, a system of glands that secrete hormones that regulate many of the body's functions. Specifically, you will learn about:

- The glands that make up the endocrine system and how hormones act as chemical messengers in the body.
- The general types of endocrine system disorders.
- The types of endocrine hormones, including steroid hormones such as sex hormones, and non-steroid hormones such as insulin; and how they affect the functions of their target cells by binding to different types of receptor proteins.
- How the levels of hormones are regulated mostly through negative, but sometimes through positive, feedback loops.
- The master gland of the endocrine system, the pituitary gland, controls other parts of the endocrine system through the hormones that it secretes; and how the pituitary itself is regulated by hormones secreted from the hypothalamus of the brain.
- The thyroid gland and its hormones, which regulate processes such as metabolism and calcium homeostasis; how the thyroid is regulated; and the disorders that can occur when there are problems in thyroid hormone regulation, such as hyperthyroidism and hypothyroidism.
- The adrenal glands, which secrete hormones that regulate processes such as metabolism, electrolyte balance, responses to stress, and reproductive functions; and the disorders that can occur when there are problems in adrenal hormone regulation, such as Cushing's syndrome and Addison's disease.
- The pancreas, which secretes hormones that regulate blood glucose levels such as insulin; and disorders of the pancreas and its hormones including diabetes.

As you read this chapter, think about the following questions:

1. Why can hormones have such a broad-range effect on the body, such as is seen in PCOS?
2. Which hormones normally regulate blood glucose and how is this related to diabetes?
3. What are androgens? How do you think their functions relate to some of the symptoms that Gabrielle is experiencing?

ATTRIBUTIONS

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8.2: INTRODUCTION TO THE ENDOCRINE SYSTEM

MOON FACE

The patient in Figure **8.2.1** has the characteristic moon face of a disorder named Cushing's syndrome. Other signs and symptoms of this disorder include abnormal weight gain, acne, and excessive hairiness, among many other abnormalities. What can cause so many different problems in one patient? The answer is the overproduction of the endocrine system hormone cortisol.



Figure **8.2.1**: a person with Cushing's syndrome

OVERVIEW OF THE ENDOCRINE SYSTEM

The **endocrine system** is a system of glands called **endocrine glands** that release chemical messenger molecules called **hormones** into the bloodstream. Other glands of the body, including sweat glands and salivary glands, also secrete substances but not into the bloodstream. Instead, they secrete them through ducts that carry them to nearby body surfaces. These other glands are called **exocrine glands.**

Endocrine hormones must travel through the bloodstream to the cells they affect, and this takes time. Because endocrine hormones are released into the bloodstream, they travel throughout the body wherever blood flows. As a result, endocrine hormones may affect many cells and have body-wide effects. Endocrine hormones may cause effects that last for days, weeks, or even months.

COMPARISON OF THE NERVOUS SYSTEM AND THE ENDOCRINE SYSTEM

Communication is a process in which a sender transmits signals to one or more receivers to control and coordinate actions. In the human body, two major organ systems participate in relatively "long distance" communication: the nervous system and the endocrine system. Together, these two systems are primarily responsible for maintaining homeostasis in the body.

NEURAL AND ENDOCRINE SIGNALING

The **nervous system** uses two types of intercellular communication —electrical and chemical signaling. Electrical signaling occurs by the direct action of an electrical potential. Chemical signaling occurs through the action of chemical neurotransmitters such as serotonin or norepinephrine. Neurotransmitters act locally and rapidly. When an electrical signal in the form of an action potential arrives at the synaptic terminal, neurotransmitters diffuse across the synaptic cleft (the gap between a sending neuron and a receiving neuron or muscle cell). Once the neurotransmitters interact (bind) with receptors on the receiving (post-synaptic) cell, the receptor stimulation is transduced into a response such as continued electrical signaling or modification of cellular response. The target cell responds within milliseconds of receiving the chemical "message"; this response then ceases very quickly once the neural signaling ends. In this way, neural communication enables body functions that involve quick, brief actions, such as movement, sensation, and cognition.I

In contrast, the **endocrine system** uses just one method of communication: chemical signaling. These signals are sent by the endocrine organs, which secrete chemicals—the hormone—into the extracellular fluid. Hormones are transported primarily via the bloodstream throughout the body, where they bind to receptors on target cells, inducing a characteristic response. As a result, endocrine signaling requires more time than neural signaling to prompt a response in target cells, though the precise amount of time varies with different hormones. For example, the hormones released when you are confronted with a dangerous or frightening situation, called the fight-or-flight response, occur by the release of adrenal hormones—epinephrine and norepinephrine—within seconds. In contrast, it may take up to 48 hours for target cells to respond to certain reproductive hormones.

In addition, endocrine signaling is typically less specific than neural signaling. The same hormone may play a role in a variety of different physiological processes depending on the target cells involved. For example, the hormone oxytocin promotes uterine contractions in people in labor. It is also important in breastfeeding, and may be involved in the sexual response and in feelings of emotional attachment in humans.

In general, the nervous system involves quick responses to rapid changes in the external environment, and the endocrine system is usually slower acting—taking care of the internal environment of the body, maintaining homeostasis, and controlling reproduction (Table **8.2.1**). So how does the fight-or-flight response that was mentioned earlier happen so quickly if hormones are usually slower acting? It is because the two systems are connected. It is the fast action of the nervous system in response to the danger in the environment that stimulates the adrenal glands to secrete their hormones. As a result, the nervous system can cause rapid endocrine responses to keep up with sudden changes in both the external and internal environments when necessary.

Endocrine and Nervous Systems

	Endocrine system	Nervous system
Signaling mechanism(s)	Chemical	Chemical/electrical
Primary chemical signal	Hormones	Neurotransmitters
Distance traveled	Long or short	Always short
Response time	Fast or slow	Always fast
Environment targeted	Internal	Internal and external

Table 8.2.1

GLANDS OF THE ENDOCRINE SYSTEM

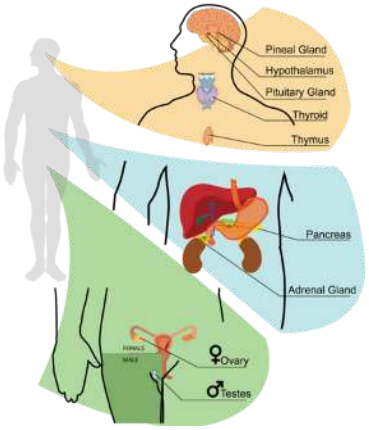


Figure 8.2.2: Pineal gland, hypothalamus, Pituitary gland, Thyroid, Thymus, Pancreas, Adrenal gland, over and testes are part of the endocrine system. Note that the ovary and testis are the only endocrine glands that differ in males and females

The major glands of the endocrine system are shown in Figure 8.2.2. The glands in the figure are described briefly in the rest of this section. Refer to the figure as you read about the glands in the following text.

PITUITARY GLAND

The pituitary gland is located at the base of the brain. It is controlled by the nervous system via the brain structure called the **hypothalamus**, to which it is connected by a thin stalk. The pituitary gland consists of two lobes, called the anterior (front) lobe and posterior (back) lobe. The posterior lobe stores and secretes hormones synthesized by the hypothalamus. The anterior lobe synthesizes and secretes its own endocrine hormones, also under the influence of the hypothalamus. One endocrine hormone secreted by the pituitary gland is growth hormone, which stimulates cells throughout the body to synthesize proteins and divide. Most of the other endocrine hormones secreted by the pituitary gland control other endocrine glands. Generally, these hormones direct the other glands to secrete either more or less of their hormones. This is why the pituitary gland is often referred to as the “master gland” of the endocrine system.

REMAINING GLANDS OF THE ENDOCRINE SYSTEM

Each of the other glands of the endocrine system is summarized below. Several of these endocrine glands are also discussed in greater detail in other concepts in the present chapter.

- The **thyroid gland** is a large gland in the neck. Thyroid hormones such as thyroxine increase the rate of metabolism in cells throughout the body. They control how quickly cells use energy and make proteins.
- The four **parathyroid glands** are located in the neck behind the thyroid gland. The parathyroid hormone helps keep the level of calcium in the blood within a narrow range. It stimulates bone cells to dissolve calcium and release it into the blood.
- The **pineal gland** is a tiny gland located near the center of the brain. It secretes the hormone melatonin, which controls the sleep-wake cycle and several other processes. The production of melatonin is stimulated by darkness and inhibited by light. Cells in the retina of the eye detect light and send signals to a structure in the brain named the suprachiasmatic nucleus (SCN). Nerve fibers carry the signals from the SCN to the pineal gland via the autonomic nervous system.
- The **pancreas** is located near the stomach. Its endocrine hormones include insulin and glucagon, which work together to control the level of glucose in the blood. The pancreas also has exocrine exocrine functions and secretes digestive enzymes into the small intestine.
- The two **adrenal glands** are located above the kidneys. Adrenal glands secrete several different endocrine hormones, including the hormone adrenaline, which is involved in the fight-or-flight response. Other endocrine hormones secreted by the adrenal glands have a variety of functions. For example, the hormone aldosterone helps to regulate the balance of minerals in the body. The hormone cortisol, which causes Cushing's syndrome when it is produced in excess, is also an adrenal gland hormone.
- The **gonads** include the ovaries in females and testes in males. They secrete sex hormones, such as testosterone (in people with testes) and estrogen (in people with ovaries). These hormones control sexual maturation during puberty and the production of gametes (sperm or egg cells) by the gonads after sexual maturation.
- The **thymus gland** is located in front of the heart. It is the site where immune system cells called T cells mature. T cells are critical to the adaptive immune system, in which the body adapts to specific pathogens.

ENDOCRINE SYSTEM DISORDERS

Diseases of the endocrine system are relatively common. An endocrine system disease usually involves the secretion of too much or not enough of a hormone. When too much hormone is secreted, the condition is called **hypersecretion.** When not enough hormone is secreted, the condition is called **hyposecretion.**

HYPERSECRETION



Figure **8.2.3**: Martin Van Buren Bates

Hypersecretion by an endocrine gland is often caused by a tumor. For example, a tumor of the pituitary gland can cause hypersecretion of growth hormone. If this occurs in childhood and goes untreated, it results in very long arms and legs and abnormally tall stature by adulthood. This condition is commonly known as gigantism. Martin Van Buren Bates is depicted in Figure **8.2.3** standing next to a man of average size. Bates was a Civil War-era American famed for his incredibly large size. He was at least 7 feet 9 inches tall and weighed close to 500 pounds. He was normal in size at birth but started to grow very rapidly by about age 6 years, presumably because of the hypersecretion of growth hormone.

HYPOSECRETION

Hyposecretion by an endocrine gland is often caused by the destruction of the hormone-secreting cells of the gland. As a result, not enough of the hormone is secreted. An example of this is type 1 diabetes, in which the body's own immune system attacks and destroys cells of the pancreas that secrete insulin. This type of diabetes is generally treated with frequent injections of insulin.

HORMONE INSENSITIVITY

In some cases, an endocrine gland secretes a normal amount of hormone, but target cells do not respond normally to it. This may occur because target cells have become resistant to the hormone. An example of this type of endocrine disorder is Androgen Insensitivity Disorder. Generally, the typical sex chromosomes of males are one X and one Y chromosome whereas females typically have two x chromosomes and no Y chromosome. Individuals with Androgen Insensitivity Disorder disorder are born with an X and Y chromosome (typical of males) but they develop and are raised as females. This is due to a mutation in the Androgen Receptor (AR) gene which is located on the X chromosome. Testosterone is an androgen hormone that causes testes to descend and typical male characteristics to develop. People with this form of the condition have the external sex characteristics of females but do not have a uterus and therefore do not menstruate and are unable to conceive a child (infertile). They are typically raised as females and have a female gender identity. Affected individuals have male internal sex organs (testes) that are undescended, which means they are located in the pelvis or abdomen. Many people with this condition are not aware that they have it until later in life, if ever.

REVIEW

1. What is the endocrine system? What is its general function?
2. Compare and contrast endocrine and exocrine glands.
3. How do endocrine system messages differ from those of the nervous system?
4. Describe the role of the pituitary gland in the endocrine system.
5. List three endocrine glands other than the pituitary gland, and identify their functions.
6. Which endocrine gland has an important function in the immune system? What is that function?
7. Define hypersecretion and hyposecretion.
8. Name an endocrine disorder in which too much of a hormone is produced.
9. What are two reasons people with diabetes might have signs and symptoms of inadequate insulin?
10. Choose one. Cushing's syndrome is an example of (hyposecretion/hypersecretion).
11. *True or False.* The hypothalamus is the master gland of the endocrine system.
12. *True or False.* Mammary glands that produce milk for offspring are part of the endocrine system.
13. Melatonin is produced by the:
    A. A. Pituitary gland
    B. B. Hypothalamus
    C. C. Pineal gland
    D. D. Pancreas
14. Besides location, what is the main difference between the anterior lobe of the pituitary and the posterior lobe of the pituitary?
15. Which endocrine glands differ between males and females? Which hormones do they produce?

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8.3: ENDOCRINE HORMONES

PILLS FROM PEE

The medication pictured above with the brand name Progynon was a drug used to control the effects of menopause in women. The pills first appeared in 1928 and contained the human sex hormone estrogen. Estrogen secretion declines in women around the time of menopause and may cause symptoms such as mood swings and hot flashes. The pills were supposed to ease the symptoms by supplementing estrogen in the body. The manufacturer of Progynon obtained estrogen for the pills from the urine of pregnant women because it was a cheap source of the hormone. Progynon is still used today to treat menopausal symptoms. Although the drug has been improved over the years, it still contains estrogen. Estrogen is an example of an endocrine hormone.



Figure **8.3.1**: Progynon pills bottle circa 1930 UK

HOW DO ENDOCRINE HORMONES WORK?

Endocrine hormones like estrogen are messenger molecules that are secreted by endocrine glands into the bloodstream. They travel throughout the body in the circulation. Although they reach virtually every cell in the body in this way, each hormone affects only certain cells, called target cells. A **target cell** is the type of cell on which a hormone has an effect. A target cell is affected by a particular hormone because it has receptor proteins — either on the cell surface or within the cell — that are specific to that hormone. An endocrine hormone travels through the bloodstream until it finds a target cell with a matching receptor to which it can bind. When the hormone binds to the receptor, it causes changes within the cell. The manner in which it changes the cell depends on whether the hormone is a steroid hormone or a non-steroid hormone.

STEROID HORMONES

A **steroid hormone** such as estrogen is made of lipids. It is fat soluble, so it can diffuse across a target cell's plasma membrane, which is also made of lipids. Once inside the cell, a steroid hormone binds with receptor proteins in the cytoplasm. As you can see in the diagram below, the steroid hormone and its receptor form a complex, called a steroid complex, which moves into the nucleus where it influences the expression of genes. Examples of steroid hormones include cortisol, which is secreted by the adrenal glands, and sex hormones, which are secreted by the gonads.

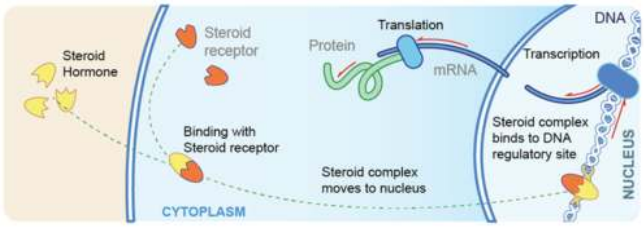


Figure **8.3.2**: A steroid hormone crosses the plasma membrane of a target cell, binds with a receptor protein within the cytoplasm, and forms a complex that moves to the nucleus where it affects gene expression.

NON-STEROID HORMONES

A **non-steroid hormone** is made of amino acids. It is not fat soluble, so it cannot diffuse across the plasma membrane of a target cell. Instead, it binds to a receptor protein on the cell membrane. In the following diagram, you can see that the binding of the hormone with the receptor activates an enzyme in the cell membrane. The enzyme then stimulates another molecule, called the second messenger, which influences processes inside the cell. Most endocrine hormones are non-steroid hormones. Examples include glucagon and insulin, both produced by the pancreas.

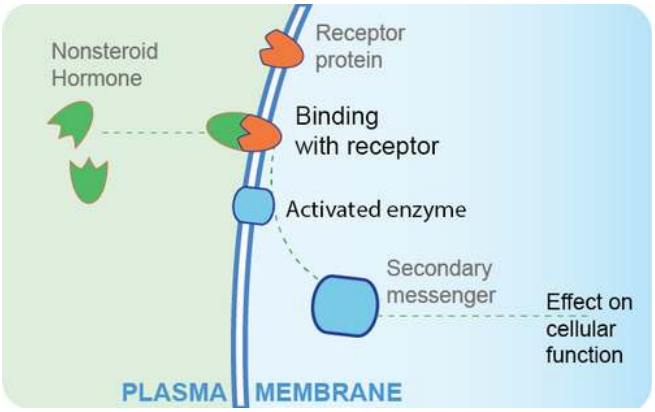


Figure **8.3.3**: A non-steroid hormone binds with a receptor protein on the plasma membrane of a target cell. This activates an enzyme, which controls a secondary messenger molecule.

ENDOCRINE GLANDS AND THEIR MAJOR HORMONES

Hormones play a critical role in the regulation of physiological processes because of the target cell responses they regulate. These responses contribute to human reproduction, growth and development of body tissues, metabolism, fluid, and electrolyte balance, sleep, and many other body functions. The major hormones of the human body and their effects are identified in Table **8.3.1**.

Endocrine Glands and Their Major Hormones

Endocrine gland	Associated hormones	Chemical class	Effect
Pituitary (anterior)	Growth hormone (GH)	Protein	Promotes growth of body tissues
Pituitary (anterior)	Prolactin (PRL)	Peptide	Promotes milk production
Pituitary (anterior)	Thyroid-stimulating hormone (TSH)	Glycoprotein	Stimulates thyroid hormone release
Pituitary (anterior)	Adrenocorticotropic hormone (ACTH)	Peptide	Stimulates hormone release by adrenal cortex
Pituitary (anterior)	Follicle-stimulating hormone (FSH)	Glycoprotein	Stimulates gamete production
Pituitary (anterior)	Luteinizing hormone (LH)	Glycoprotein	Stimulates androgen production by gonads
Pituitary (posterior)	Antidiuretic hormone (ADH)	Peptide	Stimulates water reabsorption by kidneys
Pituitary (posterior)	Oxytocin	Peptide	Stimulates uterine contractions during childbirth
Thyroid	Thyroxine (T_4), triiodothyronine (T_3)	Amine	Stimulate basal metabolic rate
Thyroid	Calcitonin	Peptide	Reduces blood Ca^{2+} levels
Parathyroid	Parathyroid hormone (PTH)	Peptide	Increases blood Ca^{2+} levels
Adrenal (cortex)	Aldosterone	Steroid	Increases blood Na^{+} levels
Adrenal (cortex)	Cortisol, corticosterone, cortisone	Steroid	Increase blood glucose levels
Adrenal (medulla)	Epinephrine, norepinephrine	Amine	Stimulate fight-or-flight response
Pineal	Melatonin	Amine	Regulates sleep cycles
Pancreas	Insulin	Protein	Reduces blood glucose levels
Pancreas	Glucagon	Protein	Increases blood glucose levels
Testes	Testosterone	Steroid	Stimulates development of sex characteristics including a deeper voice, increased muscle mass, development of body hair, and sperm production
Ovaries	Estrogens and progesterone	Steroid	Stimulate development of sex characteristics including the development of adipose and breast tissue, and prepare the body for childbirth

Table 8.3.1

REGULATION OF ENDOCRINE HORMONES

Endocrine hormones regulate many body processes, but what regulates the secretion of endocrine hormones? Most endocrine hormones are controlled by feedback mechanisms. A feedback mechanism is a loop in which a product feeds back to control its own production. Feedback loops may be either negative or positive.

- Most endocrine hormones are regulated by negative feedback loops. Negative feedback keeps the concentration of a hormone within a relatively narrow range and maintains homeostasis.
- Very few endocrine hormones are regulated by positive feedback loops. Positive feedback causes the concentration of a hormone to become increasingly higher.

REGULATION BY NEGATIVE FEEDBACK

A negative feedback loop controls the synthesis and secretion of hormones by the thyroid gland. This loop includes the hypothalamus and pituitary gland in addition to the thyroid, as shown in Figure 8.3.4. When the levels of thyroid hormones circulating in the blood fall too low, the hypothalamus secretes thyrotropin releasing hormone (TRH). This hormone travels directly to the pituitary gland through the thin stalk connecting the two structures. In the pituitary gland, TRH stimulates the pituitary to secrete thyroid stimulating hormone (TSH). TSH, in turn, travels through the bloodstream to the thyroid gland and stimulates it to secrete thyroid hormones. This continues until the blood levels of thyroid hormones are high enough. At that point, the thyroid hormones feedback to stop the hypothalamus from secreting TRH and the pituitary from secreting TSH. Without the stimulation of TSH, the thyroid gland stops secreting its hormones. Eventually, the levels of thyroid hormones in the blood start to fall too low again. When that happens, the hypothalamus releases TRH, and the loop repeats.

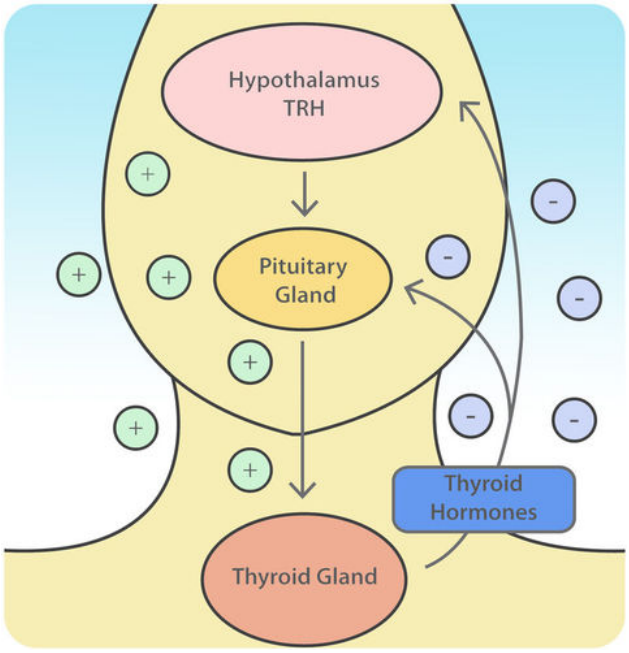


Figure 8.3.4: This diagram shows how the thyroid gland is regulated by a negative feedback loop that also involves the hypothalamus and pituitary gland.

REGULATION BY POSITIVE FEEDBACK

Prolactin is a non-steroid endocrine hormone secreted by the pituitary gland. One of the functions of prolactin is to stimulate a nursing mother's mammary glands to produce milk. The regulation of prolactin in the mother is controlled by a positive feedback loop that involves the nipples, hypothalamus, pituitary gland, and mammary glands. Positive feedback begins when a baby suckles on the mother's nipple. Nerve impulses from the nipple reach the hypothalamus, which stimulates the pituitary gland to secrete

prolactin. Prolactin travels in the blood to the mammary glands and stimulates them to produce milk. The release of milk causes the baby to continue suckling, which causes more prolactin to be secreted and more milk to be produced. The positive feedback loop continues until the baby stops suckling at the breast.

FEATURE: MYTH VS. REALITY

Anabolic steroids are synthetic versions of the naturally occurring male sex hormone testosterone. Male hormones have androgenic, or masculinizing, effects, but they also have anabolic, or muscle-building effects. The anabolic effects are the reason that synthetic steroids are used by athletes. In addition to building muscles, they also accelerate the development of bones and red blood cells, increase endurance so athletes can train harder and longer, and speed up muscle recovery. Unfortunately, these benefits of steroid use come with costs. If you ever consider taking anabolic steroids to build muscles and improve athletic performance, consider the following myths and corresponding realities.

Myth: Steroids are safe.

Reality: Steroid use may cause several serious side effects. Prolonged use may increase the risk of liver cancer, heart disease, and high blood pressure.

Myth: Steroids will not stunt your growth.

Reality: Teens who take steroids before they have finished growing in height may have their growth stunted so they remain shorter throughout life than they would otherwise have been. Such stunting occurs because steroids increase the rate at which skeletal maturity is reached. Once skeletal maturity occurs, additional growth in height is impossible.

Myth: Steroids do not cause drug dependency.

Reality: Steroid use may cause dependency as evidenced by the negative effects of stopping steroid use. These negative effects may include insomnia, fatigue, and depressed mood, among others.

Myth: There is no such thing as “roid rage.”

Reality: Steroid use has been shown to increase aggressiveness in some people. It has also been implicated in a number of violent acts committed by people who had not demonstrated violent tendencies until they started using steroids.

Myth: Only males use steroids.

Reality: Although steroid use is more common in males than females, some females also use steroids. They use them to build muscle and improve physical performance, generally either for athletic competition or for self-defense.

REVIEW

1. What are endocrine hormones?
2. Define the target cell in the context of endocrine hormones.
3. Explain how steroid hormones influence target cells.
4. How do non-steroid hormones affect target cells?
5. Compare and contrast negative and positive feedback loops.
6. Outline the way feedback controls the production of thyroid hormones.
7. Describe the feedback mechanism that controls milk production by the mammary glands.
8. Why do endocrine hormones only affect some of the cells in the body? Choose the best answer.
   A. They only reach certain cells.
   B. Many hormones cannot cross the plasma membrane of cells.
   C. Some cells feedback negatively in response to a hormone.
   D. Only some cells have receptor proteins that can bind to a given hormone.
9. People with a condition called hyperthyroidism produce too much thyroid hormone. What do you think this does to the level of TSH? Explain your answer.
10. Which is more likely to maintain homeostasis — negative feedback or positive feedback? Explain your answer.
11. Does testosterone bind to receptors on the plasma membrane of target cells or in the cytoplasm of target cells? Explain your answer.
12. *True or False.* Endocrine hormones can affect the expression of genes.
13. *True or False.* Non-steroid hormones cannot affect intracellular processes.
14. *True or False.* Insulin binds to receptors on the plasma membrane of cells.
15. Which hormone is secreted by the pituitary gland?
    A. Prolactin
    B. Insulin
    C. Cortisol
    D. Thyrotropin releasing hormone

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8.4: PITUITARY GLAND AND HYPOTHALAMUS

MILK ON DEMAND

This adorable nursing infant is part of a positive feedback loop. When he suckles on the nipple, it sends nerve impulses to his mother's hypothalamus, which "tell" her pituitary gland to release the hormone prolactin into her bloodstream. Prolactin travels to the mammary glands in the breasts and stimulates milk production, which motivates the infant to keep suckling.



Figure **8.4.1**: Nursing infant

THE PITUITARY GLAND AND THE HYPOTHALAMUS

The **hypothalamus–pituitary** complex can be thought of as the "command center" of the endocrine system. This complex secretes several hormones that directly produce responses in target tissues, as well as hormones that regulate the synthesis and secretion of hormones of other glands. In addition, the hypothalamus–pituitary complex coordinates the messages of the endocrine and nervous systems. In many cases, a stimulus received by the nervous system must pass through the hypothalamus–pituitary complex to be translated into hormones that can initiate a response.

The hypothalamus is located anterior and inferior to the thalamus (Figures **8.4.2** and **8.4.3**). It has both neural and endocrine functions, producing and secreting many hormones. In addition, the hypothalamus is anatomically and functionally related to the pituitary gland. The pituitary gland is a bean-sized organ suspended from the hypothalamus by a stem called the infundibulum (or pituitary stalk) and consists of two lobes that arise from distinct parts of embryonic tissue: the posterior pituitary is neural tissue, whereas the anterior pituitary is glandular tissue.

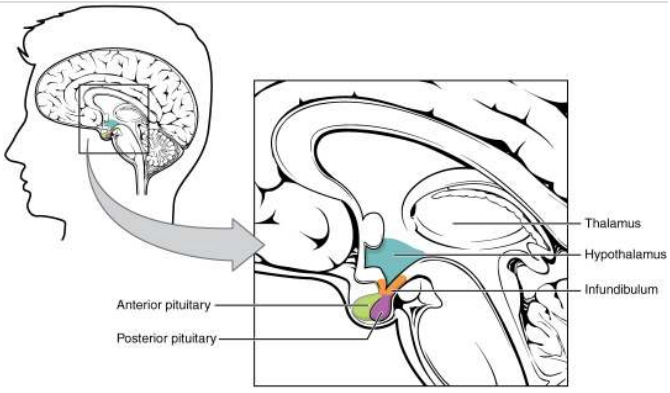


Figure **8.4.2** Hypothalamus–Pituitary Complex The hypothalamus region lies inferior and anterior to the thalamus. It connects to the pituitary gland by the stalk-like infundibulum. The pituitary gland consists of an anterior and posterior lobe, with each lobe secreting different hormones in response to signals from the hypothalamus. Pituitary Hormones

WHAT IS THE PITUITARY GLAND?

The **pituitary gland** is the master gland of the endocrine system, the system of glands that secrete hormones into the bloodstream. Endocrine hormones control virtually all physiological processes. For example, they control growth, sexual maturation, reproduction, body temperature, blood pressure, and metabolism. The pituitary gland is considered the master gland of the endocrine system because it controls the rest of the endocrine system. Many pituitary hormones either promote or inhibit hormone secretion by other endocrine glands.

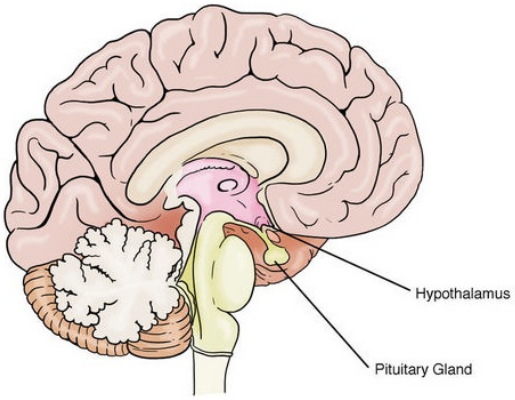


Figure **8.4.3**: The pituitary gland in the endocrine system is closely connected to the hypothalamus in the brain

STRUCTURE AND FUNCTION OF THE PITUITARY GLAND

The pituitary gland is about the size of a pea. It protrudes from the bottom of the hypothalamus at the base of the inner brain (Figure **8.4.3**). The pituitary is connected to the hypothalamus by a thin stalk (called the infundibulum). Blood vessels and nerves in the stalk allow direct connections between the hypothalamus and the pituitary

gland. The pituitary gland consists of two bulb-like lobes: an anterior lobe and a posterior lobe (Figure 8.4.4).

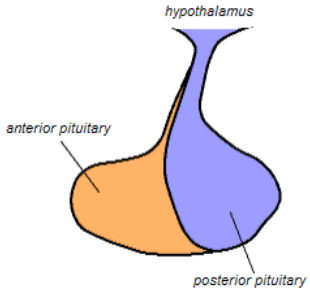


Figure 8.4.4: Both anterior and posterior lobes of the pituitary gland are directly connected to the hypothalamus by capillaries (anterior lobe) and nerve axons (posterior lobe)

ANTERIOR LOBE

The **anterior pituitary** is at the front of the pituitary gland. It synthesizes and releases hormones into the blood. Table 8.4.1 shows some of the endocrine hormones released by the anterior pituitary, including their targets and effects.

Table 8.4.1: Anterior Pituitary Hormones

Hormone	Target	Effect(s)
Adrenocorticotropic hormone (ACTH)	Adrenal glands	Stimulates the cortex of each adrenal gland to secrete its hormones
Thyroid-stimulating hormone (TSH)	Thyroid gland	Stimulates the thyroid gland to secrete thyroid hormone
Growth hormone (GH)	Body cells	Stimulates body cells to synthesize proteins and grow
Follicle-stimulating hormone (FSH)	Ovaries, testes	Stimulates the ovaries to develop mature eggs; stimulates the testes to produce sperm
Luteinizing hormone (LH)	Ovaries, testes	Stimulates the ovaries and testes to secrete sex hormones; stimulates the ovaries to release eggs
Prolactin (PRL)	Mammary glands	Stimulates the mammary glands to produce milk

The **anterior pituitary** gland is regulated mainly by hormones from the **hypothalamus**. The hypothalamus secretes hormones called releasing hormones and inhibiting hormones that travel through capillaries directly to the anterior lobe of the pituitary gland. The hormones stimulate the anterior pituitary to either release or stop releasing particular pituitary hormones. Several of these hypothalamic hormones and their effects on the anterior pituitary are shown in Table 8.4.2.

Table 8.4.2: Hypothalamic Hormones and Their Effects on the Anterior Pituitary

Hypothalamic Hormone	Effect on Anterior Pituitary
Thyrotropin releasing hormone (TRH)	Release of thyroid stimulating hormone (TSH)
Corticotropin releasing hormone (CRH)	Release of adrenocorticotropic hormone (ACTH)
Gonadotropin releasing hormone (GnRH)	Release of follicle-stimulating hormone (FSH) and luteinizing hormone (LH)
Growth hormone releasing hormone (GHRH)	Release of growth hormone (GH)
Growth hormone inhibiting hormone (GHIH) (Somatostatin)	Stopping of growth hormone release
Prolactin releasing hormone (PRH)	Release of prolactin
Prolactin inhibiting hormone (PIH) (Dopamine)	Stopping of prolactin release

POSTERIOR LOBE

The **posterior pituitary** is at the back of the pituitary gland. This lobe does not synthesize any hormones. Instead, the posterior lobe stores and releases hormones that come from the **hypothalamus** along the axons of nerves connecting the two structures (Figure Runaway argument for \eatSpaces?). The posterior pituitary then secretes the hormones into the bloodstream as needed. Hypothalamic hormones secreted by the posterior pituitary include vasopressin and oxytocin.

- Vasopressin (also called antidiuretic hormone, or ADH) helps to maintain homeostasis in body water. It stimulates the kidneys to conserve water by producing more concentrated urine. Specifically, vasopressin targets ducts in the kidneys and makes them more permeable to water. This allows more water to be resorbed by the body rather than excreted in the urine.
- Oxytocin (OXY) targets cells in the uterus to stimulate uterine contractions, for example, during childbirth. It also targets cells in the breasts of a nursing mother to stimulate the letdown of milk.

REVIEW

1. Explain why the pituitary gland is called the master gland of the endocrine system.
2. Compare and contrast the two lobes of the pituitary gland and their general functions.
3. Identify two hormones released by the anterior pituitary, their targets, and their effects.
4. Explain how the hypothalamus influences the output of hormones by the anterior lobe of the pituitary gland.
5. Name and give the function of two hypothalamic hormones released by the posterior pituitary gland.
6. *True or False.* The pituitary gland only secretes hormones that are involved in reproduction.
7. *True or False.* The brain does not produce hormones, only glands produce hormones.
8. If a releasing hormone is secreted from the hypothalamus to the pituitary gland, which part of the pituitary receives it? Explain your answer.

9. Answer the following questions about prolactin releasing hormone (PRH) and prolactin inhibiting hormone (PIH).
    A. Where are these hormones produced?
    B. Where are their target cells located?
    C. What are their effects on their target cells?
    D. What are their ultimate effects on milk production? Explain your answer.
10. e. When a baby nurses, which of these hormones is most likely released in the mother? Explain your answer.
11. For each of the following hormones, state whether it is synthesized in the pituitary or the hypothalamus.
    A. Gonadotropin releasing hormone (GnRH)
    B. Growth hormone (GH)
    C. Oxytocin
12. d. Adrenocorticotropic hormone (ACTH)

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8.5: THYROID GLAND

TOO MUCH OF A GOOD THING

The individual in Figure **8.5.1** has a goiter. A **goiter** is an abnormal enlargement of the thyroid gland, which is located in the neck. The formation of a goiter may occur in a number of different thyroid disorders. You'll learn why in this concept.



Figure **8.5.1**: Goiter

THYROID STRUCTURE

The **thyroid gland** is one of the largest endocrine glands in the body. It is located in the front of the neck below Adam's apple (see Figure **8.5.2**). The gland is butterfly-shaped and composed of two lobes. The lobes are connected by a narrow band of thyroid tissue called an isthmus. Each of the thyroid lobes are embedded with **parathyroid glands**, primarily on their posterior surfaces.

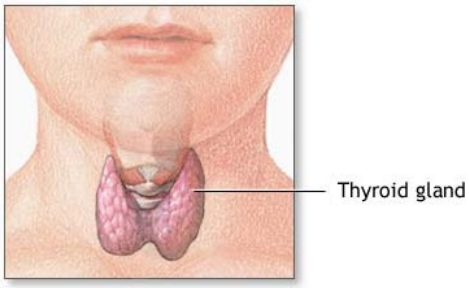


Figure **8.5.2**: The thyroid gland is a two-lobed gland in the front of the neck

Internally, the thyroid gland is composed mainly of follicles. A **follicle** is a small cluster of cells surrounding a central cavity, which stores hormones and other molecules made by the follicular cells. Thyroid follicular cells are unique in being highly specialized to absorb and use iodine. They absorb iodine as iodide ions (I^-) from the blood and use the iodide to produce thyroid hormones. The cells also use some of the iodide they absorb to form a protein called thyroglobulin, which serves to store iodide for later hormone synthesis. The outer layer of cells of each follicle secretes thyroid hormones as needed. Scattered among the follicles are another type of thyroid cells, called parafollicular cells (or C cells). These cells synthesize and secrete the hormone calcitonin.

FUNCTIONS OF THE THYROID

Like all endocrine glands, the function of the thyroid is to synthesize hormones and secrete them into the bloodstream. Once in the blood, they can travel to cells throughout the body and influence their functions.

THYROID HORMONES: T4 AND T3

There are two main thyroid hormones produced by the follicles: **thyroxine (T4),** which contains four iodide ions and is represented by the structural diagram below; and **triiodothyronine (T3),** which contains three iodide ions. T3 is much more powerful than T4, but T4 makes up about 90 percent of circulating thyroid hormone, and T3 makes up only about 10 percent. However, most of the T4 is converted to T3 by target tissues.

The thyroid hormones T_3 and T_4 are often referred to as metabolic hormones because their levels influence the body's basal metabolic rate, the amount of energy used by the body at rest. When T_3 and T_4 bind to intracellular receptors located on the mitochondria, they cause an increase in nutrient breakdown and the use of oxygen to produce ATP. In addition, T_3 and T_4 initiate the transcription of genes involved in glucose oxidation. Although these mechanisms prompt cells to produce more ATP, the process is inefficient, and an abnormally increased level of heat is released as a byproduct of these reactions. This so-called calorigenic effect (calor- = "heat") raises body temperature.

Adequate levels of thyroid hormones are also required for protein synthesis and for fetal and childhood tissue development and growth. They are especially critical for normal development of the nervous system both in utero and in early childhood, and they continue to support neurological function in adults. As noted earlier, these thyroid hormones have a complex interrelationship with reproductive hormones, and deficiencies can influence libido, fertility, and other aspects of reproductive function. Finally, thyroid hormones increase the body's sensitivity to catecholamines (epinephrine and norepinephrine) from the adrenal medulla by upregulation of receptors in the blood vessels. When levels of T_3 and T_4 hormones are excessive, this effect accelerates the heart rate, strengthens the heartbeat, and increases blood pressure. Because thyroid hormones regulate metabolism, heat production, protein synthesis, and many other body functions, thyroid disorders can have severe and widespread consequences.

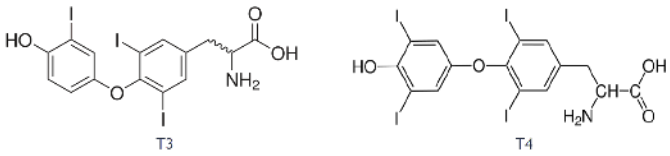


Figure **8.5.3**: This structural model represents a single molecule of triiodothyronine (T3) and thyroxine (T4). The letter I represents the iodide ions they contain. The rings consist mainly of carbon atoms

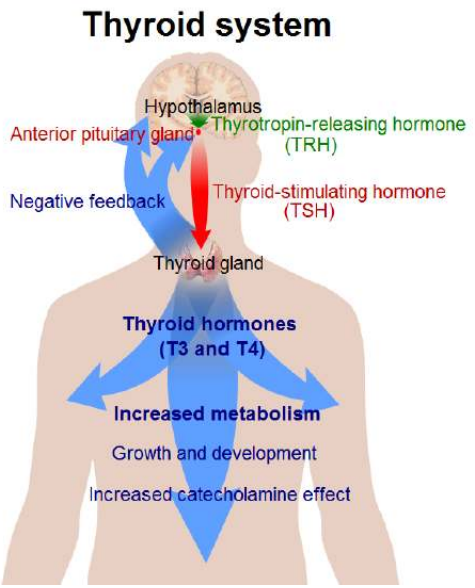


Figure **8.5.4**: The thyroid system is a negative feedback loop that includes the hypothalamus, pituitary gland, and thyroid gland. As this diagram shows, thyroid hormones increase the effect of catecholamines such as adrenaline, a fight-or-flight hormone

Like steroid hormones, T3 and T4 cross cell membranes everywhere in the body and bind to intracellular receptors to regulate gene expression. However, unlike steroid hormones, thyroid hormones can cross cell membranes only with the help of special transporter proteins. Once inside the nucleus of cells, T3 and T4 turn on genes that control protein synthesis. Thyroid hormones increase the rate of metabolism in cells, so cells absorb more carbohydrates, use more energy, and produce more heat. Thyroid hormones also increase the rate and force of the heartbeat. In addition, they increase the sensitivity of cells to fight-or-flight hormones (that is, catecholamine hormones such as adrenaline).

The production of both T4 and T3 is regulated primarily by thyroid stimulating hormone (TSH), which is secreted by the anterior pituitary gland (see the diagram below). TSH production, in turn, is regulated by thyrotropin releasing hormone (TRH), which is produced by the hypothalamus. The thyroid gland, pituitary gland, and hypothalamus form a negative feedback loop to keep thyroid hormone secretion within a normal range. TRH and TSH production is suppressed when T4 levels start to become too high. The opposite occurs when T4 levels start to become too low.

CALCITONIN

The thyroid gland also secretes a hormone called **calcitonin** that is produced by the parafollicular cells of the thyroid gland. Calcitonin is released in response to a rise in blood calcium levels and has the role of helping to regulate blood calcium levels by stimulating the movement of calcium into bone.

Calcitonin decreases blood calcium concentrations by:

- Inhibiting the activity of osteoclasts, bone cells that release calcium into the circulation by degrading bone matrix
- Increasing osteoblastic activity, bone cells that are involved in bone deposition and take up calcium from blood to build bone matrix
- Decreasing calcium absorption in the intestines
- Increasing calcium loss in the urine

Calcitonin works hand-in-hand with parathyroid hormone, which is secreted by the parathyroid glands and has the opposite effects as calcitonin. Together, these two hormones maintain calcium homeostasis.

SUMMARY TABLE OF THYROID HORMONES

Associated hormones	Effect
Thyroxine (T_4), triiodothyronine (T_3)	Stimulate basal metabolic rate
Calcitonin	Reduces blood Ca^{2+} levels

Table **8.5.1**

THYROID DISORDERS

As with other endocrine disorders, thyroid disorders are generally associated with either over or under-secretion of hormones. Abnormal secretion of thyroid hormones may occur for a variety of reasons.

HYPERTHYROIDISM

Hyperthyroidism occurs when the thyroid gland produces excessive amounts of thyroid hormones. The most common cause of hyperthyroidism is Graves' disease. **Graves' disease** is an autoimmune disorder in which abnormal antibodies produced by the immune system stimulate the thyroid to secrete excessive quantities of its hormones. This stimulation overrides the usual negative feedback mechanism that normally controls thyroid hormone output. Graves' disease often results in the formation of an enlarged thyroid (goiter) because of the continued stimulation to produce more hormones.

Besides a goiter, other signs and symptoms of hyperthyroidism may include protruding eyes (see photo below), heart palpitations, excessive sweating, diarrhea, weight loss despite increased appetite, muscle weakness, and unusual sensitivity to heat. Medications can be prescribed to mitigate the symptoms of the disease. Anti-thyroid drugs can also be given to decrease the production of thyroid hormones. If the drugs are ineffective, the gland can be partially or entirely removed. This can be done surgically or with the administration of radioactive iodine. Removal of the thyroid produces hypothyroidism.



Figure **8.5.5**: Protruding eyes are one sign of hyperthyroidism, such as Graves' disease

HYPOTHYROIDISM

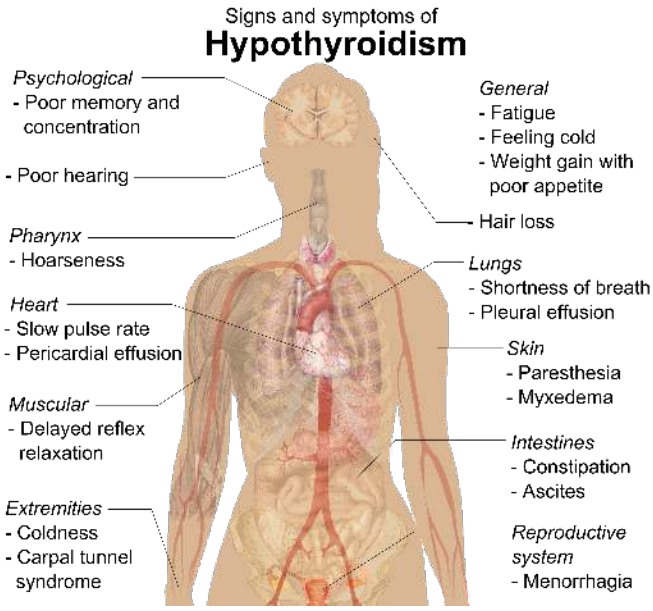


Figure **8.5.6**: the signs and symptoms of hypothyroidism may include fatigue, coldness, weight gain, shortness of breath, constipation, menorrhagia, poor memory and hearing, hoarseness, slow heart rate, delayed reflexes, and carpal tunnel syndrome.

Hypothyroidism occurs when the thyroid gland produces insufficient amounts of thyroid hormones. It can result from surgical removal of the thyroid. However, worldwide, the most common cause of hypothyroidism is dietary iodine deficiency. In cases of iodine deficiency, the negative feedback loop controlling the release of thyroid hormone causes repeated stimulation of the thyroid. This results in the thyroid gland growing in size and producing a goiter. Although the gland gets larger, it cannot increase hormone output because of the lack of iodine in the diet.

Iodine deficiency is uncommon in the Western world because iodine is added to salt. Where iodine deficiency is not a problem, the most common cause of hypothyroidism is **Hashimoto's thyroiditis.** This is another autoimmune disease, but in this case, the immune system destroys the thyroid gland, producing hypothyroidism. Hashimoto's thyroiditis tends to run in families so it is likely to have a genetic component. It usually appears after the age of 30 and is more common in females than males.

Hypothyroidism produces many signs and symptoms, as shown in Figure **8.5.6**. These may include abnormal weight gain, tiredness, baldness, cold intolerance, and slow heart rate. Hypothyroidism is generally treated with thyroid hormone replacement therapy. This may be needed for the rest of a person's life. Hypothyroidism in a pregnant woman can have serious adverse consequences for the fetus. During the fetal period, cells of the developing brain are a major target for thyroid hormones, which play a crucial role in brain maturation. When levels of thyroid hormones are too low, the fetus may suffer permanent deficits in cognitive abilities. Deafness is also a potential outcome of hypothyroidism *in utero*.

Feature: Myth vs. Reality

Thyroid disorders are relatively common, affecting as many as 20 million people in the United States. Because the disorders are common, there are also many common myths about them.

Myth: If you have a thyroid problem, you will know something is wrong because you will have obvious symptoms.

Reality: The majority of people with a thyroid disorder are not aware they have it because the symptoms are often mild, nonspecific, and easy to ignore. Generally, blood tests of thyroid hormone levels are needed to make a conclusive diagnosis.

Myth: If you are diagnosed with a thyroid disorder, you will have to take medication for the rest of your life.

Reality: Whether you need to continue thyroid medication for life depends on the cause of the disorder. For example, some women develop hypothyroidism during pregnancy but no longer need medication after the pregnancy is over and hormone levels return to normal.

Myth: As soon as you start taking thyroid medication, your symptoms will resolve.

Reality: It often takes weeks or even months for thyroid hormone levels to return to normal and symptoms to disappear.

Myth: You can take an over-the-counter iodine supplement to correct hypothyroidism.

Reality: In the United States, where dietary iodine is almost always adequate, iodine deficiency is unlikely to be the cause of hypothyroidism. Therefore, taking supplemental iodine is not likely to correct the problem.

Myth: If thyroid symptoms are mild, you don't need to take medication.

Reality: Because thyroid hormones are responsible for so many vital body functions, failing to treat even a mild thyroid disorder may lead to a range of other problems, such as osteoporosis or infertility.

Myth: Goiter may be caused by eating "goitrogenic" vegetables, such as broccoli, Brussels sprouts, and spinach.

Reality: Although these foods can interfere with the thyroid's ability to process iodide, you would have to eat huge amounts of them to cause goiter.

Myth: Thyroid disorders occur only after middle age and only in women.

Reality: Thyroid disorders may occur at any age and in any sex. Hypothyroidism occurs more commonly in older adults, but hyperthyroidism occurs more commonly in younger adults. Although women are more likely to develop thyroid disorders, about 20 percent of cases occur in men.

REVIEW

1. Describe the structure and location of the thyroid gland.
2. Identify the types of cells within the thyroid gland that produce hormones.

3. Compare and contrast T4 and T3.
4. How do T4 and T3 affect body cells?
5. Explain how T4 and T3 production is regulated.
6. What is the function of calcitonin?
7. Identify the chief cause and effects of hyperthyroidism.
8. What are two possible causes of hypothyroidism?
9. List signs and symptoms of hypothyroidism.
10. Why may both hyperthyroidism and hypothyroidism cause goiters?
11. Choose one symptom each for hyperthyroidism and hypothyroidism and explain why they occur based on the functions of thyroid hormones.
12. Which hormone is produced by the thyroid gland?
    A. T3
    B. Calcitonin
    C. Parathyroid hormone
    D. TSH
    E. A and B
13. In cases of hypothyroidism due to Hashimoto's thyroiditis or removal of the thyroid gland to treat hyperthyroidism, patients are often given medication to replace the missing thyroid hormone. Explain why the level of replacement thyroid hormone must be carefully monitored and adjusted if needed.
14. *True or False.* T3 and T4 bind to receptors on the plasma membrane of target cells.
15. Which disease causes too much thyroid hormone to be produced?
    A. Hashimoto's thyroiditis
    B. Graves' disease
    C. Goiter
    D. Iodine deficiency

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8.6: Parathyroid Glands

What are the Parathyroid Glands?

The **parathyroid glands** are tiny, round structures usually found embedded in the posterior surface of the thyroid gland (Figure 8.6.1). A thick connective tissue capsule separates the glands from the thyroid tissue. Most people have four parathyroid glands, but occasionally there are more in tissues of the neck or chest. The primary functional cells of the parathyroid glands are the chief cells. These epithelial cells produce and secrete the **parathyroid hormone** (**PTH**), the major hormone involved in the regulation of blood calcium levels.

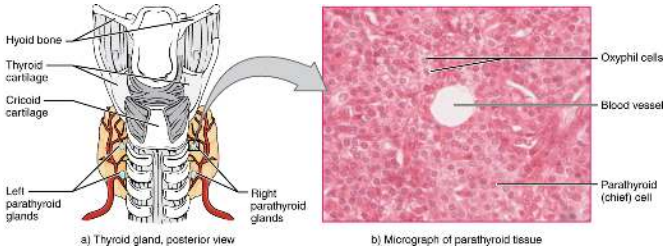


Figure 8.6.1 Parathyroid Glands The small parathyroid glands are embedded in the posterior surface of the thyroid gland. LM × 760. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The parathyroid glands produce and secrete parathyroid hormone (PTH) in response to low blood calcium levels (Figure 8.6.2). PTH secretion causes blood calcium, levels to increase by:

- Promoting the release of calcium from the bones by stimulating osteoclasts, which secrete enzymes that degrade bone and release calcium into the interstitial fluid.
- Inhibiting osteoblasts, the cells involved in bone deposition, thereby sparing blood calcium.
- Causing increased reabsorption of calcium (and magnesium) in the kidney tubules from the urine filtrate.
- Initiating the production of the steroid hormone calcitriol, which is the active form of vitamin D_3, in the kidneys. Calcitriol then stimulates increased absorption of dietary calcium by the intestines.

A negative feedback loop regulates the levels of PTH, with rising blood calcium levels inhibiting further release of PTH.

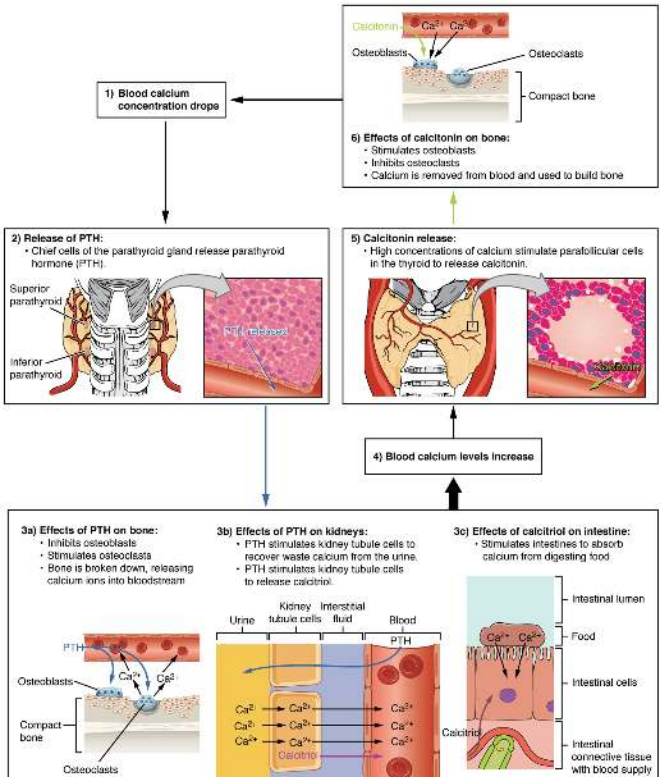


Figure 8.6.2 Parathyroid Hormone in Maintaining Blood Calcium Homeostasis Parathyroid hormone increases blood calcium levels when they drop too low. Conversely, calcitonin, which is released from the thyroid gland, decreases blood calcium levels when they become too high. These two mechanisms constantly maintain blood calcium concentration at homeostasis.

Parathyroid Disorders

Abnormally high activity of the parathyroid gland can cause **hyperparathyroidism**, a disorder caused by an overproduction of PTH that results in excessive calcium reabsorption from bone. Hyperparathyroidism can significantly decrease bone density, leading to spontaneous fractures or deformities. As blood calcium levels rise, cell membrane permeability to sodium is decreased, and the responsiveness of the nervous system is reduced. At the same time, calcium deposits may collect in the body's tissues and organs, impairing their functioning.

In contrast, abnormally low blood calcium levels may be caused by parathyroid hormone deficiency, called **hypoparathyroidism**, which may develop following injury or surgery involving the thyroid gland. Low blood calcium increases membrane permeability to sodium, resulting in muscle twitching, cramping, spasms, or convulsions. Severe deficits can paralyze muscles, including those involved in breathing, and can be fatal.

When blood calcium levels are high, calcitonin is produced and secreted by the parafollicular cells of the thyroid gland. As discussed earlier, calcitonin inhibits the activity of osteoclasts, reduces the absorption of dietary calcium in the intestine, and signals the kidneys to reabsorb less calcium, resulting in larger amounts of calcium excreted in the urine.

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8.7: ADRENAL GLANDS

EEK!

Being bitten on the nose by an eel certainly qualifies as a frightening experience! The fear this man is experiencing produces the same physiological responses in most people—racing heart, rapid breathing, clammy hands. These and other fight-or-flight responses prepare the body to either defend itself or run away from danger. Why does fear elicit these changes in the body? The responses occur in large part because of hormones secreted by the adrenal glands.



Figure **8.7.1**: Attack

INTRODUCTION TO THE ADRENAL GLANDS

The **adrenal glands** are endocrine glands that produce a variety of hormones. Adrenal hormones include the fight-or-flight hormones adrenaline (epinephrin) and noradrenaline (norepinephrine) and the steroid hormone cortisol. The two adrenal glands are located on both sides of the body, just above the kidneys ("renal" refers to the kidneys), as shown in Figure **8.7.2**. The right adrenal gland (on the left in the figure) is smaller and has a pyramidal shape. The left adrenal gland (on the right in the figure) is larger and has a half-moon shape. The adrenal glands have a rich blood supply and experience one of the highest rates of blood flow in the body.

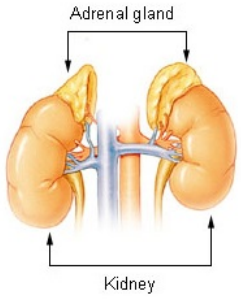


Figure **8.7.2**: Each of the two adrenal glands is found above a kidney

Each adrenal gland has two distinct parts, and each part has a different function, although both parts produce hormones. There is an outer layer, called the adrenal cortex, which produces steroid hormones including cortisol. There is also an inner layer, called the adrenal medulla, which produces non-steroid hormones including adrenaline.

THE ADRENAL GLAND AND STRESS RESPONSES

One of the major functions of the adrenal gland is to respond to stress. Stress can be either physical or psychological or both. Physical stresses include exposing the body to injury, walking outside in cold and wet conditions without a coat on, or malnutrition. Psychological stresses include the perception of a physical threat, a fight with a loved one, or just a bad day at school.

The body responds in different ways to short-term stress and long-term stress following a pattern known as the general adaptation syndrome (GAS). Stage one of GAS is called the alarm reaction. This is short-term stress, the fight-or-flight response, mediated by the hormones epinephrine and norepinephrine from the adrenal medulla. Their function is to prepare the body for extreme physical exertion. Once this stress is relieved, the body quickly returns to normal. The section on the adrenal medulla covers this response in more detail.

If the stress is not soon relieved, the body adapts to the stress in the second stage called the stage of resistance. If a person is starving for example, the body may send signals to the gastrointestinal tract to maximize the absorption of nutrients from food.

If the stress continues for a longer term however, the body responds with symptoms quite different than the fight-or-flight response. During the stage of exhaustion, individuals may begin to suffer depression, the suppression of their immune response, severe fatigue, or even a fatal heart attack. These symptoms are mediated by the hormones of the adrenal cortex, especially cortisol.

Adrenal hormones also have several non–stress-related functions, including the increase of blood sodium and glucose levels, which will be described in detail below.

ADRENAL CORTEX

The **adrenal cortex,** or the outer layer of the adrenal gland, is divided, in turn, into three additional layers, called zones (Figure **8.7.3**). Each zone has distinct enzymes that produce different hormones from the common precursor molecule cholesterol, which is a lipid.

1. Zona glomerulosa is the outermost layer of the adrenal cortex. It lies immediately under the outer fibrous capsule that encloses the adrenal gland.
2. Zona fasciculata is the middle layer of the adrenal cortex. It is the largest of the three zones, accounting for nearly 80 percent of the adrenal cortex.
3. Zona reticularis is the innermost layer of the adrenal cortex. It is directly adjacent to the medulla of the adrenal gland.

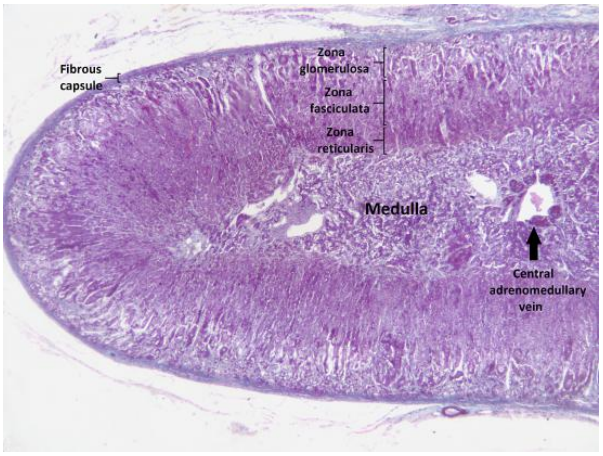


Figure 8.7.3: The adrenal cortex is divided into three zones, zona glomerulosa, zona fasciculata, and zona reticularis. Each zone produces a different type of steroid hormone. This photomicrograph also shows the medulla of the adrenal gland.

TYPES OF ADRENAL CORTEX HORMONES

Hormones produced by the adrenal cortex are called **corticosteroids.** As steroid hormones, corticosteroids are endocrine hormones that are made of lipids and exert their effects on target cells by crossing the plasma membrane and binding with receptors within the cytoplasm. A steroid hormone and its receptor form a complex that enters the cell nucleus and affects gene expression. There are three types of corticosteroids synthesized and secreted by the adrenal cortex. Each type is produced by a different zone of the adrenal cortex, as shown in Figure 8.7.3.

MINERALOCORTICOIDS

Mineralocorticoids effect levels of body minerals, especially sodium and potassium. These hormones are essential for fluid and electrolyte (mineral salts) balance. They are produced in the zona glomerulosa and include the hormone **aldosterone**. In the kidneys, aldosterone increases the reabsorption of sodium ions and the excretion of potassium ions. Aldosterone also stimulates the retention of sodium ions by cells in the colon and by the sweat glands. The amount of sodium in the body affects the volume of extracellular fluids including the blood and thereby affects blood pressure. In this way, mineralocorticoids help control blood volume and blood pressure.

GLUCOCORTICOIDS

Glucocorticoids, which play a role in glucose metabolism, are produced in the zona fasciculata and include the hormone **cortisol,** which is released in response to stress and is considered the primary stress hormone. Glucocorticoids help control the rate of metabolism of proteins, fats, and sugars. In general, they increase the level of glucose and fatty acids circulating in the blood. Cells rely primarily on glucose for energy, but they can also use fatty acids for energy as an alternative to glucose. Glucocorticoids are also involved in the suppression of the immune system, having a potent anti-inflammatory effect. In addition, cortisol reduces the production of new bone and decreases the absorption of calcium from the gastrointestinal tract.

ANDROGENS

Androgens are produced in the zona reticularis and include the hormone DHEA (dehydroepiandrosterone). Androgens are a general term for male sex hormones, although this is somewhat misleading as adrenal cortex androgens are produced by both males and females. In adult males, they are converted to more potent androgens such as testosterone in the male gonads (testes). In adult females, they are converted to female sex hormones called estrogens in the female gonads (ovaries).

REGULATION OF ADRENAL CORTEX HORMONES

Steroid hormone production by the three zones of the adrenal cortex is regulated by hormones secreted by the anterior lobe of the pituitary gland as well as by other physiological stimuli. For example, the production of glucocorticoids such as cortisol is stimulated by adrenocorticotropic hormone (ACTH) from the anterior pituitary, which in turn is stimulated by corticotropin releasing hormone (CRH) from the hypothalamus. When levels of glucocorticoids start to rise too high, they provide negative feedback to the hypothalamus and pituitary gland to stop secreting CRH and ACTH, respectively. This negative feedback mechanism is illustrated in Figure 8.7.4. The opposite occurs when levels of glucocorticoids start to fall too low.

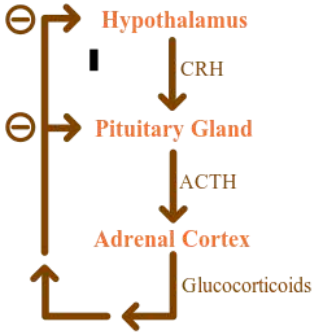


Figure 8.7.4: The negative feedback loop that controls the production of glucocorticoids includes the pituitary gland and hypothalamus in addition to the adrenal cortex.

ADRENAL MEDULLA

As noted earlier, the adrenal cortex releases glucocorticoids in response to long-term stress such as severe illness. In contrast, the adrenal medulla releases its hormones in response to acute, short-term stress mediated by the sympathetic nervous system (SNS).

The **adrenal medulla** is at the center of each adrenal gland and is surrounded by the adrenal cortex. It contains a dense network of blood vessels into which it secretes its hormones. The hormones synthesized and secreted by the adrenal medulla are called **catecholamines**, and they include **adrenaline** (also called **epinephrine**) and **noradrenaline** (also called **norepinephrine**). These are water-soluble, non-steroid hormones are made of amino acids. As non-steroid hormones, they cannot cross the plasma membrane of target cells. Instead, they exert their effects by binding to receptors on the surface of target cells. The binding of hormones and receptors activates an enzyme in the plasma membrane that

controls a second messenger. It is the second messenger that influences processes inside the cell.

Catecholamines function to produce a rapid response throughout the body in stressful situations. They bring about such changes as increased heart rate, more rapid breathing, constriction of blood vessels in certain parts of the body, and an increase in blood pressure. The release of catecholamines by the adrenal medulla is stimulated by activation of the sympathetic division of the autonomic nervous system.

HORMONES OF THE ADRENAL GLANDS

Adrenal gland	Associated hormones	Chemical class	Effect
Adrenal cortex	Aldosterone	Steroid	Increases blood Na^+ levels
Adrenal cortex	Cortisol, corticosterone, cortisone	Steroid	Increase blood glucose levels
Adrenal medulla	Epinephrine, norepinephrine	Amine	Stimulate fight-or-flight response

Table **8.7.1**

DISORDERS OF THE ADRENAL GLANDS

Disorders of the adrenal glands generally include either hypersecretion or hyposecretion of adrenal hormones. The underlying cause of the abnormal secretion may be a problem with the adrenal glands or with the pituitary gland, which controls adrenal cortex hormone production. Both adrenal and pituitary glands are subject to the formation of tumors, which may cause adrenal disorders. The adrenal gland may also be affected by infections or autoimmune diseases.

ADRENAL HYPERSECRETION: CUSHING'S SYNDROME

Hypersecretion of the glucocorticoid hormone cortisol leads to a disorder named **Cushing's syndrome.** The most common cause of Cushing's syndrome is a pituitary tumor, which causes excessive production of ACTH. The disease produces a wide variety of signs and symptoms, which may include high glucose levels, obesity, diabetes, high blood pressure (hypertension), excessive body hair, osteoporosis, and depression. A distinctive sign of Cushing's syndrome is the appearance of stretch marks in the skin, as the skin becomes progressively thinner. Another distinctive sign is a moon face shown in the section *Introduction to the Endocrine System*, in which fat deposits give the face a rounded appearance. Other common signs of Cushing's disease include the development of a buffalo hump on the back of the neck, rapid weight gain, and hair loss. Chronically elevated glucose levels are also associated with an elevated risk of developing type 2 diabetes. In addition to hyperglycemia, chronically elevated glucocorticoids compromise immunity, resistance to infection, and memory, and can result in rapid weight gain and hair loss. Treatment of Cushing's syndrome depends on its cause and may include surgery to remove a tumor or medications to suppress the activity of the adrenal glands.

ADRENAL HYPOSECRETION: ADDISON'S DISEASE



Figure **8.7.5**: Hyperpigmentation of the skin is a characteristic sign of Addison's disease. The photo on the left shows the dark skin pigmentation of an Addison's patient before treatment. The photo on the right shows the same patient after treatment.

Hyposecretion of the glucocorticoid hormone cortisol leads to a disorder named **Addison's disease**. There may also be hyposecretion of mineralocorticoids with this disorder. Addison's disease is generally an autoimmune disorder, in which the immune system produces abnormal antibodies that attack cells of the adrenal cortex. Untreated infections, especially of tuberculosis, may also damage the adrenal cortex and cause Addison's disease. A third possible cause is the decreased output of ACTH by the pituitary gland, generally due to a pituitary tumor. A distinctive sign of Addison's disease is hyperpigmentation of the skin (Figure **8.7.5**). Other symptoms tend to be nonspecific and include excessive fatigue. Addison's disease is generally treated with replacement hormones in pill form.

FEATURE: MY HUMAN BODY



Figure **8.7.6**: Base Jump

Does just looking at this photo cause you to break out in a cold sweat and experience heart palpitations? Imagine how scary it would be to fling yourself backward off a tall building like the BASE jumper in the photo. There would be very little time to use a parachute to slow your fall before you hit the ground. BASE jumping is called the most dangerous sport on Earth. In fact, it is so dangerous that it is outlawed in some places.

People who participate in such dangerous activities as BASE jumping are likely to be adrenaline "junkies." They are addicted

to the adrenaline rush and euphoria, or "high," it causes when their fight-or-flight response is triggered by danger. Why does adrenaline have this effect? Adrenaline is closely related to dopamine, a chemical messenger in the brain that plays a major role in pleasure and addiction.

Adrenaline addicts don't have to participate in BASE jumping or other dangerous sports to get an adrenaline rush. They might choose a dangerous occupation such as firefighting, participate in risky behaviors such as reckless driving or bank robbing, or just pick fights with other people. They might even create their own stress by always taking on too much work or delaying projects until close to their deadline.

While some excitement in one's life is generally a good thing, always putting oneself in danger or constantly being under stress are obviously not good things. If you think you might be an adrenaline addict, note that there are healthier ways to experience a hormonal "high." Running, biking, or participating in some other form of vigorous aerobic exercise causes the pituitary gland and hypothalamus to produce opiate-like endorphins, leading to a so-called "runner's high." Like the euphoric feeling adrenaline causes, a runner's high may last for hours.

REVIEW

1. Describe the structure and location of the adrenal glands.
2. Compare and contrast the adrenal cortex and adrenal medulla.
3. Identify the three layers of the adrenal cortex and the type of hormones each layer produces.
4. Give an example of each type of corticosteroid and state its function.
5. Explain how the production of glucocorticoids is regulated.
6. What is a catecholamine? Give an example of a catecholamine and state its function.
7. Compare and contrast Cushing's syndrome and Addison's disease.
8. Cortisol is a type of:
   A. Corticosteroid
   B. Mineralocorticoid
   C. Glucocorticoid
   D. A and C
9. *True or False.* The adrenal glands help regulate the body's stress response and reproductive functions.
10. *True or False.* The left adrenal gland produces steroid hormones, while the right adrenal gland produces non-steroid hormones.
11. Would it help to give someone with Cushing's syndrome more ACTH? Explain your answer.
12. What are two ways in which the nervous system (which includes the brain, spinal cord, and nerves) controls the adrenal gland?
13. If the level of cortisol rises too high, the amount of CRH secreted will normally:
    A. not change
    B. become excessively high
    C. become slightly higher
    D. decrease
14. Noradrenaline is also called:
    A. norepinephrine
    B. adrenaline
    C. adrenocorticotropin
    D. glucocorticoid
15. Explain why a pituitary tumor can cause either hypersecretion or hyposecretion of cortisol.

EXPLORE MORE

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8.8: PANCREAS

A SHOT IN THE ARM

Giving yourself an injection can be difficult, but for someone with diabetes, it may be a matter of life or death. The person in the photo has diabetes and is injecting themself with insulin, the hormone that helps control the level of glucose in the blood. Insulin is produced by the pancreas.



Figure **8.8.1**: Insulin Application

INTRODUCTION TO THE PANCREAS

The **pancreas** is a long, slender organ, most of which is located in the upper left abdomen posterior to the bottom half of the stomach, as shown in the figure below. The pancreas is about 15 centimeters (6 in.) long; and it has a flat, oblong shape. Structurally, the pancreas is divided into a head, body, and tail. Functionally, the pancreas serves as both an endocrine gland and an exocrine gland.

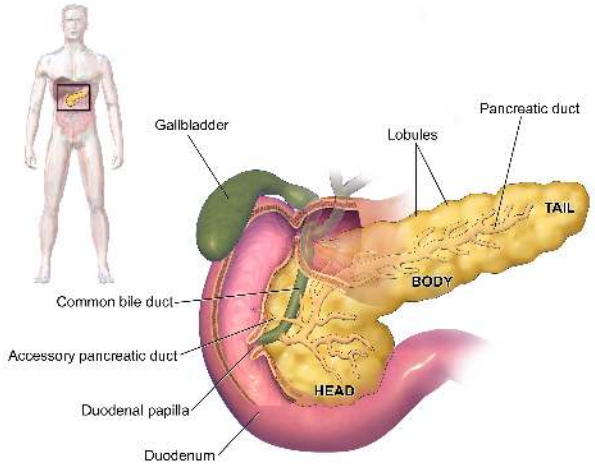


Figure **8.8.2**: The pancreas is located behind the stomach and near the upper part of the small intestine (duodenum). Its main parts are tail, body, and head. Its ducts carry digestive enzymes into the small intestine. The endocrine hormones it produces are secreted into the blood.

- As an **endocrine gland**, the pancreas is part of the endocrine system. As such, it releases hormones, such as insulin, directly into the bloodstream for transport to cells throughout the body.
- As an **exocrine gland**, the pancreas is part of the digestive system. As such, it releases digestive enzymes into ducts that carry the enzymes to the gastrointestinal tract where they assist with digestion. In this concept, the focus is on the pancreas as an endocrine gland. You can read about the pancreas as an exocrine gland in the chapter *Digestive System*.

THE PANCREAS AS AN ENDOCRINE GLAND

The tissues within the pancreas that have an endocrine role exist as clusters of cells called **pancreatic islets.** They are also called by the older term the islets of Langerhans. In Figure **8.8.3**, you can see pancreatic tissue, including islets. There are approximately 3 million pancreatic islets, and they are crisscrossed by a dense network of capillaries. The capillaries are lined by layers of islet cells that have direct contact with the blood vessels, into which they secrete their endocrine hormones.

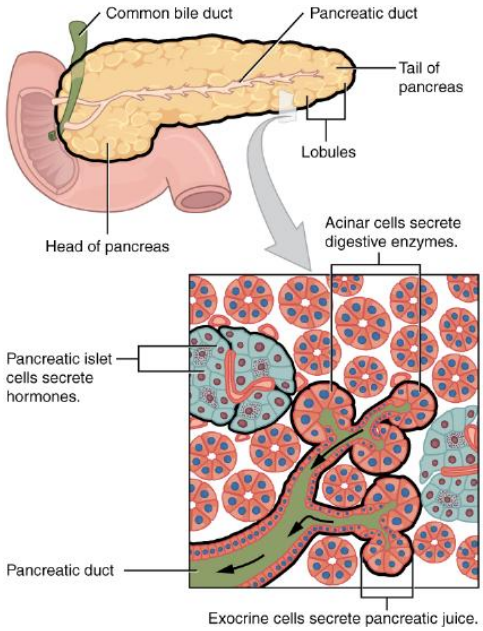


Figure **8.8.3**: Anatomy of the pancreas. The inset diagram shows pancreatic islet cells that produce endocrine hormones. It also shows the cells (called acinar cells) that secrete exocrine substances involved in digestion into pancreatic ducts.

The pancreatic islets consist of four main types of cells, each of which secretes a different endocrine hormone. However, all of the hormones produced by the pancreatic islets play crucial roles in glucose metabolism and the regulation of blood glucose levels, among other functions.

1. Islet cells called alpha (α) cells secrete the hormone **glucagon**; low blood glucose levels stimulate its release. The function of glucagon is to increase the level of glucose in the blood. It does this by stimulating the liver to convert stored glycogen into glucose, which is released into the bloodstream.
2. Islet cells called beta (β) cells, which make up approximately 75 percent of each islet, secrete the hormone **insulin**. Elevated blood glucose levels stimulate the release of insulin. The function of insulin is to decrease the level of glucose in the blood. It does this by promoting the absorption of glucose from the blood into fat, liver, and skeletal muscle cells. In these tissues, the absorbed glucose is converted into glycogen, fats (triglycerides), or both.

3. Islet cells called delta (δ) cells secrete the hormone **somatostatin.** This hormone is also called the growth hormone inhibiting hormone because it inhibits the anterior lobe of the pituitary gland from producing growth hormone. Somatostatin also inhibits the secretion of the pancreatic endocrine hormones glucagon and insulin and pancreatic exocrine enzymes.
4. Islet cells called gamma (γ) cells secrete the hormone pancreatic polypeptide. The function of pancreatic polypeptide is to help regulate the secretion of both endocrine and exocrine substances by the pancreas. It is thought to play a role in appetite, as well as in the regulation of pancreatic exocrine and endocrine secretions. Pancreatic polypeptide released following a meal may reduce further food consumption; however, it is also released in response to fasting.

REGULATION OF BLOOD GLUCOSE LEVELS BY INSULIN AND GLUCAGON

Glucose is required for cellular respiration and is the preferred fuel for all body cells. The body derives glucose from the breakdown of the carbohydrate-containing foods and drinks we consume. Glucose not immediately taken up by cells for fuel can be stored by the liver and muscles as glycogen, or converted to triglycerides and stored in the adipose tissue. Hormones regulate both the storage and the utilization of glucose as required. Receptors located in the pancreas sense blood glucose levels, and subsequently the pancreatic cells secrete glucagon or insulin to maintain normal levels.

GLUCAGON

Receptors in the pancreas can sense the decline in blood glucose levels, such as during periods of fasting or during prolonged labor or exercise (Figure 8.8.4). In response, the alpha cells of the pancreas secrete the hormone glucagon, which has several effects:

- It stimulates the liver to convert its stores of glycogen back into glucose. This response is known as glycogenolysis. The glucose is then released into the circulation for use by body cells.
- It stimulates the liver to take up amino acids from the blood and convert them into glucose. This response is known as gluconeogenesis.
- Taken together, these actions increase blood glucose levels. The activity of glucagon is regulated through a negative feedback mechanism; rising blood glucose levels inhibit further glucagon production and secretion.

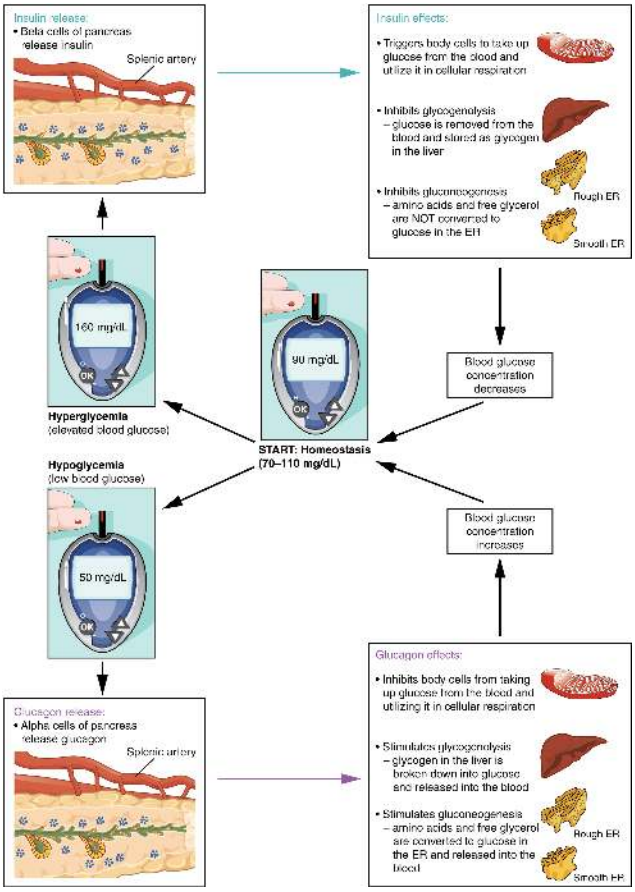


Figure 8.8.4: Homeostatic Regulation of Blood Glucose Levels Blood glucose concentration is tightly maintained between 70 mg/dL and 110 mg/dL. If blood glucose concentration rises above this range, insulin is released, which stimulates body cells to remove glucose from the blood. If blood glucose concentration drops below this range, glucagon is released, which stimulates body cells to release glucose into the blood.

INSULIN

The primary function of insulin is to facilitate the uptake of glucose into body cells. Red blood cells, as well as cells of the brain, liver, kidneys, and the lining of the small intestine, do not have insulin receptors on their cell membranes and do not require insulin for glucose uptake. Although all other body cells do require insulin if they are to take glucose from the bloodstream, skeletal muscle cells and adipose cells are the primary targets of insulin.

The presence of food in the intestine triggers the release of gastrointestinal tract hormones such as glucose-dependent insulinotropic peptide (previously known as gastric inhibitory peptide). This is in turn the initial trigger for insulin production and secretion by the beta cells of the pancreas. Once nutrient absorption occurs, the resulting surge in blood glucose levels further stimulates insulin secretion.

Precisely how insulin facilitates glucose uptake is not entirely clear. However, insulin appears to activate a tyrosine kinase

receptor, triggering the phosphorylation of many substrates within the cell. These multiple biochemical reactions converge to support the movement of intracellular vesicles containing facilitative glucose transporters to the cell membrane. In the absence of insulin, these transport proteins are normally recycled slowly between the cell membrane and cell interior. Insulin triggers the rapid movement of a pool of glucose transporter vesicles to the cell membrane, where they fuse and expose the glucose transporters to the extracellular fluid. The transporters then move glucose by facilitated diffusion into the cell interior.

Insulin also reduces blood glucose levels by stimulating glycolysis, the metabolism of glucose for generation of ATP. Moreover, it stimulates the liver to convert excess glucose into glycogen for storage, and it inhibits enzymes involved in glycogenolysis and gluconeogenesis. Finally, insulin promotes triglyceride and protein synthesis. The secretion of insulin is regulated through a negative feedback mechanism. As blood glucose levels decrease, further insulin release is inhibited.

HORMONES OF THE PANCREAS

Associated hormones	Chemical class	Effect
Insulin (beta cells)	Protein	Reduces blood glucose levels
Glucagon (alpha cells)	Protein	Increases blood glucose levels
Somatostatin (delta cells)	Protein	Inhibits insulin and glucagon release
Pancreatic polypeptide (PP cells)	Protein	Role in appetite

Table **8.8.1** The pancreatic hormones are summarized in Table **8.8.1**.

DISORDERS OF THE PANCREAS

There are a variety of disorders that affect the pancreas, including diabetes mellitus, pancreatitis, and pancreatic cancer.

DIABETES MELLITUS

By far the most common type of pancreatic disorder is diabetes mellitus, more commonly called simply diabetes. It is caused by dysfunction of insulin production and secretion, as well as the target cells' responsiveness to insulin. An increasingly common disease, diabetes mellitus has been diagnosed in more than 18 million adults in the United States, and more than 200,000 children. It is estimated that up to 7 million more adults have the condition but have not been diagnosed. In addition, approximately 79 million people in the US are estimated to have pre-diabetes, a condition in which blood glucose levels are abnormally high, but not yet high enough to be classified as diabetes.

There are several types of diabetes mellitus; the two major types are called type 1 diabetes and type 2 diabetes. The two types have different causes and may also have different treatments, but they generally produce the same initial symptoms, which include excessive urination and thirst. These symptoms occur because the kidneys excrete more urine in an attempt to rid the blood of excess glucose, and loss of water in urine stimulates greater thirst. Other signs and symptoms of diabetes are listed in Figure **8.8.5**.

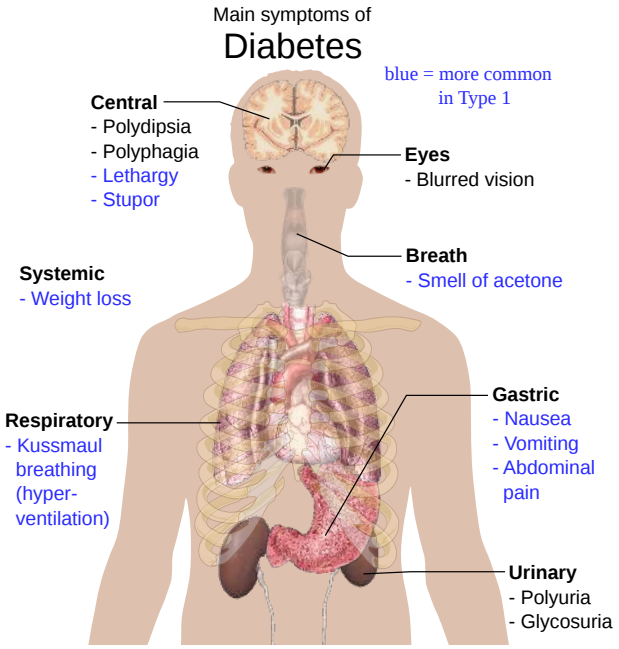


Figure **8.8.5**: Diabetes can affect many systems of the body. The symptoms shared by both type 1 and type 2 diabetes, such as blurred vision, polyuria, glycosuria, polydipsia, and polyphagia are listed in black, and the symptoms more common in type 1 diabetes, such as the smell of acetone, nausea, vomiting, abdominal pain, lethargy, stupor, weight loss, and hyperventilation are listed in blue.

When diabetes is not well controlled, it is likely to have several serious long-term consequences. Most of these consequences are due to damage to small blood vessels because of high blood levels of glucose. Damage to blood vessels, in turn, may lead to an increased risk of coronary artery disease and stroke. Damage to blood vessels in the retina of the eye can result in gradual vision loss and blindness. Damage to blood vessels in the kidneys can lead to chronic kidney disease, sometimes requiring dialysis or a kidney transplant. Long-term consequences of diabetes may also include damage to the nerves of the body, known as diabetic neuropathy. In fact, this is the most common complication of diabetes. Symptoms of diabetic neuropathy may include numbness, tingling, and pain in the extremities.

TYPE 1 DIABETES

Type 1 diabetes is a chronic autoimmune disorder in which the immune system attacks the insulin-secreting beta cells of the pancreas. As a result, people with type 1 diabetes lack the insulin needed to keep blood glucose levels within the normal range. Type 1 diabetes may develop in people of any age but is most often diagnosed before adulthood. For type 1 diabetics, insulin injections are critical for survival. This form of diabetes accounts for less than five percent of all diabetes cases.

TYPE 2 DIABETES

Type 2 diabetes is the single most common form of diabetes, accounting for approximately 95 percent of all cases. It is acquired, and lifestyle factors such as poor diet, inactivity, and the presence of

pre-diabetes greatly increase a person's risk. About 80 to 90 percent of people with type 2 diabetes are overweight or obese. The cause of high blood glucose in this form of diabetes usually includes a combination of insulin resistance and impaired insulin secretion. In type 2 diabetes, cells become resistant to the effects of insulin. In response, the pancreas increases its insulin secretion, but over time, the beta cells become exhausted. In many cases, type 2 diabetes can be reversed by moderate weight loss, regular physical activity, and consumption of a healthy diet; however, if blood glucose levels cannot be controlled, the person with diabetes will eventually require insulin. Both genetic and environmental factors play roles in the development of type 2 diabetes. Management of type 2 diabetes includes changes in diet and physical activity, which may increase insulin sensitivity and help reduce blood glucose levels to normal ranges. Medications may also be used as part of the treatment, as may insulin injections.

DIAGNOSIS, SYMPTOMS, AND EFFECTS

Two of the early manifestations of diabetes are excessive urination and excessive thirst. They demonstrate how the out-of-control levels of glucose in the blood affect kidney function. The kidneys are responsible for filtering glucose from the blood. Excessive blood glucose draws water into the urine, and as a result the person eliminates an abnormally large quantity of sweet urine. The use of body water to dilute the urine leaves the body dehydrated, and so the person is unusually and continually thirsty. The person may also experience persistent hunger because the body cells are unable to access the glucose in the bloodstream.

Over time, persistently high levels of glucose in the blood injure tissues throughout the body, especially those of the blood vessels and nerves. Inflammation and injury of the lining of arteries lead to atherosclerosis and an increased risk of heart attack and stroke. Damage to the microscopic blood vessels of the kidney impairs kidney function and can lead to kidney failure. Damage to blood vessels that serve the eyes can lead to blindness. Blood vessel damage also reduces circulation to the limbs, whereas nerve damage leads to a loss of sensation, called neuropathy, particularly in the hands and feet. Together, these changes increase the risk of injury, infection, and tissue death (necrosis), contributing to a high rate of toe, foot, and lower leg amputations in people with diabetes. Uncontrolled diabetes can also lead to a dangerous form of metabolic acidosis called ketoacidosis. Deprived of glucose, cells increasingly rely on fat stores for fuel. However, in a glucose-deficient state, the liver is forced to use an alternative lipid metabolism pathway that results in the increased production of ketone bodies (or ketones), which are acidic. The build-up of ketones in the blood causes ketoacidosis, which—if left untreated—may lead to a life-threatening "diabetic coma." Together, these complications make diabetes the seventh leading cause of death in the United States.

Diabetes is diagnosed when lab tests reveal that blood glucose levels are higher than normal, a condition called hyperglycemia. The treatment of diabetes depends on the type, the severity of the condition, and the ability of the patient to make lifestyle changes. As noted earlier, moderate weight loss, regular physical activity, and consumption of a healthful diet can reduce blood glucose levels. Some patients with type 2 diabetes may be unable to control their disease with these lifestyle changes, and will require medication. Historically, the first-line treatment of type 2 diabetes was insulin. Research advances have resulted in alternative options, including medications that enhance pancreatic function.

FEATURE: HUMAN BIOLOGY IN THE NEWS

Some patients with type 1 diabetes have been given pancreatic islet cells transplants from other human donors. If the transplanted cells are not rejected by the recipient's immune system, they can cure the patient of diabetes. However, only about 1,000 such surgeries have been performed over the past 10 years because of a shortage of appropriate human donors.

In June of 2016, a research team led by Dr. David K.C. Cooper at the Thomas E. Starzl Transplantation Institute in Pittsburgh, Pennsylvania, reported on their work developing pig islet cells for transplant into human diabetes patients. The researchers genetically engineered the pig islet cells to be protected from the human immune response. As a result, patients receiving transplanted cells would require only minimal suppression of their immune system after the surgery. The pig islet cells would also be less likely to transmit pathogenic agents because the animals could be raised in a controlled environment.

The researchers have successfully transplanted the pig islet cells into monkey models of type 1 diabetes. As of June 2016, the scientists were looking for funding to undertake clinical trials in humans with type 1 diabetes. Dr. Cooper predicted then that if the human trials go as well as expected, the pig islet cells could be available for curing patients in as little as two years.

PANCREATITIS

Pancreatitis is inflammation of the pancreas. It has a variety of possible causes including gallstones, chronic alcohol use, infections such as measles or mumps, genetic causes, and certain medications. Pancreatitis occurs when digestive enzymes produced by the pancreas damage the gland's tissues, which causes problems with fat digestion. The disorder is usually associated with intense pain in the central abdomen, and the pain may radiate to the back. Yellowing of the skin and whites of the eyes (Figure 8.8.6), which is called jaundice, is a common sign of pancreatitis. People with pancreatitis may also have pale stools and dark urine. Treatment of pancreatitis includes administering drugs to manage pain and addressing the underlying cause of the disease, for example, by removing gallstones.



Figure 8.8.6: Jaundice, or yellowing of the skin and whites of the eyes, is a common sign of pancreatitis.

PANCREATIC CANCER

There are several different types of pancreatic cancer that may affect either the endocrine or the exocrine tissues of the gland. Cancers affecting the endocrine tissues are all relatively rare. However, their incidence has been rising sharply. It is unclear to what extent this reflects increased detection, especially through medical imaging techniques. Unfortunately, pancreatic cancer is usually diagnosed at a relatively late stage when it is too late for surgery, which is the only way to cure the disorder. In the United States, pancreatic cancer is the fourth most common cause of death due to cancer.

Pancreatic cancer is rare before the age of 40 and occurs most often after the age of 60. Factors that increase the risk of developing pancreatic cancer include smoking, chronic pancreatitis, and diabetes. About one in four cases of pancreatic cancer are attributable to smoking. Certain rare genetic conditions are also risk factors for pancreatic cancer.

REVIEW

1. Describe the structure and location of the pancreas.
2. Distinguish between the endocrine and exocrine functions of the pancreas.
3. Identify the four types of pancreatic islet cells and the endocrine hormone each type of cell produces.
4. What is pancreatitis? What are the possible causes and effects of pancreatitis?
5. Describe the incidence, prognosis, and risk factors of cancer of the endocrine tissues of the pancreas.
6. Compare and contrast type 1 and type 2 diabetes.
7. If the alpha islet cells of the pancreas were damaged to the point that they no longer functioned, how would this affect blood glucose levels? Would the administration of insulin be more likely to help or hurt the condition? Explain your answer.
8. Explain how the pancreas is able to regulate the production of its own endocrine hormones, to some extent.
9. True or False. The pancreas is part of both the digestive system and the endocrine system.
10. Give an example of how the pancreas can regulate the production of hormones from the pituitary gland.
11. Which is the most common form of diabetes mellitus?
12. Explain why diabetes causes excessive thirst.
13. Damage to _____ is the underlying cause of many of the long-term consequences of diabetes.

    A. the adrenal gland
    B. gamma islet cells
    C. blood vessels
    D. the pituitary gland

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8.9: CASE STUDY CONCLUSION- HORMONAL AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: HORMONAL HAVOC

Gabrielle, who you read about in the beginning of this chapter, has polycystic ovary syndrome (PCOS). PCOS is named for the multiple fluid-filled sacs, or cysts, that are present in the ovaries of women with this syndrome. You can see these cysts in the illustration above, which compares a normal ovary with a polycystic ovary. The cysts result from follicles in the ovary that did not properly produce and release an egg. Mature eggs are normally released from follicles monthly during the process of ovulation, but in PCOS this often does not occur. Ovarian cysts can be common and do not necessarily mean that a woman has PCOS, but the presence of multiple ovarian cysts plus other telltale signs and symptoms may cause her physician suspect PCOS.

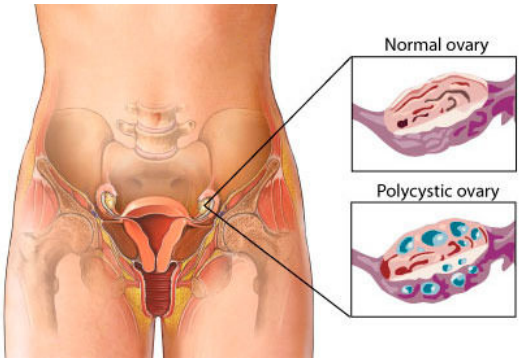


Figure **8.9.1**: Polycystic Ovary

Gabrielle's symptoms of PCOS included irregular menstrual periods, weight gain, acne, and excess facial hair. There are many other symptoms of PCOS that women can experience, such as male-pattern baldness, pelvic pain, and depression, among others. As you may recall, Gabrielle also had some abnormal blood test results, such as high levels of androgens and blood glucose. These can also be indications of PCOS.

As you have learned, androgens are a term for male sex hormones, but females also normally produce androgens, albeit to a lesser extent than males. In women with PCOS, the level of androgens is abnormally high. These androgens include testosterone, which is produced by the ovaries, and DHEA, which is produced by the adrenal glands. This increase in androgens can have a "masculinizing" effect on women, including an increase in facial and body hair, male-pattern baldness, and interference with the menstrual cycle by preventing ovulation. Androgens also can cause weight gain and acne — two of the other common symptoms of PCOS.

In addition to hypersecretion of androgens, PCOS often causes high blood glucose as a result of insulin resistance. As you have learned, insulin is a hormone secreted by the pancreas that works in conjunction with other pancreatic hormones (such as glucagon) to regulate the level of blood glucose. What is another disease involving insulin resistance? If you answered type 2 diabetes, you are correct! In fact, women with PCOS are at a high risk of developing type 2 diabetes because of their resistance to insulin. More than 50 percent of women with PCOS will develop diabetes or pre-diabetes before they are 40 years old.

Besides diabetes, women with PCOS have a higher chance of developing fertility problems, heart disease, sleep apnea (briefly stopping breathing during sleep), and uterine cancer, among other diseases and disorders. There is hope, however. Lifestyle modifications and medicines not only can help women cope with the symptoms of PCOS, but may also reduce the risk of some of the possible long-term consequences by lowering blood sugar and androgen levels. For instance, eating a healthy diet and exercising regularly can help women with PCOS lose weight. This can help lower blood glucose levels, improve insulin functioning, and can even make the menstrual cycle more regular. Medications such as birth control pills and anti-androgens can help restore a more regular menstrual cycle and reduce facial and body hair and acne. The diabetes medication metformin can be used to treat several of the symptoms of PCOS, and even may prevent type 2 diabetes, by improving insulin functioning and lowering testosterone. Finally, women with PCOS who are trying to conceive may be helped with fertility medications that stimulate ovulation.

The underlying cause of PCOS is not definitively known, although it is thought that both genetic and environmental factors play a role. PCOS tends to run in families, and women with a sister with PCOS are twice as likely to also have it. Researchers think that the insulin resistance seen in PCOS may cause an increase in androgens, illustrating how hormonal systems can influence each other.

As you have seen throughout this chapter, endocrine hormones can have a wide variety of effects on the body, including the regulation of metabolism, reproductive functions, homeostasis of different ions and molecules, and mediating responses to stressful situations. Different hormones have different effects, but even a single hormone can have multiple effects. Hormones travel throughout the bloodstream and affect any cells that have the appropriate receptors for them, known as target cells. Many hormones have target cells in multiple types of organs and tissues, or they regulate molecules, such as blood glucose, that affect many organ systems. These are some of the reasons why changes in the normal level of an endocrine hormone — either hypersecretion or hyposecretion — can result in a wide variety of symptoms, such as is seen in Cushing's syndrome, diabetes, and PCOS. By understanding what goes wrong in these disorders, you can better appreciate how important the endocrine system is for regulating the many diverse functions of the human body.

CHAPTER SUMMARY

In this chapter, you learned about the glands and hormones of the endocrine system, their functions, how they are regulated, and some diseases and disorders of the endocrine system. Specifically, you learned that:

- The endocrine system is a system of glands that release chemical messenger molecules called hormones into the bloodstream. Other glands, called exocrine glands, release substances onto nearby body surfaces through ducts.
- Endocrine hormones travel more slowly than nerve impulses, which are the body's other way of sending messages. However, the effects of endocrine hormones may be much longer lasting.
- The pituitary gland is the master gland of the endocrine system. Most of the hormones it produces control other endocrine glands. These glands include the thyroid gland, parathyroid glands, pineal gland, pancreas, adrenal glands, gonads (testes and ovaries), and thymus gland.
- Diseases of the endocrine system are relatively common. An endocrine disease usually involves hypersecretion or hyposecretion of a hormone. Hypersecretion is frequently caused by a tumor. Hyposecretion is often caused by the destruction of hormone-secreting cells by the body's own immune system.
- Endocrine hormones travel throughout the body but affect only certain cells, called target cells, which have receptors specific to particular hormones.
- Steroid hormones such as estrogen are endocrine hormones made of lipids that cross plasma membranes and bind to receptors inside target cells. The hormone-receptor complexes then move into the nucleus where they influence gene expression.
- Non-steroid hormones such as insulin are endocrine hormones made of amino acids that bind to receptors on the surface of target cells. This activates an enzyme in the plasma membrane, and the enzyme controls a second messenger molecule, which influences cell processes.
- Most endocrine hormones are controlled by negative feedback loops in which rising levels of hormone feedback to stop its own production — and vice-versa. For example, a negative feedback loop controls the production of thyroid hormones. The loop includes the hypothalamus, pituitary gland, and thyroid gland.
- Only a few endocrine hormones are controlled by positive feedback loops in which rising levels of hormone feedback to stimulate continued production of the hormone. Prolactin, the pituitary hormone that stimulates milk production by mammary glands, is controlled by a positive feedback loop. The loop includes the nipples, hypothalamus, pituitary gland, and mammary glands.
- The pituitary gland is at the base of the brain, where it is connected to the hypothalamus by nerves and capillaries. It has an anterior (front) lobe that synthesizes and secretes pituitary hormones and a posterior (back) lobe that stores and secretes hormones from the hypothalamus.
    - Hormones synthesized and secreted by the anterior pituitary include growth hormone, which stimulates cell growth throughout the body, and thyroid stimulating hormone (TSH), which stimulates the thyroid gland to secrete its hormones.
    - Hypothalamic hormones stored and secreted by the posterior pituitary include vasopressin, which helps maintain homeostasis in body water; and oxytocin, which stimulates uterine contractions during birth and the letdown of milk during lactation.
- The thyroid gland is a large endocrine gland in the front of the neck. It is composed mainly of clusters of cells called follicles, which are specialized to absorb iodine and use it to make thyroid hormones. Parafollicular cells among the follicles synthesize the hormone calcitonin.
    - The thyroid hormones thyroxine (T4) and triiodothyronine (T3) cross cell membranes and regulate gene expression to control the rate of metabolism in cells body-wide, among other functions. The production of T4 and T3 is regulated by thyroid stimulating hormone (TSH) from the pituitary, which is regulated, in turn, by thyrotropin-releasing hormone (TRH) from the hypothalamus.
    - Calcitonin helps regulate blood calcium levels by stimulating the movement of calcium into bone. It works in conjunction with parathyroid hormone to maintain calcium homeostasis.
    - Abnormal secretion of thyroid hormones may occur for a variety of reasons and may lead to the development of a goiter. The most common cause of hyperthyroidism is Graves' disease, an autoimmune disorder. Iodine deficiency is a common cause of hypothyroidism worldwide. In the United States, the most common cause of hypothyroidism is Hashimoto's thyroiditis, another autoimmune disorder. Hypothyroidism in pregnant women may cause permanent cognitive deficits in children.
- The adrenal glands are endocrine glands that produce a variety of hormones. The two adrenal glands are located on both sides of the body, just above the kidneys. Each gland has two layers: an outer layer called the adrenal cortex and an inner layer called the adrenal medulla.
    - The adrenal cortex produces steroid hormones called by the general term corticosteroids, of which there are three types: mineralocorticoids such as aldosterone, which helps control electrolyte balance; glucocorticoids such as cortisol, which helps control the rate of metabolism and suppresses the immune system; and androgens such as DHEA, which is converted to sex hormones in the gonads.
    - The adrenal medulla produces non-steroid catecholamine hormones including adrenaline and noradrenaline. These hormones stimulate the fight-or-flight response.
    - Disorders of the adrenal glands generally include either hypersecretion or hyposecretion of adrenal hormones. The cause may be a problem with the adrenal glands or with the pituitary gland, which controls adrenal cortex hormone production. Examples include Cushing's syndrome, in which there is hypersecretion of cortisol; and Addison's disease, in which there is hyposecretion of cortisol and mineralocorticoids.
- The pancreas is a gland located in the upper left abdomen behind the stomach that functions as both an endocrine gland and an exocrine gland. As an endocrine gland, the pancreas releases

hormones, such as insulin, directly into the bloodstream. As an exocrine gland, the pancreas releases digestive enzymes into ducts that carry them to the gastrointestinal tract.

- Tissues in the pancreas that have an endocrine role exist as clusters of cells called pancreatic islets. The islets consist of four main types of cells, each of which secretes a different endocrine hormone. Alpha (α) cells secrete glucagon, beta (β) cells secrete insulin, delta (δ) cells secrete somatostatin, and gamma (γ) cells secrete pancreatic polypeptide.
- The endocrine hormones secreted by the pancreatic islets all play a role, either directly or indirectly, in glucose metabolism and homeostasis of blood glucose levels. For example, insulin stimulates the uptake of glucose by cells and decreases the level of glucose in the blood, whereas glucagon stimulates the conversion of glycogen to glucose and increases the level of glucose in the blood.
- Disorders of the pancreas include pancreatitis, pancreatic cancer, and diabetes mellitus. Pancreatitis is a painful inflammation of the pancreas that has many possible causes. Pancreatic cancer of the endocrine tissues is rare but increasing in frequency. It is generally discovered too late to cure surgically. Smoking is a major risk factor for pancreatic cancer.
- Diabetes mellitus is the most common type of pancreatic disorder. In diabetes, the inadequate activity of insulin results in high blood levels of glucose. Type 1 diabetes is a chronic autoimmune disorder in which the immune system attacks the insulin-secreting beta cells of the pancreas. Type 2 diabetes is usually caused by a combination of insulin resistance and impaired insulin secretion due to a variety of environmental and genetic factors.

CHAPTER SUMMARY REVIEW

1. The pituitary gland is considered the master gland of the endocrine system because its hormones control other endocrine glands. For each of the glands below, describe one way in which it is controlled by the pituitary gland.
   A. The thyroid gland
   B. The adrenal gland
   C. The gonads (ovaries and testes)
2. What is the name of the main brain structure that secretes hormones that control the pituitary gland?
3. Define hyposecretion and give an example of an endocrine disorder involving hyposecretion. Be sure to include the name of the hormone involved.
4. Define hypersecretion and give an example of an endocrine disorder involving hypersecretion. Be sure to include the name of the hormone involved.
5. Which hormone plays a role in regulating metabolism in some way?
   A. Cortisol
   B. Thyroid hormone
   C. Glucagon
   D. All of the above
6. Which endocrine gland plays an important role in the fight-or-flight response?
7. *True or False*. Sex hormones, such as androgens, are only produced by the gonads.
8. *True or False*. Estrogen can travel to the nucleus of a cell.
9. Explain why non-steroid hormones typically require the activation of second messenger molecules to have their effects, instead of directly affecting intracellular processes themselves.
10. Explain what it means that endocrine hormones are “chemical messengers.”
11. If you were a physician, and a patient came to you complaining of excessive thirst and urination, what endocrine disorder might you suspect the patient has?
    A. In order to diagnose this disorder, what would you want to check for in the patient’s blood? Explain your answer.
12. Pancreatic islet cells all produce:
    A. Insulin
    B. Glucagon
    C. Endocrine hormones
    D. Digestive enzymes
13. Give one example of negative feedback in the endocrine system.
14. Explain the circumstances in which organs and hormones in a negative feedback loop can actually increase the level of a hormone.
15. *True or False*. The hormone vasopressin is synthesized by the hypothalamus.
16. *True or False*. Like most other hormones, prolactin is regulated by a negative feedback loop.
17. Identify the gland that secretes each of the following hormones:
    A. Melatonin
    B. Growth hormone
    C. Thyroid stimulating hormone
    D. Aldosterone
18. A goiter is an enlargement of which structure?
19. Explain why giving iodine can treat some cases of hypothyroidism, but it is not usually helpful when someone has hypothyroidism due to Hashimoto’s thyroiditis.
20. For each disease below, identify the hormone involved and whether the problem involves hyposecretion or hypersecretion of this hormone.
    A. Addison’s disease
    B. Graves’ disease
    C. Cushing’s syndrome
    D. Type 1 diabetes
21. What is an example of a disease that is due to hormone resistance?
22. *True or False*. Adrenaline is an exocrine hormone.
23. Steroid hormones:
    A. always increase muscle mass

B. are fat soluble
C. bind to receptors on the plasma membrane
D. include insulin

24. Explain generally how autoimmune disorders can disrupt the endocrine system, and give one example.

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CHAPTER OVERVIEW

9: Cardiovascular System - Blood

Chapter Objectives

- Identify the primary functions of blood, its fluid and cellular components, and its physical characteristics
- Identify the most important proteins and other solutes present in blood plasma
- Describe the formation of the formed element components of blood
- Discuss the structure and function of red blood cells and hemoglobin
- Classify and characterize white blood cells
- Describe the structure of platelets and explain the process of hemostasis
- Explain the significance of AB and Rh blood groups in blood transfusions
- Discuss a variety of blood disorders

9.1: Blood- Introduction
9.2: An Overview of Blood
9.3: Production of the Formed Elements
9.4: Erythrocytes
9.5: Leukocytes and Platelets
9.6: Hemostasis
9.7: Blood Typing
9.9: Blood- Chapter Review

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9.1: Blood- Introduction

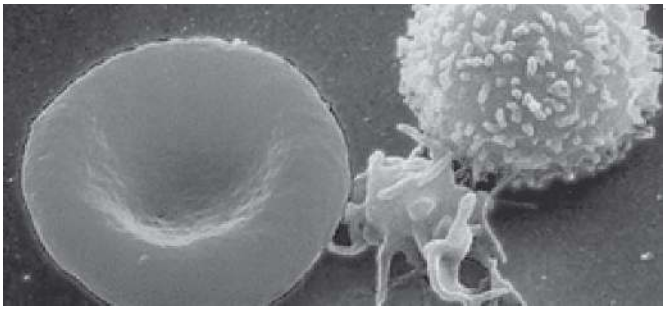


Figure 9.1.1:Blood Cells A single drop of blood contains millions of red blood cells, white blood cells, and platelets. One of each type is shown here, isolated from a scanning electron micrograph.

Chapter Objectives

After studying this chapter, you will be able to:

- Identify the primary functions of blood, its fluid and cellular components, and its physical characteristics
- Identify the most important proteins and other solutes present in blood plasma
- Describe the formation of the formed element components of blood
- Discuss the structure and function of red blood cells and hemoglobin
- Classify and characterize white blood cells
- Describe the structure of platelets and explain the process of hemostasis
- Explain the significance of AB and Rh blood groups in blood transfusions
- Discuss a variety of blood disorders

Single-celled organisms do not need blood. They obtain nutrients directly from and excrete wastes directly into their environment. The human organism cannot do that. Our large, complex bodies need blood to deliver nutrients to and remove wastes from our trillions of cells. The heart pumps blood throughout the body in a network of blood vessels. Together, these three components—blood, heart, and vessels—makes up the cardiovascular system. This chapter focuses on the medium of transport: blood.

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9.2: An Overview of Blood

Learning Objectives

By the end of this section, you will be able to:

- Identify the primary functions of blood in transportation, defense, and maintenance of homeostasis
- Name the fluid component of blood and the three major types of formed elements, and identify their relative proportions in a blood sample
- Discuss the unique physical characteristics of blood
- Identify the composition of blood plasma, including its most important solutes and plasma proteins

Recall that blood is a connective tissue. Like all connective tissues, it is made up of cellular elements and an extracellular matrix. The cellular elements—referred to as the formed elements—include red blood cells (RBCs), white blood cells (WBCs), and cell fragments called platelets. The extracellular matrix, called plasma, makes blood unique among connective tissues because it is fluid. This fluid, which is mostly water, perpetually suspends the formed elements and enables them to circulate throughout the body within the cardiovascular system.

Functions of Blood

The primary function of blood is to deliver oxygen and nutrients to and remove wastes from body cells, but that is only the beginning of the story. The specific functions of blood also include defense, distribution of heat, and maintenance of homeostasis.

Transportation

Nutrients from the foods you eat are absorbed in the digestive tract. Most of these travel in the bloodstream directly to the liver, where they are processed and released back into the bloodstream for delivery to body cells. Oxygen from the air you breathe diffuses into the blood, which moves from the lungs to the heart, which then pumps it out to the rest of the body. Moreover, endocrine glands scattered throughout the body release their products, called hormones, into the bloodstream, which carries them to distant target cells. Blood also picks up cellular wastes and byproducts, and transports them to various organs for removal. For instance, blood moves carbon dioxide to the lungs for exhalation from the body, and various waste products are transported to the kidneys and liver for excretion from the body in the form of urine or bile.

Defense

Many types of WBCs protect the body from external threats, such as disease-causing bacteria that have entered the bloodstream in a wound. Other WBCs seek out and destroy internal threats, such as cells with mutated DNA that could multiply to become cancerous, or body cells infected with viruses.

When damage to the vessels results in bleeding, blood platelets and certain proteins dissolved in the plasma, the fluid portion of the blood, interact to block the ruptured areas of the blood vessels involved. This protects the body from further blood loss.

Maintenance of Homeostasis

Recall that body temperature is regulated via a classic negative-feedback loop. If you were exercising on a warm day, your rising core body temperature would trigger several homeostatic mechanisms, including increased transport of blood from your core to your body periphery, which is typically cooler. As blood passes through the vessels of the skin, heat would be dissipated to the environment, and the blood returning to your body core would be cooler. In contrast, on a cold day, blood is diverted away from the skin to maintain a warmer body core. In extreme cases, this may result in frostbite.

Blood also helps to maintain the chemical balance of the body. Proteins and other compounds in blood act as buffers, which thereby help to regulate the pH of body tissues. Blood also helps to regulate the water content of body cells.

Summary of Blood Functions

Blood performs many important functions in the body. Major functions of blood include:

- supplying tissues with oxygen, which is needed by all cells for aerobic cellular respiration.

- supplying cells with nutrients, including glucose, amino acids, and fatty acids.
- removing metabolic wastes from cells, including carbon dioxide, urea, and lactic acid.
- helping to defend the body from pathogens and other foreign substances.
- forming clots to seal broken blood vessels and stop bleeding.
- transporting hormones and other messenger molecules.
- regulating the pH of the body, which must be kept within a narrow range (7.35 to 7.45).
- helping to regulate body temperature (through vasoconstriction and vasodilation).

Composition of Blood

You have probably had blood drawn from a superficial vein in your arm, which was then sent to a lab for analysis. Some of the most common blood tests—for instance, those measuring lipid or glucose levels in plasma—determine which substances are present within blood and in what quantities. Other blood tests check for the composition of the blood itself, including the quantities and types of formed elements.

One such test, called a hematocrit, measures the percentage of RBCs, clinically known as erythrocytes, in a blood sample. It is performed by spinning the blood sample in a specialized centrifuge, a process that causes the heavier elements suspended within the blood sample to separate from the lightweight, liquid plasma (Figure 9.2.1). Because the heaviest elements in blood are the erythrocytes, these settle at the very bottom of the hematocrit tube. Located above the erythrocytes is a pale, thin layer composed of the remaining formed elements of blood. These are the WBCs, clinically known as leukocytes, and the platelets, cell fragments also called thrombocytes. This layer is referred to as the buffy coat because of its color; it normally constitutes less than 1 percent of a blood sample. Above the buffy coat is the blood plasma, normally a pale, straw-colored fluid, which constitutes the remainder of the sample.

The volume of erythrocytes after centrifugation is also commonly referred to as packed cell volume (PCV). In normal blood, about 45 percent of a sample is erythrocytes. The hematocrit of any one sample can vary significantly, however, about 36–50 percent, according to gender and other factors. Normal hematocrit values for females range from 37 to 47, with a mean value of 41; for males, hematocrit ranges from 42 to 52, with a mean of 47. The percentage of other formed elements, the WBCs and platelets, is extremely small so it is not normally considered with the hematocrit. So the mean plasma percentage is the percent of blood that is not erythrocytes: for females, it is approximately 59 (or 100 minus 41), and for males, it is approximately 53 (or 100 minus 47).

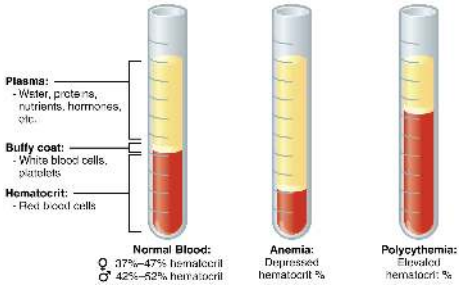


Figure 9.2.1: Composition of Blood The cellular elements of blood include a vast number of erythrocytes and comparatively fewer leukocytes and platelets. Plasma is the fluid in which the formed elements are suspended. A sample of blood spun in a centrifuge reveals that plasma is the lightest component. It floats at the top of the tube separated from the heaviest elements, the erythrocytes, by a buffy coat of leukocytes and platelets. Hematocrit is the percentage of the total sample that is comprised of erythrocytes. Depressed and elevated hematocrit levels are shown for comparison.

Characteristics of Blood

When you think about blood, the first characteristic that probably comes to mind is its color. Blood that has just taken up oxygen in the lungs is bright red, and blood that has released oxygen in the tissues is a more dusky red. This is because hemoglobin is a pigment that changes color, depending upon the degree of oxygen saturation.

Blood is viscous and somewhat sticky to the touch. It has a viscosity approximately five times greater than water. Viscosity is a measure of a fluid's thickness or resistance to flow, and is influenced by the presence of the plasma proteins and formed elements within the blood. The viscosity of blood has a dramatic impact on blood pressure and flow. Consider the difference in flow between

water and honey. The more viscous honey would demonstrate a greater resistance to flow than the less viscous water. The same principle applies to blood.

The normal temperature of blood is slightly higher than normal body temperature—about 38 °C (or 100.4 °F), compared to 37 °C (or 98.6 °F) for an internal body temperature reading, although daily variations of 0.5 °C are normal. Although the surface of blood vessels is relatively smooth, as blood flows through them, it experiences some friction and resistance, especially as vessels age and lose their elasticity, thereby producing heat. This accounts for its slightly higher temperature.

The pH of blood averages about 7.4; however, it can range from 7.35 to 7.45 in a healthy person. Blood is therefore somewhat more basic (alkaline) on a chemical scale than pure water, which has a pH of 7.0. Blood contains numerous buffers that actually help to regulate pH.

Blood constitutes approximately 8 percent of adult body weight. Adult males typically average about 5 to 6 liters of blood. Females average 4–5 liters.

Blood Plasma

Like other fluids in the body, plasma is composed primarily of water: In fact, it is about 92 percent water. Dissolved or suspended within this water is a mixture of substances, most of which are proteins. There are literally hundreds of substances dissolved or suspended in the plasma, although many of them are found only in very small quantities.

Interactive Link

Visit this site for a list of normal levels established for many of the substances found in a sample of blood. Serum, one of the specimen types included, refers to a sample of plasma after clotting factors have been removed. What types of measurements are given for levels of glucose in the blood?

Plasma Proteins

About 7 percent of the volume of plasma—nearly all that is not water—is made of proteins. These include several plasma proteins (proteins that are unique to the plasma), plus a much smaller number of regulatory proteins, including enzymes and some hormones. The major components of plasma are summarized in Figure 18.3.

The three major groups of plasma proteins are as follows:

- Albumin is the most abundant of the plasma proteins. Manufactured by the liver, albumin molecules serve as binding proteins—transport vehicles for fatty acids and steroid hormones. Recall that lipids are hydrophobic; however, their binding to albumin enables their transport in the watery plasma. Albumin is also the most significant contributor to the osmotic pressure of blood; that is, its presence holds water inside the blood vessels and draws water from the tissues, across blood vessel walls, and into the bloodstream. This in turn helps to maintain both blood volume and blood pressure. Albumin normally accounts for approximately 54 percent of the total plasma protein content, in clinical levels of 3.5–5.0 g/dL blood.
- The second most common plasma proteins are the globulins. A heterogeneous group, there are three main subgroups known as alpha, beta, and gamma globulins. The alpha and beta globulins transport iron, lipids, and the fat-soluble vitamins A, D, E, and K to the cells; like albumin, they also contribute to osmotic pressure. The gamma globulins are proteins involved in immunity and are better known as an antibodies or immunoglobulins. Although other plasma proteins are produced by the liver, immunoglobulins are produced by specialized leukocytes known as plasma cells. (Seek additional content for more information about immunoglobulins.) Globulins make up approximately 38 percent of the total plasma protein volume, in clinical levels of 1.0–1.5 g/dL blood.
- Fibrinogen is the third of the three major groups of plasma proteins. Like albumin and the alpha and beta globulins, fibrinogen is produced by the liver. It is essential for blood clotting, a process described later in this chapter. Fibrinogen accounts for about 7 percent of the total plasma protein volume, in clinical levels of 0.2–0.45 g/dL blood.

Other Plasma Solutes

In addition to proteins, plasma contains a wide variety of other substances. These include various electrolytes, such as sodium, potassium, and calcium ions; dissolved gases, such as oxygen, carbon dioxide, and nitrogen; various organic nutrients, such as

vitamins, lipids, glucose, and amino acids; and metabolic wastes. All of these nonprotein solutes combined contribute approximately 1 percent to the total volume of plasma.

Component and % of blood	Subcomponent and % of component	Type and % (where appropriate)	Site of production	Major function(s)
Plasma 46–63 percent	Water 92 percent	Fluid	Absorbed by intestinal tract or produced by metabolism	Transport medium
	Plasma proteins 7 percent	Albumin 54–60 percent	Liver	Maintain osmotic concentration, transport lipid molecules
		Globulins 35–38 percent	Alpha globulins—liver	Transport, maintain osmotic concentration
			Beta globulins—liver	Transport, maintain osmotic concentration
			Gamma globulins (immunoglobulins)—plasma cells	Immune responses
		Fibrinogen 4–7 percent	Liver	Blood clotting in hemostasis
	Regulatory proteins <1 percent	Hormones and enzymes	Various sources	Regulate various body functions
	Other solutes 1 percent	Nutrients, gases, and wastes	Absorbed by intestinal tract, exchanged in respiratory system, or produced by cells	Numerous and varied
Formed elements 37–54 percent	Erythrocytes 99 percent	Erythrocytes	Red bone marrow	Transport gases, primarily oxygen and some carbon dioxide
	Leukocytes <1 percent Platelets <1 percent	Granular leukocytes: neutrophils eosinophils basophils	Red bone marrow	Nonspecific immunity
		Agranular leukocytes: lymphocytes monocytes	Lymphocytes: bone marrow and lymphatic tissue	Lymphocytes: specific immunity
			Monocytes: red bone marrow	Monocytes: nonspecific immunity
	Platelets <1 percent		Megakaryocytes: red bone marrow	Hemostasis

Figure 9.2.2: Major Blood Components

Career Connection

Phlebotomy and Medical Lab Technology

Phlebotomists are professionals trained to draw blood (phleb- = “a blood vessel”; -tomy = “to cut”). When more than a few drops of blood are required, phlebotomists perform a venipuncture, typically of a surface vein in the arm. They perform a capillary stick on a finger, an earlobe, or the heel of an infant when only a small quantity of blood is required. An arterial stick is collected from an artery and used to analyze blood gases. After collection, the blood may be analyzed by medical laboratories or perhaps used for transfusions, donations, or research. While many allied health professionals practice phlebotomy, the American Society of Phlebotomy Technicians issues certificates to individuals passing a national examination, and some large labs and hospitals hire individuals expressly for their skill in phlebotomy.

Medical or clinical laboratories employ a variety of individuals in technical positions:

- Medical technologists (MT), also known as clinical laboratory technologists (CLT), typically hold a bachelor’s degree and certification from an accredited training program. They perform a wide variety of tests on various body fluids, including blood. The information they provide is essential to the primary care providers in determining a diagnosis and in monitoring the course of a disease and response to treatment.
- Medical laboratory technicians (MLT) typically have an associate’s degree but may perform duties similar to those of an MT.
- Medical laboratory assistants (MLA) spend the majority of their time processing samples and carrying out routine assignments within the lab. Clinical training is required, but a degree may not be essential to obtaining a position.

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9.3: Production of the Formed Elements

Learning Objectives

By the end of this section, you will be able to:

- Trace the generation of the formed elements of blood from bone marrow stem cells
- Discuss the role of hemopoietic growth factors in promoting the production of the formed elements

The lifespan of the formed elements is very brief. Although one type of leukocyte called memory cells can survive for years, most erythrocytes, leukocytes, and platelets normally live only a few hours to a few weeks. Thus, the body must form new blood cells and platelets quickly and continuously. When you donate a unit of blood during a blood drive (approximately 475 mL, or about 1 pint), your body typically replaces the donated plasma within 24 hours, but it takes about 4 to 6 weeks to replace the blood cells. This restricts the frequency with which donors can contribute their blood. The process by which this replacement occurs is called hemopoiesis, or hematopoiesis (from the Greek root haima- = “blood”; -poiesis = “production”).

Sites of Hemopoiesis

Prior to birth, hemopoiesis occurs in a number of tissues, beginning with the yolk sac of the developing embryo, and continuing in the fetal liver, spleen, lymphatic tissue, and eventually the red bone marrow. Following birth, most hemopoiesis occurs in the red marrow, a connective tissue within the spaces of spongy (cancellous) bone tissue. In children, hemopoiesis can occur in the medullary cavity of long bones; in adults, the process is largely restricted to the cranial and pelvic bones, the vertebrae, the sternum, and the proximal epiphyses of the femur and humerus.

Throughout adulthood, the liver and spleen maintain their ability to generate the formed elements. This process is referred to as extramedullary hemopoiesis (meaning hemopoiesis outside the medullary cavity of adult bones). When a disease such as bone cancer destroys the bone marrow, causing hemopoiesis to fail, extramedullary hemopoiesis may be initiated.

Differentiation of Formed Elements from Stem Cells

All formed elements arise from stem cells of the red bone marrow. Recall that stem cells undergo mitosis plus cytokinesis (cellular division) to give rise to new daughter cells: One of these remains a stem cell and the other differentiates into one of any number of diverse cell types. Stem cells may be viewed as occupying a hierarchal system, with some loss of the ability to diversify at each step. The totipotent stem cell is the zygote, or fertilized egg. The totipotent (toti- = “all”) stem cell gives rise to all cells of the human body. The next level is the pluripotent stem cell, which gives rise to multiple types of cells of the body and some of the supporting fetal membranes. Beneath this level, the mesenchymal cell is a stem cell that develops only into types of connective tissue, including fibrous connective tissue, bone, cartilage, and blood, but not epithelium, muscle, and nervous tissue. One step lower on the hierarchy of stem cells is the hematopoietic stem cell, or hemocytoblast. All of the formed elements of blood originate from this specific type of cell.

Hemopoiesis begins when the hematopoietic stem cell is exposed to appropriate chemical stimuli collectively called hemopoietic growth factors, which prompt it to divide and differentiate. One daughter cell remains a hematopoietic stem cell, allowing hemopoiesis to continue. The other daughter cell becomes either of two types of more specialized stem cells (Figure 9.3.1):

- Lymphoid stem cells give rise to a class of leukocytes known as lymphocytes, which include the various T cells, B cells, and natural killer (NK) cells, all of which function in immunity. However, hemopoiesis of lymphocytes progresses somewhat differently from the process for the other formed elements. In brief, lymphoid stem cells quickly migrate from the bone marrow to lymphatic tissues, including the lymph nodes, spleen, and thymus, where their production and differentiation continues. B cells are so named since they mature in the bone marrow, while T cells mature in the thymus.
- Myeloid stem cells give rise to all the other formed elements, including the erythrocytes; megakaryocytes that produce platelets; and a myeloblast lineage that gives rise to monocytes and three forms of granular leukocytes: neutrophils, eosinophils, and basophils.

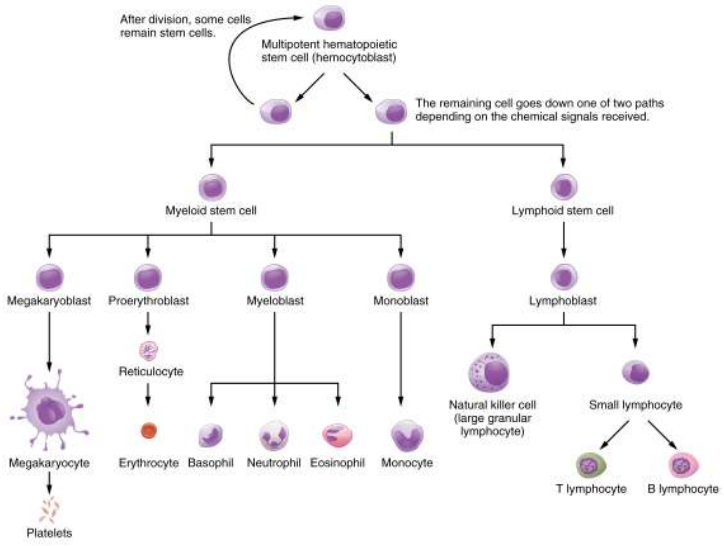


Figure 9.3.1: Hematopoietic System of Bone Marrow Hemopoiesis is the proliferation and differentiation of the formed elements of blood.

Lymphoid and myeloid stem cells do not immediately divide and differentiate into mature formed elements. As you can see in Figure 18.4, there are several intermediate stages of precursor cells (literally, forerunner cells), many of which can be recognized by their names, which have the suffix -blast. For instance, megakaryoblasts are the precursors of megakaryocytes, and proerythroblasts become reticulocytes, which eject their nucleus and most other organelles before maturing into erythrocytes.

Hemopoietic Growth Factors

Development from stem cells to precursor cells to mature cells is again initiated by hemopoietic growth factors. These include the following:

- Erythropoietin (EPO) is a glycoprotein hormone secreted by the interstitial fibroblast cells of the kidneys in response to low oxygen levels. It prompts the production of erythrocytes. Some athletes use synthetic EPO as a performance-enhancing drug (called blood doping) to increase RBC counts and subsequently increase oxygen delivery to tissues throughout the body. EPO is a banned substance in most organized sports, but it is also used medically in the treatment of certain anemia, specifically those triggered by certain types of cancer, and other disorders in which increased erythrocyte counts and oxygen levels are desirable.
- Thrombopoietin, another glycoprotein hormone, is produced by the liver and kidneys. It triggers the development of megakaryocytes into platelets.
- Cytokines are glycoproteins secreted by a wide variety of cells, including red bone marrow, leukocytes, macrophages, fibroblasts, and endothelial cells. They act locally as autocrine or paracrine factors, stimulating the proliferation of progenitor cells and helping to stimulate both nonspecific and specific resistance to disease. There are two major subtypes of cytokines known as colony-stimulating factors and interleukins.
    - Colony-stimulating factors (CSFs) are glycoproteins that act locally, as autocrine or paracrine factors. Some trigger the differentiation of myeloblasts into granular leukocytes, namely, neutrophils, eosinophils, and basophils. These are referred to as granulocyte CSFs. A different CSF induces the production of monocytes, called monocyte CSFs. Both granulocytes and monocytes are stimulated by GM-CSF; granulocytes, monocytes, platelets, and erythrocytes are stimulated by multi-CSF. Synthetic forms of these hormones are often administered to patients with various forms of cancer who are receiving chemotherapy to revive their WBC counts.
    - Interleukins are another class of cytokine signaling molecules important in hemopoiesis. They were initially thought to be secreted uniquely by leukocytes and to communicate only with other leukocytes, and were named accordingly, but are now known to be produced by a variety of cells including bone marrow and endothelium. Researchers now suspect that interleukins may play other roles in body functioning, including differentiation and maturation of cells, producing immunity and inflammation. To date, more than a dozen interleukins have been identified, with others likely to follow. They are generally numbered IL-1, IL-2, IL-3, etc.

Everyday Connection

Blood Doping

In its original intent, the term blood doping was used to describe the practice of injecting by transfusion supplemental RBCs into an individual, typically to enhance performance in a sport. Additional RBCs would deliver more oxygen to the tissues, providing extra aerobic capacity, clinically referred to as VO_2 max. The source of the cells was either from the recipient (autologous) or from a donor with compatible blood (homologous). This practice was aided by the well-developed techniques of harvesting, concentrating, and freezing of the RBCs that could be later thawed and injected, yet still retain their functionality. These practices are considered illegal in virtually all sports and run the risk of infection, significantly increasing the viscosity of the blood and the potential for transmission of blood-borne pathogens if the blood was collected from another individual.

With the development of synthetic EPO in the 1980s, it became possible to provide additional RBCs by artificially stimulating RBC production in the bone marrow. Originally developed to treat patients suffering from anemia, renal failure, or cancer treatment, large quantities of EPO can be generated by recombinant DNA technology. Synthetic EPO is injected under the skin and can increase hematocrit for many weeks. It may also induce polycythemia and raise hematocrit to 70 or greater. This increased viscosity raises the resistance of the blood and forces the heart to pump more powerfully; in extreme cases, it has resulted in death. Other drugs such as cobalt II chloride have been shown to increase natural EPO gene expression. Blood doping has become problematic in many sports, especially cycling. Lance Armstrong, winner of seven Tour de France and many other cycling titles, was stripped of his victories and admitted to blood doping in 2013.

Interactive Link



Watch this video to see doctors discuss the dangers of blood doping in sports. What are the some potential side effects of blood doping?

Bone Marrow Sampling and Transplants

Sometimes, a healthcare provider will order a bone marrow biopsy, a diagnostic test of a sample of red bone marrow, or a bone marrow transplant, a treatment in which a donor's healthy bone marrow—and its stem cells—replaces the faulty bone marrow of a patient. These tests and procedures are often used to assist in the diagnosis and treatment of various severe forms of anemia, such as thalassemia major and sickle cell anemia, as well as some types of cancer, specifically leukemia.

In the past, when a bone marrow sample or transplant was necessary, the procedure would have required inserting a large-bore needle into the region near the iliac crest of the pelvic bones (os coxae). This location was preferred, since its location close to the body surface makes it more accessible, and it is relatively isolated from most vital organs. Unfortunately, the procedure is quite painful.

Now, direct sampling of bone marrow can often be avoided. In many cases, stem cells can be isolated in just a few hours from a sample of a patient's blood. The isolated stem cells are then grown in culture using the appropriate hemopoietic growth factors, and analyzed or sometimes frozen for later use.

For an individual requiring a transplant, a matching donor is essential to prevent the immune system from destroying the donor cells—a phenomenon known as tissue rejection. To treat patients with bone marrow transplants, it is first necessary to destroy the patient's own diseased marrow through radiation and/or chemotherapy. Donor bone marrow stem cells are then intravenously infused. From the bloodstream, they establish themselves in the recipient's bone marrow.

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9.4: Erythrocytes

Learning Objectives

By the end of this section, you will be able to:

- Describe the anatomy of erythrocytes
- Discuss the various steps in the lifecycle of an erythrocyte
- Explain the composition and function of hemoglobin

The erythrocyte, commonly known as a red blood cell (or RBC), is by far the most common formed element: A single drop of blood contains millions of erythrocytes and just thousands of leukocytes. Specifically, males have about 5.4 million erythrocytes per microliter (μL) of blood, and females have approximately 4.8 million per μL. In fact, erythrocytes are estimated to make up about 25 percent of the total cells in the body. As you can imagine, they are quite small cells, with a mean diameter of only about 7–8 micrometers (μm) (Figure 9.4.1). The primary functions of erythrocytes are to pick up inhaled oxygen from the lungs and transport it to the body's tissues, and to pick up some (about 24 percent) carbon dioxide waste at the tissues and transport it to the lungs for exhalation. Erythrocytes remain within the vascular network. Although leukocytes typically leave the blood vessels to perform their defensive functions, movement of erythrocytes from the blood vessels is abnormal.

Formed element	Major subtypes	Numbers present per microliter (μL) and mean (range)	Appearance in a standard blood smear	Summary of functions	Comments
Erythrocytes (red blood cells)		5.2 million (4.4–6.0 million)	Flattened biconcave disk; no nucleus; pale red color	Transport oxygen and some carbon dioxide between tissues and lungs	Lifespan of approximately 120 days
Leukocytes (white blood cells)		7000 (5000–10,000)	Obvious dark-staining nucleus	All function in body defenses	Exit capillaries and move into tissues; lifespan of usually a few hours or days
	Granulocytes including neutrophils, eosinophils, and basophils	4360 (1800–9950)	Abundant granules in cytoplasm; nucleus normally lobed	Nonspecific (innate) resistance to disease	Classified according to membrane-bound granules in cytoplasm
	Neutrophils	4150 (1800–7300)	Nuclear lobes increase with age; pale lilac granules	Phagocytic; particularly effective against bacteria. Release cytotoxic chemicals from granules	Most common leukocyte; lifespan of minutes to days
	Eosinophils	165 (0–700)	Nucleus generally two-lobed; bright red-orange granules	Phagocytic cells; particularly effective with antigen- antibody complexes. Release antihistamines. Increase in allergies and parasitic infections	Lifespan of minutes to days
	Basophils	44 (0–150)	Nucleus generally two-lobed but difficult to see due to presence of heavy, dense, dark purple granules	Promotes inflammation	Least common leukocyte; lifespan unknown
	Agranulocytes including lymphocytes and monocytes	2640 (1700–4950)	Lack abundant granules in cytoplasm; have a simple-shaped nucleus that may be indented	Body defenses	Group consists of two major cell types from different lineages
	Lymphocytes	2185 (1500–4000)	Spherical cells with a single often large nucleus occupying much of the cell's volume; stains purple; seen in large (natural killer cells) and small (B and T cells) variants	Primarily specific (adaptive) immunity: T cells directly attack other cells (cellular immunity); B cells release antibodies (humoral immunity); natural killer cells are similar to T cells but nonspecific	Initial cells originate in bone marrow, but secondary production occurs in lymphatic tissue; several distinct subtypes; memory cells form after exposure to a pathogen and rapidly increase responses to subsequent exposure; lifespan of many years
	Monocytes	455 (200–950)	Largest leukocyte with an indented or horseshoe-shaped nucleus	Very effective phagocytic cells engulfing pathogens or worn out cells; also serve as antigen-presenting cells (APCs) for other components of the immune system	Produced in red bone marrow; referred to as macrophages after leaving circulation
Platelets		350,000 (150,000–500,000)	Cellular fragments surrounded by a plasma membrane and containing granules; purple stain	Hemostasis plus release growth factors for repair and healing of tissue	Formed from megakaryocytes that remain in the red bone marrow and shed platelets into circulation

Figure 9.4.1:Summary of Formed Elements in Blood

Shape and Structure of Erythrocytes

As an erythrocyte matures in the red bone marrow, it extrudes its nucleus and most of its other organelles. During the first day or two that it is in the circulation, an immature erythrocyte, known as a reticulocyte, will still typically contain remnants of organelles. Reticulocytes should comprise approximately 1–2 percent of the erythrocyte count and provide a rough estimate of the rate of RBC production, with abnormally low or high rates indicating deviations in the production of these cells. These remnants, primarily of networks (reticulum) of ribosomes, are quickly shed, however, and mature, circulating erythrocytes have few internal cellular structural components. Lacking mitochondria, for example, they rely on anaerobic respiration. This means that they do not utilize any of the oxygen they are transporting, so they can deliver it all to the tissues. They also lack endoplasmic reticula and do not synthesize proteins. Erythrocytes do, however, contain some structural proteins that help the blood cells maintain their unique structure and enable them to change their shape to squeeze through capillaries. This includes the protein spectrin, a cytoskeletal protein element.

Erythrocytes are biconcave disks; that is, they are plump at their periphery and very thin in the center (Figure 9.4.2). Since they lack most organelles, there is more interior space for the presence of the hemoglobin molecules that, as you will see shortly, transport gases. The biconcave shape also provides a greater surface area across which gas exchange can occur, relative to its volume; a sphere of a similar diameter would have a lower surface area-to-volume ratio. In the capillaries, the oxygen carried by the erythrocytes can diffuse into the plasma and then through the capillary walls to reach the cells, whereas some of the carbon dioxide produced by the cells as a waste product diffuses into the capillaries to be picked up by the erythrocytes. Capillary beds are extremely narrow, slowing the passage of the erythrocytes and providing an extended opportunity for gas exchange to occur. However, the space within capillaries can be so minute that, despite their own small size, erythrocytes may have to fold in on themselves if they are to make their way through. Fortunately, their structural proteins like spectrin are flexible, allowing them to bend over themselves to a surprising degree, then spring back again when they enter a wider vessel. In wider vessels, erythrocytes may stack up much like a roll of coins, forming a rouleaux, from the French word for “roll.”



Figure 9.4.2: Shape of Red Blood Cells Erythrocytes are biconcave discs with very shallow centers. This shape optimizes the ratio of surface area to volume, facilitating gas exchange. It also enables them to fold up as they move through narrow blood vessels.

Hemoglobin

Hemoglobin is a large molecule made up of proteins and iron. It consists of four folded chains of a protein called globin, designated alpha 1 and 2, and beta 1 and 2 (Figure 9.4.3**a**). Each of these globin molecules is bound to a red pigment molecule called heme, which contains an ion of iron (Fe^{2+}) (Figure 9.4.3**b**).

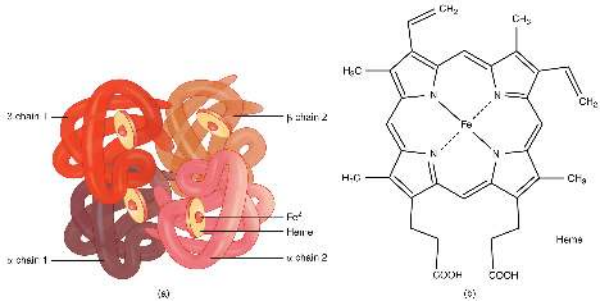


Figure 9.4.3: Hemoglobin (a) A molecule of hemoglobin contains four globin proteins, each of which is bound to one molecule of the iron-containing pigment heme. (b) A single erythrocyte can contain 300 million hemoglobin molecules, and thus more than 1 billion oxygen molecules.

Each iron ion in the heme can bind to one oxygen molecule; therefore, each hemoglobin molecule can transport four oxygen molecules. An individual erythrocyte may contain about 300 million hemoglobin molecules, and therefore can bind to and transport up to 1.2 billion oxygen molecules (see Figure 18.7**b**).

In the lungs, hemoglobin picks up oxygen, which binds to the iron ions, forming oxyhemoglobin. The bright red, oxygenated hemoglobin travels to the body tissues, where it releases some of the oxygen molecules, becoming darker red deoxyhemoglobin, sometimes referred to as reduced hemoglobin. Oxygen release depends on the need for oxygen in the surrounding tissues, so hemoglobin rarely if ever leaves all of its oxygen behind. In the capillaries, carbon dioxide enters the bloodstream. About 76 percent dissolves in the plasma, some of it remaining as dissolved CO_2, and the remainder forming bicarbonate ion. About 23–24 percent of it binds to the amino acids in hemoglobin, forming a molecule known as carbaminohemoglobin. From the capillaries, the hemoglobin carries carbon dioxide back to the lungs, where it releases it for exchange of oxygen.

Changes in the levels of RBCs can have significant effects on the body's ability to effectively deliver oxygen to the tissues. Ineffective hematopoiesis results in insufficient numbers of RBCs and results in one of several forms of anemia. An overproduction of RBCs produces a condition called polycythemia. The primary drawback with polycythemia is not a failure to directly deliver enough oxygen to the tissues, but rather the increased viscosity of the blood, which makes it more difficult for the heart to circulate the blood.

In patients with insufficient hemoglobin, the tissues may not receive sufficient oxygen, resulting in another form of anemia. In determining oxygenation of tissues, the value of greatest interest in healthcare is the percent saturation; that is, the percentage of hemoglobin sites occupied by oxygen in a patient's blood. Clinically this value is commonly referred to simply as "percent sat."

Percent saturation is normally monitored using a device known as a pulse oximeter, which is applied to a thin part of the body, typically the tip of the patient's finger. The device works by sending two different wavelengths of light (one red, the other infrared) through the finger and measuring the light with a photodetector as it exits. Hemoglobin absorbs light differentially depending upon its saturation with oxygen. The machine calibrates the amount of light received by the photodetector against the amount absorbed by the partially oxygenated hemoglobin and presents the data as percent saturation. Normal pulse oximeter readings range from 95–100 percent. Lower percentages reflect hypoxemia, or low blood oxygen. The term hypoxia is more generic and simply refers to low oxygen levels. Oxygen levels are also directly monitored from free oxygen in the plasma typically following an arterial stick. When this method is applied, the amount of oxygen present is expressed in terms of partial pressure of oxygen or simply P_{O2} or PO2 and is typically recorded in units of millimeters of mercury, mm Hg.

The kidneys filter about 180 liters (~380 pints) of blood in an average adult each day, or about 20 percent of the total resting volume, and thus serve as ideal sites for receptors that determine oxygen saturation. In response to hypoxemia, less oxygen will exit the vessels supplying the kidney, resulting in hypoxia (low oxygen concentration) in the tissue fluid of the kidney where oxygen concentration is actually monitored. Interstitial fibroblasts within the kidney secrete EPO, thereby increasing erythrocyte production and restoring oxygen levels. In a classic negative-feedback loop, as oxygen saturation rises, EPO secretion falls, and vice versa, thereby maintaining homeostasis. Populations dwelling at high elevations, with inherently lower levels of oxygen in the atmosphere, naturally maintain a hematocrit higher than people living at sea level. Consequently, people traveling to high elevations may experience symptoms of hypoxemia, such as fatigue, headache, and shortness of breath, for a few days after their arrival. In response to the hypoxemia, the kidneys secrete EPO to step up the production of erythrocytes until homeostasis is

achieved once again. To avoid the symptoms of hypoxemia, or altitude sickness, mountain climbers typically rest for several days to a week or more at a series of camps situated at increasing elevations to allow EPO levels and, consequently, erythrocyte counts to rise. When climbing the tallest peaks, such as Mt. Everest and K2 in the Himalayas, many mountain climbers rely upon bottled oxygen as they near the summit.

Lifecycle of Erythrocytes

Production of erythrocytes in the marrow occurs at the staggering rate of more than 2 million cells per second. For this production to occur, a number of raw materials must be present in adequate amounts. These include the same nutrients that are essential to the production and maintenance of any cell, such as glucose, lipids, and amino acids. However, erythrocyte production also requires several trace elements:

- Iron. We have said that each heme group in a hemoglobin molecule contains an ion of the trace mineral iron. On average, less than 20 percent of the iron we consume is absorbed. Heme iron, from animal foods such as meat, poultry, and fish, is absorbed more efficiently than non-heme iron from plant foods. Upon absorption, iron becomes part of the body's total iron pool. The bone marrow, liver, and spleen can store iron in the protein compounds ferritin and hemosiderin. Ferroportin transports the iron across the intestinal cell plasma membranes and from its storage sites into tissue fluid where it enters the blood. When EPO stimulates the production of erythrocytes, iron is released from storage, bound to transferrin, and carried to the red marrow where it attaches to erythrocyte precursors.
- Copper. A trace mineral, copper is a component of two plasma proteins, hephaestin and ceruloplasmin. Without these, hemoglobin could not be adequately produced. Located in intestinal villi, hephaestin enables iron to be absorbed by intestinal cells. Ceruloplasmin transports copper. Both enable the oxidation of iron from Fe^{2+} to Fe^{3+}, a form in which it can be bound to its transport protein, transferrin, for transport to body cells. In a state of copper deficiency, the transport of iron for heme synthesis decreases, and iron can accumulate in tissues, where it can eventually lead to organ damage.
- Zinc. The trace mineral zinc functions as a co-enzyme that facilitates the synthesis of the heme portion of hemoglobin.
- Erythrocytes live up to 120 days in the circulation, after which the worn-out cells are removed by a type of myeloid phagocytic cell called a macrophage, located primarily within the bone marrow, liver, and spleen. The components of the degraded erythrocytes' hemoglobin are further processed as follows:
  - Globin, the protein portion of hemoglobin, is broken down into amino acids, which can be sent back to the bone marrow to be used in the production of new erythrocytes. Hemoglobin that is not phagocytized is broken down in the circulation, releasing alpha and beta chains that are removed from circulation by the kidneys.
  - The iron contained in the heme portion of hemoglobin may be stored in the liver or spleen, primarily in the form of ferritin or hemosiderin, or carried through the bloodstream by transferrin to the red bone marrow for recycling into new erythrocytes.
  - The breakdown pigments formed from the destruction of hemoglobin can be seen in a variety of situations. At the site of an injury, biliverdin from damaged RBCs produces some of the dramatic colors associated with a bruise. With a failing liver, bilirubin cannot be removed effectively from circulation and causes the body to assume a yellowish tinge associated with jaundice. Stercobilins within the feces produce the typical brown color associated with this waste. And the yellow of urine is associated with the urobilins.

    The erythrocyte lifecycle is summarized in Figure 9.4.4.

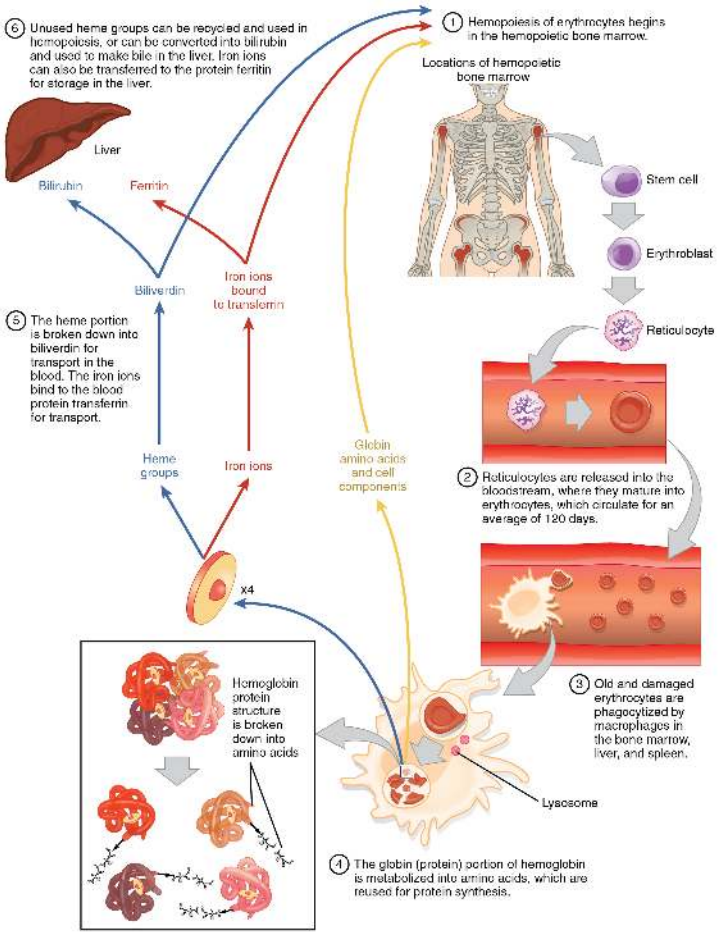


Figure 9.4.4 Erythrocyte Lifecycle Erythrocytes are produced in the bone marrow and sent into the circulation. At the end of their lifecycle, they are destroyed by macrophages, and their components are recycled.

Disorders of Erythrocytes

The size, shape, and number of erythrocytes, and the number of hemoglobin molecules can have a major impact on a person's health. When the number of RBCs or hemoglobin is deficient, the general condition is called anemia. There are more than 400 types of anemia and more than 3.5 million Americans suffer from this condition. Anemia can be broken down into three major groups: those caused by blood loss, those caused by faulty or decreased RBC production, and those caused by excessive destruction of RBCs. Clinicians often use two groupings in diagnosis: The kinetic approach focuses on evaluating the production, destruction, and removal of RBCs, whereas the morphological approach examines the RBCs themselves, paying particular emphasis to their size. A common test is the mean corpuscle volume (MCV), which measures size. Normal-sized cells are referred to as normocytic, smaller-than-normal cells are referred to as microcytic, and larger-than-normal cells are referred to as macrocytic. Reticulocyte counts are also important and may reveal inadequate production of RBCs. The effects of the various anemias are widespread, because reduced numbers of RBCs or hemoglobin will result in lower levels of oxygen being delivered to body tissues. Since oxygen is required for tissue functioning, anemia produces fatigue, lethargy, and an increased risk for infection. An oxygen deficit in the brain impairs the ability to think clearly, and may prompt headaches and irritability. Lack of oxygen leaves the patient short of breath, even as the heart and lungs work harder in response to the deficit.

Blood loss anemias are fairly straightforward. In addition to bleeding from wounds or other lesions, these forms of anemia may be due to ulcers, hemorrhoids, inflammation of the stomach (gastritis), and some cancers of the gastrointestinal tract. The excessive use of aspirin or other nonsteroidal anti-inflammatory drugs such as ibuprofen can trigger ulceration and gastritis. Excessive menstruation and loss of blood during childbirth are also potential causes.

Anemias caused by faulty or decreased RBC production include sickle cell anemia, iron deficiency anemia, vitamin deficiency anemia, and diseases of the bone marrow and stem cells.

- A characteristic change in the shape of erythrocytes is seen in sickle cell disease (also referred to as sickle cell anemia). A genetic disorder, it is caused by production of an abnormal type of hemoglobin, called hemoglobin S, which delivers less oxygen to tissues and causes erythrocytes to assume a sickle (or crescent) shape, especially at low oxygen concentrations (Figure 9.4.5). These abnormally shaped cells can then become lodged in narrow capillaries because they are unable to fold in on themselves to squeeze through, blocking blood flow to tissues and causing a variety of serious problems from painful joints to delayed growth and even blindness and cerebrovascular accidents (strokes). Sickle cell anemia is a genetic condition particularly found in individuals of African descent.



Figure 9.4.5 Sickle Cells Sickle cell anemia is caused by a mutation in one of the hemoglobin genes. Erythrocytes produce an abnormal type of hemoglobin, which causes the cell to take on a sickle or crescent shape. (credit: Janice Haney Carr)

- Iron deficiency anemia is the most common type and results when the amount of available iron is insufficient to allow production of sufficient heme. This condition can occur in individuals with a deficiency of iron in the diet and is especially common in teens and children as well as in vegans and vegetarians. Additionally, iron deficiency anemia may be caused by either an inability to absorb and transport iron or slow, chronic bleeding.
- Vitamin-deficient anemias generally involve insufficient vitamin B12 and folate.
  - Megaloblastic anemia involves a deficiency of vitamin B12 and/or folate, and often involves diets deficient in these essential nutrients. Lack of meat or a viable alternate source, and overcooking or eating insufficient amounts of vegetables may lead to a lack of folate.
  - Pernicious anemia is caused by poor absorption of vitamin B12 and is often seen in patients with Crohn's disease (a severe intestinal disorder often treated by surgery), surgical removal of the intestines or stomach (common in some weight loss surgeries), intestinal parasites, and AIDS.
  - Pregnancies, some medications, excessive alcohol consumption, and some diseases such as celiac disease are also associated with vitamin deficiencies. It is essential to provide sufficient folic acid during the early stages of pregnancy to reduce the risk of neurological defects, including spina bifida, a failure of the neural tube to close.
- Assorted disease processes can also interfere with the production and formation of RBCs and hemoglobin. If myeloid stem cells are defective or replaced by cancer cells, there will be insufficient quantities of RBCs produced.
  - Aplastic anemia is the condition in which there are deficient numbers of RBC stem cells. Aplastic anemia is often inherited, or it may be triggered by radiation, medication, chemotherapy, or infection.
  - Thalassemia is an inherited condition typically occurring in individuals from the Middle East, the Mediterranean, African, and Southeast Asia, in which maturation of the RBCs does not proceed normally. The most severe form is called Cooley's anemia.
  - Lead exposure from industrial sources or even dust from paint chips of iron-containing paints or pottery that has not been properly glazed may also lead to destruction of the red marrow.
- Various disease processes also can lead to anemias. These include chronic kidney diseases often associated with a decreased production of EPO, hypothyroidism, some forms of cancer, lupus, and rheumatoid arthritis.

In contrast to anemia, an elevated RBC count is called polycythemia and is detected in a patient's elevated hematocrit. It can occur transiently in a person who is dehydrated; when water intake is inadequate or water losses are excessive, the plasma volume falls. As a result, the hematocrit rises. For reasons mentioned earlier, a mild form of polycythemia is chronic but normal in people living at high altitudes. Some elite athletes train at high elevations specifically to induce this phenomenon. Finally, a type of bone marrow disease called polycythemia vera (from the Greek vera = "true") causes an excessive production of immature erythrocytes. Polycythemia vera can dangerously elevate the viscosity of blood, raising blood pressure and making it more difficult for the heart to pump blood throughout the body. It is a relatively rare disease that occurs more often in males than in females, and is more likely to be present in elderly patients those over 60 years of age.

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9.5: Leukocytes and Platelets

Learning Objectives

By the end of this section, you will be able to:

- Describe the general characteristics of leukocytes
- Classify leukocytes according to their lineage, their main structural features, and their primary functions
- Discuss the most common malignancies involving leukocytes
- Identify the lineage, basic structure, and function of platelets

The leukocyte, commonly known as a white blood cell (or WBC), is a major component of the body's defenses against disease. Leukocytes protect the body against invading microorganisms and body cells with mutated DNA, and they clean up debris. Platelets are essential for the repair of blood vessels when damage to them has occurred; they also provide growth factors for healing and repair.

Characteristics of Leukocytes

Although leukocytes and erythrocytes both originate from hematopoietic stem cells in the bone marrow, they are very different from each other in many significant ways. For instance, leukocytes are far less numerous than erythrocytes: Typically there are only 5000 to 10,000 per μL. They are also larger than erythrocytes and are the only formed elements that are complete cells, possessing a nucleus and organelles. And although there is just one type of erythrocyte, there are many types of leukocytes. Most of these types have a much shorter lifespan than that of erythrocytes, some as short as a few hours or even a few minutes in the case of acute infection.

One of the most distinctive characteristics of leukocytes is their movement. Whereas erythrocytes spend their days circulating within the blood vessels, leukocytes routinely leave the bloodstream to perform their defensive functions in the body's tissues. For leukocytes, the vascular network is simply a highway they travel and soon exit to reach their true destination. When they arrive, they are often given distinct names, such as macrophage or microglia, depending on their function. As shown in Figure 18.10, they leave the capillaries—the smallest blood vessels—or other small vessels through a process known as emigration (from the Latin for "removal") or diapedesis (dia- = "through"; -pedan = "to leap") in which they squeeze through adjacent cells in a blood vessel wall.

Once they have exited the capillaries, some leukocytes will take up fixed positions in lymphatic tissue, bone marrow, the spleen, the thymus, or other organs. Others will move about through the tissue spaces very much like amoebas, continuously extending their plasma membranes, sometimes wandering freely, and sometimes moving toward the direction in which they are drawn by chemical signals. This attracting of leukocytes occurs because of positive chemotaxis (literally "movement in response to chemicals"), a phenomenon in which injured or infected cells and nearby leukocytes emit the equivalent of a chemical "911" call, attracting more leukocytes to the site. In clinical medicine, the differential counts of the types and percentages of leukocytes present are often key indicators in making a diagnosis and selecting a treatment.

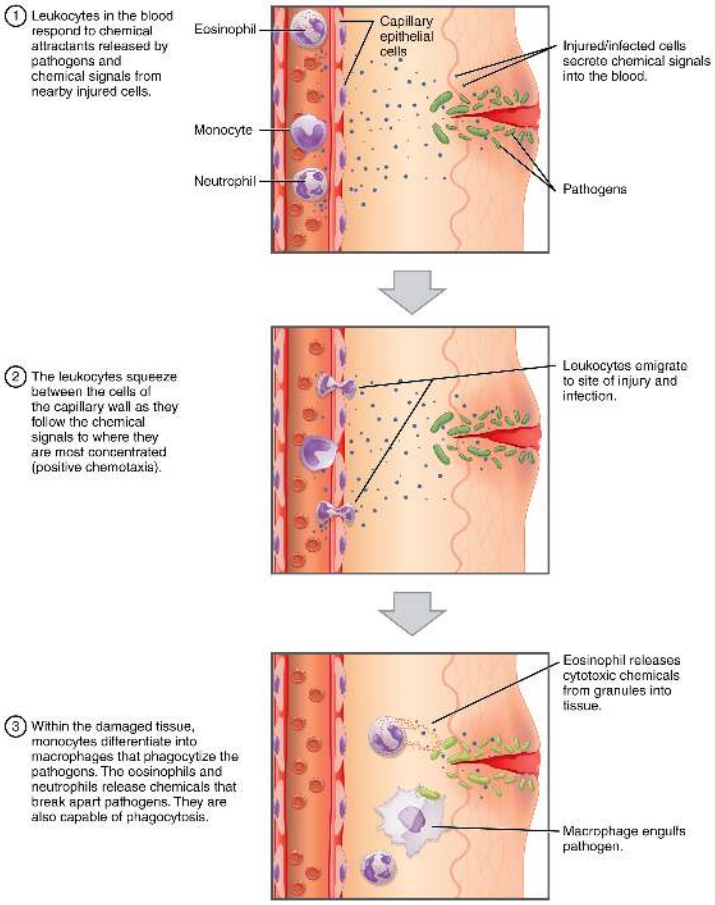


Figure 9.5.1: Emigration Leukocytes exit the blood vessel and then move through the connective tissue of the dermis toward the site of a wound. Some leukocytes, such as the eosinophil and neutrophil, are characterized as granular leukocytes. They release chemicals from their granules that destroy pathogens; they are also capable of phagocytosis. The monocyte, an agranular leukocyte, differentiates into a macrophage that then phagocytizes the pathogens.

Classification of Leukocytes

When scientists first began to observe stained blood slides, it quickly became evident that leukocytes could be divided into two groups, according to whether their cytoplasm contained highly visible granules:

- Granular leukocytes contain abundant granules within the cytoplasm. They include neutrophils, eosinophils, and basophils (you can view their lineage from myeloid stem cells in Figure 9.5.2).
- While granules are not totally lacking in agranular leukocytes, they are far fewer and less obvious. Agranular leukocytes include monocytes, which mature into macrophages that are phagocytic, and lymphocytes, which arise from the lymphoid stem cell line.

Granular Leukocytes

We will consider the granular leukocytes in order from most common to least common. All of these are produced in the red bone marrow and have a short lifespan of hours to days. They typically have a lobed nucleus and are classified according to which type of stain best highlights their granules (Figure 18.11).



Figure 9.5.2: Granular Leukocytes A neutrophil has small granules that stain light lilac and a nucleus with two to five lobes. An eosinophil's granules are slightly larger and stain reddish-orange, and its nucleus has two to three lobes. A basophil has large

granules that stain dark blue to purple and a two-lobed nucleus.

The most common of all the leukocytes, neutrophils will normally comprise 50–70 percent of total leukocyte count. They are 10–12 μm in diameter, significantly larger than erythrocytes. They are called neutrophils because their granules show up most clearly with stains that are chemically neutral (neither acidic nor basic). The granules are numerous but quite fine and normally appear light lilac. The nucleus has a distinct lobed appearance and may have two to five lobes, the number increasing with the age of the cell. Older neutrophils have increasing numbers of lobes and are often referred to as polymorphonuclear (a nucleus with many forms), or simply "polys." Younger and immature neutrophils begin to develop lobes and are known as "bands."

Neutrophils are rapid responders to the site of infection and are efficient phagocytes with a preference for bacteria. Their granules include lysozyme, an enzyme capable of lysing, or breaking down, bacterial cell walls; oxidants such as hydrogen peroxide; and defensins, proteins that bind to and puncture bacterial and fungal plasma membranes, so that the cell contents leak out. Abnormally high counts of neutrophils indicate infection and/or inflammation, particularly triggered by bacteria, but are also found in burn patients and others experiencing unusual stress. A burn injury increases the proliferation of neutrophils in order to fight off infection that can result from the destruction of the barrier of the skin. Low counts may be caused by drug toxicity and other disorders, and may increase an individual's susceptibility to infection.

Eosinophils typically represent 2–4 percent of total leukocyte count. They are also 10–12 μm in diameter. The granules of eosinophils stain best with an acidic stain known as eosin. The nucleus of the eosinophil will typically have two to three lobes and, if stained properly, the granules will have a distinct red to orange color.

The granules of eosinophils include antihistamine molecules, which counteract the activities of histamines, inflammatory chemicals produced by basophils and mast cells. Some eosinophil granules contain molecules toxic to parasitic worms, which can enter the body through the integument, or when an individual consumes raw or undercooked fish or meat. Eosinophils are also capable of phagocytosis and are particularly effective when antibodies bind to the target and form an antigen-antibody complex. High counts of eosinophils are typical of patients experiencing allergies, parasitic worm infestations, and some autoimmune diseases. Low counts may be due to drug toxicity and stress.

Basophils are the least common leukocytes, typically comprising less than one percent of the total leukocyte count. They are slightly smaller than neutrophils and eosinophils at 8–10 μm in diameter. The granules of basophils stain best with basic (alkaline) stains. Basophils contain large granules that pick up a dark blue stain and are so common they may make it difficult to see the two-lobed nucleus.

In general, basophils intensify the inflammatory response. They share this trait with mast cells. In the past, mast cells were considered to be basophils that left the circulation. However, this appears not to be the case, as the two cell types develop from different lineages.

The granules of basophils release histamines, which contribute to inflammation, and heparin, which opposes blood clotting. High counts of basophils are associated with allergies, parasitic infections, and hypothyroidism. Low counts are associated with pregnancy, stress, and hyperthyroidism.

Agranular Leukocytes

Agranular leukocytes contain smaller, less-visible granules in their cytoplasm than do granular leukocytes. The nucleus is simple in shape, sometimes with an indentation but without distinct lobes. There are two major types of agranulocytes: lymphocytes and monocytes (see Figure 18.4).

Lymphocytes are the only formed element of blood that arises from lymphoid stem cells. Although they form initially in the bone marrow, much of their subsequent development and reproduction occurs in the lymphatic tissues. Lymphocytes are the second most common type of leukocyte, accounting for about 20–30 percent of all leukocytes, and are essential for the immune response. The size range of lymphocytes is quite extensive, with some authorities recognizing two size classes and others three. Typically, the large cells are 10–14 μm and have a smaller nucleus-to-cytoplasm ratio and more granules. The smaller cells are typically 6–9 μm with a larger volume of nucleus to cytoplasm, creating a "halo" effect. A few cells may fall outside these ranges, at 14–17 μm. This finding has led to the three size range classification.

The three major groups of lymphocytes include natural killer cells, B cells, and T cells. Natural killer (NK) cells are capable of recognizing cells that do not express "self" proteins on their plasma membrane or that contain foreign or abnormal markers. These

"nonself" cells include cancer cells, cells infected with a virus, and other cells with atypical surface proteins. Thus, they provide generalized, nonspecific immunity. The larger lymphocytes are typically NK cells.

B cells and T cells, also called B lymphocytes and T lymphocytes, play prominent roles in defending the body against specific pathogens (disease-causing microorganisms) and are involved in specific immunity. One form of B cells (plasma cells) produces the antibodies or immunoglobulins that bind to specific foreign or abnormal components of plasma membranes. This is also referred to as humoral (body fluid) immunity. T cells provide cellular-level immunity by physically attacking foreign or diseased cells. A memory cell is a variety of both B and T cells that forms after exposure to a pathogen and mounts rapid responses upon subsequent exposures. Unlike other leukocytes, memory cells live for many years. B cells undergo a maturation process in the bone marrow, whereas T cells undergo maturation in the thymus. This site of the maturation process gives rise to the name B and T cells. The functions of lymphocytes are complex and will be covered in detail in the chapter covering the lymphatic system and immunity. Smaller lymphocytes are either B or T cells, although they cannot be differentiated in a normal blood smear.

Abnormally high lymphocyte counts are characteristic of viral infections as well as some types of cancer. Abnormally low lymphocyte counts are characteristic of prolonged (chronic) illness or immunosuppression, including that caused by HIV infection and drug therapies that often involve steroids.

Monocytes originate from myeloid stem cells. They normally represent 2–8 percent of the total leukocyte count. They are typically easily recognized by their large size of 12–20 μm and indented or horseshoe-shaped nuclei. Macrophages are monocytes that have left the circulation and phagocytize debris, foreign pathogens, worn-out erythrocytes, and many other dead, worn out, or damaged cells. Macrophages also release antimicrobial defensins and chemotactic chemicals that attract other leukocytes to the site of an infection. Some macrophages occupy fixed locations, whereas others wander through the tissue fluid.

Abnormally high counts of monocytes are associated with viral or fungal infections, tuberculosis, and some forms of leukemia and other chronic diseases. Abnormally low counts are typically caused by suppression of the bone marrow.

Lifecycle of Leukocytes

Most leukocytes have a relatively short lifespan, typically measured in hours or days. Production of all leukocytes begins in the bone marrow under the influence of CSFs and interleukins. Secondary production and maturation of lymphocytes occurs in specific regions of lymphatic tissue known as germinal centers. Lymphocytes are fully capable of mitosis and may produce clones of cells with identical properties. This capacity enables an individual to maintain immunity throughout life to many threats that have been encountered in the past.

Disorders of Leukocytes

Leukopenia is a condition in which too few leukocytes are produced. If this condition is pronounced, the individual may be unable to ward off disease. Excessive leukocyte proliferation is known as leukocytosis. Although leukocyte counts are high, the cells themselves are often nonfunctional, leaving the individual at increased risk for disease.

Leukemia is a cancer involving an abundance of leukocytes. It may involve only one specific type of leukocyte from either the myeloid line (myelocytic leukemia) or the lymphoid line (lymphocytic leukemia). In chronic leukemia, mature leukocytes accumulate and fail to die. In acute leukemia, there is an overproduction of young, immature leukocytes. In both conditions the cells do not function properly.

Lymphoma is a form of cancer in which masses of malignant T and/or B lymphocytes collect in lymph nodes, the spleen, the liver, and other tissues. As in leukemia, the malignant leukocytes do not function properly, and the patient is vulnerable to infection. Some forms of lymphoma tend to progress slowly and respond well to treatment. Others tend to progress quickly and require aggressive treatment, without which they are rapidly fatal.

Platelets

You may occasionally see platelets referred to as thrombocytes, but because this name suggests they are a type of cell, it is not accurate. A platelet is not a cell but rather a fragment of the cytoplasm of a cell called a megakaryocyte that is surrounded by a plasma membrane. Megakaryocytes are descended from myeloid stem cells (see Figure 18.4) and are large, typically 50–100 μm in diameter, and contain an enlarged, lobed nucleus. As noted earlier, thrombopoietin, a glycoprotein secreted by the kidneys and liver, stimulates the proliferation of megakaryoblasts, which mature into megakaryocytes. These remain within bone marrow tissue

(Figure 9.5.3) and ultimately form platelet-precursor extensions that extend through the walls of bone marrow capillaries to release into the circulation thousands of cytoplasmic fragments, each enclosed by a bit of plasma membrane. These enclosed fragments are platelets. Each megakarocyte releases 2000–3000 platelets during its lifespan. Following platelet release, megakaryocyte remnants, which are little more than a cell nucleus, are consumed by macrophages.

Platelets are relatively small, 2–4 μm in diameter, but numerous, with typically 150,000–160,000 per μL of blood. After entering the circulation, approximately one-third migrate to the spleen for storage for later release in response to any rupture in a blood vessel. They then become activated to perform their primary function, which is to limit blood loss. Platelets remain only about 10 days, then are phagocytized by macrophages.

Platelets are critical to hemostasis, the stoppage of blood flow following damage to a vessel. They also secrete a variety of growth factors essential for growth and repair of tissue, particularly connective tissue. Infusions of concentrated platelets are now being used in some therapies to stimulate healing.

Disorders of Platelets

Thrombocytosis is a condition in which there are too many platelets. This may trigger formation of unwanted blood clots (thrombosis), a potentially fatal disorder. If there is an insufficient number of platelets, called thrombocytopenia, blood may not clot properly, and excessive bleeding may result.

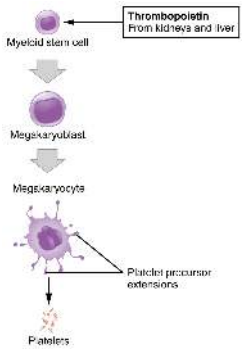


Figure 9.5.3 Platelets Platelets are derived from cells called megakaryocytes.

Interactive Link

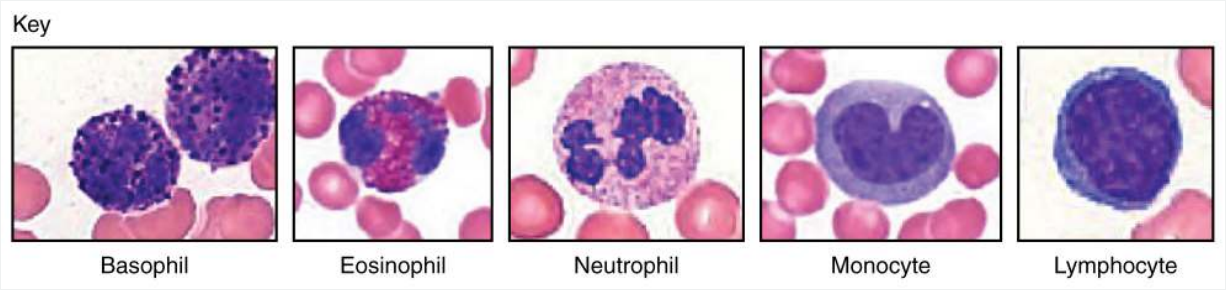


Figure 9.5.4 Leukocytes (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

View University of Michigan Webscopes and explore the blood slides in greater detail. The Webscope feature allows you to move the slides as you would with a mechanical stage. You can increase and decrease the magnification. There is a chance to review each of the leukocytes individually after you have attempted to identify them from the first two blood smears. In addition, there are a few multiple choice questions.

Are you able to recognize and identify the various formed elements? You will need to do this is a systematic manner, scanning along the image. The standard method is to use a grid, but this is not possible with this resource. Try constructing a simple table with each leukocyte type and then making a mark for each cell type you identify. Attempt to classify at least 50 and perhaps as many as 100 different cells. Based on the percentage of cells that you count, do the numbers represent a normal blood smear or does something appear to be abnormal?

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9.6: Hemostasis

Learning Objectives

By the end of this section, you will be able to:

- Describe the three mechanisms involved in hemostasis
- Explain how the extrinsic and intrinsic coagulation pathways lead to the common pathway, and the coagulation factors involved in each
- Discuss disorders affecting hemostasis

Platelets are key players in hemostasis, the process by which the body seals a ruptured blood vessel and prevents further loss of blood. Although rupture of larger vessels usually requires medical intervention, hemostasis is quite effective in dealing with small, simple wounds. There are three steps to the process: vascular spasm, the formation of a platelet plug, and coagulation (blood clotting). Failure of any of these steps will result in hemorrhage—excessive bleeding.

Vascular Spasm

When a vessel is severed or punctured, or when the wall of a vessel is damaged, vascular spasm occurs. In vascular spasm, the smooth muscle in the walls of the vessel contracts dramatically. This smooth muscle has both circular layers; larger vessels also have longitudinal layers. The circular layers tend to constrict the flow of blood, whereas the longitudinal layers, when present, draw the vessel back into the surrounding tissue, often making it more difficult for a surgeon to locate, clamp, and tie off a severed vessel. The vascular spasm response is believed to be triggered by several chemicals called endothelins that are released by vessel-lining cells and by pain receptors in response to vessel injury. This phenomenon typically lasts for up to 30 minutes, although it can last for hours.

Formation of the Platelet Plug

In the second step, platelets, which normally float free in the plasma, encounter the area of vessel rupture with the exposed underlying connective tissue and collagenous fibers. The platelets begin to clump together, become spiked and sticky, and bind to the exposed collagen and endothelial lining. This process is assisted by a glycoprotein in the blood plasma called von Willebrand factor, which helps stabilize the growing platelet plug. As platelets collect, they simultaneously release chemicals from their granules into the plasma that further contribute to hemostasis. Among the substances released by the platelets are:

- adenosine diphosphate (ADP), which helps additional platelets to adhere to the injury site, reinforcing and expanding the platelet plug
- serotonin, which maintains vasoconstriction
- prostaglandins and phospholipids, which also maintain vasoconstriction and help to activate further clotting chemicals, as discussed next

A platelet plug can temporarily seal a small opening in a blood vessel. Plug formation, in essence, buys the body time while more sophisticated and durable repairs are being made. In a similar manner, even modern naval warships still carry an assortment of wooden plugs to temporarily repair small breaches in their hulls until permanent repairs can be made.

Coagulation

Those more sophisticated and more durable repairs are collectively called coagulation, the formation of a blood clot. The process is sometimes characterized as a cascade, because one event prompts the next as in a multi-level waterfall. The result is the production of a gelatinous but robust clot made up of a mesh of fibrin—an insoluble filamentous protein derived from fibrinogen, the plasma protein introduced earlier—in which platelets and blood cells are trapped. Figure 9.6.1 summarizes the three steps of hemostasis.

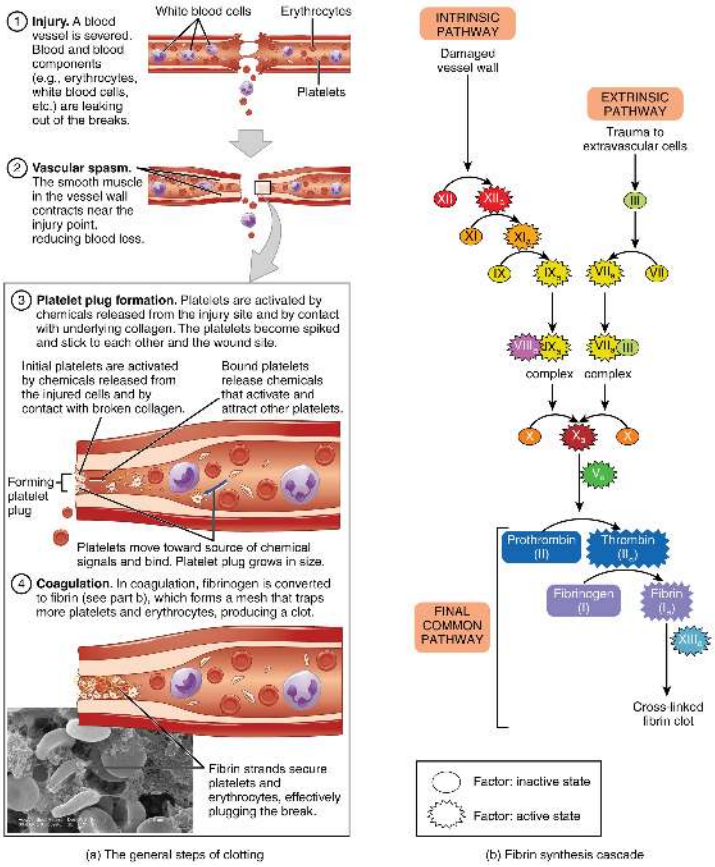


Figure 9.6.1: Hemostasis (a) An injury to a blood vessel initiates the process of hemostasis. Blood clotting involves three steps. First, vascular spasm constricts the flow of blood. Next, a platelet plug forms to temporarily seal small openings in the vessel. Coagulation then enables the repair of the vessel wall once the leakage of blood has stopped. (b) The synthesis of fibrin in blood clots involves either an intrinsic pathway or an extrinsic pathway, both of which lead to a common pathway. (credit a: Kevin MacKenzie)

Clotting Factors Involved in Coagulation

In the coagulation cascade, chemicals called clotting factors (or coagulation factors) prompt reactions that activate still more coagulation factors. The process is complex, but is initiated along two basic pathways:

- The extrinsic pathway, which normally is triggered by trauma.
- The intrinsic pathway, which begins in the bloodstream and is triggered by internal damage to the wall of the vessel.

Both of these merge into a third pathway, referred to as the common pathway (see Figure 9.6.1**b**). All three pathways are dependent upon the 12 known clotting factors, including Ca^{2+} and vitamin K (Table 9.6.1). Clotting factors are secreted primarily by the liver and the platelets. The liver requires the fat-soluble vitamin K to produce many of them. Vitamin K (along with biotin and folate) is somewhat unusual among vitamins in that it is not only consumed in the diet but is also synthesized by bacteria residing in the large intestine. The calcium ion, considered factor IV, is derived from the diet and from the breakdown of bone. Some recent evidence indicates that activation of various clotting factors occurs on specific receptor sites on the surfaces of platelets.

The 12 clotting factors are numbered I through XIII according to the order of their discovery. Factor VI was once believed to be a distinct clotting factor, but is now thought to be identical to factor V. Rather than renumber the other factors, factor VI was allowed to remain as a placeholder and also a reminder that knowledge changes over time.

Table 9.6.1: Clotting Factors

Factor number	Name	Type of molecule	Source	Pathway(s)
I	Fibrinogen	Plasma protein	Liver	Common; converted into fibrin
II	Prothrombin	Plasma protein	Liver*	Common; converted into thrombin
III	Tissue thromboplastin or tissue factor	Lipoprotein mixture	Damaged cells and platelets	Extrinsic
IV	Calcium ions	Inorganic ions in plasma	Diet, platelets, bone matrix	Entire process
V	Proaccelerin	Plasma protein	Liver, platelets	Extrinsic and intrinsic
VI	Not used	Not used	Not used	Not used
VII	Proconvertin	Plasma protein	Liver *	Extrinsic
VIII	Antihemolytic factor A	Plasma protein factor	Platelets and endothelial cells	Intrinsic; deficiency results in hemophilia A
IX	Antihemolytic factor B (plasma thromboplastin component)	Plasma protein	Liver*	Intrinsic; deficiency results in hemophilia B
X	Stuart–Prower factor (thrombokinase)	Protein	Liver*	Extrinsic and intrinsic
XI	Antihemolytic factor C (plasma thromboplastin antecedent)	Plasma protein	Liver	Intrinsic; deficiency results in hemophilia C
XII	Hageman factor	Plasma protein	Liver	Intrinsic; initiates clotting in vitro also activates plasmin
XIII	Fibrin-stabilizing factor	Plasma protein	Liver, platelets	Stabilizes fibrin; slows fibrinolysis

*Vitamin K required.

Extrinsic Pathway

The quicker responding and more direct extrinsic pathway (also known as the tissue factor pathway) begins when damage occurs to the surrounding tissues, such as in a traumatic injury. Upon contact with blood plasma, the damaged extravascular cells, which are extrinsic to the bloodstream, release factor III (thromboplastin). Sequentially, Ca^{2+} then factor VII (proconvertin), which is activated by factor III, are added, forming an enzyme complex. This enzyme complex leads to activation of factor X (Stuart–Prower factor), which activates the common pathway discussed below. The events in the extrinsic pathway are completed in a matter of seconds.

Intrinsic Pathway

The intrinsic pathway (also known as the contact activation pathway) is longer and more complex. In this case, the factors involved are intrinsic to (present within) the bloodstream. The pathway can be prompted by damage to the tissues, resulting from internal factors such as arterial disease; however, it is most often initiated when factor XII (Hageman factor) comes into contact with foreign materials, such as when a blood sample is put into a glass test tube. Within the body, factor XII is typically activated when it encounters negatively charged molecules, such as inorganic polymers and phosphate produced earlier in the series of intrinsic pathway reactions. Factor XII sets off a series of reactions that in turn activates factor XI (antihemolytic factor C or plasma

thromboplastin antecedent) then factor IX (antihemolytic factor B or plasma thromboplasmin). In the meantime, chemicals released by the platelets increase the rate of these activation reactions. Finally, factor VIII (antihemolytic factor A) from the platelets and endothelial cells combines with factor IX (antihemolytic factor B or plasma thromboplasmin) to form an enzyme complex that activates factor X (Stuart–Prower factor or thrombokinase), leading to the common pathway. The events in the intrinsic pathway are completed in a few minutes.

Common Pathway

Both the intrinsic and extrinsic pathways lead to the common pathway, in which fibrin is produced to seal off the vessel. Once factor X has been activated by either the intrinsic or extrinsic pathway, the enzyme prothrombinase converts factor II, the inactive enzyme prothrombin, into the active enzyme thrombin. (Note that if the enzyme thrombin were not normally in an inactive form, clots would form spontaneously, a condition not consistent with life.) Then, thrombin converts factor I, the soluble fibrinogen, into the insoluble fibrin protein strands. Factor XIII then stabilizes the fibrin clot.

Fibrinolysis

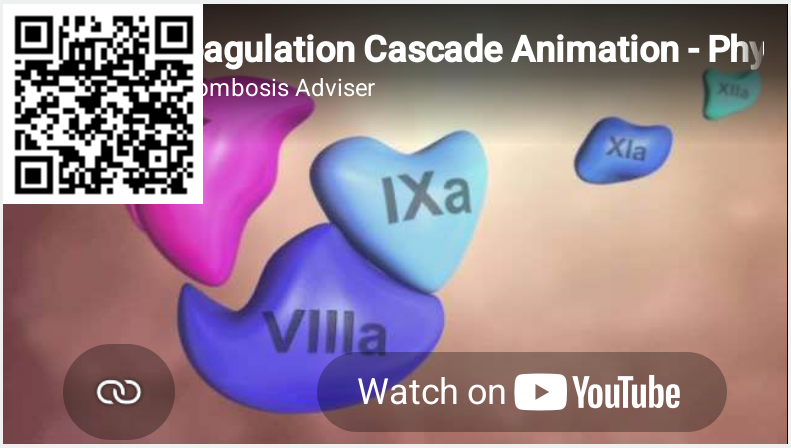
The stabilized clot is acted upon by contractile proteins within the platelets. As these proteins contract, they pull on the fibrin threads, bringing the edges of the clot more tightly together, somewhat as we do when tightening loose shoelaces (see Figure 18.14**a**). This process also wrings out of the clot a small amount of fluid called serum, which is blood plasma without its clotting factors.

To restore normal blood flow as the vessel heals, the clot must eventually be removed. Fibrinolysis is the gradual degradation of the clot. Again, there is a fairly complicated series of reactions that involves factor XII and protein-catabolizing enzymes. During this process, the inactive protein plasminogen is converted into the active plasmin, which gradually breaks down the fibrin of the clot. Additionally, bradykinin, a vasodilator, is released, reversing the effects of the serotonin and prostaglandins from the platelets. This allows the smooth muscle in the walls of the vessels to relax and helps to restore the circulation.

Plasma Anticoagulants

An anticoagulant is any substance that opposes coagulation. Several circulating plasma anticoagulants play a role in limiting the coagulation process to the region of injury and restoring a normal, clot-free condition of blood. For instance, a cluster of proteins collectively referred to as the protein C system inactivates clotting factors involved in the intrinsic pathway. TFPI (tissue factor pathway inhibitor) inhibits the conversion of the inactive factor VII to the active form in the extrinsic pathway. Antithrombin inactivates factor X and opposes the conversion of prothrombin (factor II) to thrombin in the common pathway. And as noted earlier, basophils release heparin, a short-acting anticoagulant that also opposes prothrombin. Heparin is also found on the surfaces of cells lining the blood vessels. A pharmaceutical form of heparin is often administered therapeutically, for example, in surgical patients at risk for blood clots.

Interactive Link



View these animations to explore the intrinsic, extrinsic, and common pathways that are involved the process of coagulation. The coagulation cascade restores hemostasis by activating coagulation factors in the presence of an injury. How does the

endothelium of the blood vessel walls prevent the blood from coagulating as it flows through the blood vessels?

Disorders of Clotting

Either an insufficient or an excessive production of platelets can lead to severe disease or death. As discussed earlier, an insufficient number of platelets, called thrombocytopenia, typically results in the inability of blood to form clots. This can lead to excessive bleeding, even from minor wounds.

Another reason for failure of the blood to clot is the inadequate production of functional amounts of one or more clotting factors. This is the case in the genetic disorder hemophilia, which is actually a group of related disorders, the most common of which is hemophilia A, accounting for approximately 80 percent of cases. This disorder results in the inability to synthesize sufficient quantities of factor VIII. Hemophilia B is the second most common form, accounting for approximately 20 percent of cases. In this case, there is a deficiency of factor IX. Both of these defects are linked to the X chromosome and are typically passed from a healthy (carrier) female to their male offspring, since males are XY. Females would need to inherit a defective gene from each parent to manifest the disease, since they are XX. Patients with hemophilia bleed from even minor internal and external wounds, and leak blood into joint spaces after exercise and into urine and stool. Hemophilia C is a rare condition that is triggered by an autosomal (not sex) chromosome that renders factor XI nonfunctional. It is not a true recessive condition, since even individuals with a single copy of the mutant gene show a tendency to bleed. Regular infusions of clotting factors isolated from healthy donors can help prevent bleeding in hemophiliac patients. At some point, genetic therapy will become a viable option.

In contrast to the disorders characterized by coagulation failure is thrombocytosis, also mentioned earlier, a condition characterized by excessive numbers of platelets that increases the risk for excessive clot formation, a condition known as thrombosis. A thrombus (plural = thrombi) is an aggregation of platelets, erythrocytes, and even WBCs typically trapped within a mass of fibrin strands. While the formation of a clot is normal following the hemostatic mechanism just described, thrombi can form within an intact or only slightly damaged blood vessel. In a large vessel, a thrombus will adhere to the vessel wall and decrease the flow of blood, and is referred to as a mural thrombus. In a small vessel, it may actually totally block the flow of blood and is termed an occlusive thrombus. Thrombi are most commonly caused by vessel damage to the endothelial lining, which activates the clotting mechanism. These may include venous stasis, when blood in the veins, particularly in the legs, remains stationary for long periods. This is one of the dangers of long airplane flights in crowded conditions and may lead to deep vein thrombosis. Thrombophilia, also called hypercoagulation, is a condition in which there is a tendency to form thrombosis. This may be familial (genetic) or acquired. Acquired forms include the autoimmune disease lupus, immune reactions to heparin, polycythemia vera, thrombocytosis, sickle cell disease, pregnancy, and even obesity. A thrombus can seriously impede blood flow to or from a region and will cause a local increase in blood pressure. If flow is to be maintained, the heart will need to generate a greater pressure to overcome the resistance.

When a portion of a thrombus breaks free from the vessel wall and enters the circulation, it is referred to as an embolus. An embolus that is carried through the bloodstream can be large enough to block a vessel critical to a major organ. When it becomes trapped, an embolus is called an embolism. In the heart, brain, or lungs, an embolism may accordingly cause a heart attack, a stroke, or a pulmonary embolism. These are medical emergencies.

Among the many known biochemical activities of aspirin is its role as an anticoagulant. Aspirin (acetylsalicylic acid) is very effective at inhibiting the aggregation of platelets. It is routinely administered during a heart attack or stroke to reduce the adverse effects. Physicians sometimes recommend that patients at risk for cardiovascular disease take a low dose of aspirin on a daily basis as a preventive measure. However, aspirin can also lead to serious side effects, including increasing the risk of ulcers. A patient is well advised to consult a physician before beginning any aspirin regimen.

A class of drugs collectively known as thrombolytic agents can help speed up the degradation of an abnormal clot. If a thrombolytic agent is administered to a patient within 3 hours following a thrombotic stroke, the patient's prognosis improves significantly. However, some strokes are not caused by thrombi, but by hemorrhage. Thus, the cause must be determined before treatment begins. Tissue plasminogen activator is an enzyme that catalyzes the conversion of plasminogen to plasmin, the primary enzyme that breaks down clots. It is released naturally by endothelial cells but is also used in clinical medicine. New research is progressing using compounds isolated from the venom of some species of snakes, particularly vipers and cobras, which may eventually have therapeutic value as thrombolytic agents.

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9.7: Blood Typing

Learning Objectives

By the end of this section, you will be able to:

- Describe the two basic physiological consequences of transfusion of incompatible blood
- Compare and contrast ABO and Rh blood groups
- Identify which blood groups may be safely transfused into patients with different ABO types
- Discuss the pathophysiology of hemolytic disease of the newborn

Blood transfusions in humans were risky procedures until the discovery of the major human blood groups by Karl Landsteiner, an Austrian biologist and physician, in 1900. Until that point, physicians did not understand that death sometimes followed blood transfusions, when the type of donor blood infused into the patient was incompatible with the patient's own blood. Blood groups are determined by the presence or absence of specific marker molecules on the plasma membranes of erythrocytes. With their discovery, it became possible for the first time to match patient-donor blood types and prevent transfusion reactions and deaths.

Antigens, Antibodies, and Transfusion Reactions

Antigens are substances that the body does not recognize as belonging to the "self" and that therefore trigger a defensive response from the leukocytes of the immune system. (Seek more content for additional information on immunity.) Here, we will focus on the role of immunity in blood transfusion reactions. With RBCs in particular, you may see the antigens referred to as isoantigens or agglutinogens (surface antigens) and the antibodies referred to as isoantibodies or agglutinins. In this chapter, we will use the more common terms antigens and antibodies. (Figure 9.7.1 shows an antibody and antigens.)

Antigens are generally large proteins, but may include other classes of organic molecules, including carbohydrates, lipids, and nucleic acids. Following an infusion of incompatible blood, erythrocytes with foreign antigens appear in the bloodstream and trigger an immune response. Proteins called antibodies (immunoglobulins), which are produced by certain B lymphocytes called plasma cells, attach to the antigens on the plasma membranes of the infused erythrocytes and cause them to adhere to one another.

- Because the arms of the Y-shaped antibodies attach randomly to more than one nonself erythrocyte surface, they form clumps of erythrocytes. This process is called agglutination.
- The clumps of erythrocytes block small blood vessels throughout the body, depriving tissues of oxygen and nutrients.
- As the erythrocyte clumps are degraded, in a process called hemolysis, their hemoglobin is released into the bloodstream. This hemoglobin travels to the kidneys, which are responsible for filtration of the blood. However, the load of hemoglobin released can easily overwhelm the kidney's capacity to clear it, and the patient can quickly develop kidney failure.

More than 50 antigens have been identified on erythrocyte membranes, but the most significant in terms of their potential harm to patients are classified in two groups: the ABO blood group and the Rh blood group.

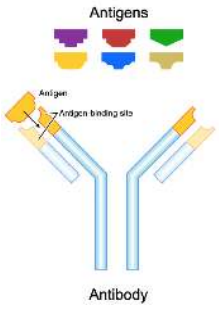


Figure 9.7.1: Model of antigen and matching antibody

The ABO Blood Group

Although the ABO blood group name consists of three letters, ABO blood typing designates the presence or absence of just two antigens, A and B. Both are glycoproteins. People whose erythrocytes have A antigens on their erythrocyte membrane surfaces are

designated blood type A, and those whose erythrocytes have B antigens are blood type B. People can also have both A and B antigens on their erythrocytes, in which case they are blood type AB. People with neither A nor B antigens are designated blood type O. ABO blood types are genetically determined.

The body must be exposed to a foreign antigen before an antibody can be produced. ABO blood group antigens are found in foods and microbes throughout nature. Thus, the human immune system is exposed to A and B antigens at an early age and antibodies are formed naturally. Individuals with type A blood—without any prior exposure to incompatible blood—have naturally-formed antibodies to the B antigen circulating in their blood plasma. These antibodies, referred to as anti-B antibodies, will cause agglutination and hemolysis if they ever encounter erythrocytes with B antigens. Similarly, an individual with type B blood has naturally-formed anti-A antibodies. Individuals with type AB blood, which has both antigens, do not have naturally-formed antibodies to either of these. People with type O blood lack antigens A and B on their erythrocytes, but both anti-A and anti-B antibodies circulate in their blood plasma.

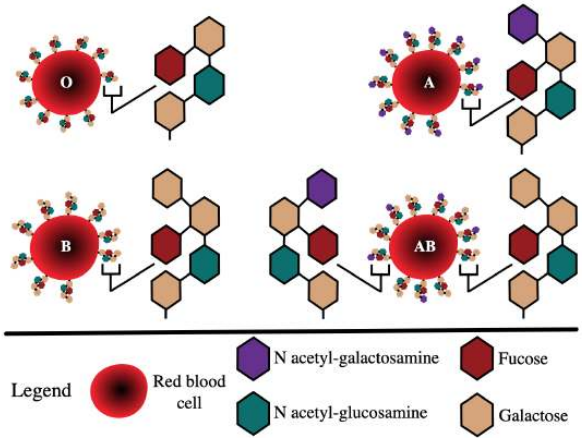


Figure: ABO antigen molecules

The **ABO blood group system** is the best known human blood group system. Antigens in this system are glycoproteins. These antigen compounds are shown in Figure above. There are four common blood types for the ABO system:

1. Type A, in which only the A antigen is present
2. Type B, in which only the B antigen is present
3. Type AB, in which both the A and B antigens are present
4. Type O, in which neither the A nor the B antigen is present

Rh Blood Groups

The Rh blood group is classified according to the presence or absence of a second erythrocyte antigen identified as Rh. (It was first discovered in a type of primate known as a rhesus macaque, which is often used in research, because its blood is similar to that of humans.) Although dozens of Rh antigens have been identified, only one, designated D, is clinically important. Those who have the Rh D antigen present on their erythrocytes—about 85 percent of Americans—are described as Rh positive (Rh^+) and those who lack it are Rh negative (Rh^-). Note that the Rh group is distinct from the ABO group, so any individual, no matter their ABO blood type, may have or lack this Rh antigen. When identifying a patient's blood type, the Rh group is designated by adding the word positive or negative to the ABO type. For example, A positive (A^+) means ABO group A blood with the Rh antigen present, and AB negative (AB^-) means ABO group AB blood without the Rh antigen.

The Table below 9.7.1 summarizes the distribution of the ABO and Rh blood types within the United States.

Table 9.7.1: Summary of ABO and Rh Blood Types within the United States

Blood Type	Asian	Black non-Hispanic	Hispanic	North American Indian	White non-Hispanic
A^+	27.3	24.0	28.7	31.3	33.0
A^-	0.5	1.9	2.4	3.8	6.8
B^+	25.0	18.4	9.2	7.0	9.1
B^-	0.4	1.3	0.7	0.9	1.8
AB^+	7.0	4.0	2.3	2.2	3.4
AB^-	0.1	0.3	0.2	0.3	0.7
O^+	39.0	46.6	52.6	50.0	37.2
O^-	0.7	3.6	3.9	4.7	8.0

In contrast to the ABO group antibodies, which are preformed, antibodies to the Rh antigen are produced only in Rh^- individuals after exposure to the antigen. This process, called sensitization, occurs following a transfusion with Rh-incompatible blood or, more commonly, with the birth of an Rh^+ baby to an Rh^- person. Problems are rare in a first pregnancy, since the baby's Rh^+ cells rarely cross the placenta (the organ of gas and nutrient exchange between the fetus and the pregnant person). However, during or immediately after birth, the Rh^- parent can be exposed to the baby's Rh^+ cells (Figure 9.7.2). Research has shown that this occurs in about 13−14 percent of such pregnancies. After exposure, the immune system of the person who has given birth begins to generate anti-Rh antibodies. If the same person should then become pregnant with another Rh^+ baby, the Rh antibodies they have produced can cross the placenta into the fetal bloodstream and destroy the fetal RBCs. This condition, known as hemolytic disease of the newborn (HDN) or erythroblastosis fetalis, may cause anemia in mild cases, but the agglutination and hemolysis can be so severe that without treatment the fetus may die in the womb or shortly after birth.

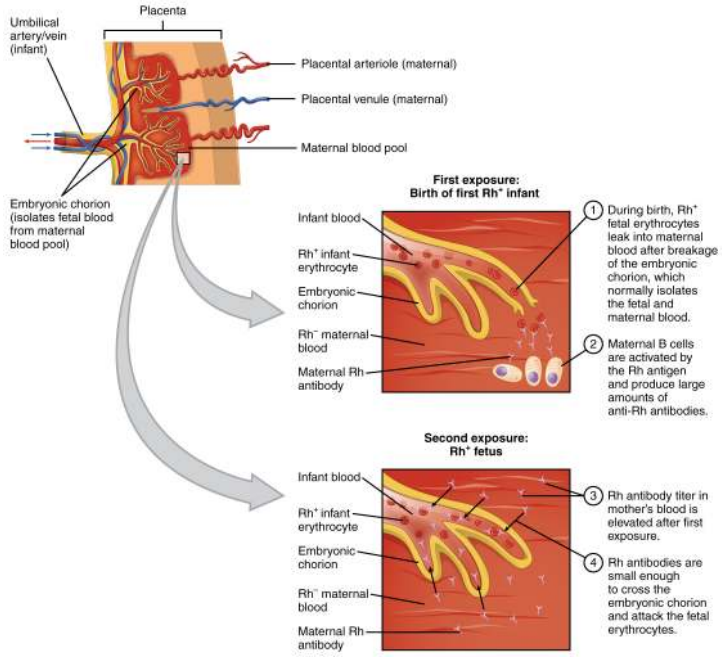


Figure 9.7.2: Erythroblastosis Fetalis The first exposure of an Rh^- person to Rh^+ erythrocytes during pregnancy induces sensitization. Anti-Rh antibodies begin to circulate in the pregnant person's bloodstream. A second exposure occurs with a subsequent pregnancy with an Rh^+ fetus in the uterus. During that subsequent pregnancy, the pregnant person's anti-Rh antibodies may cross the placenta and enter the fetal bloodstream, causing agglutination and hemolysis of fetal erythrocytes.

A drug known as RhoGAM, short for Rh immune globulin, can temporarily prevent the development of Rh antibodies in the Rh^- parent, thereby averting this potentially serious disease for the fetus. RhoGAM antibodies destroy any fetal Rh^+ erythrocytes that

may cross the placental barrier. RhoGAM is normally administered to Rh^- pregnant people during weeks 26–28 of pregnancy and within 72 hours following birth. It has proven remarkably effective in decreasing the incidence of HDN. Earlier we noted that the incidence of HDN in an Rh^+ subsequent pregnancy to an Rh^- person is about 13–14 percent without preventive treatment. Since the introduction of RhoGAM in 1968, the incidence has dropped to about 0.1 percent in the United States.

Determining ABO Blood Types

Clinicians are able to determine a patient's blood type quickly and easily using commercially prepared antibodies. An unknown blood sample is allocated into separate wells. Into one well a small amount of anti-A antibody is added, and to another a small amount of anti-B antibody. If the antigen is present, the antibodies will cause visible agglutination of the cells (Figure 9.7.3). The blood should also be tested for Rh antibodies.

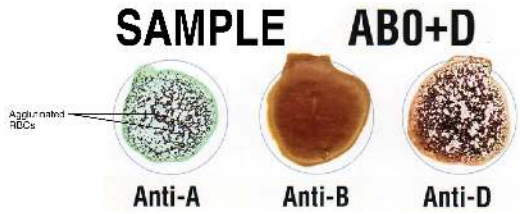


Figure 9.7.3: Cross Matching Blood Types This sample of a commercially produced "bedside" card enables quick typing of both a recipient's and donor's blood before transfusion. The card contains three reaction sites or wells. One is coated with an anti-A antibody, one with an anti-B antibody, and one with an anti-D antibody (tests for the presence of Rh factor D). Mixing a drop of blood and saline into each well enables the blood to interact with a preparation of type-specific antibodies, also called anti-seras. Agglutination of RBCs in a given site indicates a positive identification of the blood antigens, in this case A and Rh antigens for blood type A^+. For the purpose of transfusion, the donor's and recipient's blood types must match.

ABO Transfusion Protocols

To avoid transfusion reactions, it is best to transfuse only matching blood types; that is, a type B^+ recipient should ideally receive blood only from a type B^+ donor and so on. That said, in emergency situations, when acute hemorrhage threatens the patient's life, there may not be time for cross matching to identify blood type. In these cases, blood from a universal donor—an individual with type O^- blood—may be transfused. Recall that type O erythrocytes do not display A or B antigens. Thus, anti-A or anti-B antibodies that might be circulating in the patient's blood plasma will not encounter any erythrocyte surface antigens on the donated blood and therefore will not be provoked into a response. One problem with this designation of universal donor is if the O^- individual had prior exposure to Rh antigen, Rh antibodies may be present in the donated blood. Also, introducing type O blood into an individual with type A, B, or AB blood will nevertheless introduce antibodies against both A and B antigens, as these are always circulating in the type O blood plasma. This may cause problems for the recipient, but because the volume of blood transfused is much lower than the volume of the patient's own blood, the adverse effects of the relatively few infused plasma antibodies are typically limited. Rh factor also plays a role. If Rh^- individuals receiving blood have had prior exposure to Rh antigen, antibodies for this antigen may be present in the blood and trigger agglutination to some degree. Although it is always preferable to cross match a patient's blood before transfusing, in a true life-threatening emergency situation, this is not always possible, and these procedures may be implemented.

A patient with blood type AB^+ is known as the universal recipient. This patient can theoretically receive any type of blood, because the patient's own blood—having both A and B antigens on the erythrocyte surface—does not produce anti-A or anti-B antibodies. In addition, an Rh^+ patient can receive both Rh^+ and Rh^- blood. However, keep in mind that the donor's blood will contain circulating antibodies, again with possible negative implications. Figure 9.7.4 summarizes the blood types and compatibilities.

At the scene of multiple-vehicle accidents, military engagements, and natural or human-caused disasters, many victims may suffer simultaneously from acute hemorrhage, yet type O blood may not be immediately available. In these circumstances, medics may at least try to replace some of the volume of blood that has been lost. This is done by intravenous administration of a saline solution that provides fluids and electrolytes in proportions equivalent to those of normal blood plasma. Research is ongoing to develop a safe and effective artificial blood that would carry out the oxygen-carrying function of blood without the RBCs, enabling transfusions in the field without concern for incompatibility. These blood substitutes normally contain hemoglobin- as well as perfluorocarbon-based oxygen carriers.

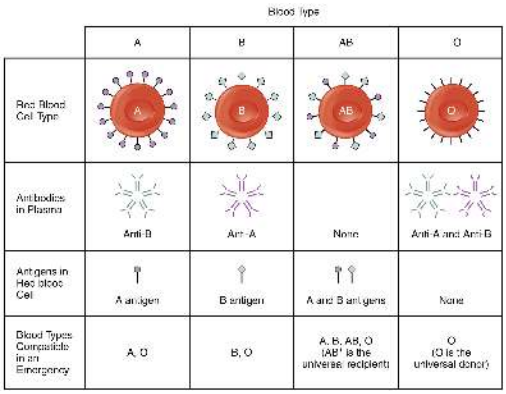


Figure 9.7.4: ABO Blood Group This chart summarizes the characteristics of the blood types in the ABO blood group. See the text for more on the concept of a universal donor or recipient.

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9.9: Blood- Chapter Review

18.1 An Overview of Blood

Blood is a fluid connective tissue critical to the transportation of nutrients, gases, and wastes throughout the body; to defend the body against infection and other threats; and to the homeostatic regulation of pH, temperature, and other internal conditions. Blood is composed of formed elements—erythrocytes, leukocytes, and cell fragments called platelets—and a fluid extracellular matrix called plasma. More than 90 percent of plasma is water. The remainder is mostly plasma proteins—mainly albumin, globulins, and fibrinogen—and other dissolved solutes such as glucose, lipids, electrolytes, and dissolved gases. Because of the formed elements and the plasma proteins and other solutes, blood is sticky and more viscous than water. It is also slightly alkaline, and its temperature is slightly higher than normal body temperature.

18.2 Production of the Formed Elements

Through the process of hemopoiesis, the formed elements of blood are continually produced, replacing the relatively short-lived erythrocytes, leukocytes, and platelets. Hemopoiesis begins in the red bone marrow, with hematopoietic stem cells that differentiate into myeloid and lymphoid lineages. Myeloid stem cells give rise to most of the formed elements. Lymphoid stem cells give rise only to the various lymphocytes designated as B and T cells, and NK cells. Hemopoietic growth factors, including erythropoietin, thrombopoietin, colony-stimulating factors, and interleukins, promote the proliferation and differentiation of formed elements.

18.3 Erythrocytes

The most abundant formed elements in blood, erythrocytes are red, biconcave disks packed with an oxygen-carrying compound called hemoglobin. The hemoglobin molecule contains four globin proteins bound to a pigment molecule called heme, which contains an ion of iron. In the bloodstream, iron picks up oxygen in the lungs and drops it off in the tissues; the amino acids in hemoglobin then transport carbon dioxide from the tissues back to the lungs. Erythrocytes live only 120 days on average, and thus must be continually replaced. Worn-out erythrocytes are phagocytized by macrophages and their hemoglobin is broken down. The breakdown products are recycled or removed as wastes: Globin is broken down into amino acids for synthesis of new proteins; iron is stored in the liver or spleen or used by the bone marrow for production of new erythrocytes; and the remnants of heme are converted into bilirubin, or other waste products that are taken up by the liver and excreted in the bile or removed by the kidneys. Anemia is a deficiency of RBCs or hemoglobin, whereas polycythemia is an excess of RBCs.

18.4 Leukocytes and Platelets

Leukocytes function in body defenses. They squeeze out of the walls of blood vessels through emigration or diapedesis, then may move through tissue fluid or become attached to various organs where they fight against pathogenic organisms, diseased cells, or other threats to health. Granular leukocytes, which include neutrophils, eosinophils, and basophils, originate with myeloid stem cells, as do the agranular monocytes. The other agranular leukocytes, NK cells, B cells, and T cells, arise from the lymphoid stem cell line. The most abundant leukocytes are the neutrophils, which are first responders to infections, especially with bacteria. About 20–30 percent of all leukocytes are lymphocytes, which are critical to the body’s defense against specific threats. Leukemia and lymphoma are malignancies involving leukocytes. Platelets are fragments of cells known as megakaryocytes that dwell within the bone marrow. While many platelets are stored in the spleen, others enter the circulation and are essential for hemostasis; they also produce several growth factors important for repair and healing.

18.5 Hemostasis

Hemostasis is the physiological process by which bleeding ceases. Hemostasis involves three basic steps: vascular spasm, the formation of a platelet plug, and coagulation, in which clotting factors promote the formation of a fibrin clot. Fibrinolysis is the process in which a clot is degraded in a healing vessel. Anticoagulants are substances that oppose coagulation. They are important in limiting the extent and duration of clotting. Inadequate clotting can result from too few platelets, or inadequate production of clotting factors, for instance, in the genetic disorder hemophilia. Excessive clotting, called thrombosis, can be caused by excessive numbers of platelets. A thrombus is a collection of fibrin, platelets, and erythrocytes that has accumulated along the lining of a blood vessel, whereas an embolus is a thrombus that has broken free from the vessel wall and is circulating in the bloodstream.

Antigens are nonself molecules, usually large proteins, which provoke an immune response. In transfusion reactions, antibodies attach to antigens on the surfaces of erythrocytes and cause agglutination and hemolysis. ABO blood group antigens are designated A and B. People with type A blood have A antigens on their erythrocytes, whereas those with type B blood have B antigens. Those with AB blood have both A and B antigens, and those with type O blood have neither A nor B antigens. The blood plasma contains preformed antibodies against the antigens not present on a person's erythrocytes.

A second group of blood antigens is the Rh group, the most important of which is Rh D. People with Rh^- blood do not have this antigen on their erythrocytes, whereas those who are Rh^+ do. About 85 percent of Americans are Rh^+. When a person who is Rh^- becomes pregnant with an Rh^+ fetus, their body may begin to produce anti-Rh antibodies. If the person subsequently becomes pregnant with a second Rh^+ fetus and is not treated preventively with RhoGAM, the fetus will be at risk for an antigen-antibody reaction, including agglutination and hemolysis. This is known as hemolytic disease of the newborn.

Cross matching to determine blood type is necessary before transfusing blood, unless the patient is experiencing hemorrhage that is an immediate threat to life, in which case type O^- blood may be transfused.

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CHAPTER OVERVIEW

10: CARDIOVASCULAR SYSTEM- HEART AND BLOOD VESSELS

This chapter provides a detailed description of the heart, blood vessels, and blood. It explains how they function together to transport substances throughout the body and maintain homeostasis. The chapter also describes several diseases of the cardiovascular system and lifestyle choices that can help prevent most of them.

10.1: Case Study- Your Body's Transportation System

10.2: Introduction to the Cardiovascular System

10.3: Heart

10.4: Cardiac Cycle and Electrical Activity

10.5: Cardiac Cycle

10.6: Blood Vessels

10.7: Cardiovascular Disease

10.8: Case Study Conclusion- Flight and Chapter Summary

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10.1: CASE STUDY- YOUR BODY'S TRANSPORTATION SYSTEM

CASE STUDY: FLIGHT RISK

Nineteen-year-old Antônio is about to take his first plane flight. Shortly after he boards the plane and sits down, a man in his late sixties sits next to him in the aisle seat. About half an hour after the plane takes off, the pilot announces that she is turning the seat belt light off and that "it is now safe to move about the cabin."



Figure **10.1.1**: Airplane aisle

The man in the aisle seat, who has introduced himself to Antônio as Ahaya, immediately unbuckles his seat belt and paces up and down the aisle a few times before returning to his seat. After about forty-five minutes, Ahaya gets up again, walks some more, then sits back down and does some foot and leg exercises. After the third time, Ahaya gets up and paces the aisles, Antônio asks him whether he is walking so much to accumulate steps on a pedometer or fitness tracking device. Ahaya laughs and says no, he is trying to do something even more important for his health—prevent a blood clot from forming in his legs.

Ahaya explains that he has a chronic condition called heart failure. Although it sounds scary, his condition is currently well-managed and he is able to lead a relatively normal lifestyle. However, it does put him at risk of developing other serious health conditions such as deep vein thrombosis (DVT), which is when a blood clot occurs in the deep veins, usually in the legs. Air travel, or other situations where a person has to sit for a long period of time, increases the risk of DVT. Ahaya's doctor said that he was healthy enough to fly, but that he should walk frequently and do leg exercises to help avoid a blood clot.

As you read this chapter, you will learn about the heart, blood vessels, and blood that make up the cardiovascular system, as well as disorders of the cardiovascular system such as heart failure. At the end of the chapter, you will learn more about why DVT occurs, why Ahaya has to take extra precautions when he flies, and what can be done to lower the risk of DVT and its potentially deadly consequences.

CHAPTER OVERVIEW: CARDIOVASCULAR SYSTEM

In this chapter, you will learn about the cardiovascular system, which transports substances throughout the body. Specifically, you will learn about:

- The major components of the cardiovascular system: the heart, blood vessels, and blood.
- The functions of the cardiovascular system, including transporting needed substances such as oxygen and nutrients to the cells of the body and picking up waste products.
- How blood is oxygenated through the pulmonary circulation, which transports blood between the heart and lungs.
- How blood is circulated throughout the body through the systemic circulation.
- The components of blood, including plasma, red blood cells, white blood cells, and platelets, and their specific functions.
- Types of blood vessels, including arteries, veins, and capillaries, and their functions, similarities, and differences.
- The structure of the heart, how it pumps blood, and how contractions of the heart are controlled.
- What blood pressure is and how it is regulated.
- Blood types: A, B, AB, and O
- Blood disorders, including anemia, HIV, and leukemia.
- Cardiovascular diseases including heart attack, stroke, and angina, and the risk factors and precursors, such as high blood pressure and atherosclerosis, which contribute to them.

As you read the chapter, think about the following questions:

1. What is heart failure? How do you think it increases the risk of DVT?
2. What is a blood clot? What are the possible health consequences of blood clots?
3. Why do you think sitting for long periods of time increases the risk of DVT and why does walking and exercising the legs help reduce this risk?

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10.2: INTRODUCTION TO THE CARDIOVASCULAR SYSTEM

ANT HILL OR PLUMBING SYSTEM?

What do you think Figure **10.2.1** shows? Does it show a maze of underground passageways in an anthill? A network of interconnected pipes in a complex plumbing system? The picture actually shows something that, like ant tunnels and plumbing pipes, functions as a transportation system. It shows a network of blood vessels. Blood vessels are part of the cardiovascular system.

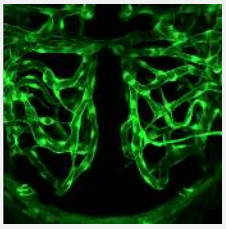


Figure **10.2.1**: Blood Vessels

WHAT IS THE CARDIOVASCULAR SYSTEM?

The **cardiovascular system**, also called the circulatory system, is the organ system that transports materials to and from all the cells of the body.

"Cardio" refers to the heart and "vascular" refers to the blood vessels. Although the term “heart” is an English word, cardiac (heart-related) terminology can be traced back to the Latin term, “kardia.” Cardiology is the study of the heart, and cardiologists are the physicians who deal primarily with the heart.

The materials carried in the blood by the cardiovascular system include oxygen from the lungs, nutrients from the digestive system, hormones from glands of the endocrine system, and waste materials from cells throughout the body. Transport of these and many other materials is necessary to maintain homeostasis of the body. The main components of the cardiovascular system are the heart, blood vessels, and blood. Each of these components is shown in Figure **10.2.2** and introduced in the text.

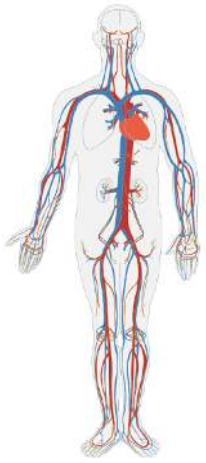


Figure **10.2.2**: This simplified drawing of the cardiovascular system shows its main structures. The heart is shown in the chest in red. Blood vessels called arteries are also shown in red, and blood vessels called veins are shown in blue.

HEART

The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue and pumps blood through blood vessels by repeated, rhythmic contractions. As shown in Figure **10.2.3**, the heart has four inner chambers: a right atrium and ventricle and a left atrium and ventricle. On each side of the heart, blood is pumped from the atrium to the ventricle below it and from the ventricle out of the heart. The heart also contains several valves that allow blood to flow only in the proper direction through the heart.

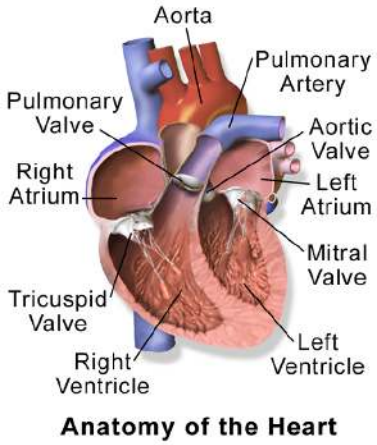


Figure **10.2.3**: The right side of the heart includes the right atrium and right ventricle. The left side includes the left atrium and left ventricle. The valves between the chambers and the major vessels are also visible

Unlike skeletal muscle, cardiac muscle routinely contracts without stimulation by the nervous system. Specialized cardiac muscle cells send out electrical impulses that stimulate the contractions. As a result, the atria and ventricles normally contract with just the right timing to keep blood pumping efficiently through the heart.

BLOOD VESSELS

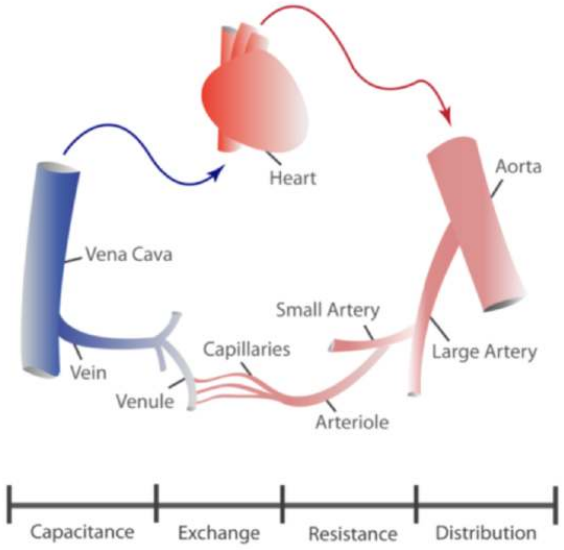


Figure **10.2.4**: This diagram represents the structure and functions of the different types of blood vessels in the cardiovascular system. Arteries carry blood from the heart and to capillaries. Veins carry blood from the capillaries back to the heart.

The blood vessels of the cardiovascular system are like a network of interconnected, one-way roads that range from superhighways to back alleys. Like a network of roads, the blood vessels have the job of allowing the transport of materials from one place to another. There are three major types of blood vessels: arteries, veins, and capillaries. They are illustrated in Figure **10.2.4**.

- Arteries are blood vessels that carry blood away from the heart (except for the arteries that actually supply blood to the heart muscle). Most arteries carry oxygen-rich blood, and one of their main functions is distributing oxygen to tissues throughout the body. The smallest arteries are called arterioles.
- Veins are blood vessels that carry blood toward the heart. Most veins carry deoxygenated blood. The smallest veins are called venules.
- Capillaries are the smallest blood vessels. They connect arterioles and venules. As they pass through tissues, they exchange substances including oxygen with cells.

TWO CIRCULATIONS

Cells throughout the body need a constant supply of oxygen. They get oxygen from capillaries in the systemic circulation. The systemic circulation is just one of two interconnected circulations that make up the human cardiovascular system. The other circulation is the pulmonary system. This is where the blood picks up oxygen to carry to cells. It takes blood about 20 seconds to make one complete transit through both circulations.

PULMONARY CIRCULATION

The **pulmonary circulation** involves only the heart and lungs and the major blood vessels that connect them. It is illustrated in Figure **10.2.5**. Blood moves through the pulmonary circulation from the heart to the lungs, and back to the heart again, becoming oxygenated in the process. Specifically, the right ventricle of the heart pumps deoxygenated blood into the right and left pulmonary arteries. These arteries carry the blood to the right and left lungs, respectively. Oxygenated blood then returns from the right and left lungs through the two right and two left pulmonary veins. All four pulmonary veins enter the left atrium of the heart.

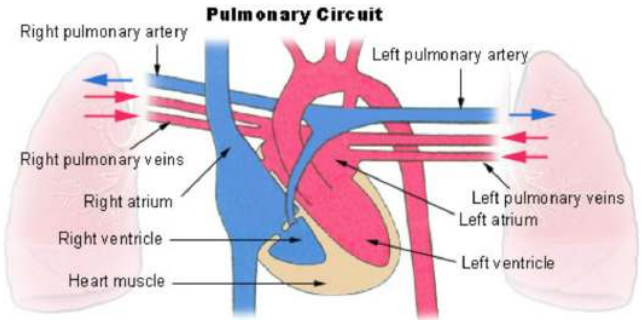


Figure **10.2.5**: This diagram shows the heart, lungs, and major vessels that make up the pulmonary circulation. The colored arrows indicate the direction of blood flow. Oxygenated blood (in red) flows from the lungs to the left side of the heart. Deoxygenated blood (in blue) flows from the right side of the heart to the lungs.

What happens to the blood while it is in the lungs? It passes through increasingly smaller arteries and finally through capillary networks surrounding the alveoli (Figure **10.2.6**). This is where gas exchange takes place. The deoxygenated blood in the capillaries picks up oxygen from the alveoli and gives up carbon dioxide to the alveoli. As a result, the blood returning to the heart in the pulmonary veins is almost completely saturated with oxygen.

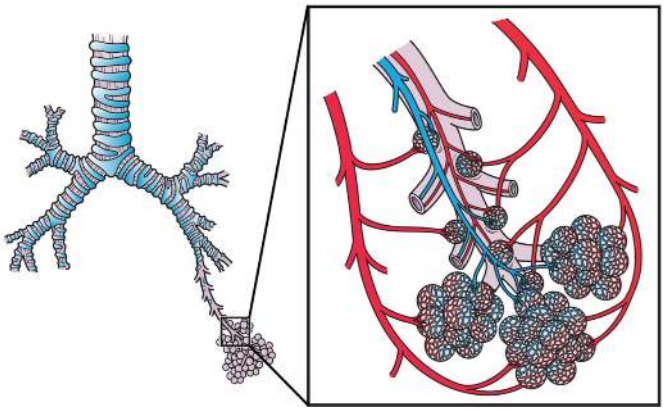


Figure **10.2.6**: This diagram illustrates clusters of alveoli in the lungs where gas exchange takes place with blood in capillaries as it passes through the pulmonary circulation.

SYSTEMIC CIRCULATION

The oxygenated blood that enters the left atrium of the heart in the pulmonary circulation then passes into the **systemic circulation.** This is the part of the cardiovascular system that transports blood to and from all of the tissues of the body to provide oxygen and nutrients and pick up wastes. It consists of the heart and blood vessels that supply the metabolic needs of all the cells in the body, including those of the heart and lungs.

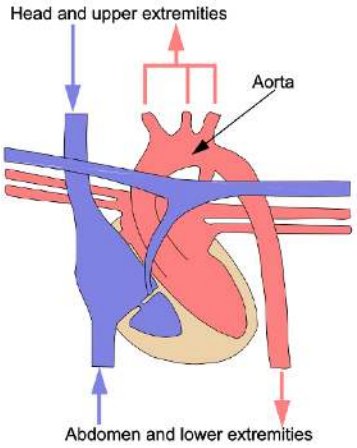


Figure **10.2.7**: The systemic circulation includes the aorta (red), which carries oxygenated blood away from the heart to the rest of the body; and the inferior and superior venae cavae (blue), which return deoxygenated blood to the heart from the body. The colored arrows in the diagram indicate the direction of blood flow, red for oxygenated and blue for deoxygenated.

As shown in Figure **10.2.7**, in the systemic circulation, the left atrium pumps oxygenated blood to the left ventricle, which pumps the blood directly into the aorta, the body's largest artery. Major arteries branching off the aorta carry the blood to the head and upper extremities. The aorta continues down through the abdomen and carries blood to the abdomen and lower extremities. The blood then returns to the heart through the network of increasingly larger veins of the systemic circulation. All of the returning blood eventually collects in the superior vena cava (upper body) and inferior vena cava (lower body), which empty directly into the right atrium of the heart.

BLOOD

Blood is a fluid connective tissue that circulates throughout the body in blood vessels by the pumping action of the heart. Blood carries oxygen and nutrients to all the body's cells, and it carries carbon dioxide and other wastes away from the cells to be excreted. Blood also transports many other substances, defends the body against infection, repairs body tissues, and controls the body's pH, among other functions.

The fluid part of blood is called plasma. It is a yellowish, watery liquid that contains many dissolved substances and blood cells. Types of blood cells in plasma include red blood cells, white blood cells, and platelets, all of which are illustrated in Figure **10.2.8** and explained in the text.

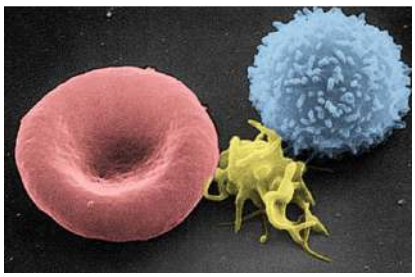


Figure **10.2.8**: The three types of cells in the blood are pictured here: red blood cell (left), platelet (center), and white blood cell (right).

- Red blood cells have the main function of carrying oxygen in the blood. Red blood cells consist mostly of hemoglobin, a protein containing iron that binds with oxygen.
- White blood cells are far fewer in number than red blood cells. They defend the body in various ways. For example, white blood cells called phagocytes swallow and destroy pathogens, dead cells, and other debris in the blood.
- Platelets are cell fragments involved in blood clotting. They stick to tears in blood vessels and to each other, forming a plug at the site of injury. They also release chemicals that are needed for clotting to occur.

REVIEW

1. What is the cardiovascular system? What are its main components?
2. Describe the heart and how it functions.
3. List the three major types of blood vessels and their basic functions.
4. Compare and contrast the pulmonary and systemic circulations.
5. What is blood? What are its chief constituents?
6. *True or False.* The circulatory system brings blood to and from the body, while the cardiovascular system brings blood to and from the lungs only.
7. *True or False.* Arteries carry mainly oxygenated blood.
8. Name three different types of substances that are transported by the cardiovascular system.
9. Describe where and how the pulmonary and systemic circulation systems meet.
10. Which of the following carries blood to the lungs? Choose all that apply.

    A. Left pulmonary artery

    B. Left pulmonary vein

    C. Right pulmonary artery

    D. Right pulmonary vein
11. Put the following structures in order of how blood flows from the heart out to the body and back again.

    capillaries; venules; aorta; veins; arteries
12. Explain why the heart and lungs need blood from the systemic circulation.
13. *Choose one.* Blood vessels carrying deoxygenated blood from the body back to the heart get increasingly (larger/smaller).
14. Blood becomes oxygenated in the lungs through gas exchange into:

    A. Arterioles

    B. Capillaries

    C. Venules

    D. Bronchioles
15. Which type of blood cell carries oxygen?

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10.3: HEART

LUB DUB

Lub dub, lub dub, lub dub... That's how the sound of a beating heart is typically described. In a normal, healthy heart, those are the only two sounds that should be audible when listening to the heart through a stethoscope. If a physician assistant hears something different from the normal lub dub sounds, it's a sign of a possible heart abnormality. What causes the heart to produce the characteristic lub dub sounds? Read on to find out.



Figure **10.3.1**: Listening to a heartbeat

LOCATION OF THE HEART

The **heart** is a muscular organ behind the sternum (breastbone), slightly to the left of the center of the chest (Figure **10.3.2**). A normal adult heart is about the size of a fist. The function of the heart is to pump blood through the blood vessels of the cardiovascular system. The continuous flow of blood through the system is necessary to provide all the cells of the body with oxygen and nutrients and to remove their metabolic wastes.

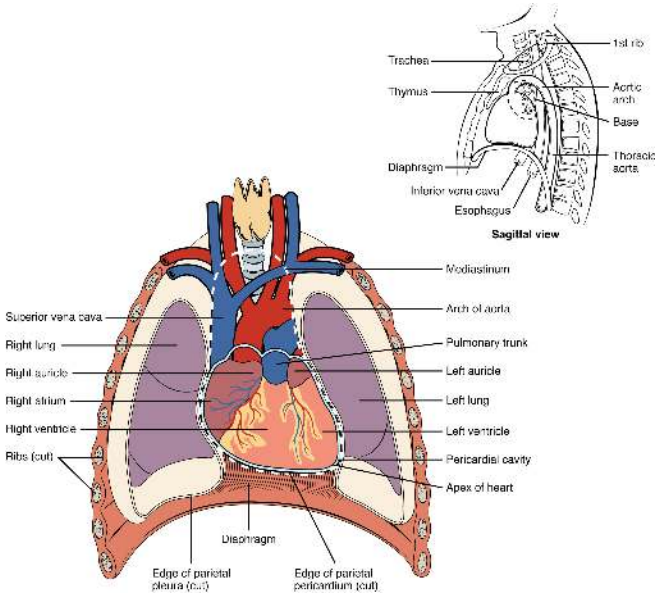


Figure **10.3.2**: Position of the Heart in the Thorax The heart is located within the thoracic cavity, medially between the lungs in the mediastinum. It is about the size of a fist, is broad at the top, and tapers toward the base.

STRUCTURE OF THE HEART

The heart has a thick muscular wall that consists of several layers of tissue. Internally, the heart is divided into four chambers through which blood flows. Blood flows in just one direction through the chambers due to heart valves.

HEART WALL

As shown in Figure **10.3.3**, the wall of the heart is made up of three layers, called the endocardium, myocardium, and pericardium.

- The endocardium is the innermost layer of the heart wall. It is made up primarily of simple epithelial cells. It covers the heart chambers and valves. A thin layer of connective tissue joins the endocardium to the myocardium.
- The myocardium is the middle and thickest layer of the heart wall. It consists of cardiac muscle surrounded by a framework of collagen. There are two types of cardiac muscle cells in the myocardium: pacemaker cells, which have the ability to contract easily; and pacemaker cells, which conduct electrical impulses that cause the cardiomyocytes to contract. About 99 percent of cardiac muscle cells are cardiomyocytes, and the remaining 1 percent are pacemaker cells. The myocardium is supplied with blood vessels and nerve fibers via the pericardium.
- The epicardium is the third and outer layer of the heart. It is also the innermost layer of the pericardium, a protective sac that encloses and protects the heart. Pericardium literally translates as "around the heart". The pericardium consists of two membranes (visceral pericardium called epicardium and parietal pericardium), between which there is a fluid-filled cavity. The fluid helps to cushion the heart and also lubricates its outer surface.

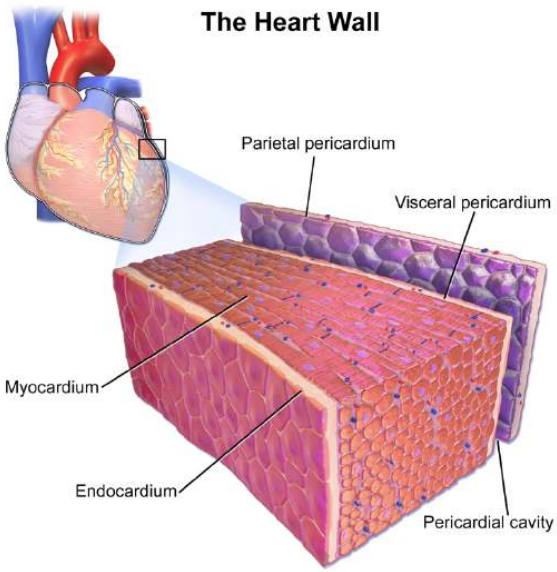


Figure 10.3.3: The wall of the heart is made up mainly of the myocardium, which consists largely of cardiac muscle.

HEART CHAMBERS

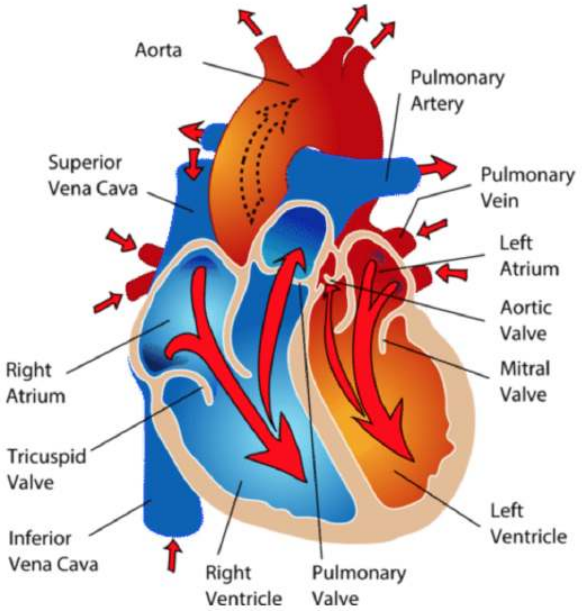


Figure 10.3.4: This cross-sectional diagram of the heart shows its four chambers and four valves. The red arrows indicate the direction of blood flow through the heart chambers.

As shown in Figures 10.3.4 and 10.3.5, the four chambers of the heart include two upper chambers called **atria (singular, atrium)** and two lower chambers called **ventricles**. The atria are also referred to as receiving chambers because blood coming into the heart first enters these two chambers. The right atrium receives blood from the upper and lower body through the superior vena cava and inferior vena cava, respectively; and the left atrium receives blood from the lungs through the pulmonary veins. The ventricles are also referred to as discharging chambers because the blood leaving the heart passes out through these two chambers. The right ventricle discharges blood to the lungs through the pulmonary artery, and the left ventricle discharges blood to the rest of the body through the aorta. The four chambers are separated from each other by dense connective tissue consisting mainly of collagen.

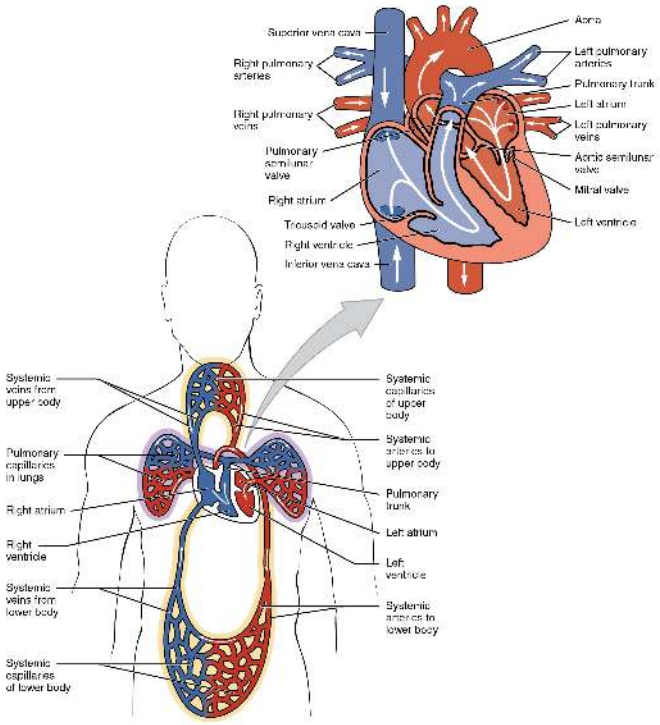


Figure 10.3.5 Dual System of the Human Blood Circulation Blood flows from the right atrium to the right ventricle, where it is pumped into the pulmonary circuit. The blood in the pulmonary artery branches is low in oxygen but relatively high in carbon dioxide. Gas exchange occurs in the pulmonary capillaries (oxygen into the blood, carbon dioxide out), and blood high in oxygen and low in carbon dioxide is returned to the left atrium. From here, blood enters the left ventricle, which pumps it into the systemic circuit. Following exchange in the systemic capillaries (oxygen and nutrients out of the capillaries and carbon dioxide and wastes in), blood returns to the right atrium and the cycle is repeated.

HEART VALVES

Valves ensure unidirectional blood flow through the heart. Figures 10.3.4 and 10.3.6 show the location of the four valves of the heart. The heart valves allow blood to flow from the atria to the ventricles and from the ventricles to the pulmonary artery and aorta. The valves are constructed in such a way that blood can flow through them in only one direction, thus preventing the backflow of blood. The atrioventricular valves are located between the atria and ventricles; the semilunar valves are located between the ventricles and aorta and pulmonary arteries, which are the major arteries exiting the heart. The four valves are the:

1. tricuspid valve (also called the right atrioventricular valve), which allows blood to flow from the right atrium to the right ventricle.
2. bicuspid valve (also called the mitral valve or the left atrioventricular valve), which allows blood to flow from the left atrium to the left ventricle.

3. pulmonary valve (also called the right semilunar valve), which allows blood to flow from the right ventricle to the pulmonary artery.
4. the aortic valve (also called the left semilunar valve), which allows blood to flow from the left ventricle to the aorta.

The tricuspid and mitral valves are also called atrioventricular (or AV) valves because they are found between the atrium and the ventricle. The pulmonary and aortic valves are also called semilunar valves because they are shaped like half-moons.

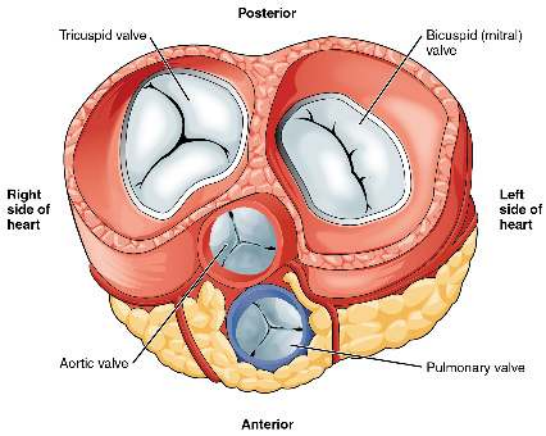


Figure **10.3.6** This transverse section through the heart slightly above the level of the atrioventricular septum reveals all four heart valves along the same plane. Heart Valves shown with the atria and major vessels removed, all four valves are clearly visible, although it is difficult to distinguish the three separate cusps of the tricuspid valve.

BLOOD CIRCULATION THROUGH THE HEART

Figure **10.3.7** shows how blood circulates through the chambers of the heart. The right atrium collects blood from two large veins, the superior vena cava (from the upper body) and the inferior vena cava (from the lower body). The blood that collects in the right atrium is pumped through the tricuspid valve into the right ventricle. From the right ventricle, the blood is pumped through the pulmonary valve into the pulmonary artery. The pulmonary artery carries the blood to the lungs, where it enters the pulmonary circulation, gives up carbon dioxide, and picks up oxygen. The oxygenated blood travels back from the lungs through the pulmonary veins (of which there are four) and enters the left atrium of the heart. From the left atrium, the blood is pumped through the bicuspid (mitral) valve into the left ventricle. From the left ventricle, the blood is pumped through the aortic valve into the aorta, which subsequently branches into smaller arteries that carry the blood throughout the rest of the body. After passing through capillaries and exchanging substances with cells, the blood returns to the right atrium via the superior vena cava and inferior vena cava, and the process begins anew.

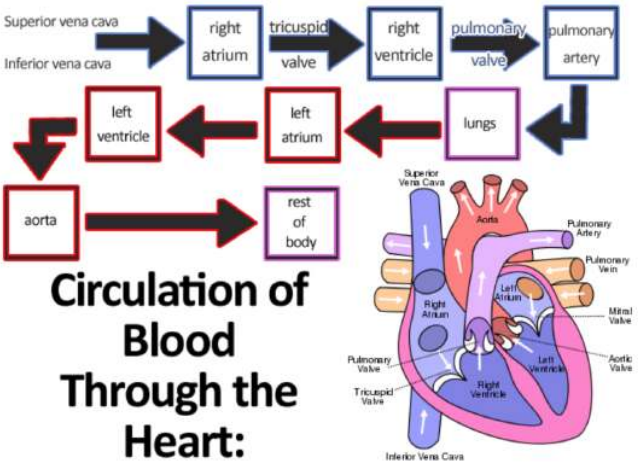


Figure **10.3.7**: The flow chart in this diagram summarizes the pathway blood takes as it flows into, through, and out of the heart. Trace the path of blood flow in the diagram of the heart as you follow it through the flow chart.

CORONARY CIRCULATION

You will recall that the heart is a remarkable pump composed largely of cardiac muscle cells that are incredibly active throughout life. Like all other cells, a cardiomyocyte requires a reliable supply of oxygen and nutrients, and a way to remove wastes, so it needs a dedicated, complex, and extensive coronary circulation. And because of the critical and nearly ceaseless activity of the heart throughout life, this need for a blood supply is even greater than for a typical cell.

The cardiomyocytes of the muscular walls of the heart are very active cells because they are responsible for the constant beating of the heart. These cells need a continuous supply of oxygen and nutrients. The carbon dioxide and waste products they produce also must be continuously removed. The blood vessels that carry blood to and from the heart muscle cells make up the coronary circulation. Note that the blood vessels of the coronary circulation supply heart tissues with blood and are different from the blood vessels that carry blood to and from the chambers of the heart as part of the general circulation. **Coronary arteries** supply oxygen-rich blood to the heart muscle cells. Coronary veins remove deoxygenated blood from the heart muscle cells.

- There are two coronary arteries: a right coronary artery that supplies the right side of the heart and a left coronary artery that supplies the left side of the heart. These arteries branch repeatedly into smaller and smaller arteries and finally into capillaries, which exchange gases, nutrients, and waste products with cardiomyocytes.
- At the back of the heart, small cardiac veins drain into larger veins and finally into the great cardiac vein, which empties into the right atrium. At the front of the heart, small cardiac veins drain directly into the right atrium.

CARDIAC CYCLE

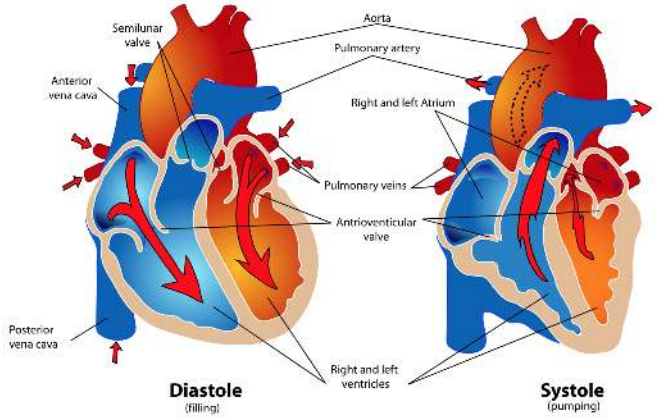


Figure **10.3.5**: Diastole is referred to as the filling stage because this is when the ventricles fill with blood. Systole is referred to as the pumping stage because this is when the ventricles pump blood out of the heart.

The cardiac cycle refers to a single complete heartbeat, which includes one iteration of the lub and dub sounds heard through a stethoscope. During the cardiac cycle, the atria and ventricles work in a coordinated fashion so that blood is pumped efficiently through and out of the heart. The cardiac cycle includes two parts, called diastole and systole, which are illustrated in Figure **10.3.5**.

- During **diastole,** the atria contract and pump blood into the ventricles, while the ventricles relax and fill with blood from the atria.
- During **systole,** the atria relax and collect blood from the lungs and body, while the ventricles contract and pump blood out of the heart.

ELECTRICAL STIMULATION OF THE HEART

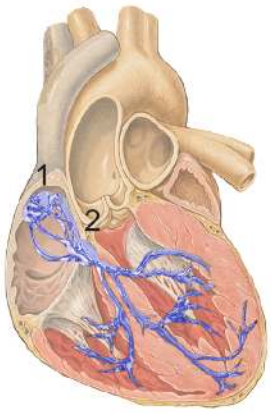


Figure **10.3.6**: In this drawing of the heart, the numbers refer to (1) the sinoatrial node and (2) the atrioventricular node. The blue lines in the drawing indicate the path of transmission of electrical signals through the heart.

The normal, rhythmical beating of the heart is called **sinus rhythm.** It is established by the heart's **pacemaker** cells, which are located in an area of the heart called the sinoatrial node (Figure **10.3.6**). The pacemaker cells create electrical signals by the movement of electrolytes (sodium, potassium, and calcium ions) into and out of the cells. For each cardiac cycle, an electrical signal rapidly travels first from the sinoatrial node to the right and left atria so they contract together. Then the signal travels to another node, called the atrioventricular node (also shown in Figure **10.3.6**), and from there to the right and left ventricles, which also contract together, just a split second after the atria contract.

The normal sinus rhythm of the heart is influenced by the autonomic nervous system through sympathetic and parasympathetic nerves. These nerves arise from two paired cardiovascular centers in the medulla of the brainstem. The parasympathetic nerves act to decrease the heart rate, and the sympathetic nerves act to increase the heart rate. Parasympathetic input normally predominates. Without it, the pacemaker cells of the heart would generate a resting heart rate of about 100 beats per minute, instead of a normal resting heart rate of about 72 beats per minute. The cardiovascular centers receive input from receptors throughout the body and act through the sympathetic nerves to increase the heart rate as needed. For example, increased physical activity is detected by receptors in muscles, joints, and tendons. These receptors send nerve impulses to the cardiovascular centers, causing sympathetic nerves to increase the heart rate. This allows more blood to flow to the muscles.

Besides the autonomic nervous system, other factors can also affect the heart rate. For example, thyroid hormones and adrenal hormones such as epinephrine can stimulate the heart to beat faster. The heart rate also increases when blood pressure drops or the body is dehydrated or overheated. On the other hand, cooling of the body and relaxation, among other factors, can contribute to a decrease in the heart rate.

FEATURE: HUMAN BIOLOGY IN THE NEWS

When a patient's heart is too diseased or damaged to sustain life, a heart transplant is likely to be the only long-term solution. The first successful heart transplant was undertaken in South Africa in 1967. For the past two decades in the United States, about 2,400 hearts were transplanted each year. The problem is that far too few hearts are available for transplant, and many patients die each year waiting for a life-saving heart to become available.

Hearts for transplant have to be used within four hours of the death of the donor. In addition, hearts can only come from brain-dead individuals whose hearts are removed while they are still healthy. Then the hearts are placed on ice inside picnic coolers to be transported to a waiting recipient. The four-hour window means that traffic jams, bad weather, or other unforeseen delays often result in a heart being in less than optimal condition by the time it arrives at its destination. Unfortunately, there is no way to know if the heart will start up again after it is transplanted until it is actually placed in the recipient's body. In up to seven percent of cases, a transplanted heart does not work and has to be removed.

A medical device company in Massachusetts named TransMedic was featured in many news stories when it developed the Organ Care System, commonly referred to as

"heart in a box." The system takes a new approach to maintain donated hearts until they are transplanted. The box is heated and contains a device that pumps oxygenated blood through the heart while it is being transported to the recipient. This extends the time up to 12 hours that the heart can remain healthy and usable. It also allows the heart to be monitored so it is kept in optimal condition while it is on the route. The end result, ideally, is that the recipient gets a healthier heart with less chance of failure of the new organ and a lower risk of death.

As of mid-2016, the heart-in-a-box system had already been used for several successful heart transplants in other countries. At that time, the system was also undergoing clinical trials in the United States to assess its effectiveness in promoting positive recipient outcomes. Developers of the heart-in-a-box predict that the system could increase the number of usable donor hearts by as much as 30 percent, thus greatly increasing the number of patients who are saved from death due to heart failure.

REVIEW

1. What is the heart, where is located, and what is its function?
2. Outline the structure of the heart.
3. Describe the coronary circulation.
4. Summarize how blood flows into, through, and out of the heart.
5. Define the cardiac cycle, and identify its two parts.
6. Explain what controls the beating of the heart.
7. a. What are the two types of cardiac muscle cells in the myocardium?

   b. What are the differences between these two types of cells?
8. Match each of the three layers of the walls of the heart (endocardium, myocardium, and pericardium) with the description that best matches it below.

   a. Protects the heart

   b. Covers the heart valves

   c. Responsible for the beating of the heart
9. Is the blood flowing through the mitral valve oxygenated or deoxygenated? Explain your reasoning.
10. *True or False.* The coronary arteries carry blood to the heart.
11. *True or False.* Systole is when the heart is contracting, diastole is when the heart is fully relaxed.
12. Explain why the blood from the cardiac veins empties into the right atrium of the heart. Focus on function rather than anatomy in your answer.

EXPLORE MORE

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10.4: Cardiac Cycle and Electrical Activity

Cardiac Cycle Overview

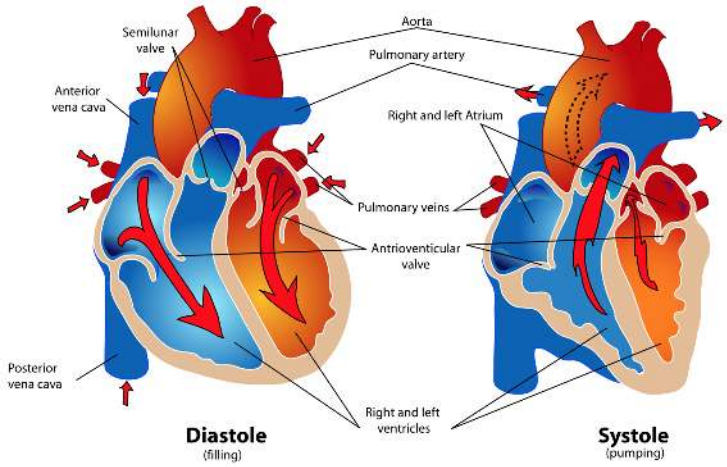


Figure 10.4.1: Diastole is referred to as the filling stage because this is when the ventricles fill with blood. Systole is referred to as the pumping stage because this is when the ventricles pump blood out of the heart.

The cardiac cycle refers to a single complete heartbeat, which includes one iteration of the lub and dub sounds heard through a stethoscope. During the cardiac cycle, the atria and ventricles work in a coordinated fashion so that blood is pumped efficiently through and out of the heart. The cardiac cycle includes two parts, called diastole and systole, which are illustrated in Figure 10.4.1.

- During **diastole,** the atria contract and pump blood into the ventricles, while the ventricles relax and fill with blood from the atria.
- During **systole,** the atria relax and collect blood from the lungs and body, while the ventricles contract and pump blood out of the heart.

Electrical Stimulation of the Heart

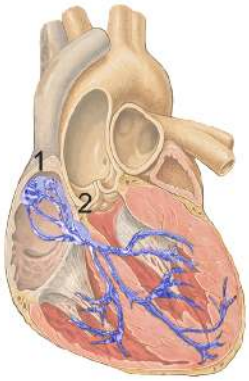


Figure 10.4.2: In this drawing of the heart, the numbers refer to (1) the sinoatrial node and (2) the atrioventricular node. The blue lines in the drawing indicate the path of transmission of electrical signals through the heart.

The normal, rhythmical beating of the heart is called **sinus rhythm.** It is established by the heart's **pacemaker** cells, which are located in an area of the heart called the sinoatrial (SA) node (Figure 10.4.2). The pacemaker cells create electrical signals by the movement of electrolytes (sodium, potassium, and calcium ions) into and out of the cells. For each cardiac cycle, an electrical signal rapidly travels first from the sinoatrial node to the right and left atria so they contract together. Then the signal travels to another node, called the atrioventricular (AV) node (also shown in Figure 10.4.2), and from there to the right and left ventricles, which also contract together, just a split second after the atria contract.

The normal sinus rhythm of the heart is influenced by the autonomic nervous system through sympathetic and parasympathetic nerves. These nerves arise from two paired cardiovascular centers in the medulla of the brainstem. The parasympathetic nerves act

to decrease the heart rate, and the sympathetic nerves act to increase the heart rate. Parasympathetic input normally predominates. Without it, the pacemaker cells of the heart would generate a resting heart rate of about 100 beats per minute, instead of a normal resting heart rate of about 72 beats per minute. The cardiovascular centers receive input from receptors throughout the body and act through the sympathetic nerves to increase the heart rate as needed. For example, increased physical activity is detected by receptors in muscles, joints, and tendons. These receptors send nerve impulses to the cardiovascular centers, causing sympathetic nerves to increase the heart rate. This allows more blood to flow to the muscles.

Besides the autonomic nervous system, other factors can also affect the heart rate. For example, thyroid hormones and adrenal hormones such as epinephrine can stimulate the heart to beat faster. The heart rate also increases when blood pressure drops or the body is dehydrated or overheated. On the other hand, cooling of the body and relaxation, among other factors, can contribute to a decrease in the heart rate.

Recall that cardiac muscle shares a few characteristics with both skeletal muscle and smooth muscle, but it has some unique properties of its own. Not the least of these exceptional properties is its ability to initiate an electrical potential at a fixed rate that spreads rapidly from cell to cell to trigger the contractile mechanism. This property is known as autorhythmicity. Neither smooth nor skeletal muscle can do this. Even though cardiac muscle has autorhythmicity, heart rate is modulated by the endocrine and nervous systems.

There are two major types of cardiac muscle cells: myocardial contractile cells and myocardial conducting cells. The myocardial contractile cells constitute the bulk (99 percent) of the cells in the atria and ventricles. Contractile cells conduct impulses and are responsible for contractions that pump blood through the body. The myocardial conducting cells (1 percent of the cells) form the conduction system of the heart. Except for Purkinje cells, they are generally much smaller than the contractile cells and have few of the myofibrils or filaments needed for contraction. Their function is similar in many respects to neurons, although they are specialized muscle cells. Myocardial conduction cells initiate and propagate the action potential (the electrical impulse) that travels throughout the heart and triggers the contractions that propel the blood.

Structure of Cardiac Muscle

Compared to the giant cylinders of skeletal muscle, cardiac muscle cells, or cardiomyocytes, are considerably shorter with much smaller diameters. Cardiac muscle also demonstrates striations, the alternating pattern of dark A bands and light I bands attributed to the precise arrangement of the myofilaments and fibrils that are organized in sarcomeres along the length of the cell (Figure 10.4.3 a). These contractile elements are virtually identical to skeletal muscle. T (transverse) tubules penetrate from the surface plasma membrane, the sarcolemma, to the interior of the cell, allowing the electrical impulse to reach the interior. The T tubules are only found at the Z discs, whereas in skeletal muscle, they are found at the junction of the A and I bands. Therefore, there are one-half as many T tubules in cardiac muscle as in skeletal muscle. In addition, the sarcoplasmic reticulum stores few calcium ions, so most of the calcium ions must come from outside the cells. The result is a slower onset of contraction. Mitochondria are plentiful, providing energy for the contractions of the heart. Typically, cardiomyocytes have a single, central nucleus, but two or more nuclei may be found in some cells.

Cardiac muscle cells branch freely. A junction between two adjoining cells is marked by a critical structure called an intercalated disc, which helps support the synchronized contraction of the muscle (Figure 10.4.3 **b**). The sarcolemmas from adjacent cells bind together at the intercalated discs. They consist of desmosomes, specialized linking proteoglycans, tight junctions, and large numbers of gap junctions that allow the passage of ions between the cells and help to synchronize the contraction (Figure 19.17**c**). Intercellular connective tissue also helps to bind the cells together. The importance of strongly binding these cells together is necessitated by the forces exerted by contraction.

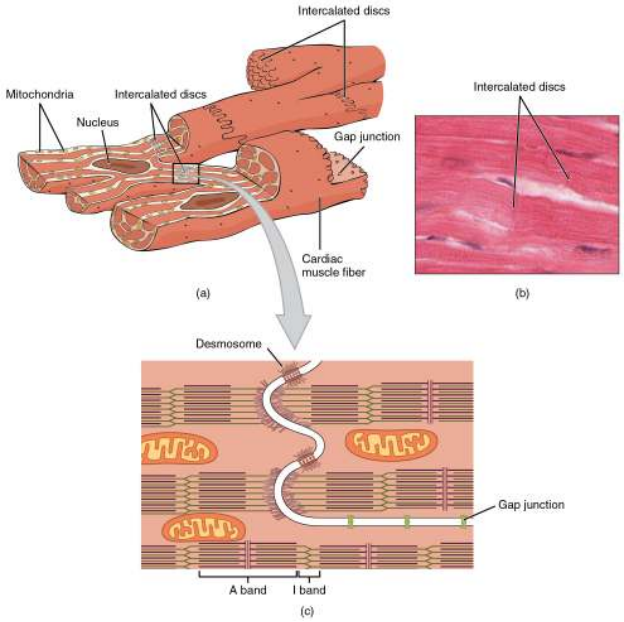


Figure 10.4.3: Cardiac Muscle (a) Cardiac muscle cells have myofibrils composed of myofilaments arranged in sarcomeres, T tubules to transmit the impulse from the sarcolemma to the interior of the cell, numerous mitochondria for energy, and intercalated discs that are found at the junction of different cardiac muscle cells. (b) A photomicrograph of cardiac muscle cells shows the nuclei and intercalated discs. (c) An intercalated disc connects cardiac muscle cells and consists of desmosomes and gap junctions. LM × 1600. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

Cardiac muscle undergoes aerobic respiration patterns, primarily metabolizing lipids and carbohydrates. Myoglobin, lipids, and glycogen are all stored within the cytoplasm. Cardiac muscle cells undergo twitch-type contractions with long refractory periods followed by brief relaxation periods. The relaxation is essential so the heart can fill with blood for the next cycle. The refractory period is very long to prevent the possibility of tetany, a condition in which muscle remains involuntarily contracted. In the heart, tetany is not compatible with life, since it would prevent the heart from pumping blood.

Everyday Connection

Repair and Replacement

Damaged cardiac muscle cells have extremely limited abilities to repair themselves or to replace dead cells via mitosis. Recent evidence indicates that at least some stem cells remain within the heart that continue to divide and at least potentially replace these dead cells. However, newly formed or repaired cells are rarely as functional as the original cells, and cardiac function is reduced. In the event of a heart attack or MI, dead cells are often replaced by patches of scar tissue. Autopsies performed on individuals who had successfully received heart transplants show some proliferation of original cells. If researchers can unlock the mechanism that generates new cells and restore full mitotic capabilities to heart muscle, the prognosis for heart attack survivors will be greatly enhanced. To date, myocardial cells produced within the patient (*in situ*) by cardiac stem cells seem to be nonfunctional, although those grown in Petri dishes (*in vitro*) do beat. Perhaps soon this mystery will be solved, and new advances in treatment will be commonplace.

Conduction System of the Heart

If embryonic heart cells are separated into a Petri dish and kept alive, each is capable of generating its own electrical impulse followed by contraction. When two independently beating embryonic cardiac muscle cells are placed together, the cell with the higher inherent rate sets the pace, and the impulse spreads from the faster to the slower cell to trigger a contraction. As more cells are joined together, the fastest cell continues to assume control of the rate. A fully developed adult heart maintains the capability of generating its own electrical impulse, triggered by the fastest cells, as part of the cardiac conduction system. The components of the cardiac conduction system include the sinoatrial node, the atrioventricular node, the atrioventricular bundle, the atrioventricular bundle branches, and the Purkinje cells (Figure 10.4.4).

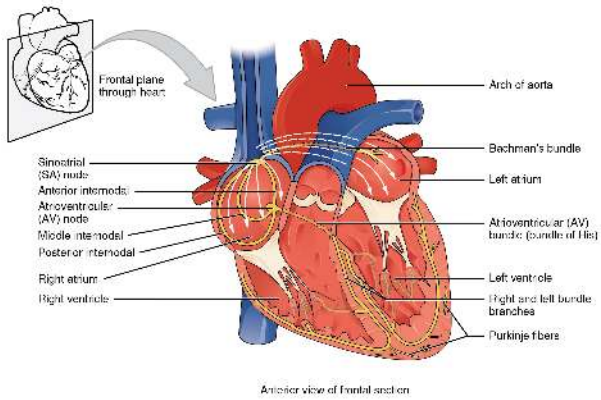


Figure 10.4.4: Conduction System of the Heart Specialized conducting components of the heart include the sinoatrial node, the internodal pathways, the atrioventricular node, the atrioventricular bundle, the right and left bundle branches, and the Purkinje fibers.

Sinoatrial (SA) Node

Normal cardiac rhythm is established by the sinoatrial (SA) node, a specialized clump of myocardial conducting cells located in the superior and posterior walls of the right atrium in close proximity to the orifice of the superior vena cava. The SA node has the highest inherent rate of depolarization and is known as the pacemaker of the heart. It initiates the sinus rhythm, or normal electrical pattern followed by contraction of the heart.

This impulse spreads from its initiation in the SA node throughout the atria through specialized internodal pathways, to the atrial myocardial contractile cells and the atrioventricular node. The internodal pathways consist of three bands (anterior, middle, and posterior) that lead directly from the SA node to the next node in the conduction system, the atrioventricular node (see Figure 10.4.4). The impulse takes approximately 50 ms (milliseconds) to travel between these two nodes. As the impulse reaches the atrioventricular septum, the connective tissue of the cardiac skeleton prevents the impulse from spreading into the myocardial cells in the ventricles except at the atrioventricular node. Figure 10.4.5 illustrates the initiation of the impulse in the SA node that then spreads the impulse throughout the atria to the atrioventricular node.

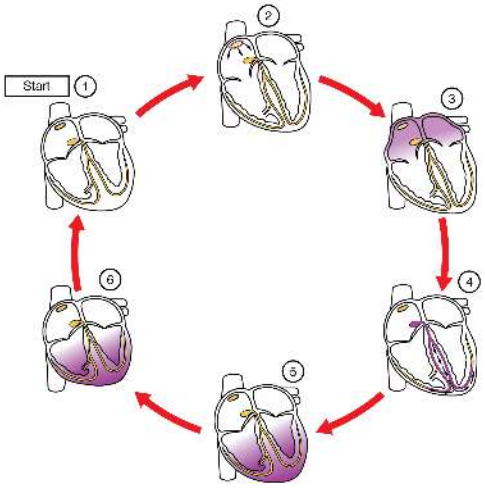


Figure 10.4.5: Cardiac Conduction (1) The sinoatrial (SA) node and the remainder of the conduction system are at rest. (2) The SA node initiates the action potential, which sweeps across the atria. (3) After reaching the atrioventricular node, there is a delay of approximately 100 ms that allows the atria to complete pumping blood before the impulse is transmitted to the atrioventricular bundle. (4) Following the delay, the impulse travels through the atrioventricular bundle and bundle branches to the Purkinje fibers, and also reaches the right papillary muscle via the moderator band. (5) The impulse spreads to the contractile fibers of the ventricle. (6) Ventricular contraction begins.

The electrical event, the wave of depolarization, is the trigger for muscular contraction. The wave of depolarization begins in the right atrium, and the impulse spreads across the superior portions of both atria and then down through the contractile cells. The

contractile cells then begin contraction from the superior to the inferior portions of the atria, efficiently pumping blood into the ventricles.

Atrioventricular (AV) Node

The atrioventricular (AV) node is a second clump of specialized myocardial conductive cells, located in the inferior portion of the right atrium within the atrioventricular septum. The septum prevents the impulse from spreading directly to the ventricles without passing through the AV node. There is a critical pause before the AV node depolarizes and transmits the impulse to the atrioventricular bundle (see Figure 10.4.5, step 3). This delay in transmission is partially attributable to the small diameter of the cells of the node, which slow the impulse. Also, conduction between nodal cells is less efficient than between conducting cells. These factors mean that it takes the impulse approximately 100 ms to pass through the node. This pause is critical to heart function, as it allows the atrial cardiomyocytes to complete their contraction that pumps blood into the ventricles before the impulse is transmitted to the cells of the ventricle itself. With extreme stimulation by the SA node, the AV node can transmit impulses maximally at 220 per minute. This establishes the typical maximum heart rate in a healthy young individual. Damaged hearts or those stimulated by drugs can contract at higher rates, but at these rates, the heart can no longer effectively pump blood.

Atrioventricular Bundle (Bundle of His), Bundle Branches, and Purkinje Fibers

Arising from the AV node, the atrioventricular bundle, or bundle of His, proceeds through the interventricular septum before dividing into two atrioventricular bundle branches, commonly called the left and right bundle branches. The left bundle branch has two fascicles. The left bundle branch supplies the left ventricle, and the right bundle branch the right ventricle. Since the left ventricle is much larger than the right, the left bundle branch is also considerably larger than the right. Portions of the right bundle branch are found in the moderator band and supply the right papillary muscles. Because of this connection, each papillary muscle receives the impulse at approximately the same time, so they begin to contract simultaneously just prior to the remainder of the myocardial contractile cells of the ventricles. This is believed to allow tension to develop on the chordae tendineae prior to right ventricular contraction. There is no corresponding moderator band on the left. Both bundle branches descend and reach the apex of the heart where they connect with the Purkinje fibers (see Figure 10.4.5, step 4). This passage takes approximately 25 ms.

The Purkinje fibers are additional myocardial conductive fibers that spread the impulse to the myocardial contractile cells in the ventricles. They extend throughout the myocardium from the apex of the heart toward the atrioventricular septum and the base of the heart. The Purkinje fibers have a fast inherent conduction rate, and the electrical impulse reaches all of the ventricular muscle cells in about 75 ms (see Figure 10.4.5, step 5). Since the electrical stimulus begins at the apex, the contraction also begins at the apex and travels toward the base of the heart, similar to squeezing a tube of toothpaste from the bottom. This allows the blood to be pumped out of the ventricles and into the aorta and pulmonary trunk. The total time elapsed from the initiation of the impulse in the SA node until depolarization of the ventricles is approximately 225 ms.

Comparative Rates of Conduction System Firing

Since the SA node is the pacemaker, it reaches threshold faster than any other component of the conduction system. It will initiate the impulses spreading to the other conducting cells. The SA node, without nervous or endocrine control, would initiate a heart impulse approximately 80–100 times per minute. Although each component of the conduction system is capable of generating its own impulse, the rate progressively slows as you proceed from the SA node to the Purkinje fibers. Without the SA node, the AV node would generate a heart rate of 40–60 beats per minute. If the AV node were blocked, the atrioventricular bundle would fire at a rate of approximately 30–40 impulses per minute. The bundle branches would have an inherent rate of 20–30 impulses per minute, and the Purkinje fibers would fire at 15–20 impulses per minute. While a few exceptionally trained aerobic athletes demonstrate resting heart rates in the range of 30–40 beats per minute (the lowest recorded figure is 28 beats per minute for Miguel Indurain, a cyclist), for most individuals, rates lower than 50 beats per minute would indicate a condition called bradycardia. Depending upon the specific individual, as rates fall much below this level, the heart would be unable to maintain adequate flow of blood to vital tissues, initially resulting in decreasing loss of function across the systems, unconsciousness, and ultimately death.

Electrocardiogram

By careful placement of surface electrodes on the body, it is possible to record the complex, compound electrical signal of the heart. This tracing of the electrical signal is the electrocardiogram (ECG), also commonly abbreviated EKG (K coming kardiology,

from the German term for cardiology). Careful analysis of the ECG reveals a detailed picture of both normal and abnormal heart function, and is an indispensable clinical diagnostic tool.

A normal ECG tracing is presented in Figure 10.4.6. Each component, segment, and interval is labeled and corresponds to important electrical events, demonstrating the relationship between these events and contraction in the heart.

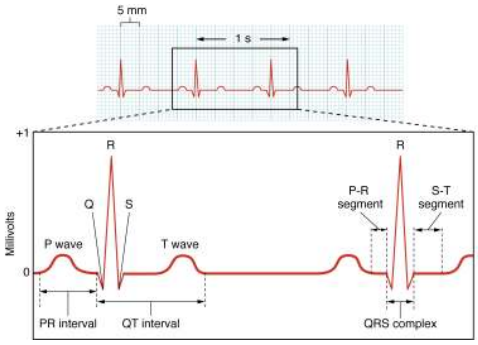


Figure 10.4.6: Electrocardiogram A normal tracing shows the P wave, QRS complex, and T wave. Also indicated are the PR, QT, QRS, and ST intervals, plus the P-R and S-T segments.

There are five prominent points on the ECG: the P wave, the QRS complex, and the T wave. The small P wave represents the depolarization of the atria. The atria begin contracting approximately 25 ms after the start of the P wave. The large QRS complex represents the depolarization of the ventricles, which requires a much stronger electrical signal because of the larger size of the ventricular cardiac muscle. The ventricles begin to contract as the QRS reaches the peak of the R wave. Lastly, the T wave represents the repolarization of the ventricles. The repolarization of the atria occurs during the QRS complex, which masks it on an ECG.The major segments and intervals of an ECG tracing are indicated in Figure 10.4.6. Segments are defined as the regions between two waves. Intervals include one segment plus one or more waves. For example, the PR segment begins at the end of the P wave and ends at the beginning of the QRS complex. The PR interval starts at the beginning of the P wave and ends with the beginning of the QRS complex. The PR interval is more clinically relevant, as it measures the duration from the beginning of atrial depolarization (the P wave) to the initiation of the QRS complex. Since the Q wave may be difficult to view in some tracings, the measurement is often extended to the R that is more easily visible. Should there be a delay in passage of the impulse from the SA node to the AV node, it would be visible in the PR interval. Figure 10.4.7 correlates events of heart contraction to the corresponding segments and intervals of an ECG.

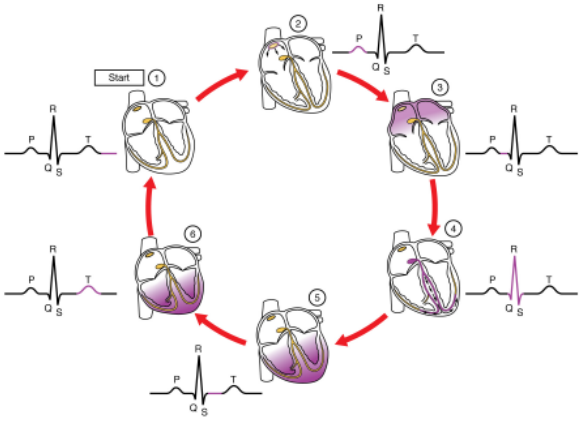


Figure 10.4.7: ECG Tracing Correlated to the Cardiac Cycle This diagram correlates an ECG tracing with the electrical and mechanical events of a heart contraction. Each segment of an ECG tracing corresponds to one event in the cardiac cycle.

Everyday Connection

ECG Abnormalities

Occassionally, an area of the heart other than the SA node will initiate an impulse that will be followed by a premature contraction. Such an area, which may actually be a component of the conduction system or some other contractile cells, is known as an ectopic focus or ectopic pacemaker. An ectopic focus may be stimulated by localized ischemia; exposure to certain drugs, including caffeine, digitalis, or acetylcholine; elevated stimulation by both sympathetic or parasympathetic divisions of the autonomic nervous system; or a number of disease or pathological conditions. Occasional occurences are generally transitory and nonlife threatening, but if the condition becomes chronic, it may lead to either an arrhythmia, a deviation from the normal pattern of impulse conduction and contraction, or to fibrillation, an uncoordinated beating of the heart.

While interpretation of an ECG is possible and extremely valuable after some training, a full understanding of the complexities and intricacies generally requires several years of experience. In general, the size of the electrical variations, the duration of the events, and detailed vector analysis provide the most comprehensive picture of cardiac function. For example, an amplified P wave may indicate enlargement of the atria, an enlarged Q wave may indicate a MI, and an enlarged suppressed or inverted Q wave often indicates enlarged ventricles. T waves often appear flatter when insufficient oxygen is being delivered to the myocardium. An elevation of the ST segment above baseline is often seen in patients with an acute MI, and may appear depressed below the baseline when hypoxia is occurring.

As useful as analyzing these electrical recordings may be, there are limitations. For example, not all areas suffering a MI may be obvious on the ECG. Additionally, it will not reveal the effectiveness of the pumping, which requires further testing, such as an ultrasound test called an echocardiogram or nuclear medicine imaging. It is also possible for there to be pulseless electrical activity, which will show up on an ECG tracing, although there is no corresponding pumping action. Common abnormalities that may be detected by the ECGs are shown in Figure 10.4.9.

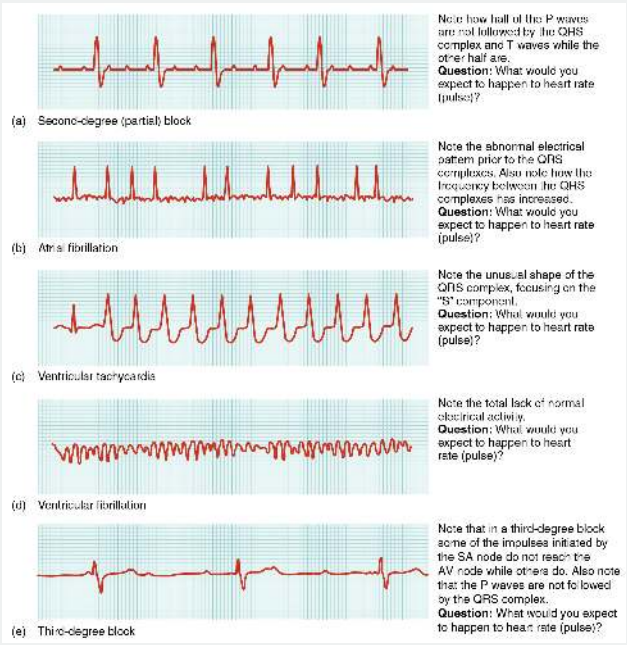


Figure 10.4.9: Common ECG Abnormalities (a) In a second-degree or partial block, one-half of the P waves are not followed by the QRS complex and T waves while the other half are. (b) In atrial fibrillation, the electrical pattern is abnormal prior to the QRS complex, and the frequency between the QRS complexes has increased. (c) In ventricular tachycardia, the shape of the QRS complex is abnormal. (d) In ventricular fibrillation, there is no normal electrical activity. (e) In a third-degree block, there is no correlation between atrial activity (the P wave) and ventricular activity (the QRS complex).

Everyday Connection

External Automated Defibrillators

In the event that the electrical activity of the heart is severely disrupted, cessation of electrical activity or fibrillation may occur. In fibrillation, the heart beats in a wild, uncontrolled manner, which prevents it from being able to pump effectively. Atrial fibrillation (see Figure 10.4.9**b**) is a serious condition, but as long as the ventricles continue to pump blood, the patient's life may not be in immediate danger. Ventricular fibrillation (see Figure 10.4.9**d**) is a medical emergency that requires life support, because the ventricles are not effectively pumping blood. In a hospital setting, it is often described as "code blue." If untreated for as little as a few minutes, ventricular fibrillation may lead to brain death. The most common treatment is defibrillation, which uses special paddles to apply a charge to the heart from an external electrical source in an attempt to establish a normal sinus rhythm (Figure 10.4.10). A defibrillator effectively stops the heart so that the SA node can trigger a normal conduction cycle. Because of their effectiveness in reestablishing a normal sinus rhythm, external automated defibrillators (EADs) are being placed in areas frequented by large numbers of people, such as schools, restaurants, and airports. These devices contain simple and direct verbal instructions that can be followed by nonmedical personnel in an attempt to save a life.



Figure 10.4.10 Defibrillators (a) An external automatic defibrillator can be used by nonmedical personnel to reestablish a normal sinus rhythm in a person with fibrillation. (b) Defibrillator paddles are more commonly used in hospital settings. (credit b: "widerider107"/flickr.com)

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10.5: Cardiac Cycle

Learning Objectives

By the end of this section, you will be able to:

- Describe the relationship between blood pressure and blood flow
- Summarize the events of the cardiac cycle
- Compare atrial and ventricular systole and diastole
- Relate heart sounds detected by auscultation to action of heart's valves

The period of time that begins with contraction of the atria and ends with ventricular relaxation is known as the cardiac cycle (Figure 10.5.1). The period of contraction that the heart undergoes while it pumps blood into circulation is called systole. The period of relaxation that occurs as the chambers fill with blood is called diastole. Both the atria and ventricles undergo systole and diastole, and it is essential that these components be carefully regulated and coordinated to ensure blood is pumped efficiently to the body.

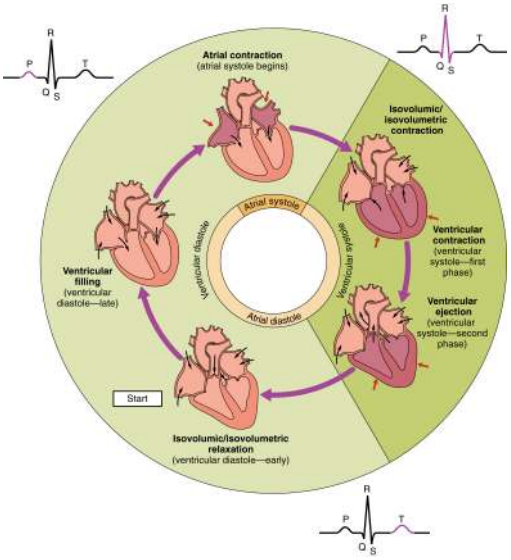


Figure 10.5.1: Overview of the Cardiac Cycle The cardiac cycle begins with atrial systole and progresses to ventricular systole, atrial diastole, and ventricular diastole, when the cycle begins again. Correlations to the ECG are highlighted.

Pressures and Flow

Fluids, whether gases or liquids, are materials that flow according to pressure gradients—that is, they move from regions that are higher in pressure to regions that are lower in pressure. Accordingly, when the heart chambers are relaxed (diastole), blood will flow into the atria from the veins, which are higher in pressure. As blood flows into the atria, the pressure will rise, so the blood will initially move passively from the atria into the ventricles. When the action potential triggers the muscles in the atria to contract (atrial systole), the pressure within the atria rises further, pumping blood into the ventricles. During ventricular systole, pressure rises in the ventricles, pumping blood into the pulmonary trunk from the right ventricle and into the aorta from the left ventricle. Again, as you consider this flow and relate it to the conduction pathway, the elegance of the system should become apparent.

Phases of the Cardiac Cycle

At the beginning of the cardiac cycle, both the atria and ventricles are relaxed (diastole). Blood is flowing into the right atrium from the superior and inferior venae cavae and the coronary sinus. Blood flows into the left atrium from the four pulmonary veins. The two atrioventricular valves, the tricuspid and mitral valves, are both open, so blood flows unimpeded from the atria and into the ventricles. Approximately 70–80 percent of ventricular filling occurs by this method. The two semilunar valves, the pulmonary and aortic valves, are closed, preventing backflow of blood into the right and left ventricles from the pulmonary trunk on the right and the aorta on the left.

Atrial Systole and Diastole

Contraction of the atria follows depolarization, represented by the P wave of the ECG. As the atrial muscles contract from the superior portion of the atria toward the atrioventricular septum, pressure rises within the atria and blood is pumped into the ventricles through the open atrioventricular (tricuspid, and mitral or bicuspid) valves. At the start of atrial systole, the ventricles are normally filled with approximately 70–80 percent of their capacity due to inflow during diastole. Atrial contraction, also referred to as the "atrial kick," contributes the remaining 20–30 percent of filling (see Figure 10.5.1). Atrial systole lasts approximately 100 ms and ends prior to ventricular systole, as the atrial muscle returns to diastole and blood flow into the atria resumes.

Ventricular Systole

Ventricular systole (see Figure 10.5.1) follows the depolarization of the ventricles and is represented by the QRS complex in the ECG. It may be conveniently divided into two phases, lasting a total of 270 ms. At the end of atrial systole and just prior to ventricular contraction, the ventricles contain approximately 130 mL blood in a resting adult in a standing position. This volume is known as the end diastolic volume (EDV) or preload.

Initially, as the muscles in the ventricle contract, the pressure of the blood within the chamber rises, but it is not yet high enough to open the semilunar (pulmonary and aortic) valves and be ejected from the heart. However, blood pressure quickly rises above that of the atria that are now relaxed and in diastole. This increase in pressure causes blood to flow back toward the atria, closing the tricuspid and mitral valves. Since blood is not being ejected from the ventricles at this early stage, the volume of blood within the chamber remains constant. Consequently, this initial phase of ventricular systole is known as isovolumic contraction, also called isovolumetric contraction (see Figure 10.5.1).

In the second phase of ventricular systole, the ventricular ejection phase, the contraction of the ventricular muscle has raised the pressure within the ventricle to the point that it is greater than the pressures in the pulmonary trunk and the aorta. Blood is pumped from the heart, pushing open the pulmonary and aortic semilunar valves. Pressure generated by the left ventricle will be appreciably greater than the pressure generated by the right ventricle, since the existing pressure in the aorta will be so much higher. Nevertheless, both ventricles pump the same amount of blood. This quantity is referred to as stroke volume. Stroke volume will normally be in the range of 70–80 mL. Since ventricular systole began with an EDV of approximately 130 mL of blood, this means that there is still 50–60 mL of blood remaining in the ventricle following contraction. This volume of blood is known as the end systolic volume (ESV).

Ventricular Diastole

Ventricular relaxation, or diastole, follows repolarization of the ventricles and is represented by the T wave of the ECG. It too is divided into two distinct phases and lasts approximately 430 ms.

During the early phase of ventricular diastole, as the ventricular muscle relaxes, pressure on the remaining blood within the ventricle begins to fall. When pressure within the ventricles drops below pressure in both the pulmonary trunk and aorta, blood flows back toward the heart, producing the dicrotic notch (small dip) seen in blood pressure tracings. The semilunar valves close to prevent backflow into the heart. Since the atrioventricular valves remain closed at this point, there is no change in the volume of blood in the ventricle, so the early phase of ventricular diastole is called the isovolumic ventricular relaxation phase, also called isovolumetric ventricular relaxation phase (see Figure 10.5.1).

In the second phase of ventricular diastole, called late ventricular diastole, as the ventricular muscle relaxes, pressure on the blood within the ventricles drops even further. Eventually, it drops below the pressure in the atria. When this occurs, blood flows from the atria into the ventricles, pushing open the tricuspid and mitral valves. As pressure drops within the ventricles, blood flows from the major veins into the relaxed atria and from there into the ventricles. Both chambers are in diastole, the atrioventricular valves are open, and the semilunar valves remain closed (see Figure 10.5.1). The cardiac cycle is complete.

Figure 10.5.2 illustrates the relationship between the cardiac cycle and the ECG.

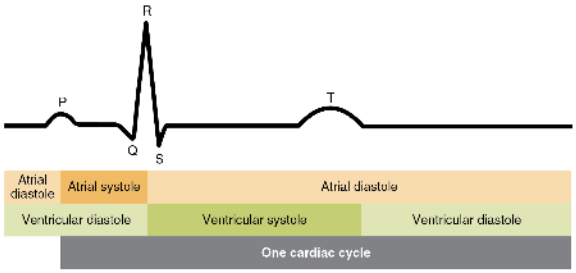


Figure 10.5.2: Relationship between the Cardiac Cycle and ECG Initially, both the atria and ventricles are relaxed (diastole). The P wave represents depolarization of the atria and is followed by atrial contraction (systole). Atrial systole extends until the QRS complex, at which point, the atria relax. The QRS complex represents depolarization of the ventricles and is followed by ventricular contraction. The T wave represents the repolarization of the ventricles and marks the beginning of ventricular relaxation.

Heart Sounds

One of the simplest, yet effective, diagnostic techniques applied to assess the state of a patient's heart is auscultation using a stethoscope.

In a normal, healthy heart, there are only two audible heart sounds: S_1 and S_2. S_1 is the sound created by the closing of the atrioventricular valves during ventricular contraction and is normally described as a "lub," or first heart sound. The second heart sound, S_2, is the sound of the closing of the semilunar valves during ventricular diastole and is described as a "dub" (Figure 10.5.3). In both cases, as the valves close, the openings within the atrioventricular septum guarded by the valves will become reduced, and blood flow through the opening will become more turbulent until the valves are fully closed. There is a third heart sound, S_3, but it is rarely heard in healthy individuals. It may be the sound of blood flowing into the atria, or blood sloshing back and forth in the ventricle, or even tensing of the chordae tendineae. S_3 may be heard in youth, some athletes, and pregnant people. If the sound is heard later in life, it may indicate congestive heart failure, warranting further tests. Some cardiologists refer to the collective S_1, S_2, and S_3 sounds as the "Kentucky gallop," because they mimic those produced by a galloping horse. The fourth heart sound, S_4, results from the contraction of the atria pushing blood into a stiff or hypertrophic ventricle, indicating failure of the left ventricle. S_4 occurs prior to S_1 and the collective sounds S_4, S_1, and S_2 are referred to by some cardiologists as the "Tennessee gallop," because of their similarity to the sound produced by a galloping horse with a different gait. A few individuals may have both S_3 and S_4, and this combined sound is referred to as S_7.

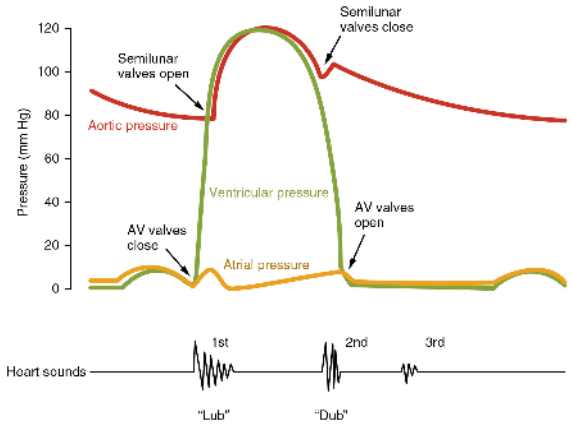


Figure 10.5.3: Heart Sounds and the Cardiac Cycle In this illustration, the x-axis reflects time with a recording of the heart sounds. The y-axis represents pressure.

The term murmur is used to describe an unusual sound coming from the heart that is caused by the turbulent flow of blood. Murmurs are graded on a scale of 1 to 6, with 1 being the most common, the most difficult sound to detect, and the least serious. The most severe is a 6. Phonocardiograms or auscultograms can be used to record both normal and abnormal sounds using specialized electronic stethoscopes.

During auscultation, it is common practice for the clinician to ask the patient to breathe deeply. This procedure not only allows for listening to airflow, but it may also amplify heart murmurs. Inhalation increases blood flow into the right side of the heart and may increase the amplitude of right-sided heart murmurs. Expiration partially restricts blood flow into the left side of the heart and may amplify left-sided heart murmurs. Figure 10.5.4 indicates proper placement of the bell of the stethoscope to facilitate auscultation.

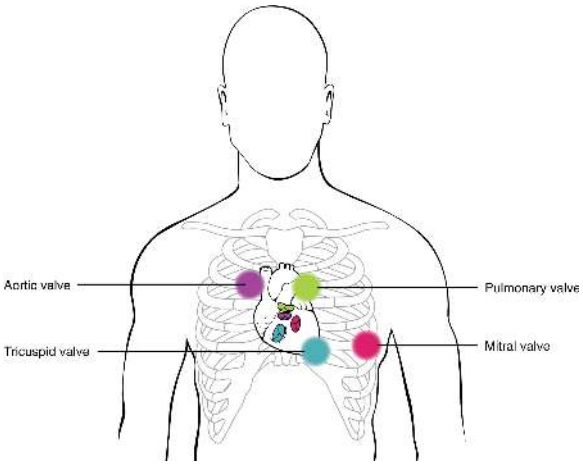


Figure 10.5.4: Stethoscope Placement for Auscultation Proper placement of the bell of the stethoscope facilitates auscultation. At each of the four locations on the chest, a different valve can be heard.

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10.6: BLOOD VESSELS

BULGING VEINS

Why do bodybuilders have such prominent veins? Bulging muscles push surface veins closer to the skin. Couple that with a virtual lack of subcutaneous fat, and you have bulging veins as well as bulging muscles. Veins are one of three major types of blood vessels in the cardiovascular system.



Figure **10.6.1**: 2012 Hong Kong Bodybuilding Championship participant

TYPES OF BLOOD VESSELS

Blood vessels are part of the cardiovascular system that transports blood throughout the human body. There are three major types of blood vessels: veins, arteries, and capillaries.

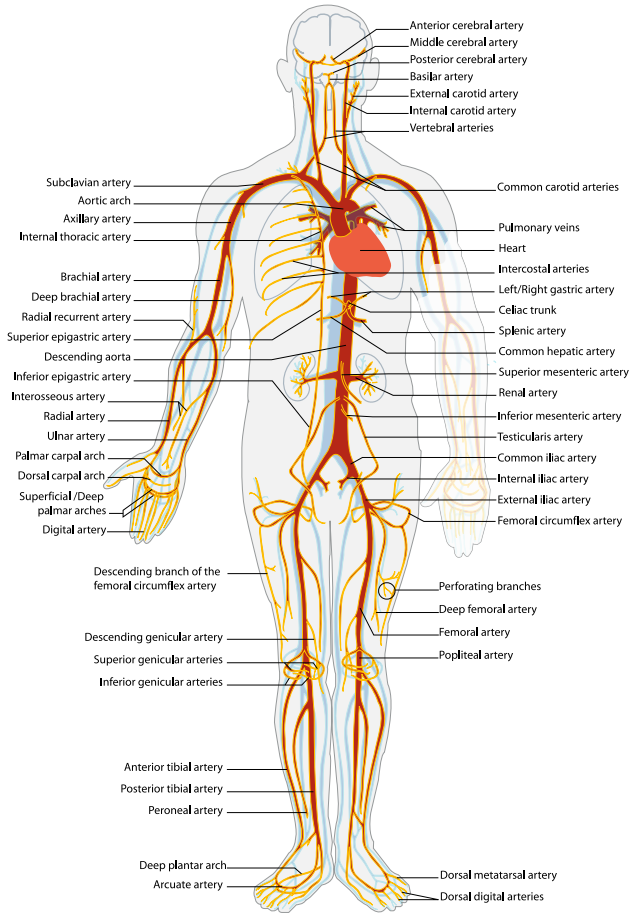


Figure **10.6.2**: This figure shows the heart and the major arteries of the cardiovascular system. The pulmonary veins are included in the diagram because, like arteries, they carry oxygenated blood.

Arteries are defined as blood vessels that carry blood away from the heart. Blood flows through arteries largely because it is under pressure from the pumping action of the heart. It should be noted that coronary arteries, which supply heart muscle cells with blood, travel toward the heart but not as part of the blood flow that travels through the chambers of the heart. Most arteries, including coronary arteries, carry oxygenated blood, but there are a few exceptions, most notably the pulmonary artery. This artery carries deoxygenated blood from the heart to the lungs, where it picks up oxygen and releases carbon dioxide. In virtually all other arteries, the hemoglobin in red blood cells is highly saturated with oxygen (95-100 percent). These arteries distribute oxygenated blood to tissues throughout the body.

The largest artery in the body is the aorta, which is connected to the heart and extends down into the abdomen (Figure **10.6.2**). The aorta has high-pressure, oxygenated blood pumped directly into it from the left ventricle of the heart. The aorta has many branches, and the branches subdivide repeatedly, with the subdivisions growing smaller and smaller in diameter. The smallest arteries are called arterioles.

VEINS

Veins are defined as blood vessels that carry blood toward the heart. Blood traveling through veins is not under pressure from the beating heart. It gets help moving along by the squeezing action of skeletal muscles, for example, when you walk or breathe. It is also prevented from flowing backward by valves in the larger veins, as illustrated in Figure **10.6.3**. Veins are called capacitance blood vessels because the majority (about 60 percent) of the body's total volume of blood is contained within veins.

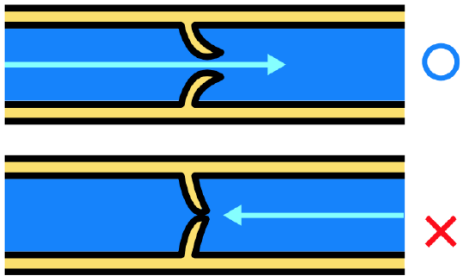


Figure **10.6.3**: The two flaps that make up a venous valve can open in just one direction, so blood can flow in only one direction through the vein.

Most veins carry deoxygenated blood, but there are a few exceptions, including the four pulmonary veins. These veins carry oxygenated blood from the lungs to the heart, which then pumps the blood to the rest of the body. In virtually all other veins, hemoglobin is relatively unsaturated with oxygen (about 75 percent).

The two largest veins in the body are the **superior vena cava**, which carries blood from the upper body directly to the right atrium of the heart, and the **inferior vena cava**, which carries blood from the lower body directly to the right atrium. The inferior vena cava is labeled in the figure below. The superior vena cava is not labeled in Figure **10.6.4** but is clearly visible entering the right atrium of the heart. Like arteries, veins form a complex, branching system of larger and smaller vessels. The smallest veins are called venules. They receive blood from capillaries and transport it to larger veins. Each venule receives blood from multiple capillaries.

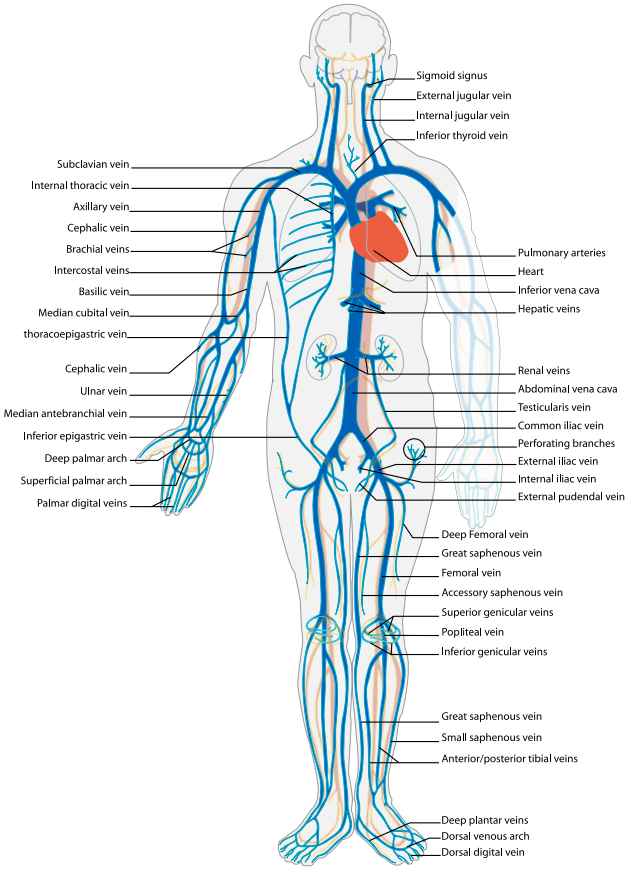


Figure **10.6.4**: This diagram shows the heart and major veins of the cardiovascular system. The pulmonary arteries are included in the diagram because, like veins, they carry deoxygenated blood.

CAPILLARIES

Capillaries are the smallest blood vessels in the cardiovascular system. They are so small that only one red blood cell at a time can squeeze through a capillary, and then only if the red blood cell deforms. Capillaries connect arterioles and venules, as shown in Figure **10.6.5**. Capillaries generally form a branching network of vessels, called a capillary bed, that provides a large surface area for the exchange of substances between the blood and surrounding tissues.

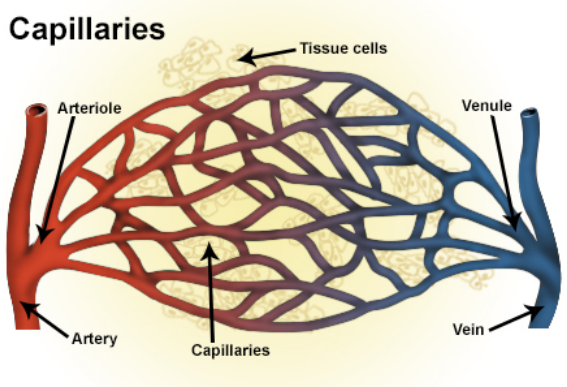


Figure **10.6.5**: Capillaries form beds of tiny blood vessels that exchange substances with the cells of tissues.

STRUCTURE OF BLOOD VESSELS

All blood vessels are basically hollow tubes with an internal space, called a lumen, through which blood flows. The lumen of an artery is shown in cross-section in the photomicrograph below. The width of blood vessels varies, but they all have a lumen. The walls of blood vessels differ depending on the type of vessel. In general, arteries and veins are more similar to one another than capillaries in the structure of their walls.

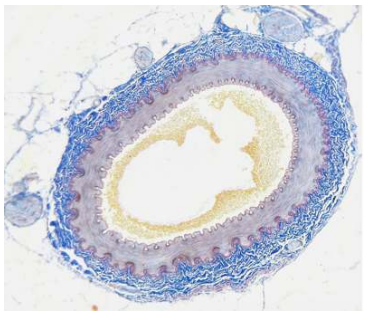


Figure **10.6.6**: The lumen is the white space in the center of this cross-sectional slice of an artery. You can see that the walls of the artery have multiple layers.

WALLS OF ARTERIES AND VEINS

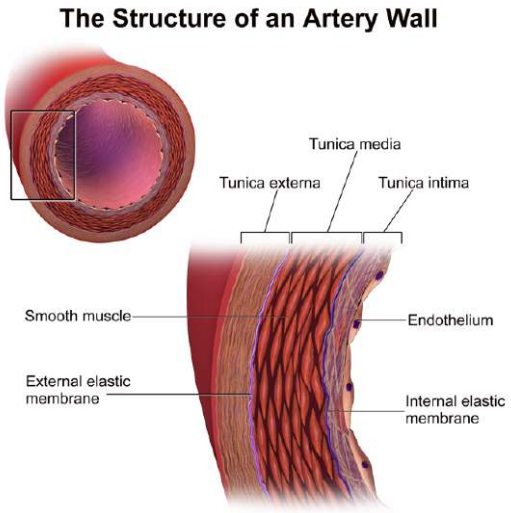


Figure **10.6.7**: The wall of an artery is made of three layers: tunica intima, tunica media, and tunica externa. A vein has the same three layers as the artery shown here, but the middle layer (tunica media) of a vein is thinner and lacks smooth muscle tissue.

The walls of both arteries and veins have three layers: the tunica intima, tunica media, and tunica adventitia. You can see the three layers for an artery in Figure **10.6.7**.

1. The tunica intima is the inner layer of arteries and veins. It is also the thinnest layer, consisting of a single layer of endothelial cells surrounded by a thin layer of connective tissues. It reduces friction between the blood and the inside of the blood vessel walls.
2. The tunica media is the middle layer of arteries and veins. In arteries, this is the thickest layer. It consists mainly of elastic fibers and connective tissues. In arteries, this is the thickest layer because it also contains smooth muscle tissues, which control the diameter of the vessels.
3. The tunica externa (also called tunica adventitia) is the outer layer of arteries and veins. It consists of connective tissue and also contains nerves. In veins, this is the thickest layer. In general, the tunica externa protects and strengthens vessels and attaches them to surrounding structures.

CAPILLARY WALLS

The walls of capillaries consist of little more than a single layer of epithelial cells. Being just one cell thick, the walls are well suited for the exchange of substances between the blood inside them and the cells of surrounding tissues. Substances including water, oxygen, glucose, and other nutrients as well as waste products such as carbon dioxide can pass quickly and easily through the extremely thin walls of capillaries.

BLOOD PRESSURE

The blood in arteries is normally under pressure because of the beating of the heart. The pressure is highest when the heart contracts and pumps out blood, and lowest when the heart relaxes and refills with blood. (You can feel this variation in pressure in your wrist or neck when you count your pulse.) **Blood pressure** is a measure of

the force that blood exerts on the walls of arteries. It is generally measured in millimeters of mercury (mm Hg) and expressed as a double number: a higher number for systolic pressure when the ventricles contract; and a lower number for diastolic pressure when the ventricles relax. Normal blood pressure is generally defined as less than 120 mm Hg (systolic)/80 mm Hg (diastolic) when measured in the arm at the level of the heart. It decreases as blood flows farther away from the heart and into smaller arteries.

As arteries grow smaller, there is increasing resistance to blood flow through them because of the friction of the blood against the arterial walls. This resistance restricts blood flow so less blood reaches smaller, downstream vessels, thus reducing blood pressure before the blood flows into the tiniest vessels, the capillaries. Without this reduction in blood pressure, capillaries would not be able to withstand the pressure of the blood without bursting. By the time blood flows through the veins, it is under very little pressure. The pressure of blood against the walls of veins is always about the same and normally no more than 10 mm Hg.

VASOCONSTRICTION AND VASODILATION

Smooth muscles in the walls of arteries can contract or relax to cause vasoconstriction (narrowing of the lumen of blood vessels) or vasodilation (widening of the lumen of blood vessels). This allows the arteries — especially the arterioles — to contract or relax as needed to help regulate blood pressure. In this regard, the arterioles act like an adjustable nozzle on a garden hose. When they narrow, the increased friction with the arterial walls causes less blood to flow downstream from the narrowing, resulting in a drop in blood pressure. These actions are controlled by the autonomic nervous system in response to pressure-sensitive sensory receptors in the walls of larger arteries.

Arteries can also dilate or constrict to help regulate body temperature by allowing more or less blood to flow from the warm body core to the body's surface. In addition, vasoconstriction and vasodilation play roles in the fight-or-flight response, under the control of the sympathetic nervous system. For example, vasodilation allows more blood to flow to skeletal muscles and vasoconstriction reduces blood flow to digestive organs.

FEATURE: MY HUMAN BODY

The lumpy appearance of this man's leg is caused by *varicose veins*. Do you have varicose veins? If you do, you may wonder whether they are a sign of a significant health problem. You may also wonder whether you should have them treated, and if so, what treatments are available. As is usually the case, when it comes to your health, "knowledge is power."



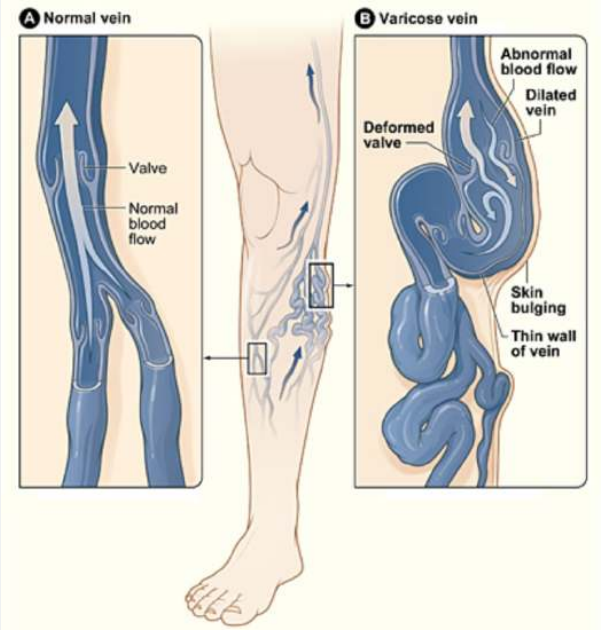


Figure **10.6.8**: Varicose veins form when a deformed valve allows blood to pool creating a bulge in the vein.

First, the "back story:" varicose veins are veins that have become enlarged and twisted because their valves have become ineffective (see Figure 10.6.8). As a consequence, blood pools in the veins and stretches them out. Varicose veins occur most frequently in the superficial veins of the legs, but they may also occur in other parts of the body. They are most common in older adults, females, and people who have a family history of the condition. Obesity and pregnancy also increase the risk of developing varicose veins. A job that requires standing for long periods of time, chronic constipation, and long-term alcohol consumption are additional risk factors.

Varicose veins usually are not serious. In many people, they are only a cosmetic issue. However, in severe cases, varicose veins may cause pain and other problems. For example, the affected leg(s) may feel heavy and achy, especially after long periods of standing. Ankles may become swollen by the end of the day. Minor injuries may bleed more than normal. The skin over varicosity may become red, dry, and itchy. In very severe cases, skin ulcers may develop.

If you are concerned about varicose veins, call them to the attention of your doctor, who can determine the best course of action for your case. There are many potential treatments for varicose veins. Some of the treatments have potential adverse side effects; and with many of the treatments, varicose veins

may return. Which treatment is best for a given patient depends in part on the severity of the condition.

- If varicose veins are not serious, then conservative treatment options may be recommended. These include avoiding standing or sitting for long periods, frequently elevating the legs, and wearing graduated compression stockings.
- For more serious cases, less conservative but non-surgical options may be advised. These include sclerotherapy, in which medicine is injected into the veins to make them shrink. Another non-surgical approach is endovenous thermal ablation. In this type of treatment, laser light, radio-frequency energy, or steam is used to heat the walls of the veins, causing them to shrink and collapse.
- For the most serious cases, surgery may be the best option. The most invasive surgery is vein stripping, in which all or part of the main trunk of a vein is tied off and removed from the leg while the patient is under general anesthesia. In a less invasive surgery, called ambulatory phlebectomy, short segments of a vein are removed through tiny incisions under local anesthesia.

REVIEW

1. What are the blood vessels? Name the three major types of blood vessels.
2. Describe arteries. Identify the largest artery in the body.
3. How are veins defined? What are the two largest veins in the body?
4. Compare and contrast how blood moves through arteries and veins.
5. What are capillaries, and what is their function?
6. Compare and contrast the structure of the walls of arteries, veins, and capillaries.
7. What is blood pressure, and how is it expressed? What blood pressure is considered normal?
8. Identify the functions of vasoconstriction and vasodilation of arteries.
9. Does the blood in most veins have any oxygen at all? Explain your answer.
10. *True or False.* Only one red blood cell can pass through the lumen of a capillary at a given time.
11. *True or False.* The pulmonary artery carries oxygenated blood.
12. Which tissue in blood vessels is responsible for vasodilation and vasoconstriction? Where is it located?
13. The blood pressure at the arterioles is generally _____ the blood pressure at the aorta.
    A. lower than
    B. higher than
    C. the same as
    D. not related to
14. Explain why it is important that the walls of capillaries are very thin.
15. Most of the blood in the body is in the:
    A. Capillaries
    B. Arteries
    C. Heart
    D. Veins

EXPLORE MORE

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10.7: CARDIOVASCULAR DISEASE

HEART ATTACK ON A PLATE

Eating this greasy cheeseburger smothered in bacon may not literally cause a heart attack. However, regularly eating high-fat, low-fiber foods such as this may increase the risk of a heart attack or other type of cardiovascular disease. In fact, unhealthy lifestyle choices such as this may account for as many as 90 percent of cases of cardiovascular disease.



Figure **10.7.1**: Bacon Cheeseburger

WHAT IS CARDIOVASCULAR DISEASE?

Cardiovascular disease is a class of diseases that involve the cardiovascular system. They include diseases of the coronary arteries that supply the heart muscle with oxygen and nutrients; diseases of arteries such as the carotid artery that provide blood flow to the brain; and diseases of the peripheral arteries that carry blood throughout the body. Worldwide, cardiovascular disease is the leading cause of death, causing about a third of all deaths each year.

Most cases of the cardiovascular disease occur in people over the age of 60, with disease onset typically being about a decade earlier in males than females. The LGBT (lesbian, gay, bisexual, and transgender) community belongs to almost every race, ethnicity, religion, age, and socioeconomic group. The LGBT youth are at a higher risk for cardiovascular diseases, obesity, anxiety, and depression as compared to the general population. LGBT youth receive poor quality of care due to stigma, lack of healthcare providers' awareness, and insensitivity to the unique needs of this community. Young LGBT individuals find it difficult to report their sexual identity to their clinicians. Some clinicians are not well trained in addressing the concerns of members of this community.

You can't control your age or sex, but you can control other factors that increase the risk of cardiovascular disease. Not smoking, maintaining a healthy weight, eating a healthy diet, taking medications as needed to control diabetes and cholesterol, and getting regular exercise are all ways to prevent cardiovascular disease or keep it from progressing. It should be noted that high blood lipid levels are definitely risk factors for cardiovascular disease. High levels of cholesterol in the diet do not appear to lead directly to high levels of cholesterol in the blood. Clearly, cardiovascular disease is multifactorial in terms of its causes.

PRECURSORS OF CARDIOVASCULAR DISEASE

There are two very common conditions that are precursors to virtually all cases of cardiovascular disease: hypertension (hypertension) and atherosclerosis (hardening of blood wall). Both conditions affect the arteries and their ability to maintain normal blood flow.

HYPERTENSION

Hypertension is a chronic medical condition in which the blood pressure in the arteries is persistently elevated, as defined in Table **10.7.1**. Hypertension usually does not cause symptoms, so more than half of the people with high blood pressure are unaware of their condition. Hypertension is typically diagnosed when blood pressure is routinely measured during a medical visit for some other health problem.

Table **10.7.1**: Classification of Blood Pressure (in Adults)

Category	Systolic (mm Hg)	Diastolic (mm Hg)
Normal blood pressure	90-119	60-79
Prehypertension	120-139	80-89
Hypertension	140 or higher	90 or higher

High blood pressure is classified as either primary or secondary high blood pressure. At least 90% of cases are primary high blood pressure, which is caused by some combination of genetic and lifestyle factors. Numerous genes have been identified as having small effects on blood pressure. Lifestyle factors that increase the risk of high blood pressure include excess dietary salt and alcohol consumption in addition to the risk factors for cardiovascular disease stated above. Secondary high blood pressure, which makes up the remaining 10% of cases of hypertension, is attributable to chronic kidney disease or an endocrine disorder such as Cushing's disease.

Treating hypertension is important for reducing the risk of all types of cardiovascular disease, especially stroke. These and other complications of persistent high blood pressure are shown in Figure **10.7.2**. Lifestyle changes, such as reducing salt intake and adopting a healthier diet may be all that is needed to lower blood pressure to the normal range. In many cases, however, medications are also required.

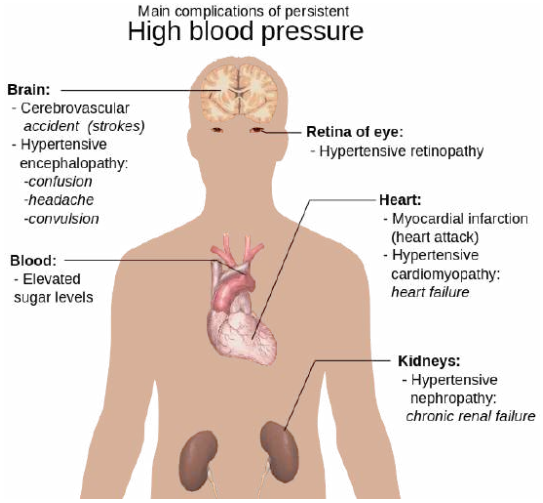


Figure **10.7.2**: If high blood pressure is not brought under control, it can eventually cause hypertensive retinopathy, myocardial infarction, heart failure, nephropathy, stokes, confusion, headache, convulsion, and elevated sugar levels.

ATHEROSCLEROSIS

Atherosclerosis is a condition in which artery walls thicken and stiffen as a result of the buildup of plaques inside the arteries. Plaques consist of white blood cells, cholesterol, and other fats. Typically, there is also a proliferation of smooth muscle cells that make the plaque fibrous as well as fatty. Over time, the plaques may harden with the addition of calcium crystals. This reduces the elasticity of the artery walls. As plaques increase in size, the artery walls dilate to compensate so blood flow is not affected. Eventually, however, the lumen of the arteries is likely to become so narrowed by plaque buildup that blood flow is reduced or even blocked entirely. Figure **10.7.3** illustrates the formation of a plaque in a coronary artery.

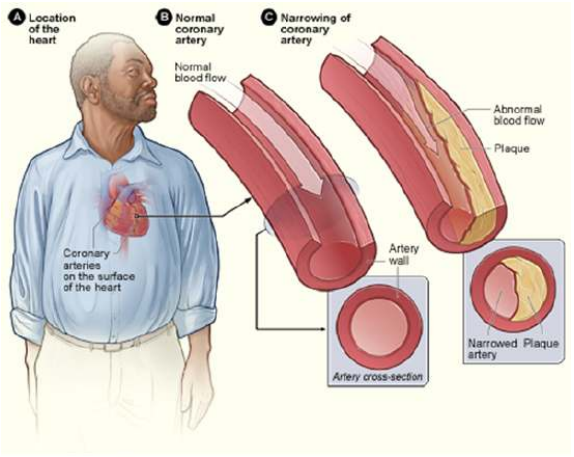


Figure **10.7.3**: Plaque accumulation in a coronary artery may reduce blood flow to cardiac muscle cells.

In most people, plaques start to form in arteries during childhood and progress throughout life. Individuals may develop just a few plaques or dozens of them. Plaques typically remain asymptomatic for decades. Signs and symptoms appear only after there is severe narrowing (stenosis) or complete blockage of arteries. As plaques increase in size and interfere with blood flow, they commonly lead to the formation of blood clots. These may plug arteries at the site of the plaque or travel elsewhere in the circulation. Sometimes plaques rupture or become detached from an arterial wall and become lodged in a smaller, downstream artery. Blockage of arteries by plaques or clots may cause a heart attack, stroke, or other potentially life-threatening cardiovascular events. If blood flow to the kidneys is affected, it may lead to chronic kidney disease.

The process in which plaques form is not yet fully understood, but it is thought that it begins when low-density lipoproteins (LDLs) accumulate inside endothelial cells in artery walls, causing inflammation. The inflammation attracts white blood cells that start to form a plaque. Continued inflammation and a cascade of other immune responses cause the plaque to keep growing. Risk factors for the development of atherosclerosis include hypertension, high cholesterol (especially LDL cholesterol), diabetes, and smoking. The chance of developing atherosclerosis also increases with age, male sex, and a family history of cardiovascular disease.

Treatment of atherosclerosis often includes both lifestyle changes and medications to lower cholesterol, control blood pressure, and reduce the risk of blood clot formation. In extreme cases or when other treatments are inadequate, surgery may be recommended. Surgery may involve the placement of stents in arteries to keep them open and improve blood flow or the use of grafts to divert blood flow around blocked arteries.

CORONARY ARTERY DISEASE

Coronary artery diseases are a group of diseases that result from atherosclerosis of coronary arteries. Treatment of the diseases mainly involves treating underlying atherosclerosis. Two of the most common coronary artery diseases are angina and myocardial infarction.

ANGINA

Angina is chest pain or pressure that occurs when heart muscle cells do not receive adequate blood flow and become starved of oxygen (a condition called ischemia). It is illustrated in Figure **10.7.4**. There may also be a pain in the back, neck, shoulders, or jaw; and in some cases, the pain may be accompanied by shortness of breath, sweating, or nausea. The main goals of the treatment of angina are relieving the symptoms and slowing the progression of underlying atherosclerosis.

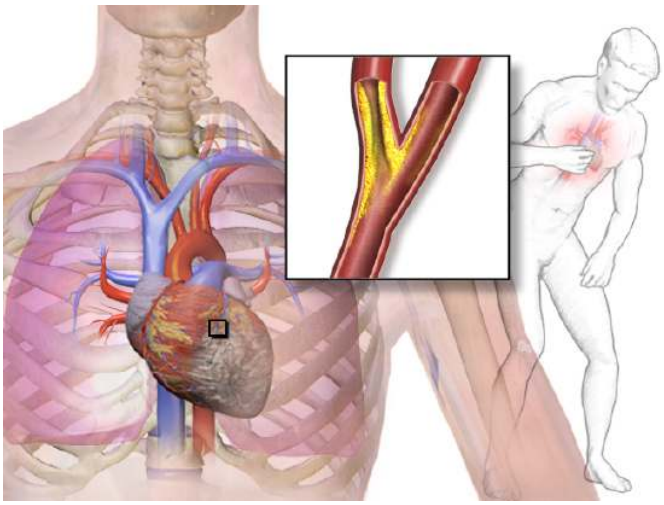


Figure **10.7.4**: Angina is a pain in the chest due to reduced blood flow in coronary arteries so the heart muscle does not receive adequate oxygen.

Angina may be classified as either stable angina or unstable angina:

- Stable angina is angina in which pain is precipitated by exertion (say, from brisk walking or running) and improves quickly with rest or the administration of nitroglycerin, which dilates coronary arteries and improves blood flow. Stable angina may develop into unstable angina.
- Unstable angina is angina in which pain occurs during rest, lasts more than 15 minutes, and is of new onset. This type of angina is more dangerous and may be a sign of an imminent heart attack. It requires urgent medical attention.

MYOCARDIAL INFARCTION

A **myocardial infarction (MI)**, commonly known as a heart attack, occurs when blood flow stops to a part of the heart causing damage to the heart muscle and the death of myocardial cells. An MI usually occurs because of complete blockage of a coronary artery, often due to a blood clot or the rupture of a plaque (Figure **10.7.5**). An MI typically causes chest pain and pressure, among other possible symptoms, but at least one-quarter of MIs do not cause any symptoms.

In the worst case, an MI may cause sudden death. Even if the patient survives, an MI often causes permanent damage to the heart. This puts the heart at risk of heart arrhythmias, heart failure, and cardiac arrest.

- Heart arrhythmias are abnormal heart rhythms, which are potentially life-threatening. Heart arrhythmias often can be interrupted with a cardiac defibrillator, which delivers an electrical shock to the heart, in effect “rebooting” it.
- Heart failure occurs when the pumping action of the heart is impaired so tissues do not get adequate oxygen. This is a chronic condition that tends to get worse over time, although it can be managed with medications.
- Cardiac arrest occurs when the heart no longer pumps blood or pumps blood so poorly that vital organs can no longer function. This is a medical emergency requiring immediate intervention.

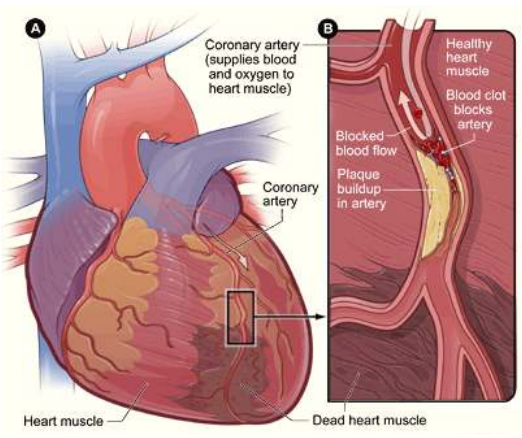


Figure **10.7.5**: A myocardial infarction occurs when cardiac muscle cells die due to blockage of a coronary artery.

OTHER CARDIOVASCULAR DISEASES

Hypertension and atherosclerosis often cause other cardiovascular diseases. These commonly include stroke and peripheral artery disease.

STROKE

A **stroke,** also known as a cerebrovascular accident or brain attack, occurs when blocked or broken arteries in the brain result in the death of brain cells. There are two main types of stroke: ischemic stroke and hemorrhagic stroke. Ischemic storke is illustrated in Figure **10.7.6**.

1. An ischemic stroke occurs when an embolus (blood clot) breaks off from a plaque or forms in the heart because of arrhythmia and travels to the brain where it becomes lodged in an artery. This blocks blood flow to the part of the brain that is served by arteries downstream from the blockage. Lack of oxygen causes the death of brain cells. Treatment with a clot-busting drug within a few hours of the stroke may prevent permanent damage. Almost 90 percent of strokes are ischemic strokes.
2. A hemorrhagic stroke occurs when an artery in the brain ruptures and causes bleeding in the brain. This deprives downstream tissues of adequate blood flow and also puts pressure on brain tissue. Both factors can lead to the death of brain cells. Surgery to temporarily open the cranium may be required to relieve the pressure. Only about 10 percent of strokes are hemorrhagic strokes, but they are more likely to be fatal than ischemic strokes.

In both types of stroke, the part of the brain that is damaged loses is the ability to function normally. Signs and symptoms of stroke may include an inability to move, feel, or see on one side of the body; problems understanding speech or difficulty speaking; memory problems; confusion; and dizziness. Hemorrhagic strokes may also cause a severe headache. The symptoms of a stroke usually occur within seconds or minutes of the brain injury. Depending on the severity of the stroke and how quickly treatment is provided, the symptoms may be temporary or permanent. If the symptoms of a stroke go away on their own in less than an hour or two, the stroke is

called a transient ischemic attack. Stroke is the leading cause of disability in the United States, but rehabilitation with physical, occupational, speech, or other types of therapy may significantly improve functioning.

The main risk factor for stroke is high blood pressure. Therefore, keeping blood pressure within the normal range, whether with lifestyle changes or medications, is the best way to reduce the risk of stroke. Another possible cause of stroke is the use of illicit drugs such as amphetamines or cocaine. Having had a stroke in the past greatly increases one's risk of future strokes. Men are also more likely than women to have strokes.

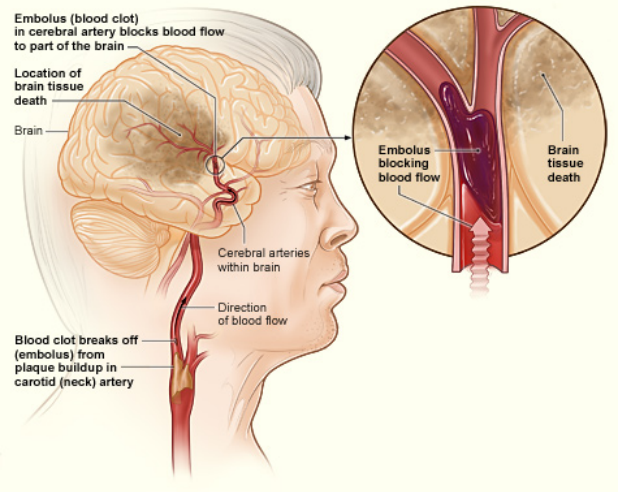


Figure **10.7.6**: In an ischemic stroke, brain cells die due to a blocked artery in the brain. The blockage happens when a blood clot breaks from a buildup in the carotid artery and blocks blood flow to part of the brain. As a result, the brain tissue dies. The traveling clot is called embolus.

PERIPHERAL ARTERY DISEASE

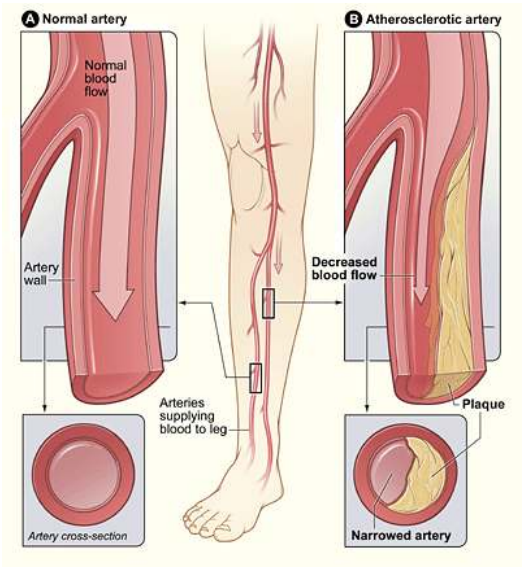


Figure **10.7.7**: Peripheral artery disease (PAD) develops when plaque accumulates in the wall of the leg artery. PAD typically causes pain and other symptoms because of decreased blood flow in the leg or other areas of the body served by peripheral arteries.

Peripheral artery disease (PAD) is the narrowing of the arteries other than those that supply the heart or brain due to atherosclerosis. Figure **10.7.7** shows how the PAD occurs. PAD most commonly affects the legs, but other arteries may also be involved. The classic symptom is leg pain when walking, which usually resolves with rest. This symptom is known as intermittent claudication. Other symptoms may include skin ulcers, bluish skin, cold skin, or poor nail and hair growth in the affected leg(s). However, up to half of all cases of PAD do not have any symptoms.

The main risk factor for PAD is smoking. Other risk factors include diabetes, high blood pressure, and high blood cholesterol. The underlying mechanism is usually atherosclerosis. PAD is typically diagnosed when blood pressure readings taken at the ankle are lower than blood pressure readings taken at the upper arm. It is important to diagnose PAD and treat underlying atherosclerosis because people with this disorder have a four to five times higher risk of myocardial infarction or stroke. Surgery to expand the affected arteries or to graft vessels in order to bypass blockages may be recommended in some cases.

FEATURE: MY HUMAN BODY

You read in this concept about the many dangers of hypertension. Do you know whether you have hypertension? The only way to know for sure is to have your blood pressure measured. Measuring blood pressure is quick and painless, but several measurements are needed to accurately diagnose hypertension. Some people have what is called "white coat disease." Their blood pressure rises just because they are being examined by a physician (in a white coat). Blood pressure also fluctuates from time to time due to factors such as hydration, stress, and time of day. Repeatedly measuring and recording your own blood pressure at home can provide your doctor with valuable diagnostic data. Digital blood pressure monitors for home use, like the one pictured in Figure **10.7.8**, are relatively inexpensive, easy to use, and available at most pharmacies.



Figure **10.7.8**: This personal blood pressure monitor is worn on the wrist.

REVIEW

1. What is cardiovascular disease? How much mortality do cardiovascular diseases cause?
2. List risk factors for cardiovascular disease.
3. What is hypertension?

4. Define atherosclerosis.
5. What is coronary artery disease?
6. Identify two specific coronary artery diseases.
7. Explain how a stroke occurs and how it affects the patient.
8. Describe the cause of peripheral artery disease.
9. What are two cardiovascular diseases that can be caused by atherosclerosis? Explain specifically how atherosclerosis contributes to each of them.
10. *True or False.* A heart attack is the same thing as cardiac arrest.
11. *True or False.* Plaques in arteries can cause blood clots.
12. What are the similarities between angina and ischemic stroke?
13. How can kidney disease be caused by problems in the cardiovascular system?
14. In peripheral artery disease, the blood pressure at the ankle is typically _____ the blood pressure at the upper arm.

    A. erratic compared to B. the same as

    C. higher than D. lower than
15. Name three components of the plaque that can build up in arteries.

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10.8: CASE STUDY CONCLUSION- FLIGHT AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: FLIGHT RISK

At the beginning of this chapter, you learned about Antônio and Ahaya, who met while sitting next to each other on a plane. During the flight, Ahaya got up to take frequent walks and was doing leg exercises to try to avoid the medical condition depicted in Figure 10.8.1—**deep vein thrombosis** (DVT). DVT occurs when a blood clot forms in a deep vein, usually in the leg. It can be very dangerous—even deadly.

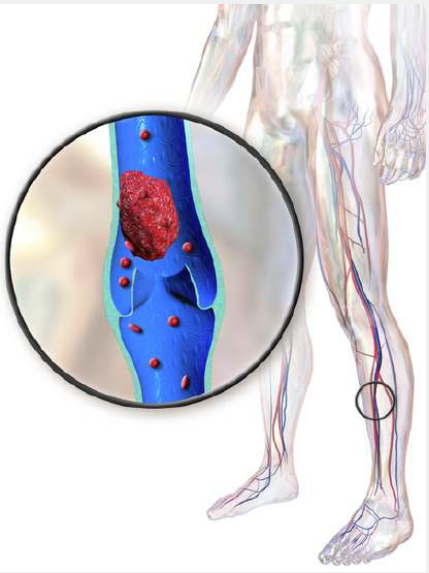


Figure **10.8.1**: Illustration of a blood clot in a deep vein in the leg, which is called deep vein thrombosis (DVT).

As you learned in this chapter, a blood clot is an aggregation of platelets and proteins. Blood clots are helpful to prevent blood loss when a blood vessel is damaged. But in some situations, they can be extremely dangerous. For example, blood clots can cause heart attacks or strokes by blocking the flow of blood to the heart or brain, respectively.

When DVT occurs, one of the major risks is pulmonary embolism (PE). PE is when the blood clot breaks off, travels through the blood vessels, and lodges in a pulmonary artery, like the blood clot shown in Figure **10.8.2**. Recall what the pulmonary arteries do: they carry deoxygenated blood from the heart to the lungs, where the blood picks up oxygen and releases carbon dioxide due to gas exchange between the capillaries and the alveoli of the lungs. Imagine what would happen if this flow of blood to the lungs was partially or completely blocked by a blood clot. Depending on the size of the blood clot and where it is lodged, a PE can cause a variety of serious consequences ranging from lung damage to instant death, because of the disruption of the pulmonary circulation.

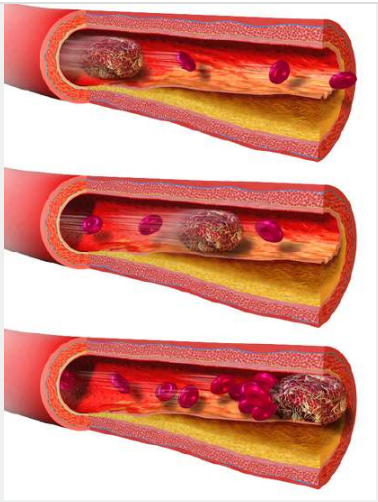


Figure **10.8.2**: Illustration of how a moving blood clot can get stuck in a blood vessel. When this occurs in a pulmonary artery, it is called a pulmonary embolism (PE).

Ahaya has a higher risk of DVT and its consequences because he has heart failure. As you have learned, heart failure is a chronic condition in which the pumping action of the heart is impaired. One reason that heart failure is thought to increase the risk of DVT is that the blood is not being pushed strongly enough through the cardiovascular system, allowing blood clots to form more easily.

Ahaya needs to be particularly concerned about DVT while on a long plane flight. Why do you think this is? Think about how blood flows through arteries and veins. Blood is pushed through arteries mainly due to the pumping action of the heart. Veins, on the other hand, rely on the movement of the surrounding skeletal muscles to help push blood through them. Sitting still for long periods of time in cramped quarters, such as on a plane, can cause blood to pool in the deep veins of the legs. This can lead to the formation of a blood clot.

CHAPTER SUMMARY

In this chapter, you learned about the structure, functions, and disorders of the cardiovascular system. Specifically, you learned that:

- The cardiovascular system is the organ system that transports materials to and from all the cells of the body. The main components of the cardiovascular system are the heart, blood vessels, and blood.
- The cardiovascular system has two interconnected circulations. The pulmonary circulation carries blood between the heart and lungs, where blood is oxygenated. The systemic circulation carries blood between the heart and the rest of the body, where it delivers oxygen.
- The heart is a muscular organ in the chest that consists mainly of cardiac muscle and pumps blood through blood vessels by repeated, rhythmic contractions.

- The wall of the heart consists of three layers. The middle layer, the myocardium, is the thickest layer and consists mainly of cardiac muscle.
- The interior of the heart consists of four chambers, with an upper atrium and lower ventricle on each side of the heart. Blood enters the heart through the atria, which pump it to the ventricles. Then the ventricles pump blood out of the heart. Four valves in the heart keep blood flowing in the correct direction and prevent backflow.
- Deoxygenated blood flows into the right atrium through veins from the upper and lower body (superior and inferior vena cava, respectively), and oxygenated blood flows into the left atrium through four pulmonary veins from the lungs. Each atrium pumps the blood to the ventricle below it. From the right ventricle, deoxygenated blood is pumped to the lungs through the two pulmonary arteries. From the left ventricle, oxygenated blood is pumped to the rest of the body through the aorta.
- The coronary circulation consists of blood vessels that carry blood to and from the heart muscle cells. There are two coronary arteries that supply the two sides of the heart with oxygenated blood. Cardiac veins drain deoxygenated blood back into the heart.
- The cardiac cycle refers to a single complete heartbeat. It includes diastole when the atria contract; and systole when the ventricles contract.
- The normal, rhythmic beating of the heart is called sinus rhythm. It is established by the heart's pacemaker cells in the sinoatrial node. Electrical signals from the pacemaker cells travel to the atria and cause them to contract. Then the signals travel to the atrioventricular node and from there to the ventricles, causing them to contract. Electrical stimulation from the autonomic nervous system and hormones from the endocrine system can also influence heartbeat.

- Blood vessels carry blood throughout the body. Major types of blood vessels are arteries, veins, and capillaries.
  - Arteries are blood vessels that usually carry blood away from the heart (except for coronary arteries that supply the heart muscle with blood). Most arteries carry oxygenated blood. The largest artery is the aorta, which is connected to the heart and extends into the abdomen. Blood moves through arteries due to pressure from the beating of the heart.
  - Veins are blood vessels that usually carry blood toward the heart. Most veins carry deoxygenated blood. The largest veins are the superior and inferior venae cavae. Blood moves through veins by the squeezing action of surrounding skeletal muscles. Valves in veins prevent the backflow of blood.
  - Capillaries are the smallest blood vessels. They connect arterioles and venules. They form capillary beds where substances are exchanged between the blood and surrounding tissues.
  - The walls of arteries and veins have three layers. The middle layer is thickest in arteries, in which it contains smooth muscle tissue that controls the diameter of the vessels. The outer layer is thickest in veins and consists mainly of connective tissue. The walls of capillaries consist of little more than a single layer of epithelial cells.
  - Blood pressure is a measure of the force that blood exerts on the walls of arteries. It is expressed as a double number, with the higher number representing systolic pressure when the ventricles contract and the lower number representing diastolic pressure when the ventricles relax. Normal blood pressure is generally defined as a pressure of 120/80 mm Hg or less.
  - Vasoconstriction (narrowing) and vasodilation (widening) of arteries can occur to help regulate blood pressure or body temperature or to change blood flow as part of the fight-or-flight response.
- Blood is a fluid connective tissue that circulates throughout the body in blood vessels. Blood supplies tissues with oxygen and nutrients and removes their metabolic wastes. Blood helps defend the body from pathogens and other threats, transports hormones and other substances, and helps to keep the body's pH and temperature in homeostasis. Blood consists of a liquid part, called plasma, and cells, including red blood cells, white blood cells, and platelets.
  - Plasma makes up more than half of blood by volume. It consists of water and many dissolved substances. Blood also contains blood cells and platelets.
  - Red blood cells are the most numerous cells in the blood and consist mostly of hemoglobin, which carries oxygen. Red blood cells also carry antigens that determine blood types. White blood cells are less numerous than red blood cells and are part of the body's immune system. They protect the body from abnormal cells, microorganisms, and other harmful substances. There are several different types of white blood cells that differ in their specific immune functions.
  - Platelets are cell fragments that play important roles in blood clotting or coagulation. They stick together at breaks in blood vessels to form a clot and stimulate the production of fibrin, which strengthens the clot.
  - All blood cells form by the proliferation of stem cells in red bone marrow in a process called hematopoiesis. When blood cells die, they are phagocytized by white blood cells and removed from circulation.
  - Disorders of the blood include leukemia, which is a cancer of the bone-forming cells; hemophilia, which is any of several genetic blood-clotting disorders; carbon monoxide poisoning, which prevents red blood cells from binding with oxygen and causes suffocation; HIV infection, which destroys certain white blood cells and can cause AIDS; and anemia, in which there are not enough red blood cells to carry adequate oxygen to body tissues.
- Blood type (or blood group) is a genetic characteristic associated with the presence or absence of antigens on the surface of red blood cells. A blood group system refers to all of the gene(s),

alleles, and possible genotypes and phenotypes that exist for a particular set of blood type antigens.

- Cardiovascular disease is a class of diseases that involve the cardiovascular system. Worldwide, it is the leading cause of death. Most cases occur in people over age 60, and onset is typically about a decade earlier in males than females. Other risk factors include smoking, obesity, diabetes, high blood cholesterol, and lack of exercise.
- Antigens are molecules that the immune system identifies as either self or nonself. If antigens are identified as nonself, the immune system responds by forming antibodies that are specific to the nonself antigens, leading to the destruction of cells bearing the antigens.
- The ABO blood group system is a system of red blood cell antigens controlled by a single gene with three common alleles on chromosome 9. There are four possible ABO blood types: A, B, AB, and O. The ABO system is the most important blood group system in blood transfusions. People with type O blood are universal donors, and people with type AB blood are universal recipients.
- The Rhesus blood group system is a system of red blood cell antigens controlled by two genes with many alleles on chromosome 1. There are five common Rhesus antigens, of which antigen D is most significant. Individuals who have antigen D are called Rh+, and individuals who lack antigen D are called Rh-. Rh- mothers of Rh+ fetuses may produce antibodies against the D antigen in the fetal blood, causing hemolytic disease of the newborn (HDN).

- Two common conditions that lead to most cases of cardiovascular disease are hypertension and atherosclerosis. Hypertension is blood pressure that is persistently at or above 140/90 mm Hg. Atherosclerosis is a buildup of fatty, fibrous plaques in arteries that may reduce or block blood flow. Treating these conditions is important for preventing cardiovascular disease.
  - Coronary artery disease is a group of diseases that result from atherosclerosis of coronary arteries. Two of the most common are angina and myocardial infarction (heart attack). In angina, cardiac cells receive inadequate oxygen, which causes chest pain. In a heart attack, cardiac cells die because blood flow to part of the heart is blocked. A heart attack may cause death or lead to heart arrhythmias, heart failure, or cardiac arrest.
  - A stroke occurs when blocked or broken arteries in the brain result in the death of brain cells. This may occur when an artery is blocked by a clot or plaque or when an artery ruptures and bleeds in the brain. In both cases, part of the brain is damaged and functions such as speech and controlled movements may be impaired, either temporarily or permanently.
  - Peripheral artery disease occurs when atherosclerosis narrows peripheral arteries, usually in the legs, often causing pain when walking. It is important to diagnose this disease so underlying atherosclerosis can be treated before it causes a heart attack or stroke.

In this chapter, you learned that the cardiovascular system carries nutrients to the cells of the body. Read the next chapter about the Digestive System to learn about how your body transforms your meals into the nutrients that cells need to function.

CHAPTER SUMMARY REVIEW QUESTIONS

1. Alex goes to the doctor and learns that his blood pressure is 135/90 mm Hg. Answer the following questions about his blood pressure.
   A. Is this normal blood pressure? Why or why not?
   B. Which number refers to the systolic pressure and which number refers to the diastolic pressure?
   C. Describe what the atria and ventricles of Alex's heart are doing when the pressure is at 135 mm Hg.
   D. Alex's doctor would like him to lower his blood pressure. Why do you think he would like Alex to do this and what are some ways in which he may be able to lower his blood pressure?
2. What are the three functions of the cardiovascular system?
3. What is the watery part of the blood called?
4. Which are the chambers of the heart that receive blood? Which are the chambers of the heart that pump blood out of the heart?
5. Which chambers of the heart contain deoxygenated blood?
   A. Right and left atria
   B. Right and left ventricles
   C. Right atrium and right ventricle
   D. Left atrium and left ventricle
6. What are two different places in the cardiovascular system where valves are located?
7. Valves prevent blood from flowing backward in the cardiovascular system. Why do you think this is important?
8. Explain how pacemaker cells in the heart work together with the nervous system to regulate the beating of the heart.
9. *True or False.* Red marrow is the source of white blood cells.
10. *True or False.* Plaques that build up in arteries are made completely of fats.
11. The aorta is:
    A. An artery
    B. A chamber of the heart
    C. A vein
    D. A valve
12. Compare the coronary arteries, pulmonary arteries, and arteries elsewhere in the body in terms of their target tissues (i.e. where they bring blood to) and whether they are carrying oxygenated or deoxygenated blood.
13. The superior vena cava empties into which structure of the heart? The inferior vena cava empties into which structure of the heart?
    A. right atrium; left atrium
    B. right atrium; right atrium

C. right atrium; right ventricle
D. right ventricle; left ventricle

14. Venules receive blood from what?
15. Define blood type and blood group system. Explain the relationship between antigens and antibodies.
16. Identify the alleles, genotypes, and phenotypes in the ABO blood group system.
17. Discuss the medical significance of the ABO blood group system.
18. Give examples of how different ABO blood types vary in their susceptibility to diseases.
19. Describe the Rhesus blood group system.
20. Relate Rhesus blood groups to blood transfusions.
21. What causes hemolytic disease of the newborn?
22. A woman is blood type O and Rh- and her husband is blood type AB and Rh+. Answer the following questions about this couple and their offspring.
    A. What are the possible genotypes of their offspring in terms of ABO blood group?
    B. What are the possible phenotypes of their offspring in terms of ABO blood group?
    C. Can the woman donate blood to her husband? Explain your answer.
    D. Can the man donate blood to his wife? Explain your answer.
23. *True or False.* The D antigen is part of the ABO blood group system.
24. Explain why hemolytic disease of the newborn may be more likely to occur in a second pregnancy than in a first.
25. Anemia causes weakness and fatigue due to a reduction in the amount of oxygen that gets to the cells of the body. Explain how oxygen is transported to the cells of the body and which blood cells are affected in anemia.
26. What are the two conditions that are precursors to virtually all cases of cardiovascular disease?
27. What is another name for a heart attack?
    A. Heart arrhythmia
    B. Myocardial infarction
    C. Angina
    D. Heart failure
28. *True or False.* Strokes can be due to a blood clot or to a broken artery.
29. *True or False.* After an injury to a blood vessel, platelets respond by losing their nuclei.
30. What are the main differences between coronary circulation, pulmonary circulation, and systemic circulation?
31. Define the term *sinus rhythm.*
32. Which is generally a more serious and immediately life-threatening condition: heart failure or cardiac arrest? Explain your answer.
33. Match each of the following descriptions to the disease or disorder from the list below that *best* matches it. Use each disease or disorder only once. Diseases and disorders: hypertension; atherosclerosis; coronary artery disease; peripheral artery disease
    A. Blood flow to the muscle cells of the heart is impaired.
    B. Blood pressure is too high.
    C. Arteries in the legs specifically become more narrow.
    D. Plaque builds up in arteries (in general).

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ATTRIBUTIONS

1. Deep vein thrombosis by Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". *WikiJournal of Medicine* **1** (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. CC BY 3.0 via Wikimedia Commons.
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CHAPTER OVERVIEW

11: LYMPHATIC AND IMMUNE SYSTEMS

This chapter outlines the layered responses of the human immune system, including both innate and adaptive immune responses. It also describes the structures and functions of the lymphatic system, with a focus on its roles in host defense. In addition, the chapter examines three different types of immune system disorders.

11.1: Case Study- Your Defense System

11.2: Introduction to the Immune System

11.3: Lymphatic System

11.4: Innate Immune System

11.5: Adaptive Immune System

11.6: Disorders of the Immune System

11.7: Human Microbiome

11.8: Case Study Conclusion- Lymphoma and Chapter Summary

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11.1: CASE STUDY- YOUR DEFENSE SYSTEM

CASE STUDY: DEFENDING YOUR DEFENSES

Twenty-six-year-old Wei isn't feeling well. Wei uses he/him/his pronouns. He is more tired than usual, dragging through his workdays despite going to bed earlier and napping on the weekends. He doesn't have much of an appetite and has started losing weight. When he presses on the side of his neck, like the doctor is doing in Figure **11.1.1**, he notices an unusual lump.



Figure **11.1.1**: Palpating lymph nodes

Wei goes to his doctor, who performs a physical exam and determines that the lump is a swollen lymph node. Lymph nodes are part of the immune system, and they will often become enlarged when the body is fighting off an infection. Dr. Bouazizi thinks that the swollen lymph node and fatigue could be signs of a viral or bacterial infection, or indicate a type of cancer called lymphoma. However, an infection is a more likely cause, particularly in a young person like Wei. Dr. Bouazizi prescribes an antibiotic in case Wei has a bacterial infection and advises him to return in a few weeks if his lymph node does not shrink or if he is not feeling better.

Wei returns a few weeks later. He is not feeling better and his lymph node is still enlarged. Dr. Bouazizi is concerned and orders a biopsy of the enlarged lymph node. A lymph node biopsy for suspected lymphoma often involves the surgical removal of all or part of a lymph node, to determine whether the tissue contains cancerous cells.

The initial results of the biopsy indicate that Wei does have lymphoma. Although lymphoma is more common in older people, young adults and even children can get this disease. There are many types of lymphoma, with the two main types being Hodgkin and non-Hodgkin lymphoma. Non-Hodgkin lymphoma (NHL), in turn, has many subtypes depending on factors such as which cell types are affected. For instance, some subtypes of NHL affect immune system cells called B cells, while others affect different immune system cells called T cells.

Dr. Bouazizi explains to Wei that it is important to determine which type of lymphoma he has, in order to choose the best course of treatment. Wei's biopsied tissue will be further examined and tested to see which cell types are affected and which specific cell-surface proteins, called antigens, are present. This should help in identifying his specific type of lymphoma.

As you read this chapter, you will learn about the functions of the immune system, and the specific roles that its cells and organs—such as B and T cells and lymph nodes— play in defending the body. At the end of this chapter, you will learn what type of lymphoma Wei has and what some of his treatment options are, including treatments that make use of the biochemistry of the immune system to fight cancer with the immune system itself.

CHAPTER OVERVIEW: IMMUNE SYSTEM

In this chapter, you will learn about the immune system—the system that defends the body against infections and other causes of disease such as cancerous cells. Specifically, you will learn about:

- How the immune system identifies normal cells of the body as "self" and pathogens and damaged cells as "non-self."
- The two major subsystems of the general immune system: the innate immune system, which provides a quick but non-specific response; and the adaptive immune system, which is slower but provides a specific response that often results in long-lasting immunity.
- The specialized immune system that protects the brain and spinal cord called the neuroimmune system.
- The organs, cells, and responses of the innate immune system, which include physical barriers such as skin and mucus, chemical and biological barriers, inflammation, activation of the complement system of molecules, and non-specific cellular responses such as phagocytosis.
- The lymphatic system—which includes white blood cells called lymphocytes; lymphatic vessels that transport a fluid called lymph; and organs such as the spleen, tonsils, and lymph nodes —and its important role in the adaptive immune system.
- Specific cells of the immune system and their functions, including B cells, T cells, plasma cells, and natural killer cells.
- How the adaptive immune system can generate specific and often long-lasting immunity against pathogens through the production of antibodies.
- How vaccines work to generate immunity.
- How cells in the immune system detect and kill cancerous cells.
- Some strategies that pathogens employ to evade the immune system.
- Disorders of the immune system, including allergies, autoimmune diseases (such as diabetes and multiple sclerosis), and immunodeficiency resulting from conditions such as HIV infection.

As you read the chapter, think about the following questions:

1. What are the functions of lymph nodes?
2. What are B and T cells and how do they relate to lymph nodes?
3. What are cell-surface antigens? How do they relate to the immune system and to cancer?

ATTRIBUTIONS

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11.2: INTRODUCTION TO THE IMMUNE SYSTEM

WORM ATTACK!

Does this organism look like a space alien? A scary creature from a nightmare? In fact, it's a 1-cm long worm in the genus *Schistosoma*. It may invade and take up residence in the human body, causing a very serious illness known as schistosomiasis. The worm gains access to the human body while it is in a microscopic life stage. It enters through a hair follicle when the skin comes into contact with contaminated water. The worm then grows and matures inside the human organism, causing disease.



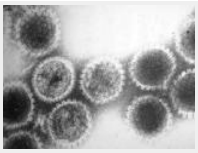
Figure **11.2.1**: Schistosome Parasite

HOST VS. PATHOGEN

The *Schistosoma* worm has a parasitic relationship with humans. In this type of relationship, one organism, called the parasite, lives on or in another organism, called the host. The parasite always benefits from the relationship and the host is always harmed. The human host of the *Schistosoma* worm is clearly harmed by the parasite when it invades the host's tissues. The urinary tract or intestines may be infected, and signs and symptoms may include abdominal pain, diarrhea, bloody stool, or blood in the urine. Those who have been infected a long time may experience liver damage, kidney failure, infertility, or bladder cancer. In children, *Schistosoma* infection may cause poor growth and difficulty learning. Table **11.2.1** lists some of the microscopic pathogens, their images, description, and the diseases that they cause.

Like the Schistosoma worm, many other organisms can make us sick if they manage to enter our body. Any such agent that can cause disease is called a **pathogen**. Most pathogens are microorganisms, although some, such as the Schistosoma worm, are much larger. In addition to worms, common types of pathogens of human hosts include bacteria, viruses, fungi, and single-celled organisms called protists. You can see examples of each of these types of pathogens in Table **11.2.1**. Fortunately for us, our immune system is able to keep most potential pathogens out of the body or to quickly destroy them if they do manage to get in. When you read this chapter, you'll learn how your immune system usually keeps you safe from harm — including from scary creatures like the Schistosoma worm!

Table **11.2.1**: Types of Pathogens

Type of Pathogen	Example and their Image	Description	Human Disease caused by pathogens of that type
Bacteria	 such as *Escherichia coli*	Single-celled organisms without a nucleus	Strep throat, staph infections, tuberculosis, food poisoning, tetanus, pneumonia, syphilis
Viruses	 such as Herpes simplex	Particles that reproduce by taking over living cells.	Common cold, flu, genital herpes, cold sores, measles, AIDS, genital warts, chickenpox, smallpox
Fungi	 such as *Trichophyton rubrum*	Organisms with a nucleus that grow as single cells or tread-like filaments	Ringworm, athlete's foot, tineas, candidiasis, histoplasmosis
Protozoa	 Such as *Giarida lamblia*	A single-celled organism with a nucleus	Malaria, Traveler's diarrhea, giardiasis, trypanosomiasis (sleeping sickness)

WHAT IS THE IMMUNE SYSTEM?

The **immune system** is a host defense system. It comprises many biological structures —ranging from individual white blood cells to entire organs — as well as many complex biological processes. The function of the immune system is to protect the host from pathogens and other causes of disease such as tumor cells. To function properly, the immune system must be able to detect a wide variety of pathogens. It also must be able to distinguish the cells of pathogens from the host's own cells and also to distinguish cancerous or damaged host cells from healthy cells. In humans and most other vertebrates, the immune system consists of layered defenses that have increased specificity for particular pathogens or tumor cells. The layered defenses of the human immune system are usually classified into two subsystems called the innate immune system and the adaptive immune system.

INNATE IMMUNE SYSTEM

Any discussion of the innate immune response usually begins with the physical barriers that prevent pathogens from entering the body, destroy them after they enter, or flush them out before they can establish themselves in the hospitable environment of the body's soft tissues. Barrier defenses are part of the body's most basic defense mechanisms. The barrier defenses are not a response to infections, but they are continuously working to protect against a broad range of pathogens.

The **phagocytes** are the body's fast acting first line of immunological defense against organisms that have breached barrier defenses and have entered the vulnerable tissues of the body. For example, certain leukocytes (white blood cells) engulf and destroy pathogens they encounter in the process called phagocytosis. The body's response again a pathogen's breach is also called **Inflammation**. Phagocytosis and Inflammation will be discussed in detail in concept *Innate Immune System*.

ADAPTIVE IMMUNE SYSTEM

The adaptive immune system is activated if pathogens successfully enter the body and manage to evade the general defenses of the innate immune system. An adaptive response is specific to the particular type of pathogen that has invaded the body or to cancerous cells. It takes longer to launch a specific attack, but once it is underway, its specificity makes it very effective. An adaptive response also usually leads to immunity. This is a state of resistance to a specific pathogen due to the ability of the adaptive immune system to "remember" the pathogen and immediately mount a strong attack tailored to that particular pathogen if it invades again in the future.

SELF VS. NON-SELF

Both innate and adaptive immune responses depend on the ability of the immune system to distinguish between self and non-self molecules. Self molecules are those components of an organism's body that can be distinguished from foreign substances by the immune system. Virtually all body cells have surface proteins that are part of a complex called the **major histocompatibility complex (MHC)**. These proteins are one way the immune system recognizes body cells as self. Non-self proteins, in contrast, are recognized as foreign because they are different from self-proteins.

ANTIGENS AND ANTIBODIES

Many non-self molecules comprise a class of compounds called antigens. Antigens, which are usually proteins, bind to specific receptors on immune system cells and elicit an adaptive immune response. Some adaptive immune system cells (B cells) respond to foreign antigens by producing antibodies. An antibody is a molecule that precisely matches and binds to a specific antigen. This may target the antigen (and the pathogen displaying it) for destruction by other immune cells.

Antigens on the surface of pathogens are how the adaptive immune system recognizes specific pathogens. Antigen specificity allows for the generation of responses tailored to the specific pathogen. It is also how the adaptive immune system ”remembers” the same pathogen in the future.

IMMUNE SURVEILLANCE

Another important role of the immune system is to identify and eliminate tumor cells. This is called **immune surveillance.** The transformed cells of tumors express antigens that are not found on normal body cells. The main response of the immune system to tumor cells is to destroy them. This is carried out primarily by aptly named killer T cells of the adaptive immune system.

LYMPHATIC SYSTEM

The lymphatic system is a human organ system that is a vital part of the adaptive immune system. It is also part of the cardiovascular system and plays a major role in the digestive system (see the concept Lymphatic System).

FEATURE: HUMAN BIOLOGY IN THE NEWS

“They'll have to rewrite the textbooks!”

That sort of response to scientific discovery is sure to attract media attention, and it did. It's what Kevin Lee, a neuroscientist at the University of Virginia, said in 2016 when his colleagues told him they had discovered human anatomical structures that had never before been detected. The structures were tiny lymphatic vessels in the meningeal layers surrounding the brain.

How these lymphatic vessels could have gone unnoticed when all human body systems have been studied so completely is amazing in its own right. The suggested implications of the discovery are equally amazing:

- The presence of these lymphatic vessels means that the brain is directly connected to the peripheral immune system, presumably allowing a close association between the human brain and human pathogens. This suggests an entirely new avenue by which humans and their pathogens may have influenced each other's evolution. The researchers speculate that our pathogens may have even influenced the evolution of our social behaviors.
- The researchers think there will also be many medical applications of their discovery. For example, the newly discovered lymphatic vessels may play a major role in neurological diseases that have an immune component, such as multiple sclerosis. The discovery might also affect how conditions such as autism spectrum disorders and schizophrenia are treated.

REVIEW

1. What is a pathogen?
2. State the purpose of the immune system.
3. Compare and contrast the innate and adaptive immune systems.
4. Explain how the immune system distinguishes self molecules from non-self molecules.
5. What are antigens?
6. Define tumor surveillance.
7. Briefly describe the lymphatic system and its role in immune function.
8. Identify the neuroimmune system.
9. Which of the following is NOT a function of the immune system?

   A. Protecting the body against fungi

B. Protecting the body against bacteria
C. Protecting the body against cancerous cells
D. None of the above

10. What does it mean that the immune system is not just composed of organs?
11. What are the general relationships between the terms *lymphocytes*, *leukocytes*, and *white blood cells*?
12. *True or False.* Phagocytosis occurs in the innate immune system.
13. *True or False.* Major histocompatibility complex proteins are antibodies.
14. *True or False.* Only the adaptive immune response requires the ability to distinguish between self and non-self.
15. Why is the immune system considered to be "layered?"

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ATTRIBUTIONS

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11.3: LYMPHATIC SYSTEM

TONSILLITIS

The white patches on either side of the throat in this picture are signs of tonsillitis. The tonsils are small structures in the throat that are very common sites of infection. The white spots on the tonsils pictured here are evidence of infection. The patches consist of large amounts of dead bacteria, cellular debris, and white blood cells; in a word, pus. Children with recurrent tonsillitis may have their tonsils removed surgically to eliminate this type of infection. The tonsils are organs of the lymphatic system.



Figure **11.3.1**:Tonsilitis

WHAT IS THE LYMPHATIC SYSTEM?

The **lymphatic system** is a collection of organs involved in the production, maturation, and harboring of white blood cells called lymphocytes. It also includes a network of vessels that transport or filter the fluid known as **lymph** in which lymphocytes circulate. Figure **11.3.2**shows major lymphatic vessels and other structures that make up the lymphatic system. Besides the tonsils, organs of the lymphatic system include the thymus, the spleen, and hundreds of lymph nodes that are distributed along the lymphatic vessels.

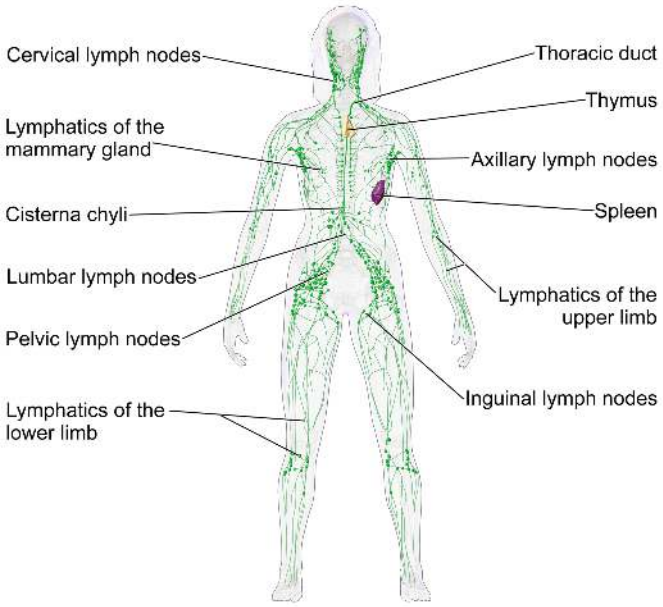


Figure **11.3.2**: The lymphatic system includes the thymus, spleen, lymph vessels, and nodes.

The lymphatic vessels form a transportation network similar in many respects to the blood vessels of the cardiovascular system. However, unlike the cardiovascular system, the lymphatic system is not a closed system. Instead, lymphatic vessels carry lymph in a single direction, always toward the upper chest, where the lymph empties from lymphatic vessels into blood vessels.

CARDIOVASCULAR FUNCTION OF THE LYMPHATIC SYSTEM

The return of lymph to the bloodstream is one of the major functions of the lymphatic system. When blood travels through capillaries of the cardiovascular system, it is under pressure, which forces some of the components of blood (such as water, oxygen, and nutrients) through the walls of the capillaries and into the tissue spaces between cells, forming tissue fluid, also called interstitial fluid (Figure **11.3.3**). Interstitial fluid bathes and nourishes cells and also absorbs their waste products. Much of the water from the interstitial fluid is reabsorbed into the capillary blood by osmosis. Most of the remaining fluid is absorbed by tiny lymphatic vessels called lymph capillaries. Once interstitial fluid enters the lymphatic vessels, it is called lymph. Lymph is very similar in composition to blood plasma. Besides water, lymph may contain proteins, waste products, cellular debris, and pathogens. It also contains numerous white blood cells, especially the subset of white blood cells known as lymphocytes. In fact, lymphocytes are the main cellular components of lymph.

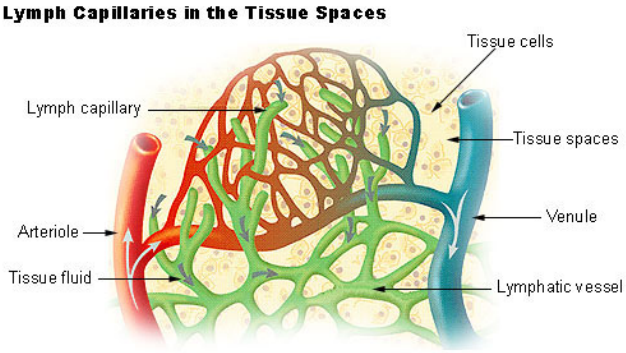


Figure **11.3.3**: Fluid and other substances in the blood are forced by blood pressure through the walls of capillaries and into the surrounding tissue spaces. Some of the tissue fluid is absorbed by tiny lymphatic vessels, forming lymph. The arrows show the direction of blood and lymph through the blood and lymphatic vessels.

The lymph that enters lymph capillaries in tissues is transported through the lymphatic vessel network to two large lymphatic ducts in the upper chest. From there, the lymph flows into two major veins (called subclavian veins) of the cardiovascular system. Unlike blood, lymph is not pumped through its network of vessels. Instead, lymph moves through lymphatic vessels via a combination of contractions of the vessels themselves and forces applied to the vessels externally by skeletal muscles. Lymphatic vessels also contain numerous valves that keep lymph flowing in just one direction, thereby preventing backflow.

DIGESTIVE FUNCTION OF THE LYMPHATIC SYSTEM

Lymphatic vessels called lacteals (Figure **11.3.4**) are present in the lining of the gastrointestinal tract, mainly in the small intestine. Each tiny villus in the lining of the small intestine has an internal bed of capillaries and lacteals. The capillaries absorb most nutrients from the digestion of food into the blood. The lacteals absorb mainly fatty acids from lipid digestion into the lymph, forming a fatty-acid-enriched fluid called chyle. Vessels of the lymphatic network then transport chyle from the small intestine to the main lymphatic ducts in the chest from which it drains into the blood circulation. The nutrients in chyle then circulate in the blood to the liver, where they are processed along with the other nutrients that reach the liver directly via the bloodstream.

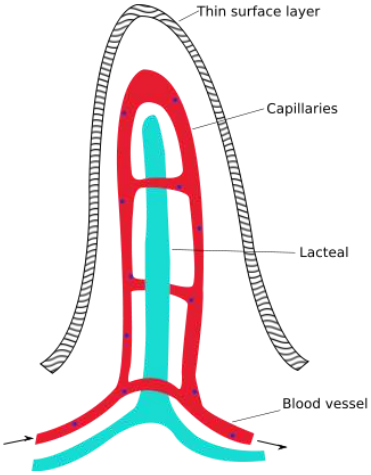


Figure **11.3.4**: Vessels called lacteals in the villi lining the small intestine are the main way that fatty acids from digestion are absorbed from the gastrointestinal tract. These nutrients eventually reach the blood circulation after traveling through the network of lymphatic vessels.

IMMUNE FUNCTION OF THE LYMPHATIC SYSTEM

The primary function of the lymphatic system is host defense as part of the immune system. This function of the lymphatic system is centered on the production, maturation, and circulation of lymphocytes. **Lymphocytes** are leukocytes that are involved in the adaptive immune system. They are responsible for the recognition of, and tailored defense against, specific pathogens or tumor cells. Lymphocytes may also create a lasting memory of pathogens so they can be attacked quickly and strongly if they ever invade the body again. In this way, lymphocytes bring about long-lasting immunity to specific pathogens.

There are two major types of lymphocytes, called B cells and T cells, which are illustrated in Figure **11.3.5**. Both B cells and T cells are involved in the adaptive immune response, but they play different roles. You can learn more about their immune functions by reading the concept Adaptive Immune System.

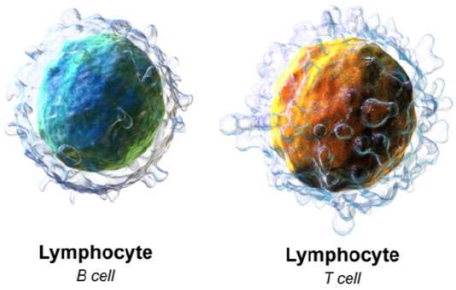


Figure **11.3.5**: Notice the large nucleus in the center of these relatively round cells.

PRODUCTION AND MATURATION OF LYMPHOCYTES

Like all other types of blood cells, including red blood cells as well as leukocytes, both B cells and T cells are produced from stem cells in the red marrow inside bones. After lymphocytes first form, they must go through a complicated maturation process before they are ready to search for pathogens. In this maturation process, they "learn" to distinguish self from non-self. Only those lymphocytes that successfully complete this maturation process go on to actually fight infections by pathogens.

B cells mature in the bone marrow, which is why they are called B cells. After they mature and leave the bone marrow, they travel first to the circulatory system and then enter the lymphatic system to search for pathogens. T cells, on the other hand, mature in the thymus, which is why they are called T cells. The **thymus** is illustrated in Figure **11.3.6**. It is a small lymphatic organ in the chest that consists of an outer cortex and inner medulla, all surrounded by a fibrous capsule. After maturing in the thymus, T cells enter the rest of the lymphatic system to join B cells in the hunt for pathogens. The bone marrow and thymus are called primary lymphoid organs because of their role in the production and/or maturation of lymphocytes.

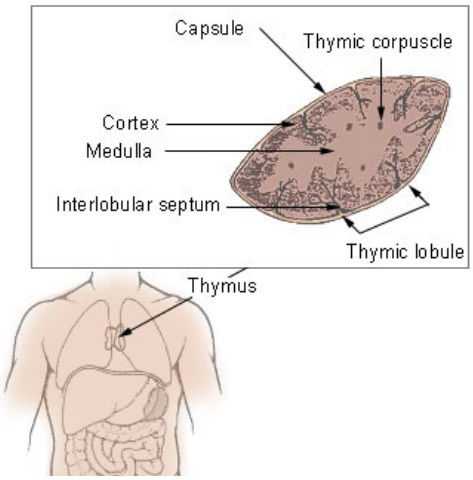


Figure **11.3.6**: The thymus (found in the chest) is an important organ of the lymphatic system because it is the location of T cell maturation.

LYMPHOCYTES IN SECONDARY LYMPHOID ORGANS

The tonsils, spleen, and lymph nodes are referred to as secondary lymphoid organs. These organs do not produce or mature lymphocytes. Instead, they filter lymph and store lymphocytes. It is in these secondary lymphoid organs that pathogens (or their antigens) activate lymphocytes and initiate adaptive immune responses. Activation leads to the cloning of pathogen-specific lymphocytes, which then circulate between the lymphatic system and the blood, searching for and destroying their specific pathogens by producing antibodies against them.

TONSILS

There are actually four pairs of human **tonsils.** Three of the four are shown in Figure 11.3.7. The fourth pair, called tubal tonsils, is located at the back of the nasopharynx. The palatine tonsils are the tonsils that are visible on either side of the throat. All four pairs of tonsils encircle a part of the anatomy where the respiratory and gastrointestinal tracts intersect and where pathogens have ready access to the body. This ring of tonsils is called **Waldeyer's ring**.

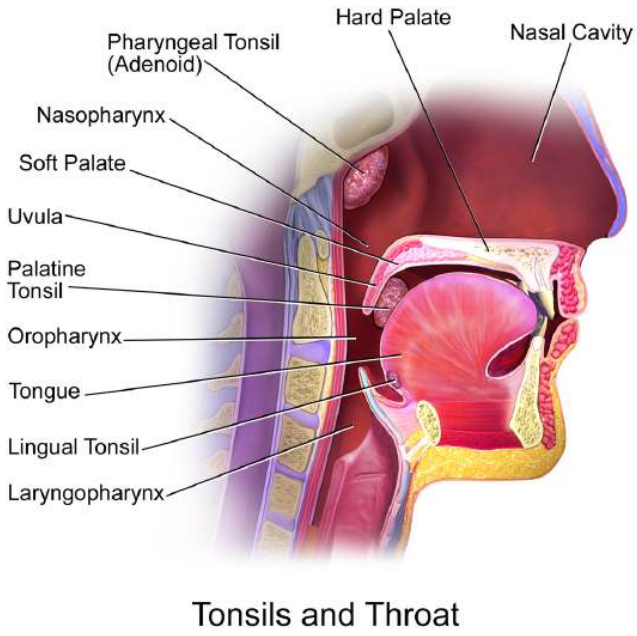


Figure 11.3.7: Three of four pairs of human tonsils are shown in this figure. Lingual tonsils are below the tongue. Palatine tonsils are at the back of the mouth. Pharyngeal (adenoid) tonsils are in the back of the nasal cavity.

SPLEEN

The spleen (Figure 11.3.8) is the largest of the secondary lymphoid organs and is centrally located in the body. Besides harboring lymphocytes and filtering lymph, the spleen also filters blood. Most dead or aged red blood cells are removed from the blood in the red pulp of the spleen. Lymph is filtered in the white pulp of the spleen. In the fetus, the spleen has the additional function of producing red blood cells. This function is taken over by bone marrow after birth.

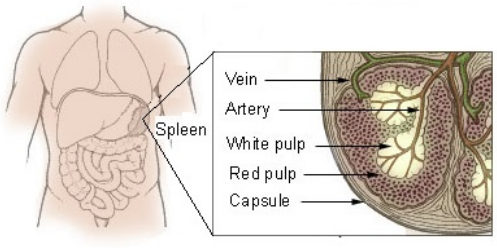


Figure 11.3.8: The spleen (found behind the stomach) is a secondary lymphoid organ where pathogens are likely to encounter lymphocytes and trigger an adaptive immune response.

LYMPH NODES

Each **lymph node** is a small but organized collection of lymphoid tissue (see green circular structures in Figure 11.3.1) that contains many lymphocytes. Lymph nodes are located at intervals along the lymphatic vessels, and lymph passes through them on their way back to the blood. There are at least 500 lymph nodes in the human body. Many of them are clustered at the base of the limbs and in the neck. Figure 11.3.9 shows the major lymph node concentrations. The figure includes the spleen and the region named Waldeyer's ring, consisting of the tonsils.

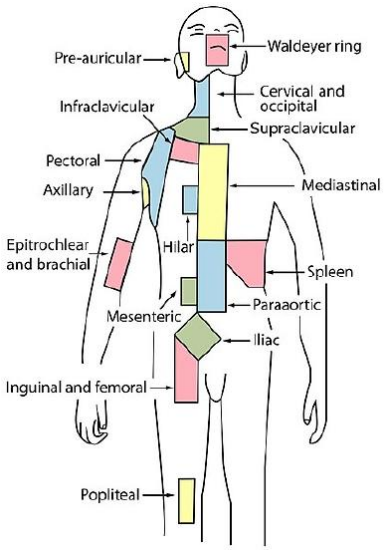


Figure 11.3.9: In this diagram, lymph node regions are just shown for the left side of the body. The same regions are also found on the right side of the body.

FEATURE: MYTH VS. REALITY

Lymph nodes near the surface of the body are obvious signs of immune system activity when they become enlarged and sometimes tender to the touch. Because it is easy to see and feel swollen lymph nodes, an individual can monitor his or her own health. It is important to be able to know the myths and realities of swollen lymph nodes.

Myth: You should see a doctor immediately whenever you have swollen lymph nodes.

Reality: Lymph nodes are constantly filtering lymph so it is expected that they will change in size with varying amounts of debris or pathogens that may be present. A minor, unnoticed infection may cause swollen lymph nodes that may last for a few weeks. Generally, lymph nodes that return to their normal size within three weeks are not a cause for concern.

Myth: Swollen lymph nodes mean you have a bacterial infection.

Reality: Although infection is the most common cause of swollen lymph nodes, not all infections are caused by bacteria. For example, mononucleosis commonly causes swollen lymph nodes, and it is caused by viruses. There are also other causes of swollen lymph nodes besides infections, such as cancer and certain medications.

Myth: A swollen lymph node means you have cancer.

Reality: Cancer is far less likely to be the cause of a swollen lymph node than is an infection.

Myth: Cancer in a lymph node always originates somewhere else. There is no cancer of the lymph nodes.

Reality: Cancers do commonly spread from their site of origin to nearby lymph nodes and then to other organs, but cancer may also originate in the lymph nodes. This type of cancer is called lymphoma.

REVIEW

1. What is the lymphatic system?
2. Describe the composition of lymph.
3. Outline the cardiovascular function of the lymphatic system.
4. Describe the role of the lymphatic system in the absorption of nutrients from the digestive system.
5. Summarize the function of the lymphatic system in host defense.
6. Name primary lymphatic organs and their functions.
7. What are the secondary lymphatic organs? State their functions in the adaptive immune system.
8. How is interstitial fluid related to lymph?
9. B and T cells are types of:
   A. Leukocytes
   B. Lymphocytes
   C. White blood cells
   D. All of the above
10. For each of the following statements, indicate whether it applies to B cells, T cells, or both.
    A. These cells are born in the red bone marrow.
    B. These cells are part of the adaptive immune system.
    C. These cells mature in the bone marrow.
11. Explain the difference between lymphocyte maturation and lymphocyte activation.
12. *True or False*. The spleen produces lymphocytes.
13. *True or False*. Tonsils are glands that produce lymph.

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11.4: INNATE IMMUNE SYSTEM

PAPER CUT

It's just a paper cut, but the break in your skin could provide an easy way for pathogens to enter your body. If bacteria were to enter through the cut and infect the wound, your innate immune system would quickly respond with a dizzying array of general defenses.



Figure **11.4.1**: Papercut

The **innate immune system** is a subset of the human immune system that produces rapid but non-specific responses to pathogens. Innate responses are generic rather than tailored to a particular pathogen. Every pathogen that is encountered is responded to in the same general ways by the innate system. Although the innate immune system provides immediate and rapid defenses against pathogens, it does not confer long-lasting immunity to them. In most organisms, the innate immune system is the dominant system of host defense. Other than most vertebrates including humans, the innate immune system is the only system of host defense.

In humans, the innate immune system includes surface barriers, inflammation, the complement system, and a variety of cellular responses. Surface barriers of various types generally keep most pathogens out of the body. If these barriers fail, then other innate defenses are triggered. The triggering event is usually the identification of pathogens by pattern-recognition receptors on cells of the innate immune system. These receptors recognize molecules that are broadly shared by pathogens but distinguishable from host molecules. Alternatively, the other innate defenses may be triggered when damaged, injured, or stressed cells send out alarm signals, many of which are recognized by the same receptors as those that recognize pathogens.

BARRIERS TO PATHOGENS

The body's first line of defense consists of three different types of barriers that keep most pathogens out of body tissues. The types of barriers are mechanical, chemical, and biological barriers.

MECHANICAL BARRIERS

Mechanical barriers are the first line of defense against pathogens, and they physically block pathogens from entering the body. The skin is the most important mechanical barrier. In fact, it is the single most important defense the body has. The outer layer of skin, the epidermis, is tough and very difficult for pathogens to penetrate. It consists of dead cells that are constantly being shed from the body surface. This helps remove bacteria and other infectious agents that have adhered to the skin. The epidermis also lacks blood vessels and is usually lacking moisture, so it does not provide a suitable environment for most pathogens. Hair, which is an accessory organ of the skin, also helps to keep out pathogens. Hairs inside the nose may trap larger pathogens and other particles in the air before they can enter the airways of the respiratory system.

Mucous membranes provide a mechanical barrier to pathogens and other particles at body openings. These membranes also line the respiratory, gastrointestinal, urinary, and reproductive tracts. Mucous membranes secrete mucus, which is a slimy and somewhat sticky substance that traps pathogens. Many mucous membranes also have hair-like cilia that sweep mucus and trapped pathogens toward body openings where they can be removed from the body. When you sneeze or cough, mucus, and pathogens are mechanically ejected from the nose and throat, as you can see in the photo below. Other mechanical defenses include tears, which wash pathogens from the eyes, and urine, which flushes pathogens out of the urinary tract.



Figure **11.4.2**: A sneeze can expel many pathogens from the respiratory tract. That's why you should always cover your mouth and nose and when you sneeze.

CHEMICAL BARRIERS

Chemical barriers also protect against infection by pathogens. They destroy pathogens on the outer body surface, at body openings, and on inner body linings. Sweat, mucus, tears, saliva, and breastmilk all contain antimicrobial substances, such as the enzyme lysozyme, that kill pathogens, especially bacteria. Sebaceous glands in the dermis of the skin secrete acids that form a very fine, slightly acidic film on the surface of the skin that acts as a barrier to bacteria, viruses, and other potential contaminants that might penetrate the skin. Urine and vaginal secretions are also too acidic for many pathogens to endure. Semen contains zinc, which most pathogens cannot tolerate, as well as defensins, which are antimicrobial proteins that act mainly by disrupting bacterial cell membranes. In the stomach, stomach acid and digestive enzymes called proteases, which break down proteins, kill most pathogens that enter the gastrointestinal tract in food or water.

BIOLOGICAL BARRIERS

Biological barriers are living organisms that help protect the body from pathogens. Trillions of harmless bacteria normally live on the human skin and in the urinary, reproductive, and gastrointestinal tracts. These bacteria use up food and surface space that help prevent pathogenic bacteria from colonizing the body. Some of these harmless bacteria also secrete substances that change the conditions

of their environment, making it less hospitable to potentially harmful bacteria. For example, they may release toxins or change the pH. All of these effects of harmless bacteria reduce the chances that pathogenic microorganisms will be able to reach sufficient numbers to cause illness.

INFLAMMATION

If pathogens manage to breach the barriers protecting the body, then one of the first active responses of the innate immune system kicks in. This response is **inflammation.** The main function of inflammation is to establish a physical barrier against the spread of infection. It also eliminates the initial cause of cell injury, clears out dead cells and tissues damaged from the original insult and the inflammatory process, and initiates tissue repair. Inflammation is often a response to infection by pathogens, but there are other possible causes, including burns, frostbite, and exposure to toxins.

The signs and symptoms of inflammation include redness, swelling, warmth, pain, and frequently some loss of function. These symptoms are caused by increased blood flow into infected tissue and a number of other processes, illustrated in Figure **11.4.3** and described below in the text.

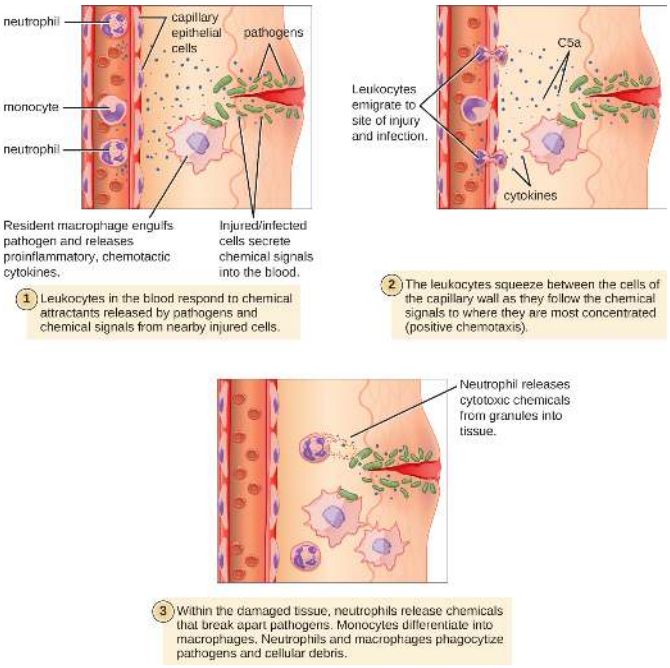


Figure **11.4.3**: This drawing shows what happens during the inflammatory response.

Inflammation is triggered by chemicals such as **cytokines** and **histamines,** which are released by injured or infected cells or by immune system cells such as macrophages (described in Figure **11.4.5**) that are already present in tissues. These chemicals cause capillaries to dilate and become leaky, increasing blood flow to the infected area and allowing blood to enter the tissues. Pathogen-destroying leukocytes, complement proteins, and tissue-repairing proteins migrate into tissue spaces from the bloodstream to attack pathogens and repair their damage. Cytokines also promote chemotaxis, which is migration to the site of infection by leukocytes that destroy pathogens. Some cytokines have anti-viral, antifungal, and antibacterial effects, such as shutting down protein synthesis in host cells, which viruses need in order to survive and replicate.

COMPLEMENT SYSTEM

The **complement system** is a complex biochemical mechanism named for its ability to "complement" the killing of pathogens directly by creating holes in the body of the pathogen and by assisting antibodies. Antibodies are produced as part of an adaptive immune response. The complement system consists of more than two dozen proteins that are normally found in the blood and synthesized in the liver. The proteins usually circulate as non-functional precursor molecules until activated.

CELLULAR RESPONSES

Cellular responses of the innate immune system involve a variety of different types of leukocytes. Many of these leukocytes circulate in the blood and act like independent, single-celled organisms, searching out and destroying pathogens in the human host. These and other immune cells of the innate system identify pathogens or debris and then help to eliminate them in some way. One way is phagocytosis.

PHAGOCYTOSIS

Phagocytosis is an important feature of innate immunity that is performed by cells classified as phagocytes. In the process of phagocytosis, phagocytes engulf and digest pathogens or other harmful particles. Phagocytes generally patrol the body searching for pathogens, but they can also be called to specific locations by the release of cytokines when inflammation occurs. Some phagocytes reside permanently in certain tissues.

As shown in Figure **11.4.4**, when a pathogen such as a bacterium is encountered by a phagocyte, the phagocyte extends a portion of its plasma membrane, wrapping the membrane around the pathogen until it is enveloped. Once inside the phagocyte, the pathogen becomes enclosed within an intracellular vesicle called a phagosome. The phagosome then fuses with another vesicle called a lysosome, forming a phagolysosome. Digestive enzymes and acids from the lysosome kill and digest the pathogen in the phagolysosome. The final step of phagocytosis is the excretion of soluble debris from the destroyed pathogen through exocytosis.

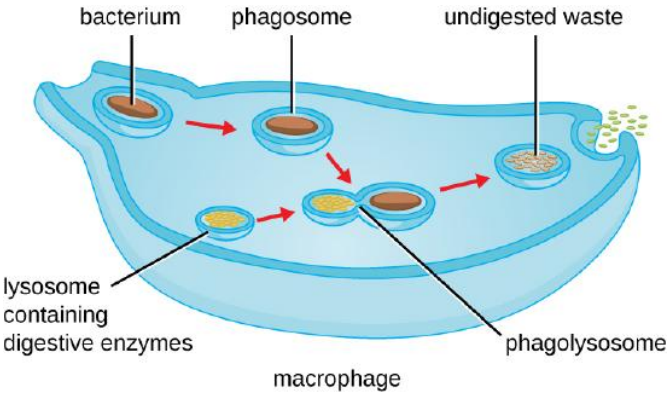


Figure **11.4.4**: Phagocytosis is a multi-step process in which a pathogen is engulfed and digested by immune cells called phagocytes.

LEUKOCYTES

Types of leukocytes that kill pathogens by phagocytosis include neutrophils, macrophages, and dendritic cells. Macrophages and dendritic cells are the derivatives of monocytes. Figure **11.4.5** shows five major types of leukocytes, lymphocytes, basophils, eosinophils, neutrophils, and monocytes. Because lymphocytes are mainly involved in the adaptive immune system, they are not discussed in this concept.

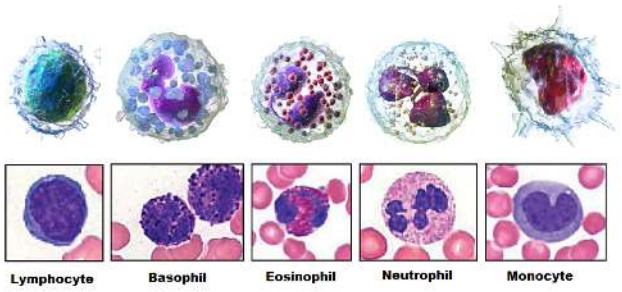


Figure **11.4.5**: Five types of leukocytes: from left to right, lymphocyte, basophil, eosinophil, neutrophil, and monocytes.

NEUTROPHILS

Neutrophils are leukocytes that travel throughout the body in the blood and are usually the first immune cells to arrive at the site of an infection. As shown in Figure **11.4.5**, these cells contain granules and carry a multilobed nucleus. They are the most numerous types of phagocytes and normally make up at least half of the total circulating leukocytes. The bone marrow of a normal healthy adult produces more than 100 billion neutrophils per day. During acute inflammation, more than 10 times that many neutrophils may be produced each day. Many neutrophils are needed to fight infections because after a neutrophil phagocytizes just a few pathogens, it generally dies.

MACROPHAGES

Macrophages are large phagocytic leukocytes that develop from monocytes. Macrophages spend much of their time within the interstitial fluid in tissues of the body. As shown in Figure **11.4.5**, monocytes do not contain granules and carry a big kidney-shaped nucleus. They are the most efficient phagocytes and can phagocytize a substantial number of pathogens or other cells. Macrophages are also versatile cells that produce a wide array of chemicals — including enzymes, complement proteins, and cytokines — in addition to their phagocytic action. As phagocytes, macrophages act as scavengers that rid tissues of worn-out cells and other debris as well as pathogens. In addition, macrophages act as antigen-presenting cells that activate the adaptive immune system. (To learn more about antigen-presenting cells, see the concept Adaptive Immune System.)

EOSINOPHILS

Eosinophils are non-phagocytic leukocytes that are related to neutrophils. They specialize in defending against parasites. As shown in Figure **11.4.5**, these cells contain granules and carry a bilobed earmuff-shaped nucleus. These leukocytes are very effective in killing large parasites such as worms by secreting a range of highly toxic substances when activated. Eosinophils may become overactive and cause allergies or asthma.

BASOPHILS

Basophils are non-phagocytic leukocytes that are also related to neutrophils. They are the least numerous of all white blood cells. As shown in Figure **11.4.5**, these cells contain granules and carry a bilobed nucleus. Basophils secrete two types of chemicals that aid in body defenses: histamines and heparin. Histamines are responsible for dilating blood vessels and increasing their permeability in inflammation. Heparin inhibits blood clotting and also promotes the movement of leukocytes into an area of infection.

DENDRITIC CELLS

Like macrophages, dendritic cells develop from monocytes (see Figure **11.4.6**. They reside in tissues that have contact with the external environment, so they are located mainly in the skin, nose, lungs, stomach, and intestines. Their plasma membrane has extensions. Besides engulfing and digesting pathogens, dendritic cells also act as antigen-presenting cells that trigger adaptive immune responses.

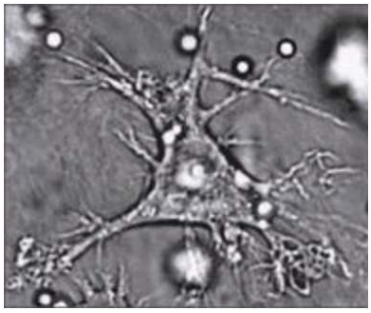


Figure **11.4.6**: dendritic cell

MAST CELLS

Mast cells are non-phagocytic leukocytes that help to initiate inflammation by secreting histamines. In some people, histamines trigger allergic reactions as well as inflammation. Mast cells may also secrete chemicals that help defend against parasites.

NATURAL KILLER CELLS

Natural killer cells are in the subset of leukocytes called lymphocytes, which are produced by the lymphatic system. Natural killer cells destroy cancerous or virus-infected host cells, although they do not directly attack invading pathogens. Natural killer cells recognize these host cells by a condition they exhibit called “missing self.” Cells with missing self have abnormally low levels of cell-surface proteins of the major histocompatibility complex (MHC), which normally identify body cells as self.

REVIEW

1. What is the innate immune system?
2. Identify the body’s first line of defense.
3. Define and give examples of mechanical and chemical barriers of the innate immune system.
4. What are biological barriers, and how do they protect the body?
5. State the purposes of inflammation.
6. What triggers inflammation, and what signs and symptoms does it cause?
7. Define the complement system. How does it help destroy pathogens?
8. List six different types of leukocytes and state their roles in innate immune responses.
9. Describe two ways that pathogens may evade the innate immune system.
10. Explain how mucus can contribute to the immune system as both a mechanical barrier and a chemical barrier.
11. Which type of immune system cell can both phagocytize pathogens and produce chemicals that promote inflammation?

    A. Macrophages

    B. Natural killer cells

    C. Basophils

    D. Mast cells
12. What are the ways in which phagocytes can encounter pathogens in the body?
13. Describe different two ways in which enzymes play a role in the innate immune response.
14. *True or False.* Complement proteins can be produced by macrophages.
15. *True or False.* The main function of inflammation is to secrete repair proteins at the site of damage.

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11.5: ADAPTIVE IMMUNE SYSTEM

THE KISS OF DEATH

The photomicrograph in Figure **11.5.1** shows a group of killer T cells (green and red) surrounding a cancer cell (blue, center). When a killer T cell makes contact with the cancer cell, it attaches to and spreads over the dangerous target. The killer T cell then uses special chemicals stored in vesicles (red) to deliver the killing blow. This event has thus been nicknamed "the kiss of death." After the target cell is killed, the killer T cells move on to find the next victim. Killer T cells like these are important players in the adaptive immune system.

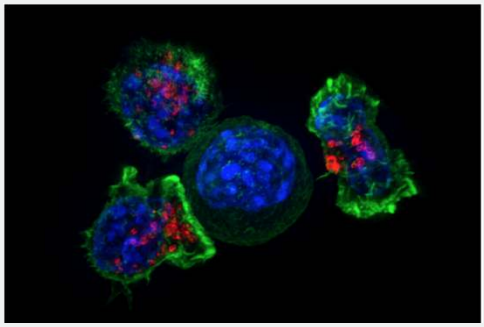


Figure **11.5.1**: Three Killer T cells surrounding Cancer Cells

The **adaptive immune system** (also called **specific immunity**) is a subsystem of the overall immune system. It is composed of highly specialized cells and processes that eliminate specific pathogens and tumor cells. An adaptive immune response is set in motion by antigens that the immune system recognizes as foreign. Unlike an innate immune response, an adaptive immune response is highly specific to a particular pathogen (or its antigen). An important function of the adaptive immune system that is not shared by the innate immune system is the creation of immunological memory or immunity. This occurs after the initial response to a specific pathogen. It allows a faster, stronger response on subsequent encounters with the same pathogen, usually before the pathogen can cause symptoms of illness.

Lymphocytes are the main cells of the adaptive immune system. They are leukocytes that arise and mature in organs of the lymphatic system, including the bone marrow and thymus. The human body normally has about 2 trillion lymphocytes, which constitute about a third of all leukocytes. Most of the lymphocytes are normally sequestered within tissue fluid or organs of the lymphatic system, including the tonsils, spleen, and lymph nodes. Only about 2 percent of the lymphocytes are normally circulating in the blood. There are two main types of lymphocytes involved in adaptive immune responses, called T cells and B cells. T cells destroy infected cells or release chemicals that regulate immune responses. B cells secrete antibodies that bind with antigens of pathogens so they can be removed by other immune cells or processes.

T CELLS

There are multiple types of **T cells** or T lymphocytes. Major types are killer (or cytotoxic) T cells and helper T cells. Both types develop from immature T cells that become activated by exposure to an antigen.

T CELL ACTIVATION

T cells must be activated. After the pathogen is phagocytized and digested by macrophages, a part of the pathogen is displayed on the surface of the macrophage. The proteins that display the antigen (part of the pathogen) are called Major Histocompatibility Complex (MHC). There are two types of MHC, MHCI and MHCII. Therefore macrophages are called antigen-presenting cells as shown in Figure **11.5.2** and Figure **11.5.3**. B lymphocytes can also act as antigen-presenting cells. Helper T cells are more easily activated than killer T cells. Activation of killer T cells is strongly regulated and may require additional stimulation from helper T cells.

HELPER T CELLS

Activated helper T cells do not kill infected or cancerous cells. Instead, their role is to "manage" both innate and adaptive immune responses by directing other cells to perform these tasks. They control other cells by releasing cytokines. These are proteins that can influence the activity of many cell types, including cytotoxic killer T cells (sometimes referred to as only killer T cells), B cells, and macrophages. For example, some cytokines released by helper T cells help activate killer T cells.

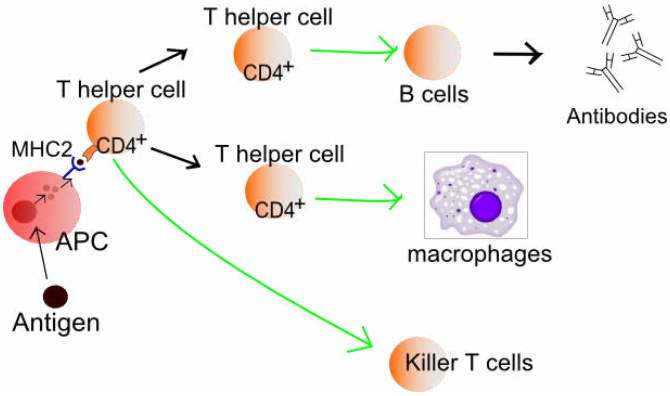


Figure **11.5.2**: After getting activated by an antigen-presenting cell, helper T cells trigger various other cells of the immune system, such as activation of B cells to produce antibodies, recruitment and activation of macrophages, and activation of cytotoxic killer T cells. In this image, APC stands for antigen-presenting cells and $CD4^+$ stands for Cluster Differentiation glycoprotein which is present on the surface of helper T cells.

KILLER T CELLS (CYTOTOXIC T CELLS)

When infected body cells present pathogen antigen to a killer T cell, it gets activated (see lower panel of Figure **11.5.3**). Activated killer T cells induce the death of cells that bear a specific non-self antigen because they are infected with pathogens or are cancerous. The antigen targets the cell for destruction by killer T cells, which travel

through the bloodstream searching for target cells to kill. Killer T cells may use various mechanisms to kill target cells. One way is by releasing toxins in granules that enter and kill infected or cancerous cells (Figure 11.5.3).

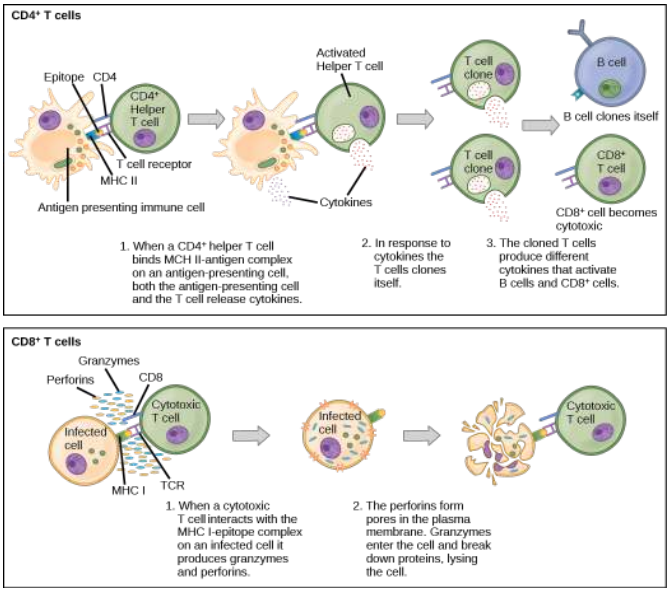


Figure 11.5.3: Naïve CD4+ (Helper) T cells engage MHC II molecules on antigen-presenting cells (APCs) and become activated. Clones of the activated helper T cell, in turn, activate B cells and CD8+ T (killer) cells, which become cytotoxic T cells. Cytotoxic T cells kill infected cells.

B CELLS AND B CELL ACTIVATION

B cells, or B lymphocytes, are the major cells involved in the creation of antibodies that circulate in blood plasma and lymph. Antibodies are large, Y-shaped proteins used by the immune system to identify and neutralize foreign invaders. Besides producing antibodies, B cells may also function as antigen-presenting cells or secrete cytokines that help control other immune cells and responses.

Before B cells can actively function to defend the host, they must be activated. As shown in Figure 11.5.4, B cell activation begins when a B cell engulfs and digests an antigen. The antigen may be either free-floating or on top of the pathogen. B cell internalize antigen and present it on its MHC to a helper T cell. The T cell activates and secretes cytokines that help the B cell to multiply and the daughter cells to mature into plasma cells and memory B cells. Plasma B cells produce antibodies.

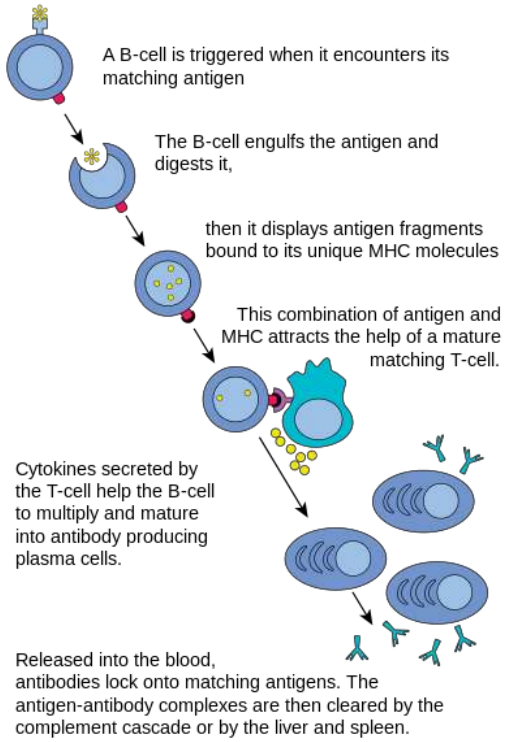


Figure 11.5.4: B cells are activated and become antibody-producing plasma cells with the help of helper T cells.

PLASMA CELLS

Plasma cells are antibody-secreting cells that form from activated B cells. Each plasma cell is like a tiny antibody factory. It may secrete millions of copies of an antibody, each of which can bind to the specific antigen that activated the original B cell. The specificity of an antibody to a specific antigen is illustrated in Figure 11.5.5. When antibodies bind with antigens, it makes the cells bearing them easier targets for phagocytes to find and destroy. Antibody-antigen complexes may also trigger the complement system of the innate immune system, which destroys the cells in a cascade of protein enzymes. In addition, the complexes are likely to clump together (agglutinate). If this occurs, they are filtered out of the blood in the spleen or liver.

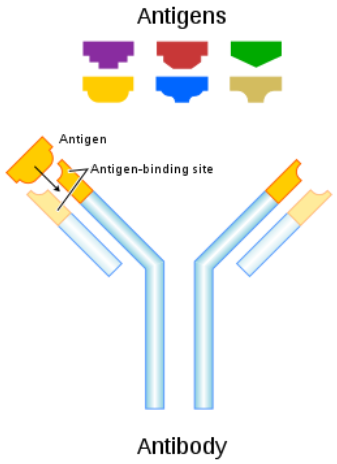


Figure **11.5.5**: Each antibody fits its antigen like a lock fits a key.

IMMUNITY

Most activated T cells and B cells die within a few days once a pathogen has been cleared from the body. However, a few of the cells survive and remain in the body as memory T cells or memory B cells. These memory cells are ready to activate an immediate response if they are exposed to the same antigen again in the future. This is the basis of **immunity.**

The earliest known reference to the concept of immunity relates to the bubonic plague (see Figure **11.5.6**). In 430 B.C., a Greek historian and general named Thucydides noted that people who had recovered from a previous bout of the plague could nurse people sick with the plague without contracting the illness a second time. We now know that this is true of many diseases and it occurs because of active immunity.



Figure **11.5.6**: Dead, blackened tissues at the fingertips and other extremities are a sign of the bubonic plague, giving rise to its other name, the black death.

ACTIVE IMMUNITY

Active immunity is the ability of the adaptive immune system to resist a specific pathogen because it has formed an immunological memory of the pathogen. Active immunity is adaptive because it occurs during the lifetime of an individual as an adaptation to infection with a specific pathogen and prepares the immune system for future challenges from that pathogen. Active immunity can come about naturally or artificially.

NATURALLY ACQUIRED ACTIVE IMMUNITY

Active immunity is acquired naturally when a pathogen invades the body and activates the adaptive immune system. When the initial infection is over, memory B cells and memory T cells remain that provide immunological memory of the pathogen. As long as the memory cells are alive, the immune system is ready to mount an immediate response if the same pathogen tries to infect the body again.

ARTIFICIALLY ACQUIRED ACTIVE IMMUNITY

Active immunity can also be acquired artificially through immunization. **Immunization** is the deliberate exposure of a person to a pathogen in order to provoke an adaptive immune response and the formation of memory cells specific to that pathogen. The pathogen is introduced in a vaccine — usually by injection, sometimes by nose or mouth (Figure **11.5.7**) — so immunization is also called vaccination.



Figure **11.5.7**: This young child is receiving an oral polio vaccine.

In a **vaccine,** only part of a pathogen, a weakened form of the pathogen, or a dead pathogen is typically used. This causes an adaptive immune response without making the immunized person sick. This is how you most likely became immune to diseases such as measles, mumps, and chickenpox. Immunizations may last for a lifetime or require periodic booster shots to maintain immunity. While immunization generally has long-lasting effects, it usually takes several weeks to develop full immunity.

Immunization is the most effective method ever discovered in preventing infectious diseases. As many as 3 million deaths are prevented each year because of vaccinations. Widespread immunity due to vaccinations is largely responsible for the worldwide eradication of smallpox and the near elimination of several other infectious diseases from many populations, including such diseases as polio and measles. Immunization is so successful because it exploits the natural specificity and inducibility of the adaptive immune system.

PASSIVE IMMUNITY

Passive immunity results when pathogen-specific antibodies or activated T cells are transferred to a person who has never been exposed to the pathogen. Passive immunity provides immediate protection from a pathogen, but the adaptive immune system does not develop immunological memory to protect the host from the same pathogen in the future. Unlike active immunity, passive immunity lasts only as long as the transferred antibodies or T cells survive in the blood. This is usually between a few days and a few

months. However, like active immunity, passive immunity can be acquired both naturally and artificially.

NATURALLY ACQUIRED PASSIVE IMMUNITY

Passive immunity is acquired naturally by a fetus through its mother's blood. Antibodies are transported from mother to fetus across the placenta, so babies have high levels of antibodies at birth. Their antibodies have the same range of antigen specificity as their mother's. Passive immunity may also be acquired by an infant through the mother's breast milk. This gives young infants protection from common pathogens in their environment while their own immune system matures.

ARTIFICIALLY ACQUIRED PASSIVE IMMUNITY

Older children and adults can acquire passive immunity artificially through the injection of antibodies or activated T cells. This may be done when there is a high risk of infection and insufficient time for the body to develop active immunity through vaccination. It may also be done to reduce symptoms of ongoing disease or to compensate for immunodeficiency diseases (for the latter, see the concept Disorders of the Immune System).

ADAPTIVE IMMUNE EVASION

Many pathogens have been around for a long time, living with human populations for generations. To persist, some have evolved mechanisms to evade the adaptive immune system of human hosts. One way they have done this is by rapidly changing their non-essential antigens. This is called antigenic variation. An example of a pathogen that takes this approach is the human immunodeficiency virus (HIV). It mutates rapidly so the proteins on its viral envelope are constantly changing. By the time the adaptive immune system responds, the virus's antigens have changed. Antigenic variation is the main reason that efforts to develop a vaccine against HIV have not yet been successful.

Another evasion approach some pathogens may take is to mask pathogen antigens with host molecules so the host's immune system cannot detect the antigens. HIV takes this approach as well. The envelope that covers the virus is formed from the outermost membrane of the host cell.

FEATURE: MY HUMAN BODY

If you think that immunizations are just for kids, think again. There are several vaccines recommended by the CDC for people over the age of 18. This link shows the vaccine schedule recommended for all adults aged 19 years and older. Additional vaccines may be recommended for certain adults based on specific medical conditions or other indications. Are you up to date with your vaccines? You can check with your doctor to be sure.

REVIEW

1. What is the adaptive immune system?
2. Describe the main cells of the adaptive immune system.
3. How are lymphocytes activated?
4. Identify two common types of T cells and their functions.
5. How do activated B cells help defend against pathogens?
6. Define immunity.
7. What are two ways active immunity may come about?
8. How does passive immunity differ from active immunity?
9. How may passive immunity occur?
10. What ways of evading the human adaptive immune system evolved in the human immunodeficiency virus (HIV)?
11. Describe two ways in which B cells and T cells work together to generate adaptive immune responses.
12. Which cells directly kill pathogen-infected or cancerous cells?
    A. A. Plasma cells
    B. B. Killer T cells
    C. C. Helper T cells
    D. D. All of the above
13. Why do vaccinations involve the exposure of a person to a version of a pathogen?
14. *True or False.* Immunization is a form of passive immunity.
15. *True or False.* Antibodies transmitted from mother to child via breast milk cause the formation of memory B cells and long-term immunity.

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11.6: DISORDERS OF THE IMMUNE SYSTEM

ALLERGY EYES

Eyes that are red, watery, and itchy are typical of an allergic reaction known as allergic rhinitis. Commonly called hay fever, allergic rhinitis is an immune system reaction typically to the pollen of certain plants. Your immune system usually protects you from pathogens and keeps you well. However, like any other body system, the immune system itself can develop problems. Sometimes it responds to harmless foreign substances as though they were pathogens. That's the basis of allergies such as hay fever.



Figure **11.6.1**: Oedema of the conjunctiva due to hay fever allergy

ALLERGIES

An **allergy** is a disorder in which the immune system makes an inflammatory response to a harmless antigen. It occurs when the immune system is hypersensitive to an antigen in the environment that causes little or no response in most people. Allergies are strongly familial: allergic parents are more likely to have allergic children and those children's allergies are likely to be more severe. This is evidence that there is a heritable tendency to develop allergies. Allergies are more common in children than adults because many children outgrow their allergies by adulthood.

ALLERGENS



Figure **11.6.2**: Common causes of allergies include pollen and poison ivy

Any antigen that causes an allergy is called an **allergen.** Common allergens are plant pollens, dust mites, mold, specific foods (such as peanuts or shellfish), insect stings, and certain common medications (such as aspirin and penicillin). Allergens may be inhaled or ingested, or they may come into contact with the skin or eyes. Symptoms vary depending on the type of exposure and the severity of the immune system response. Two common causes of allergies are ragweed and poison ivy. Inhaling ragweed pollen may cause symptoms of allergic rhinitis, such as sneezing and red itchy eyes. Skin contact with oils in poison ivy may cause an itchy rash. This type of allergy is called contact dermatitis.

PREVALENCE OF ALLERGIES

There has been a significant increase in the prevalence of allergies over the past several decades, especially in the rich nations of the world, where allergies are now very common disorders. In the developed countries, about 20 percent of people have or have had hay fever, another 20 percent have had contact dermatitis, and about 6 percent have food allergies. In the poorer nations of the world, on the other hand, allergies of all types are much less common.

One explanation for the rise in allergies in the developed world is called the hygiene hypothesis. According to this hypothesis, people in developed countries live in relatively sterile environments because of hygienic practices and sanitation systems. As a result, people in these countries are exposed to fewer pathogens than their immune system evolved to cope with. To compensate, their immune system "keeps busy" by attacking harmless antigens in allergic responses.

HOW ALLERGIES OCCUR

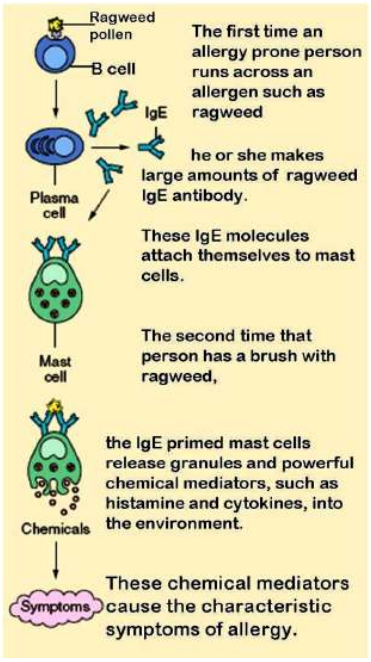


Figure **11.6.3**: This diagram shows how the adaptive immune system is activated by an otherwise harmless antigen on ragweed pollen, responding to the allergen as though it was a pathogen.

The diagram in Figure **11.6.3** shows how an allergic reaction occurs. At the first exposure to an allergen, B cells are activated to form plasma cells that produce large amounts of antibodies to the allergen. These antibodies attach to leukocytes called mast cells. Subsequently, every time the person encounters the allergen again,

the mast cells are already primed and ready to deal with it. The primed mast cells immediately release cytokines and histamines, which in turn cause inflammation and recruitment of leukocytes, among other responses. These responses are responsible for the signs and symptoms of allergies.

TREATING ALLERGIES

The symptoms of allergies can range from mild to life-threatening. Mild allergy symptoms are often treated with antihistamines. These are drugs that reduce or eliminate the effects of the histamines that produce allergy symptoms.

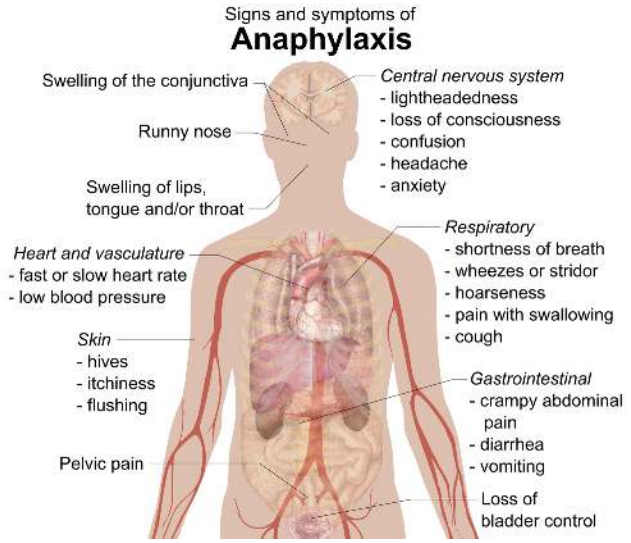


Figure **11.6.4**: Anaphylaxis is a rapid, systemic reaction to allergens that may lead to life-threatening symptoms.

TREATING ANAPHYLAXIS

The most severe allergic reaction is a systemic reaction called **anaphylaxis.** This is a life-threatening response caused by a massive release of histamines. Many of the signs and symptoms of anaphylaxis are shown in Figure **11.6.4**. Some of them include a drop in blood pressure, changes in heart rate, shortness of breath, and swelling of the tongue and throat, which may threaten the patient with suffocation unless emergency treatment is given. People who have had anaphylactic reactions may carry an epinephrine autoinjector (widely known by its brand name EpiPen®) so they can inject themselves with epinephrine if they start to experience an anaphylactic response. The epinephrine helps to control the immune reaction until medical care can be provided. Epinephrine constricts blood vessels to increase blood pressure, relaxes smooth muscles in the lungs to reduce wheezing and improve breathing, modulates heart rate, and works to reduce swelling that may otherwise block the airways.

IMMUNOTHERAPY FOR ALLERGIES

Another way to treat allergies is called **immunotherapy,** commonly called "allergy shots." This approach may actually cure specific allergies, at least for several years if not lifelong. It may be particularly beneficial for allergens such as pollen that are difficult or impossible to avoid. First, however, patients must be tested to identify the specific allergens that are causing their allergies. As shown in Figure **11.6.5**, this may involve scratching tiny amounts of common allergens into the skin and then observing whether there is a localized reaction to any of them. Each allergen is applied in a different numbered location on the skin so if there is a reaction, such as redness or swelling, the responsible allergens can be identified. Then, through periodic injections (usually weekly or monthly), patients are gradually exposed to larger and larger amounts of the allergens. Over time, generally from months to years, the immune system becomes desensitized to the allergens. This method of treating allergies is often effective for allergies to pollen or insect stings, but its usefulness for allergies to food is unclear.



Figure **11.6.5**: Skin testing for common allergens is one way to identify the cause(s) of a patient's allergic symptoms.

AUTOIMMUNE DISEASES

Autoimmune diseases occur when the immune system fails to recognize the body's own molecules as self. As a result, instead of ignoring the body's healthy cells, it attacks them, causing damage to tissues and altered organ growth and function. Most often, it is B cells that are at fault in autoimmune responses. They are generally the cells that lose tolerance for self. Why does this occur? Some autoimmune diseases are thought to be caused by exposure to pathogens that have antigens similar to the body's own molecules. After this exposure, the immune system responds to body cells as though they were pathogens as well.

Certain individuals are genetically susceptible to developing autoimmune diseases. These individuals are also more likely to develop more than one such disease. Gender is also a risk factor for autoimmunity. Females are much more likely than males to develop autoimmune diseases, probably in part because of gender differences in sex hormones.

At a population level, autoimmune diseases are less common where infectious diseases are more common. The hygiene hypothesis has been proposed to explain the inverse relationship between infectious and autoimmune diseases as well as the prevalence of allergies. According to the hypothesis, without infectious diseases to "keep it busy," the immune system may attack the body's own cells instead.

COMMON AUTOIMMUNE DISEASES

An estimated 15 million or more people worldwide have one or more autoimmune diseases. Two of the most common autoimmune diseases are type I diabetes and multiple sclerosis. Both are localized diseases in terms of the specific body cells that are attacked by the immune system. In the case of type I diabetes, the immune system

attacks and destroys insulin-secreting islet cells in the pancreas. In the case of multiple sclerosis, the immune system attacks and destroys the myelin sheaths that normally insulate the axons of neurons and allow rapid transmission of nerve impulses.

Some relatively common autoimmune diseases are systemic, or body-wide, diseases. They include rheumatoid arthritis and systemic lupus erythematosus (SLE). In these diseases, many tissues and organs may be attacked and injured by the immune system. For example, as you can see in Figure **11.6.6**, symptoms of SLE may involve the muscular, skeletal, integumentary, respiratory, and cardiovascular systems.

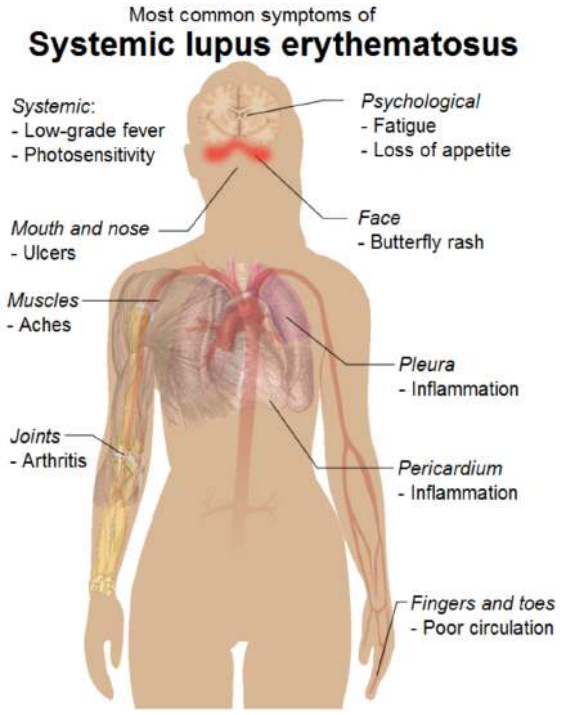


Figure **11.6.6**: Systemic lupus erythematosus is an autoimmune disease that may cause symptoms of body-wide tissue damage. The symptoms listed here are psychological fatigue and loss of appetite, butterfly rash on the face, inflammation of pleura and pericardium, poor circulation to finger and toes, fever, photosensitivity, mouth and nose ulcers, muscle aches, and joint arthritis.

TREATMENT FOR AUTOIMMUNE DISEASES

None of these common autoimmune diseases can be cured, although all of them have treatments that may help relieve symptoms and prevent some of the long-term damage they may cause. Traditional treatments for autoimmune diseases include immunosuppressive drugs to block the immune response and anti-inflammatory drugs to quell inflammation. Hormone replacement may be another option. For example, type I diabetes is treated with injections of the hormone insulin because islet cells in the pancreas can no longer secrete it.

IMMUNODEFICIENCY

Immunodeficiency occurs when the immune system is not working properly, generally because one or more components of the immune system are inactive. As a result, the immune system may be unable to fight off pathogens or cancers that a normal immune system would be able to resist. Immunodeficiency may occur for a variety of reasons.

CAUSES OF IMMUNODEFICIENCY

Dozens of rare genetic diseases can result in a defective immune system. This type of immunodeficiency is called primary immunodeficiency. One is born with one of these diseases rather than acquiring it after birth. Probably the best known of these primary immunodeficiency diseases is severe combined immunodeficiency (SCID). It is also known as “bubble boy disease” because people with this disorder are extremely vulnerable to infectious diseases and some of them have become well known for living inside a bubble that provides a sterile environment. SCID is most often caused by an X-linked recessive mutation that interferes with normal B cell and T cell production.

Other types of immunodeficiency are not present at birth but acquired due to experiences or exposures that occur after birth. Acquired immunodeficiency is called secondary immunodeficiency because it is secondary to some other event or exposure. Secondary immunodeficiency may occur for a number of different reasons:

- The immune system naturally becomes less effective as people get older. This age-related decline, called immunosenescence, generally begins at about age 50 and worsens with increasing age. Immunosenescence is why older people are generally more susceptible to disease than younger people.
- The immune system may be damaged by another disorder, such as obesity, alcoholism, or the abuse of other drugs.
- In developing countries, malnutrition is the most common cause of immune system damage and immunodeficiency. Inadequate protein intake is especially damaging to the immune system. It can lead to impaired complement system activity, phagocyte malfunction, and lower-than-normal production of antibodies and cytokines.
- Surgical removal or disease of the thymus, where T lymphocytes normally mature, results in severe immunodeficiency. People without a functioning thymus are extremely susceptible to infections.
- Certain medications can suppress the immune system. This is the intended effect of immunosuppressant drugs given to people with transplanted organs so they do not reject them. In many cases, however, immunosuppression is an unwanted side effect of drugs used to treat other disorders.
- Some pathogens attack and destroy cells of the immune system. An example is a virus known as HIV, which attacks and destroys T cells.

FOCUS ON HIV

The human immunodeficiency virus (HIV) is the most common cause of immunodeficiency in the world today, so it is the focus of the rest of this concept. It is also covered in the concept HIV and AIDS. HIV infections of human hosts are a relatively recent phenomenon. Scientists think that the virus originally infected

monkeys but then jumped to human populations, probably sometime during the early to mid-1900s. This most likely occurred in West Africa, but the virus soon spread around the world. HIV was first identified by medical researchers in 1981. Since then, HIV has killed almost 40 million people worldwide, and its economic toll has also been enormous. The hardest hit countries are in Africa, where the virus has infected human populations the longest, and medications to control the virus are least available.

HIV TRANSMISSION

HIV is transmitted through direct contact of mucous membranes or body fluids such as blood, semen, or breast milk. As shown in Figure **11.6.7**, the transmission of the virus can occur through sexual contact or the use of contaminated hypodermic needles. It can also be transmitted from an infected mother's blood during late pregnancy or childbirth or through breast milk after birth. In the past, HIV was also transmitted occasionally through blood transfusions. Because donated blood is now screened for HIV, the virus is no longer transmitted this way.

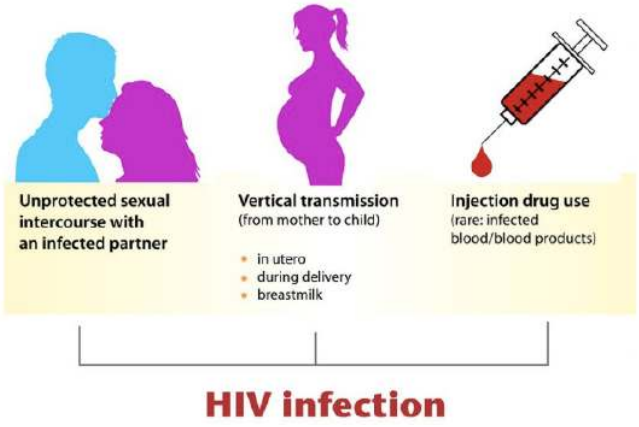


Figure **11.6.7**: HIV may be transmitted in all of the ways shown here.

HIV AND THE IMMUNE SYSTEM

HIV infects and destroys helper T cells, the type of lymphocytes that regulate the immune response. How this occurs is shown in Figure **11.6.8**. The virus injects its own nucleic acid into a helper T cell and uses the T cell's "machinery" to make copies of itself. In the process, the helper T cell is destroyed, and the virus copies go on to infect other helper T cells. HIV is able to evade the immune system and keep destroying helper T cells by mutating frequently so its surface antigens keep changing and by using the host cell's membrane to hide its own antigens.

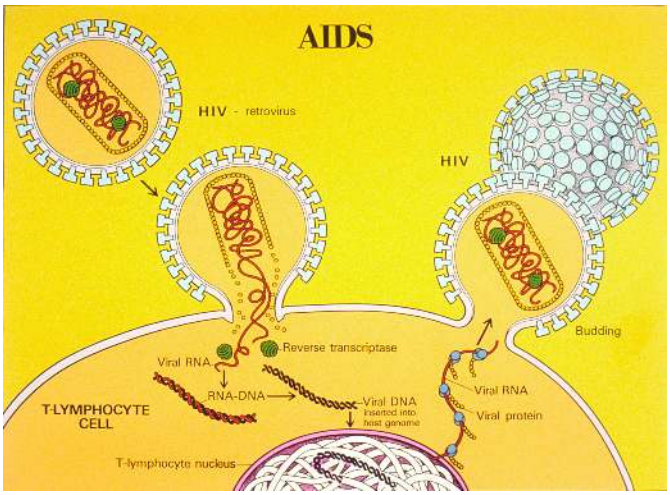


Figure **11.6.8**: The human immunodeficiency virus (HIV-I) enters the T-lymphocyte where the virus loses its outer envelope, releasing its RNA and its reverse transcriptase. The reverse transcriptase builds a complementary DNA strand from the viral RNA template. The DNA helix is inserted into the host genome. When this is transcribed by the infected cell, the new viral RNA and proteins are produced to form new viruses that then bud from the cell membrane, thus completing the life cycle of the virus.

Acquired immunodeficiency syndrome (AIDS) may result from years of damage to the immune system by HIV. It occurs when helper T cells fall to a very low level and opportunistic diseases occur. Opportunistic diseases are infections and tumors that are rare except in people with a damaged immune system. The diseases take advantage of the "opportunity" presented by people whose immune systems cannot fight back. Opportunistic diseases are usually the direct cause of death of people with AIDS.

TREATING HIV/AIDS

For patients who have access to HIV medications, infection with the virus has ceased to be the death sentence that it once was. By 1995, combinations of drugs called "highly active antiretroviral therapy" were developed. For some patients, these drugs can reduce the amount of virus they are carrying to undetectable levels. However, some amount of virus always hides in the body's immune cells and will multiply again if a patient stops taking the medications. Researchers are trying to develop drugs to kill these hidden viruses as well. If their efforts are successful, it could bring an end to AIDS.

FEATURE: HUMAN BIOLOGY IN THE NEWS

EpiPens® and their sole manufacturer, pharmaceutical company Mylan, were featured in the news headlines in 2016 but not for a good reason. A drastic price hike in EpiPens® and Mylan's apparent greed triggered the media outburst.

EpiPens® are auto-injectable syringes preloaded with a measured dose of epinephrine, a drug that can rapidly stop a life-threatening anaphylactic response to an allergen. Using the device is easy and does not require any special training. The injector just needs to be jammed against the thigh, which can be done through clothing or on bare skin. Each year, doctors write millions of prescriptions for EpiPens®. Many people with

severe allergies always carry two of the devices with them just in case they experience anaphylaxis, although most of them never need to use them. Other people with severe allergies have literally had their lives saved multiple times by EpiPens® when they had anaphylactic reactions. Even when the devices haven't been used, they must be replaced each year due to the expiration of the epinephrine.

You might think that EpiPens® would be relatively inexpensive, given their life-saving potential. As recently as 2009, a two-pack of EpiPens® cost about $100. However, in just 7 years, the cost of the same two-pack of EpiPens® skyrocketed by an incredible 400 percent! By 2016, the cost was $600 or more. Mylan apparently raised the price for the sole purpose of increasing profits. The company also raised prices significantly on many other drugs. The price hike in EpiPens® alone was certainly profitable. In 2015, the sale of EpiPens® earned Mylan $1 billion. Mylan's CEO took home almost $19 million the same year, which was an increase of more than 600 percent over her prior salary.

News coverage of the price hike in EpiPens® began in the summer of 2016 after a price increase in May of that year. Both private citizens and elected officials expressed outrage over the price increase, especially when coupled with the gluttonous profits of the company and its CEO. By late August, Mylan responded to the backlash by offering discount coupons for EpiPens®. A few days later, the company promised to introduce a cheaper, generic version of the device. Analysts quickly determined that selling a generic version would allow Mylan to make more money on the product than reducing the price of the name-brand device, which they still declined to do. By September of 2016, Mylan was being investigated for antitrust violations relating to sales of EpiPens® to public schools in New York City.

The Mylan/EpiPen® story may still be making the news. But whatever its outcome, the story has already added fuel to public and private debates about important ethical issues — issues such as the excessive costs of life-saving drugs and the huge profits of big pharma. What is the most recent news on EpiPens® and Mylan? If you are interested, you can check the headlines online to find out. What are your views on the ethical issues they raise?

REVIEW

1. What are allergies? What causes them?
2. Compare the prevalence of allergies in developed and developing countries. How does the hygiene hypothesis explain the differences in prevalence?
3. How do allergies occur?
4. How are mild allergy symptoms treated?
5. What is anaphylaxis, and how is it treated?
6. How does immunotherapy for allergies work?
7. What are autoimmune diseases?
8. Identify two risk factors for autoimmune diseases.
9. Autoimmune diseases may be specific to particular tissues, or they may be systemic. Give an example of each type of autoimmune disease.
10. What is immunodeficiency?
11. Compare and contrast primary and secondary immunodeficiency, and give an example of each.
12. What is the most common cause of immunodeficiency in the world today? How does this cause affect the immune system?
13. Distinguish between HIV and AIDS.
14. *True or False.* Allergies and autoimmune diseases both result from an over-reactive immune system.
15. *True or False.* An anaphylactic reaction can be stopped by administering a shot of histamine.

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11.7: HUMAN MICROBIOME

BENEFICIAL MICROBES: THE PHARMACY IN THE GUT

While some bacteria can cause disease, others play beneficial roles in human health. We have co-evolved with microbes in and on our body, with everyone having a unique set of microorganisms. The most abundant and well-studied microbiome is found in the gut. It has been estimated that the number of bacteria in the human gut may outnumber the cells in the body by an order of magnitude. Thus, one may consider the gut microbiome as a multicellular organ similar in size to the liver. Indeed, it is sometimes referred to as our "forgotten organ".

Generally, the microbiome within a given body habitat can be defined as the diversity and abundance distribution of distinct types of microorganisms. This microbial composition is highly influenced by individual factors such as diet, age, lifestyle, ethnicity, and host health, among others. Although no taxa are observed to be universally present among all individuals, some microbial patterns demonstrate broad prevalence. Most bacteria belong to the genera *Bacteroides*, *Clostridium*, *Fusobacterium*, *Eubacterium*, *Ruminococcus*, *Peptococcus*, *Peptostreptococcus*, and *Bifidobacterium.*

THE EVOLUTION OF MICROBIOME DURING LIFE

Recent research suggests early in-utero microbial exposure during pregnancy. Following birth, the newborn's digestive tract is quickly colonized by microorganisms from the mother (vaginal, fecal, skin, breast milk, etc.) and the environment in which the delivery takes place. Following birth, the microbiome that enters and evolves in the infant's gut is dependent upon a number of factors, with delivery mode and feeding regime (breastfeeding vs infant formula feeding) of prime importance in the early days and weeks of life. By the age of 2 to 3 years, the microbiome becomes essentially established, having reached a steady state, and remains relatively stable throughout life. However, the gut microbiome continuously changes in response to daily variations in diet, lifestyle, age, and host physiological and immunological health.

HEALTH BENEFITS OF THE MICROBIOME

On the basis of the currently available literature, the gut microbiome is known to contribute to a number of important functions in the host, from protective, immunomodulatory, metabolic to trophic roles. These are promoted via a number of mechanisms. For example, members of the gut microbiome can produce anti-inflammatory factors, pain relieving compounds, antioxidants, and vitamins to protect and nurture the body. Additionally, they may prevent attachment and action of harmful bacteria that can produce toxins causing chronic disease. This close and specific contact with human cells, exchanging nutrients and metabolic wastes, makes symbiotic bacteria essentially a human organ.

GASTROINTESTINAL INFECTION PREVENTION

The indigenous intestinal microbiome serves as a line of resistance to colonization by exogenous microbes such as *Clostridium difficile* and *Helicobacter pylori*, and thus assists in competitive exclusion of pathogens preventing the potential invasion, termed colonization resistance. Indeed, antibiotic-associated diarrhea occurs when antibiotic treatment disturbs the natural balance of the gut microbiome causing harmful bacteria (i.e., *Clostridium difficile*) to proliferate and multiply. Oral probiotics may reduce antibiotic-associated diarrhea significantly.

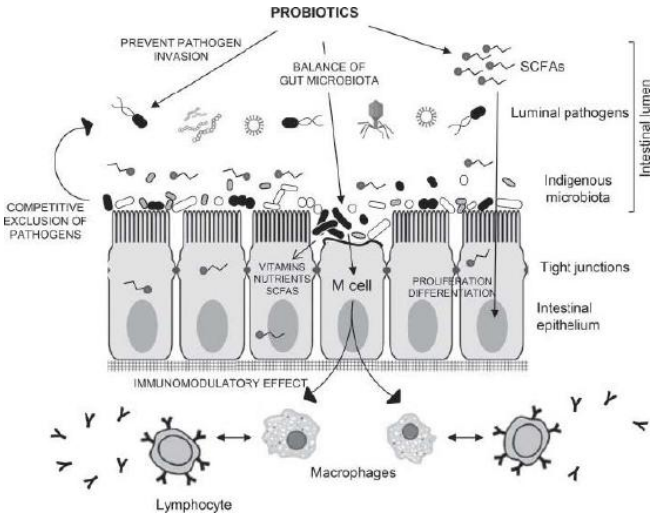


Figure **11.7.1**: Schematic representation of the cross-talk interaction of indigenous microbiome and oral probiotics with the intestinal epithelium. The intestinal microbiome protects the mucosa from invasion by pathogens. These probiotic bacteria may also allow beneficial effects through the release of nutrients (vitamins, SCFAs sugars) which are absorbed in the small intestine. Human microbes and probiotics would also interact with MALT macrophages and naive lymphocyte cells, allowing a mucosal anti-inflammatory response.

IMMUNOMODULATORY EFFECTS

Commensal bacteria can interact with the host immune system in ways that control the host's immune response and counteracts the development of the disease. The complex interactions that may occur between ingested probiotic bacteria, commensals, and the mucosal surface are possible because of the mucosa-associated immune system, typically organized into MALT (Mucosal Associated Lymphoid Tissue, such as Peyer's patches). This cross-talk interaction enhances cellular immune response characterized by activation of macrophages, antigen-specific cytotoxic T-lymphocytes, and the release of various cytokines. Furthermore, some probiotics may be effective in the prevention and/or alleviation of allergies and auto-immune diseases like irritable bowel syndrome and inflammatory bowel diseases (Crohn's disease and ulcerative colitis).

NUTRITIONAL BENEFITS

The metabolic activity of the gut microbiome makes an important contribution to the host's nutritional status via its ability to synthesize certain vitamins and various bioactive metabolites, such as short-chain fatty acids (SCFA), that then become bioavailable to the host. It has been reported that consumption of yogurt containing *Lactobacillus bulgaricus* or *acidophilus* could alleviate lactose intolerance during gastric passage through their enzyme lactase. However, the major metabolic function of the colonic microflora is the fermentation of nondigestible carbohydrates, which are key sources of energy in the colon. These carbohydrates also include large polysaccharides (i.e., resistant starches, pectins, and cellulose) and some oligosaccharides that escape digestion, as well as unabsorbed sugars and alcohols. Other benefits of the gut microbiome on human health, such as a role in supporting the health of the reproductive tract, oral cavity, lungs, skin, and gut-brain axis is currently under investigation.

PROBIOTIC IMBALANCE

When the normal composition of the microbiome is thrown off balance, there is a potential risk of disease. A decrease in microbiome diversity has been linked to cancer, asthma, Parkinson's, obesity, Alzheimer's, type-2 diabetes, cardiovascular disease, and possibly even autism in comparison to healthy subjects. Over-the-counter probiotics can help. In order to arrive alive at their workplace (i.e. the gastrointestinal tract), orally administered probiotics must be able to resist stomach acid, bile, and the effects of digestive enzymes. Certain mechanisms of action (such as the delivery of certain enzymes to the intestine) may not require live cells to play a physiologic benefit. Hence, a probiotic must contain as many live bacteria as claimed on the label. In addition, to survive the stomach and arrive at the intestine in optimal numbers, probiotic strains must be able to adhere to the intestinal epithelium and/or mucus, persist and multiply in the gut to maintain its metabolic activity and confer their probiotic properties in the human body.

RESOURCES

- BIOENGINEERED, 2016, VOL. 7, NO. 1, 11–20: http://dx.doi.org/10.1080/21655979.2015.1126015
- REVIEW: Beneficial Microbes: The pharmacy in the gut, Daniel M. Linares, Paul Ross, and Catherine Stanton, Food Biosciences Department, Teagasc Food Research Center, Moorepark, Fermoy, Cork, Ireland; APC, Microbiome Institute, University College Cork, Cork, Ireland; Biosciences Institute, University College Cork, Cork, Ireland

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ATTRIBUTION

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11.8: CASE STUDY CONCLUSION- LYMPHOMA AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: DEFENDING YOUR DEFENSES

The person in Figure **11.8.1** is participating in a bike ride to raise funds for leukemia and lymphoma research. Leukemia and lymphoma are blood cancers. About every three minutes, one person in the U.S. is diagnosed with blood cancer. Lymphoma is the most common type of blood cancer. As a lymphoma patient, Wei, whom you learned about in the beginning of this chapter, may eventually benefit from research funded by a bike ride like this one.



Figure **11.8.1**: Fundraising for research

What type of blood cell is affected in lymphoma? As the name implies, lymphoma is cancer that affects lymphocytes, which are a type of white blood cell. As you have learned in this chapter, there are different types of lymphocytes, including the B and T cells of the adaptive immune system. Different types of lymphoma affect different types of lymphocytes in different ways. It is important to correctly identify the type of lymphoma so that patients can be treated appropriately.

You may recall that one of Wei's symptoms was a swollen lymph node, and he was diagnosed with lymphoma after a biopsy of that lymph node. Swollen lymph nodes are a common symptom of lymphoma. As you have learned, lymph nodes are distributed throughout the body along lymphatic vessels as part of the lymphatic system. The lymph nodes filter lymph and store lymphocytes and therefore play an important role in fighting infections. Because of this, they will often swell in response to an infection. In Wei's case, the swelling and other symptoms did not improve after several weeks and a course of antibiotics, which caused Dr. Bouazizi to suspect lymphoma instead. The biopsy showed that Wei did indeed have cancerous lymphocytes in his lymph nodes.

But which type of lymphocytes were affected? Lymphoma most commonly affects B or T lymphocytes. The two major types of lymphoma are called Hodgkin (HL) or non-Hodgkin lymphoma (NHL). NHL is more common than HL. There are more than 70,000 cases of NHL diagnosed in the U.S. each year, compared to about 8,000 for HL. While HL is one distinct type of lymphoma, NHL has about 60 different subtypes, depending on which specific cells are affected and how.

Wei was diagnosed with a type of NHL called diffuse large B-cell lymphoma (DLBCL)—the most common type of NHL. This type of lymphoma affects B cells and causes them to appear large under the microscope. In addition to Wei's symptoms of fatigue, swollen lymph nodes, loss of appetite, and weight loss, common symptoms of this type of lymphoma include fever and night sweats. It is an aggressive and fast-growing type of lymphoma that is fatal if not treated. But the good news is that with early detection and proper treatment, about 70% of patients with DLBCL can be cured.

How do physicians determine the specific type of lymphoma? Tissue obtained from a biopsy can be examined under a microscope to observe physical changes such as abnormal cell size or shape that are characteristic of a particular subtype of lymphoma. Additionally, tests can be performed on the tissue to determine which cell-surface antigens are present. Recall that antigens are molecules that bind to specific antibodies. Antibodies can be produced in the laboratory and labeled with compounds that can be identified by their color under a microscope. When these antibodies are applied to a tissue sample, this color will appear wherever the antigen is present, because it binds to the antibody. For example, this technique was used in the photomicrograph in Figure **11.8.2** to identify the presence of a cell-surface antigen (shown as reddish-brown) in a sample of skin cells. This technique, called **immunohistochemistry**, is also commonly used to identify antigens in tissue samples from lymphoma patients.

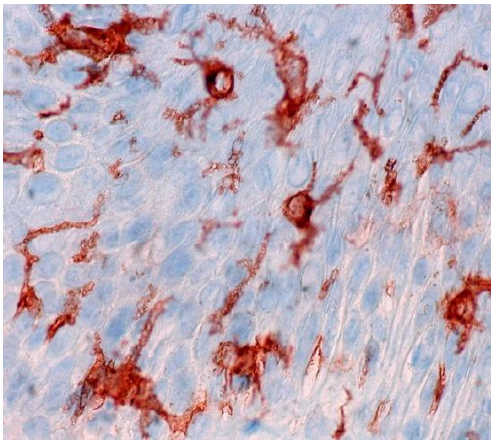


Figure **11.8.2**: Test for lymphoma

Why would identifying cell-surface antigens be important in diagnosing and treating lymphoma? As you have learned, the immune system uses antigens present on the surface of cells or pathogens to distinguish between self and non-self and to launch adaptive immune responses. Cells that become cancerous often change their cell-surface antigens, and this is one way that the immune system can identify and destroy them. Also, different cell types in the body can sometimes be identified by the presence of specific cell-surface antigens. Knowing the types of cell-surface

antigens present in a tissue sample can help physicians identify which cells are cancerous, and possibly the specific subtype of cancer. Knowing this information can be helpful in choosing more tailored and effective treatments.

In fact, one treatment for NHL is the use of medications made from antibodies that bind to cell-surface antigens present on cells affected by the specific subtype of NHL. This is called **immunotherapy**. These drugs can directly bind to and kill the cancerous cells. For patients with DLBCL such as Wei, immunotherapy is often used in conjunction with chemotherapy and radiation as a course of treatment. Although Wei has a difficult road ahead, he and his medical team are optimistic that he may be able to be cured, given the high success rate when DLBCL is caught and treated early. More research into how the immune system functions may lead to even better treatments for lymphoma, and other types of cancers, in the future.

CHAPTER SUMMARY

In this chapter, you learned about the immune system. Specifically, you learned that:

- Any agent that can cause disease is called a pathogen. Most human pathogens are microorganisms such as bacteria and viruses. The immune system is the body system that defends the human host from pathogens and cancerous cells.
- The innate immune system is a subset of the immune system that provides very quick but non-specific responses to pathogens. It includes multiple types of barriers to pathogens, leukocytes that phagocytize pathogens, and several other general responses.
- The adaptive immune system is a subset of the immune system that provides specific responses tailored to particular pathogens. It takes longer to put into effect, but it may lead to immunity to the pathogens.
- Both innate and adaptive immune responses depend on the ability of the immune system to distinguish between self and non-self molecules. Most body cells have major histocompatibility complex (MHC) proteins that identify them as self. Pathogens, infected cells, and tumor cells have non-self proteins called antigens that the immune system recognizes as foreign.
- Antigens are proteins that bind to specific receptors on immune system cells and elicit an adaptive immune response. Some immune cells (B cells) respond to foreign antigens by producing antibodies that bind with antigens and target pathogens for destruction.
- An important role of the immune system is tumor surveillance. Killer T cells of the adaptive immune system find and destroy tumor cells, which they can identify from their abnormal antigens.
- The neuroimmune system that protects the central nervous system is thought to be distinct from the peripheral immune system that protects the rest of the human body. The blood-brain and blood-spinal cord barriers are one type of protection of the neuroimmune system. Glial cells also play role in this system—for example, by carrying out phagocytosis.
- The lymphatic system is a human organ system that is a vital part of the adaptive immune system. It consists of several organs and a system of vessels that transport or filter the fluid called lymph. The main immune function of the lymphatic system is to produce, mature, harbor, and circulate white blood cells called lymphocytes, which are the main cells in the adaptive immune system and are circulated in the lymph.
- The return of lymph to the bloodstream is one of the functions of the lymphatic system. Lymph flows from tissue spaces, where it leaks out of blood vessels, to major veins in the upper chest, where it is returned to the cardiovascular system. Lymph is similar in composition to blood plasma. Its main cellular components are lymphocytes.
- Lymphatic vessels called lacteals are found in villi that line the small intestine. Lacteals absorb fatty acids from the digestion of lipids in the digestive system. The fatty acids are then transported through the network of lymphatic vessels to the bloodstream. Although it plays a role in digestion, the primary function of the lymphatic system is host defense.
- Lymphocytes, which include B cells and T cells, are the subset of white blood cells that are involved in adaptive immune responses. They may create a lasting memory of and immunity to specific pathogens.
- All lymphocytes are produced in the bone marrow and then go through a process of maturation in which they “learn” to distinguish self from non-self. B cells mature in the bone marrow, and T cells mature in the thymus. Both the bone marrow and thymus are considered primary lymphatic organs.
- Secondary lymphatic organs include the tonsils, spleen, and lymph nodes. There are four pairs of tonsils that encircle the throat. The spleen filters blood as well as lymph. There are hundreds of lymph nodes located in clusters along the lymphatic vessels. All of these secondary organs filter lymph and store lymphocytes, so they are sites where pathogens encounter and activate lymphocytes and initiate adaptive immune responses.
- Unlike the adaptive immune system, the innate immune system does not confer immunity. The innate immune system includes surface barriers, inflammation, the complement system, and a variety of cellular responses.
- The body’s first line of defense consists of three different types of barriers that keep most pathogens out of body tissues. The types of barriers are mechanical, chemical, and biological barriers.
- Mechanical barriers—which include the skin, mucous membranes, and fluids such as tears and urine—physically block pathogens from entering the body.
- Chemical barriers—such as enzymes in sweat, saliva, and semen—kill pathogens on body surfaces.
- Biological barriers are harmless bacteria that use up food and space so pathogenic bacteria cannot colonize the body.

- If pathogens breach the protective barriers, inflammation occurs. This creates a physical barrier against the spread of infection and repairs tissue damage. Inflammation is triggered by chemicals such as cytokines and histamines, and it causes swelling, redness, and warmth.
- The complement system is a complex biochemical mechanism that helps antibodies kill pathogens. Once activated, the complement system consists of more than two dozen proteins that lead to disruption of the cell membrane of pathogens and bursting of the cells.
- Cellular responses of the innate immune system involve various types of leukocytes (white blood cells). For example, neutrophils, macrophages, and dendritic cells phagocytize pathogens. Basophils and mast cells release chemicals that trigger inflammation. Natural killer cells destroy cancerous or virus-infected cells, and eosinophils kill parasites.
- Many pathogens have evolved mechanisms that help them evade the innate immune system. For example, some pathogens form a protective capsule around themselves, and some mimic host cells so the immune system does not recognize them as foreign.
- The main cells of the adaptive immune system are lymphocytes. There are two major types of lymphocytes: T cells and B cells. Both types must be activated by foreign antigens to become functioning immune cells.
- Most activated T cells become either killer T cells or helper T cells. Killer T cells destroy cells that are infected with pathogens or are cancerous. Helper T cells manage immune responses by releasing cytokines that control other types of leukocytes.
- Activated B cells form plasma cells that secrete antibodies, which bind to specific antigens on pathogens or infected cells. The antibody-antigen complexes generally lead to the destruction of the cells, for example, by attracting phagocytes or triggering the complement system.
- After an adaptive immune response occurs, long-lasting memory B cells and memory T cells may remain to confer immunity to the specific pathogen that caused the adaptive immune response. These memory cells are ready to activate an immediate response if they are exposed to the same antigen again in the future.
- Immunity may be active or passive. Active immunity occurs when the immune system has been presented with antigens that elicit an adaptive immune response. This may occur naturally as the result of an infection or artificially as the result of immunization. Active immunity may last for years or even for life.
- Passive immunity occurs without an adaptive immune response by the transfer of antibodies or activated T cells. This may occur naturally between a mother and her fetus or her nursing infant, or it may occur artificially by injection. Passive immunity lasts only as long as the antibodies or activated T cells remain alive in the body, generally just weeks or months.
- Many pathogens have evolved mechanisms to evade the adaptive immune system. For example, human immunodeficiency virus (HIV) evades the adaptive immune system by frequently changing its antigens and by forming its outer envelope from the host's cell membrane.
- An allergy is a disorder in which the immune system makes an inflammatory response to a harmless antigen. Any antigen that causes allergies is called an allergen. Common allergens include pollen, dust mites, mold, specific foods such as peanuts, insect stings, and certain medications such as aspirin.
- The prevalence of allergies has been increasing for decades, especially in developed countries where they are much more common than in developing countries. The hygiene hypothesis posits that this has occurred because humans evolved to cope with more pathogens than we now typically face in our relatively sterile environments in developed countries. As a result, the immune system "keeps busy" by attacking harmless antigens.
- Allergies occur when B cells are first activated to produce large amounts of antibodies to an otherwise harmless allergen and the antibodies attach to mast cells. On subsequent exposures to the allergen, the mast cells immediately release cytokines and histamines that cause inflammation.
- Mild allergy symptoms are frequently treated with antihistamines that counter histamines and reduce allergy symptoms. A severe systemic allergic reaction, called anaphylaxis, is a medical emergency that is usually treated with injections of epinephrine. Immunotherapy for allergies involves injecting increasing amounts of allergens to desensitize the immune system to them.
- Autoimmune diseases occur when the immune system fails to recognize the body's own molecules as self and attacks them, causing damage to tissues and organs. A family history of autoimmunity and female sex are risk factors for autoimmune diseases.
- In some autoimmune diseases, such as type I diabetes, the immune system attacks, and damages, specific body cells. In other autoimmune diseases, such as systemic lupus erythematosus, many different tissues and organs may be attacked and injured. Autoimmune diseases generally cannot be cured, but their symptoms can often be managed with drugs or other treatments.
- Immunodeficiency occurs when the immune system is not working properly, generally because one or more of its components are inactive. As a result, the immune system is unable to fight off pathogens or cancers that a normal immune system would be able to resist.
- Primarily immunodeficiency is present at birth and caused by rare genetic diseases. An example is severe combined immunodeficiency. Secondary immunodeficiency occurs because of some event or exposure experienced after birth. Possible causes include substance abuse, obesity, and malnutrition, among others.
- The most common cause of immunodeficiency in the world today is the human immunodeficiency virus (HIV), which infects and destroys helper T cells. HIV is transmitted through mucous membranes or body fluids. The virus may eventually lead to such low levels of helper T cells that opportunistic infections occur.

When this happens, the patient is diagnosed with acquired immunodeficiency syndrome (AIDS). Medications can control the multiplication of HIV in the human body but not eliminate the virus completely.

Up to this point, this book has covered body systems that carry out processes within individuals, such as the digestive, muscular, and immune systems. Read the next chapter to learn about the body system that allows humans to produce new individuals—the reproductive system.

CHAPTER SUMMARY REVIEW

1. The skin plays a role in establishing mechanical, chemical, and biological barriers that protect the body against pathogens. Give one example of how the skin contributes to each type of barrier.
2. Compare and contrast a pathogen and an allergen.
3. Describe three ways in which pathogens can enter the body.
4. For each of the following immune responses, state whether it is an innate or adaptive immune response.
   A. Inflammation
   B. Lymphocyte activation
   C. Phagocytosis by leukocytes
   D. Plasma cell maturation
5. The complement system involves the activation of several proteins to kill pathogens. Why do you think this is considered part of the innate immune system instead of the adaptive immune system?
6. Why are innate immune responses generally faster than adaptive immune responses?
7. *Rrue or False.* There is more than one type of immune system cell that can carry out phagocytosis.
8. *True or False.* Semen can act as a chemical barrier against pathogens.
9. *True or False.* Leukocytes in the innate immune system are all phagocytic.
10. Which type of immunity is triggered by vaccination?
    A. Artificially acquired active immunity
    B. Artificially acquired natural immunity
    C. Artificially acquired passive immunity
    D. Innate immunity
11. Explain how an autoimmune disease could be triggered by a pathogen.
12. What is an opportunistic infection? Name two diseases or conditions that could result in opportunistic infections. Explain your answer.
13. Match each description below with the cell type that best fits it from the list provided. Each cell type is used only once. Cell types: mast cells; B cells; killer T cells
    A. Directly destroys body cells that are cancerous or infected with a pathogen
    B. Secretes histamines and are involved in allergies
    C. Once activated, these cells multiply and their daughter cells mature into plasma cells
14. Which cell type in the immune system can be considered an "antibody factory"?
15. Besides foreign pathogens, what is one other thing that the immune system protects the body against?
16. What cell type in the immune system is infected and killed by HIV?
17. What is the difference between primary lymphoid organs and secondary lymphoid organs? Give one example of each in your answer.
18. Name two types of cells that produce cytokines in the immune system. What are two functions of cytokines in the immune system?
19. Many pathogens evade the immune system by altering their outer surface in some way. Based on what you know about the functioning of the immune system, why is this often a successful approach?
20. Major histocompatibility complex proteins:
    A. are involved in antigen-presentation by B cells
    B. help distinguish cells as self
    C. produce histamines
    D. A and B
21. What is "missing self" and how does this condition arise?
22. *True or False.* Sometimes only part of a pathogen is used to create a vaccine.
23. *True or False.* An antigen is the same thing as an allergen.

ATTRIBUTIONS

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2. Langerhans Cells in Normal Epidermis, CD1a Immunostain by Ed Uthman, CC BY 2.0 via Flickr.com
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CHAPTER OVERVIEW

12: RESPIRATORY SYSTEM

This chapter describes the structure and function of the respiratory system, including how breathing occurs and what controls it, as well as how the process of gas exchange takes place in the lungs. The chapter also describes several disorders of the respiratory system and details the adverse health effects of smoking.

12.1: Case Study- Respiratory System and Gas Exchange

12.2: Structure and Function of the Respiratory System

12.3: Breathing

12.4: Disorders of the Respiratory System

12.5: Smoking and Health

12.6: Case Study Conclusion- Bronchitis and Chapter Summary

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12.1: CASE STUDY- RESPIRATORY SYSTEM AND GAS EXCHANGE

CASE STUDY: COUGH THAT WON'T QUIT

Three weeks ago, 20-year-old Sacheen came down with symptoms typical of the common cold. She had a runny nose, fatigue, and a mild cough. Her symptoms had been starting to improve, but recently her cough has been getting worse. She coughs up a lot of thick mucus, her throat is sore from frequent coughing, and her chest feels very congested. According to her wife, Sacheen has a "chest cold." Sacheen is a smoker and wonders if her habit is making her cough worse. She decides that it is time to see a doctor.



Figure **12.1.1**: Coughing

Dr. Tsosie examines Sacheen and asks about her symptoms and health history. She checks the level of oxygen in Sacheen's blood by attaching a device called a pulse oximeter to Sacheen's finger (Figure **12.1.2**). Dr. Tsosie concludes that Sacheen has bronchitis, an infection that commonly occurs after a person has a cold or flu. Bronchitis is sometimes referred to as a "chest cold," so Sacheen's wife was right! Bronchitis causes inflammation and a build-up of mucus in the bronchial tubes in the chest.



Figure **12.1.2**: A pulse oximeter, used to measure blood oxygen levels.

Because viruses, and not bacteria, usually cause bronchitis, Dr. Tsosie tells Sacheen that antibiotics are not likely to help. Instead, she recommends that Sacheen try to thin and remove the mucus by drinking plenty of fluids and using a humidifier, or spending time in a steamy shower. She also recommends that Sacheen get plenty of rest.

Dr. Tsosie also tells Sacheen some things *not* to do—most importantly, not to smoke while she is sick and to try to quit smoking in the long term. She explains that smoking can make people more susceptible to bronchitis and can hinder recovery. She also advises Sacheen not to take over-the-counter cough suppressant medication.

As you read this chapter on the respiratory system, you will better understand what bronchitis is and why Dr. Tsosie made the treatment recommendations that she did. At the end of the chapter, you will learn more about acute bronchitis, which is the type that Sacheen has. This information may come in handy to you personally because the chances are high that you will get this common infection at some point in your life—there are millions of bronchitis cases every year!

CHAPTER OVERVIEW: RESPIRATORY SYSTEM

In this chapter, you will learn about the respiratory system, the system that exchanges gases such as oxygen and carbon dioxide between the body and the outside air. Specifically, you will learn about:

- The process of respiration, in which oxygen moves from the outside air into the body and carbon dioxide and other waste gases move from inside the body into the outside air.
- The organs of the respiratory system, including the lungs, bronchial tubes, and the rest of the respiratory tract.
- How the respiratory tract protects itself from pathogens and other potentially harmful substances in the air.
- How the rate of breathing is regulated to maintain homeostasis of blood gases and pH.
- How ventilation, or breathing, allows us to inhale air into the body and exhale air out of the body.
- The conscious and unconscious control of breathing.
- Nasal breathing compared to mouth breathing.
- What happens when a person is drowning.
- How gas exchange occurs between the air and blood in the alveoli of the lungs, and between the blood and cells throughout the body.
- Disorders of the respiratory system, including asthma, pneumonia, chronic obstructive pulmonary disease (COPD), and lung cancer.
- The negative health effects of smoking.

As you read the chapter, think about the following questions:

1. Where are the bronchial tubes, and what is their function?
2. What is the function of mucus, and why can too much mucus be a bad thing?
3. Why did Dr. Tsosie check Sacheen's blood oxygen level?
4. Why do you think Dr. Tsosie warned Sacheen not to take cough suppressant medications?
5. How does acute bronchitis compare to chronic bronchitis, and how do they both relate to smoking?

ATTRIBUTIONS

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12.2: STRUCTURE AND FUNCTION OF THE RESPIRATORY SYSTEM

SEEING YOUR BREATH

Why can you "see your breath" on a cold day? The air you exhale through your nose and mouth is warm, like the inside of your body. Exhaled air also contains a lot of water vapor because it passes over moist surfaces from the lungs to the nose or mouth. The water vapor in your breath cools suddenly when it reaches the much colder outside air. This causes the water vapor to condense into a fog of tiny droplets of liquid water. You release water vapor and other gases from your body through the process of respiration.



Figure **12.2.1**: Breath on a cold day

WHAT IS RESPIRATION?

Respiration is the life-sustaining process in which gases are exchanged between the body and the outside atmosphere. Specifically, oxygen moves from the outside air into the body; and water vapor, carbon dioxide, and other waste gases move from inside the body into the outside air. Respiration is carried out mainly by the **respiratory system.** It is important to note that respiration by the respiratory system is not the same process as cellular respiration that occurs inside cells, although the two processes are closely connected. Cellular respiration is the metabolic process in which cells obtain energy, usually by "burning" glucose in the presence of oxygen. When cellular respiration is aerobic, it uses oxygen and releases carbon dioxide as a waste product. Respiration by the respiratory system supplies the oxygen needed by cells for aerobic cellular respiration and removes the carbon dioxide produced by cells during cellular respiration.

Respiration by the respiratory system actually involves two subsidiary processes. One process is ventilation or breathing. This is the physical process of conducting air to and from the lungs. The other process is gas exchange. This is the biochemical process in which oxygen diffuses out of the air and into the blood while carbon dioxide and other waste gases diffuse out of the blood and into the air. All of the organs of the respiratory system are involved in breathing, but only the lungs are involved in gas exchange.

RESPIRATORY ORGANS

The organs of the respiratory system form a continuous system of passages called the **respiratory tract,** through which air flows into and out of the body. The respiratory tract has two major divisions: the upper respiratory tract and the lower respiratory tract. The organs in each division are shown in Figure **12.2.2**. In addition to these organs, certain muscles of the thorax (the body cavity that fills the chest) are also involved in respiration by enabling breathing. Most important is a large muscle called the diaphragm, which lies below the lungs and separates the thorax from the abdomen. Smaller muscles between the ribs also play a role in breathing. You can learn more about breathing muscles in the concept of *Breathing*.

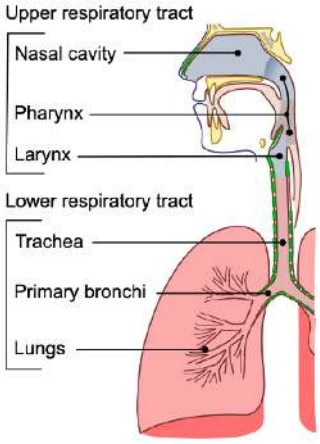


Figure **12.2.2**: During breathing, inhaled air enters the body through the nose and passes through the pharynx, larynx, trachea, bronchi, and then enters the lungs. Exhaled air travels from the lungs in the opposite direction.

UPPER RESPIRATORY TRACT

All of the organs and other structures of the upper respiratory tract are involved in the conduction or the movement of air into and out of the body. Upper respiratory tract organs provide a route for air to move between the outside atmosphere and the lungs. They also clean, humidity, and warm the incoming air. However, no gas exchange occurs in these organs.

NASAL CAVITY

The **nasal cavity** is a large, air-filled space in the skull above and behind the nose in the middle of the face. It is a continuation of the two nostrils. As inhaled air flows through the nasal cavity, it is warmed and humidified. Hairs in the nose help trap larger foreign particles in the air before they go deeper into the respiratory tract. In addition to its respiratory functions, the nasal cavity also contains chemoreceptors that are needed for the sense of smell and that contribute importantly to the sense of taste.

PHARYNX

The **pharynx** is a tube-like structure that connects the nasal cavity and the back of the mouth to other structures lower in the throat, including the larynx. The pharynx has dual functions: both air and

food (or other swallowed substances) pass through it, so it is part of both the respiratory and digestive systems. Air passes from the nasal cavity through the pharynx to the larynx (as well as in the opposite direction). Food passes from the mouth through the pharynx to the esophagus.

LARYNX

The **larynx** connects the pharynx and trachea and helps to conduct air through the respiratory tract. The larynx is also called the voice box because it contains the vocal cords, which vibrate when air flows over them, thereby producing sound. You can see the vocal cords in the larynx in Figure **12.2.3**. Certain muscles in the larynx move the vocal cords apart to allow breathing. Other muscles in the larynx move the vocal cords together to allow the production of vocal sounds. The latter muscles also control the pitch of sounds and help control their volume.

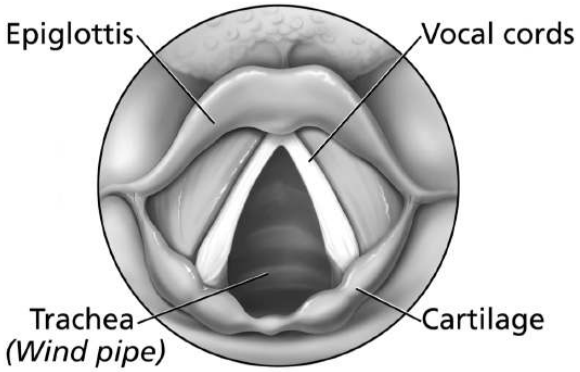


Figure **12.2.3**: The larynx is viewed from the top. opening to the trachea is closed by epiglottis during swallowing. Cartilage and vocal cords are also visible.

A very important function of the larynx is protecting the trachea from aspirated food. When swallowing occurs, the backward motion of the tongue forces a flap called the epiglottis to close over the entrance to the larynx. You can see the epiglottis in Figure **12.2.3**. This prevents swallowed material from entering the larynx and moving deeper into the respiratory tract. If swallowed material does start to enter the larynx, it irritates the larynx and stimulates a strong cough reflex. This generally expels the material out of the larynx and into the throat.

LOWER RESPIRATORY TRACT

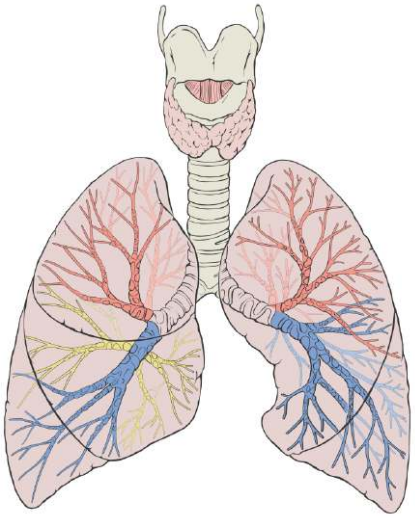


Figure **12.2.4**: This diagram illustrates the tree-like branching of the passages of the lower respiratory tract within the lungs.

The trachea and other passages of the lower respiratory tract conduct air between the upper respiratory tract and the lungs. These passages form an inverted tree-like shape (Figure **12.2.4**), with repeated branching as they move deeper into the lungs. All told, there are an astonishing 1,500 miles of airways conducting air through the human respiratory tract! It is only in the lungs, however, that gas exchange occurs between the air and the bloodstream.

TRACHEA

The **trachea,** or windpipe, is the widest passageway in the respiratory tract. It is about 2.5 cm (1 in.) wide and 10-15 cm (4-6 in.) long. It is formed by rings of cartilage, which make it relatively strong and resilient. The trachea connects the larynx to the lungs for the passage of air through the respiratory tract. The trachea branches at the bottom to form two bronchial tubes.

BRONCHI AND BRONCHIOLES

There are two main bronchial tubes, or **bronchi (singular, bronchus)**, called the right and left bronchi. The bronchi carry air between the trachea and lungs. Each bronchus branches into smaller, secondary bronchi; and secondary bronchi branch into still smaller tertiary bronchi. The smallest bronchi branch into very small tubules called bronchioles. The tiniest bronchioles end in alveolar ducts, which terminate in clusters of minuscule air sacs, called alveoli (singular, alveolus), in the lungs.

LUNGS

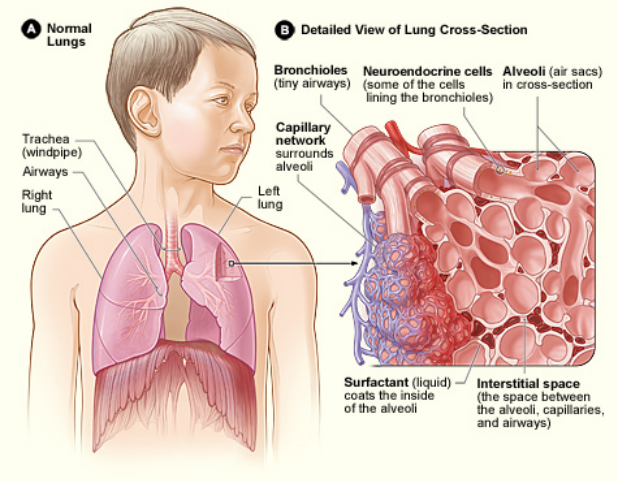


Figure **12.2.5**: The cross-section of lung tissue on the right shows the alveoli in which gas exchange takes place with the capillary network that surrounds them. Neuroendocrine cells lining the bronchioles control their diameter and the flow of air through them. A surfactant is a liquid that covers the inside of the alveoli and prevents them from collapsing and sticking together when air empties out of them during exhalation.

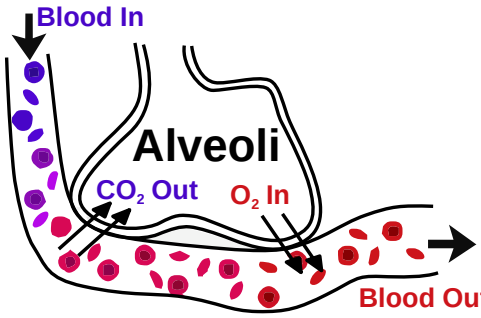


Figure **12.2.6**: The gaseous exchange between blood and outside air inside the lung alveoli.

The **lungs** are the largest organs of the respiratory tract. They are suspended within the pleural cavity of the thorax. In Figure **12.2.5**, you can see that each of the two lungs is divided into sections. These are called lobes, and they are separated from each other by connective tissues. The right lung is larger and contains three lobes. The left lung is smaller and contains only two lobes. The smaller left lung allows room for the heart, which is just left of the center of the chest.

Lung tissue consists mainly of alveoli (Figure **12.2.6**). These tiny air sacs are the functional units of the lungs where gas exchange takes place. The two lungs may contain as many as 700 million alveoli, providing a huge total surface area for gas exchange to take place. In fact, alveoli in the two lungs provide as much surface area as half a tennis court! Each time you breathe in, the alveoli fill with air, making the lungs expand. Oxygen in the air inside the alveoli is absorbed by the blood in the mesh-like network of tiny capillaries that surrounds each alveolus. The blood in these capillaries also releases carbon dioxide into the air inside the alveoli. Each time you breathe out, air leaves the alveoli and rushes into the outside atmosphere, carrying waste gases with it.

The lungs receive blood from two major sources. They receive deoxygenated blood from the heart. This blood absorbs oxygen in the lungs and carries it back to the heart to be pumped to cells throughout the body. The lungs also receive oxygenated blood from the heart that provides oxygen to the cells of the lungs for cellular respiration.

PROTECTING THE RESPIRATORY SYSTEM

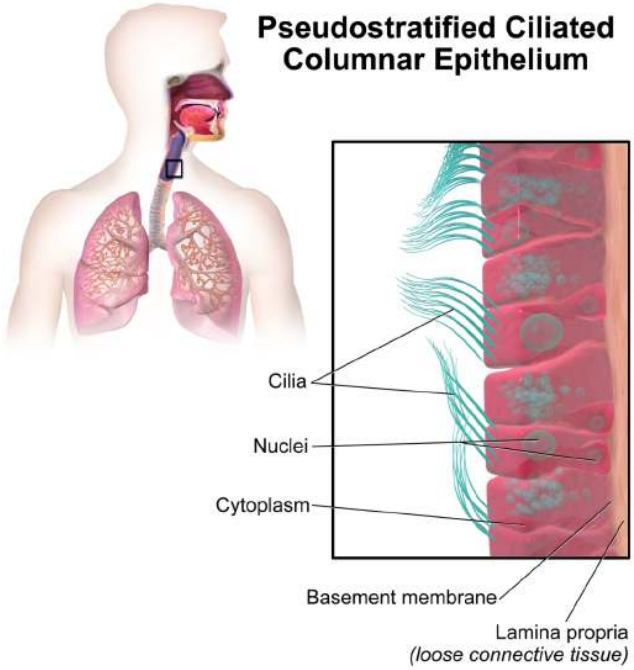


Figure **12.2.7**: The upward sweeping motion of cilia lining the respiratory tract helps keep it free from dust, pathogens, and other harmful substances.

You may be able to survive for weeks without food and for days without water, but you can survive without oxygen for only a matter of minutes except under exceptional circumstances. Therefore, protecting the respiratory system is vital. That's why making sure a patient has an open airway is the first step in treating many medical emergencies. Fortunately, the respiratory system is well protected by the ribcage of the skeletal system. However, the extensive surface area of the respiratory system is directly exposed to the outside world and all its potential dangers in inhaled air. Therefore, it should come as no surprise that the respiratory system has a variety of ways to protect itself from harmful substances such as dust and pathogens in the air.

The main way the respiratory system protects itself is called the mucociliary escalator. From the nose through the bronchi, the respiratory tract is covered in the epithelium that contains mucus-secreting goblet cells. The mucus traps particles and pathogens in the incoming air. The epithelium of the respiratory tract is also covered with tiny cell projections called cilia (singular, cilium), as shown in Figure **12.2.7**. The cilia constantly move in a sweeping motion upward toward the throat, moving the mucus and trapped particles and pathogens away from the lungs and toward the outside of the body.

What happens to the material that moves up the mucociliary escalator to the throat? It is generally removed from the respiratory tract by clearing the throat or coughing. Coughing is a largely involuntary response of the respiratory system that occurs when nerves lining the airways are irritated. The response causes air to be expelled forcefully from the trachea, helping to remove mucus and any debris it contains (called phlegm) from the upper respiratory tract to the mouth. The phlegm may spit out (expectorated), or it may be swallowed and destroyed by stomach acids.

Sneezing is a similar involuntary response that occurs when nerves lining the nasal passage are irritated. It results in forceful expulsion of air from the mouth, which sprays millions of tiny droplets of mucus and other debris out of the mouth and into the air, as shown in Figure **12.2.8**. This explains why it is so important to sneeze into a sleeve rather than the air to help prevent the transmission of respiratory pathogens.



Figure **12.2.8**: Sneezing results in tiny particles from the mouth being forcefully ejected into the air.

HOW THE RESPIRATORY SYSTEM WORKS WITH OTHER ORGAN SYSTEMS

The amount of oxygen and carbon dioxide in the blood must be maintained within a limited range for the survival of the organism. Cells cannot survive for long without oxygen, and if there is too much carbon dioxide in the blood, the blood becomes dangerously acidic (pH is too low). Conversely, if there is too little carbon dioxide in the blood, the blood becomes too basic (pH is too high). The respiratory system works hand-in-hand with the nervous and cardiovascular systems to maintain homeostasis in blood gases and pH.

It is the level of carbon dioxide rather than the level of oxygen that is most closely monitored to maintain blood gas and pH homeostasis. The level of carbon dioxide in the blood is detected by cells in the brain, which speed up or slow down the rate of breathing through the autonomic nervous system as needed to bring the carbon dioxide level within the normal range. Faster breathing lowers the carbon dioxide level (and raises the oxygen level and pH); slower breathing has the opposite effects. In this way, the levels of carbon dioxide and oxygen, as well as pH, are maintained within normal limits.

The respiratory system also works closely with the cardiovascular system to maintain homeostasis. The respiratory system exchanges gases between the blood and the outside air, but it needs the cardiovascular system to carry them to and from body cells. Oxygen is absorbed by the blood in the lungs and then transported through a vast network of blood vessels to cells throughout the body where it is needed for aerobic cellular respiration. The same system absorbs carbon dioxide from cells and carries it to the respiratory system for removal from the body.

FEATURE: MY HUMAN BODY

Choking is the mechanical obstruction of the flow of air from the atmosphere into the lungs. It prevents breathing and may be partial or complete. Partial choking allows some though inadequate airflow into the lung—prolonged or complete choking results in asphyxia, or suffocation, which is potentially fatal.

Obstruction of the airway typically occurs in the pharynx or trachea. Young children are more prone to choking than are older people, in part because they often put small objects in their mouths and do not appreciate the risk of choking that they pose. Young children may choke on small toys or parts of toys or on household objects in addition to food. Foods that can adapt their shape to that of the pharynx, such as bananas and marshmallows, are especially dangerous and may cause choking in adults as well as children.

How can you tell if a loved one is choking? The person cannot speak or cry out or has great difficulty doing so. Breathing, if possible, is labored, producing gasping or wheezing. The person may desperately clutch at his or her throat or mouth. If breathing is not soon restored, the person's face will start to turn blue from lack of oxygen. This will be followed by unconsciousness if oxygen deprivation continues beyond a few minutes.

If an infant is choking, turning the baby upside down and slapping on the back may dislodge the obstructing object. To help an older person who is choking, first, encourage the person to cough. Give them a few hardback slaps to help force the lodged object out of the airway. If these steps fail, perform the Heimlich maneuver on the person. You can easily find instructional videos online to learn how to do it. If the Heimlich maneuver also fails, call for emergency medical care immediately.



Figure **12.2.9**: The Heimlich maneuver may be needed to help force an aspirated object out of the respiratory tract.

REVIEW

1. What is respiration, as carried out by the respiratory system? Name the two subsidiary processes it involves.
2. Describe the respiratory tract.
3. Identify the organs of the upper respiratory tract, and state their functions.
4. List the organs of the lower respiratory tract. Which organs are involved only in conduction?
5. Where does gas exchange take place?
6. How does the respiratory system protect itself from potentially harmful substances in the air?
7. Explain how the rate of breathing is controlled.
8. Why does the respiratory system need the cardiovascular system to help it perform its main function of gas exchange?
9. Place the following organs or structures of the respiratory system in order of when they are encountered by air entering the body — from earliest to latest.

   trachea; nasal cavity; alveoli; bronchioles; larynx; bronchi; pharynx
10. Which organ is part of both the digestive and respiratory systems?

    A. Larynx

    B. Trachea

    C. Pharynx

    D. Bronchus
11. Describe two ways in which the body prevents food from entering the lungs.
12. *True or False.* The lungs receive some oxygenated blood.
13. *True or False.* Gas exchange occurs in both the upper and lower respiratory tracts.
14. Coughing can expel _____ from the body.

    A. mucus

    B. food particles

    C. phlegm

    D. All of the above
15. What is the relationship between respiration and cellular respiration?

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12.3: BREATHING

DOING THE 'FLY

The swimmer in this photo is doing the butterfly stroke. This swimming style requires the swimmer to carefully control his breathing so it is coordinated with his swimming movements. Breathing is the process of moving air into and out of the lungs, which are the organs in which gas exchange takes place between the atmosphere and the body. Breathing is also called **ventilation,** and it is one of two parts of the life-sustaining process of respiration, the other part being gas exchange. Before you can understand how breathing is controlled, you need to know how breathing occurs.



Figure **12.3.1**: Butterfly stroke

HOW BREATHING OCCURS

Breathing is a two-step process that includes drawing air into the lungs, or inhaling, and letting the air out of the lungs, or exhaling. Both processes are illustrated in Figure **12.3.2**.

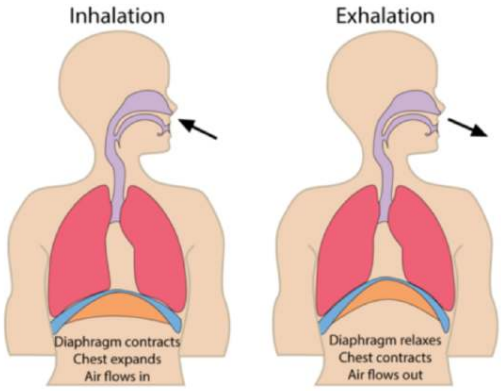


Figure **12.3.2**: Inhalation and exhalation during breathing depend mainly on repeated contractions of the diaphragm.

INHALING

Inhaling is an active process that results mainly from the contraction of a muscle called the diaphragm, shown in Figure **12.3.2**. The **diaphragm** is a large, dome-shaped muscle below the lungs that separates the thoracic (chest) and abdominal cavities. When the diaphragm contracts, the thoracic cavity expands and the contents of the abdomen are pushed downward. Other muscles, such as external intercostal muscles between the ribs, also contribute to the process of inhalation, especially when inhalation is forced, as when taking a deep breath. These muscles help increase thoracic volume by expanding the ribs outward. With the chest expanded, there is lower air pressure inside the lungs than outside the body, so outside air flows into the lungs via the respiratory tract.

EXHALING

Exhaling involves the opposite series of events. The diaphragm relaxes, so it moves upward and decreases the volume of the thorax (Figure **12.3.2**. Air pressure inside the lungs increases so it is higher than the air pressure outside the lungs. Exhaling, unlike inhaling, is typically a passive process that occurs mainly due to the elasticity of the lungs. With the change in air pressure, the lungs contract to their pre-inflated size, forcing out the air they contain in the process. Air flows out of the lungs, similar to the way air rushes out of a balloon when it is released. If exhalation is forced, internal intercostal and abdominal muscles may help move the air out of the lungs.

CONTROL OF BREATHING

Breathing is one of the few vital bodily functions that can be controlled consciously as well as unconsciously. Think about using your breath to blow up a balloon. You take a long, deep breath, and then you exhale the air as forcibly as you can into the balloon. Both the inhalation and exhalation are consciously controlled.

CONSCIOUS CONTROL OF BREATHING

You can control your breathing by holding your breath, slowing your breathing, or **hyperventilating,** which is breathing more quickly and shallowly than necessary. You can also exhale or inhale more forcefully or deeply than usual. Conscious control of breathing is common in many activities besides blowing up balloons, including swimming, speech training, singing, playing many different musical instruments (Figure **12.3.3**), and doing yoga, to name just a few.



Figure **12.3.3**: Playing the oboe is hard work. Exhaled air must be forced through a tiny opening between two very small wooden reeds.

There are limits on the conscious control of breathing. For example, it is not possible for a healthy person to voluntarily stop breathing indefinitely. Before long, there is an irrepressible urge to breathe. If you were able to stop breathing for a long enough time, you would lose consciousness. The same thing would happen if you were to

hyperventilate for too long. Once you lose consciousness so you can no longer exert conscious control over your breathing, involuntary control of breathing takes over.

UNCONSCIOUS CONTROL OF BREATHING

Unconscious breathing is controlled by **respiratory centers** in the medulla and pons of the brainstem (Figure **12.3.4**). The respiratory centers automatically and continuously regulate the rate of breathing depending on the body's needs. These are determined mainly by blood acidity or pH. When you exercise, for example, carbon dioxide levels increase in the blood because of increased cellular respiration by muscle cells. The carbon dioxide reacts with water in the blood to produce carbonic acid, making the blood more acidic, so pH falls. The drop in pH is detected by chemoreceptors in the medulla. Blood levels of oxygen and carbon dioxide, in addition to pH, are also detected by chemoreceptors in major arteries, which send the "data" to the respiratory centers. The respiratory center responds by sending nerve impulses to the diaphragm, "telling" it to contract more quickly so the rate of breathing speeds up. With faster breathing, more carbon dioxide is released into the air from the blood, and blood pH returns to the normal range.

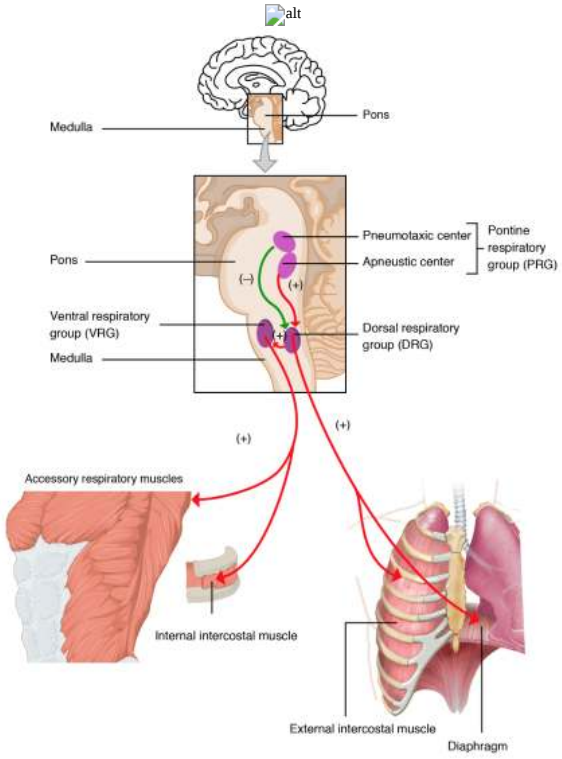


Figure **12.3.4**: Clusters of cells in the pons and medulla of the brain stem are the respiratory centers of the brain that have involuntary control over breathing muscles, such as the diaphragm and external and internal intercostal.

The opposite events occur when the level of carbon dioxide in the blood becomes too low and blood pH rises. This may occur with involuntary hyperventilation, which can happen in panic attacks, episodes of severe pain, asthma attacks, and many other situations. When you hyperventilate, you blow off a lot of carbon dioxide, leading to a drop in blood levels of carbon dioxide. The blood becomes more basic (alkaline), causing its pH to rise.

NASAL VS. MOUTH BREATHING

Nasal breathing is breathing through the nose rather than the mouth, and it is generally considered to be superior to mouth breathing. The hair-lined nasal passages do a better job of filtering particles out of the air before it moves deeper into the respiratory tract. The nasal passages are also better at warning and moistening the air, so nasal breathing is especially advantageous in the winter when the air is cold and dry. In addition, the smaller diameter of the nasal passages creates greater pressure in the lungs during exhalation. This slows the emptying of the lungs, giving them more time to extract oxygen from the air.

FEATURE: MYTH VS. REALITY

Drowning is defined as respiratory impairment from being in or under a liquid. It is further classified according to its outcome into death, ongoing health problems, or no ongoing health problems (full recovery). In the United States, accidental drowning is the second leading cause of death (after motor vehicle crashes) in children aged 12 years and younger. There are some potentially dangerous myths about drowning. Knowing what they are might save your life or the life of a loved one, especially a child.

Myth: People drown when they aspirate water into their lungs.

Reality: Generally, in the early stages of drowning, very little water enters the lungs. A small amount of water entering the trachea causes a muscular spasm in the larynx that seals the airway and prevents the passage of water into the lungs. This spasm is likely to last until unconsciousness occurs.

Myth: You can tell when someone is drowning because they will shout for help and wave their arms to attract attention.

Reality: The muscular spasm that seals the airway prevents the passage of air as well as water, so a person who is drowning is unable to shout or call for help. In addition, instinctive reactions that occur in the final minute or so before a drowning person sinks under the water may look similar to calm, safe behavior. The head is likely to be low in the water, tilted back with the mouth open. The person may have uncontrolled movements of the arms and legs, but they are unlikely to be visible above the water.

Myth: It is too late to save a person who is unconscious in the water.

Reality: An unconscious person rescued with an airway still sealed from the muscular spasm of the larynx stands a good chance of full recovery if they start receiving CPR within minutes. Without water in the lungs, CPR is much more effective. Even if the cardiac arrest has occurred so the heart is no longer beating, there is still a chance of recovery. However, the longer the brain goes without oxygen, the more likely brain

cells will die. Brain death is likely after about six minutes without oxygen, except in exceptional circumstances, such as young people drowning in very cold water. There are examples of children surviving, apparently without lasting ill effects, for as long as an hour in cold water (see Explore More below for an example). Therefore, rescuers retrieving a child from cold water should attempt resuscitation even after a protracted period of immersion.

Myth: If someone is drowning, you should start administering CPR immediately, even before you try to get the person out of the water.

Reality: Removing a drowning person from the water is the first priority because CPR is ineffective in the water. The goal should be to bring the person to stable ground as quickly as possible and then to start CPR.

Myth: You are unlikely to drown unless you are in water over your head.

Reality: Depending on circumstances, people have drowned in as little as 30 mm (about 1 ½ in.) of water. For example, inebriated people or those under the influence of drugs have been known to have drowned in puddles. Hundreds of children have drowned in the water in toilets, bathtubs, basins, showers, pails, and buckets (see figure below).



Figure **12.3.5**: Young children should never be left unattended around sources of water that pose a risk of drowning, including water in toilets, bathtubs, and buckets.

REVIEW

1. Define breathing.
2. What is another term for the process of breathing?
3. What is the main difference between the processes of inhaling and exhaling?
4. Give examples of activities in which breathing is consciously controlled.
5. Young children sometimes threaten to hold their breath until they get something they want. Why is this an idle threat?
6. Explain how unconscious breathing is controlled.
7. Why is nasal breathing generally considered to be superior to mouth breathing?
8. For each of the following, indicate whether it occurs during the process of inhalation (I) or exhalation (E).
   A. The diaphragm moves downward.
   B. The diaphragm relaxes.
   C. The thoracic cavity becomes smaller.
   D. The air pressure in the lungs is lower than outside the body.
9. Give one example of a situation that would cause blood pH to rise excessively and explain why this occurs.
10. Blood levels of oxygen and carbon dioxide and pH are detected by which of these:
    A. Mechanoreceptors
    B. Chemoreceptors
    C. Lung receptors
    D. Carbon receptors
11. True or False. The diaphragm can contract due to conscious control.
12. True or False. Hypoventilating is breathing that is fast and shallow.

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12.4: DISORDERS OF THE RESPIRATORY SYSTEM

A "MITEY" MONSTER

The scary beast in Figure **12.4.1** is likely to be lurking in your own home, where it feeds on organic debris, including human skin. What is it? It's the common dust mite, a close relative of spiders. The dust mite is so small that it is barely visible with the unaided eye, so it's obviously shown above greatly enlarged. If you think you can get rid of dust mites in your home by frequent and thorough cleaning, think again. There may be thousands of dust mites in just one gram of dust! Regardless of how clean you keep your house, you can't eliminate dust mites entirely. So why even bother trying? The feces of dust mites contain proteins that are a common trigger of asthma attacks.



Figure **12.4.1**: Dust mite

ASTHMA

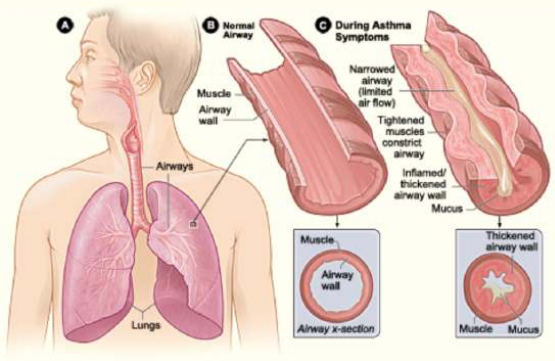


Figure **12.4.2**: During an asthma attack, airways narrow and may become clogged with mucus, making breathing difficult.

Asthma is a chronic inflammatory disease of the airways in the lungs, in which the airways periodically become inflamed. As you can see in Figure **12.4.2**, this causes swelling and narrowing of the airways, often accompanied by excessive mucus production. Symptoms of asthma include difficulty breathing, coughing, wheezing, shortness of breath, and chest tightness. Some people with asthma rarely experience symptoms, and then usually only in response to certain triggers in the environment. Other people may have symptoms almost all of the time.

Asthma is thought to be caused by a combination of genetic and environmental factors. A person with a family history of asthma is more likely to develop the disease. Dozens of genes have been found to be associated with asthma, many of which are related to the immune system. Additional risk factors include obesity and sleep apnea (see the feature My Human Body below). Environmental factors trigger asthma attacks in people who have a genetic predisposition to the disease. Besides dust mite feces, triggers may include other allergens (such as pet dander, cockroaches, and mold), certain medications including aspirin, air pollution, and stress, among other possible factors. Symptoms tend to be worse at night and early in the morning. They may also worsen during upper respiratory tract infections, strenuous exercise, or when the airways are exposed to cold air.

There is no cure for asthma at present, but the symptoms of asthma attacks usually can be reversed with the use of inhaled medications called bronchodilators. These medications soothe the constricted air passages and help to re-expand them, making breathing easier. The medications usually start to take effect almost immediately. Other medications can be taken for long-term control of the disease. These medications help prevent asthma attacks from occurring. Corticosteroids are generally considered the most effective treatment for long-term control. Another way to prevent asthma attacks is by avoiding triggers whenever possible.

PNEUMONIA

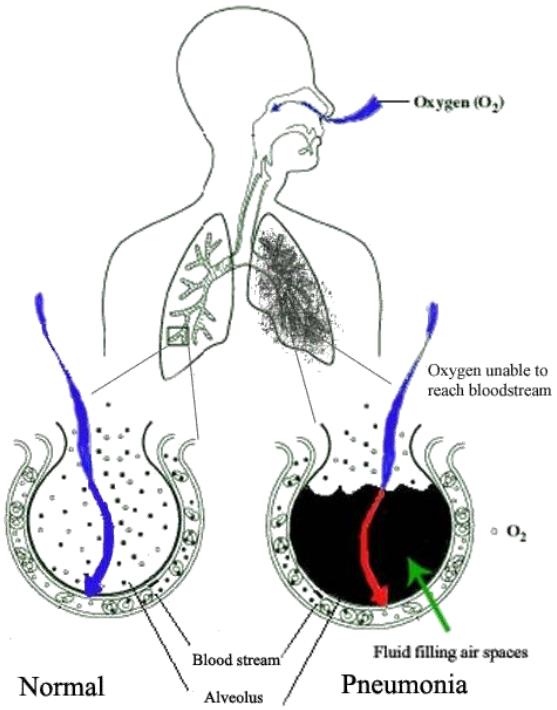


Figure **12.4.3**: Fluid-filled alveoli characteristic of pneumonia inhibit normal gas exchange with the blood.

Another common inflammatory disease of the respiratory tract is **pneumonia.** In pneumonia, the inflammation affects primarily the alveoli, which are the tiny air sacs of the lungs. Inflammation causes some of the alveoli to become filled with fluid so that gas exchange cannot occur. This is illustrated in Figure **12.4.3**. Symptoms of pneumonia typically include coughing, chest pain, difficulty breathing, and fever.

Pneumonia often develops as a consequence of an upper respiratory tract infection such as the common cold or flu, especially in the very young and the elderly. It is usually caused by bacteria or viruses, although some cases may be caused by other microorganisms such as fungi. The majority of cases are caused by just a few pathogens, the most common being the bacterium *Streptococcus pneumoniae.* Pneumonia is more likely to develop in people who have other lung diseases such as asthma, a history of smoking, heart failure, or a weakened immune system.

Vaccines are available to prevent certain types of bacterial and viral pneumonia, including pneumonia caused by *Streptococcus pneumoniae.* Treatment of pneumonia depends on the cause. For example, if it is caused by bacteria, antibiotics are generally prescribed. In cases of severe pneumonia, hospitalization and supplemental oxygen may be required.

CHRONIC OBSTRUCTIVE PULMONARY DISEASE

Chronic obstructive pulmonary disease (COPD) is a lung disease characterized by chronic poor airflow. The main symptoms include shortness of breath and a cough that produces phlegm. These symptoms are usually present for a long period of time and typically become worse over time. Eventually, walking upstairs and similar activities become difficult because of shortness of breath.

COPD formerly was referred to as chronic bronchitis or emphysema. Now, the term *chronic bronchitis* is used to refer to the symptoms of COPD, and the term *emphysema* is used to refer to the lung changes that occur with COPD. Some of these lung changes are shown in Figure **12.4.4**. They include a breakdown of connective tissues that reduces the number and elasticity of alveoli. As a result, the patient can no longer fully exhale air from the lungs, so the air becomes trapped in the lungs. Gas exchange is hampered and may lead to low oxygen levels and too much carbon dioxide in the blood.

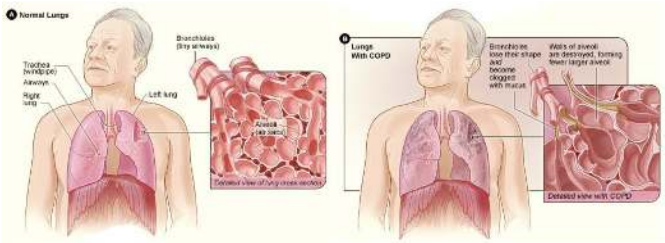


Figure **12.4.4**: The physiological changes that occur with COPD include a breakdown of alveolar walls, reducing the surface area for gas exchange.

Tobacco smoking is the major cause of COPD, with a number of other factors such as air pollution and genetics playing smaller roles. Of people who are life-long smokers, about half will eventually develop COPD. Exposure to secondhand smoke in nonsmokers also increases the risk of COPD and accounts for about 20 percent of cases. Most cases of COPD could have been prevented by never smoking. In people who have already been diagnosed with COPD, cessation of smoking can slow down the rate at which COPD worsens. People with COPD may be treated with supplemental oxygen and inhaled bronchodilators. These treatments may reduce the symptoms but there is no cure for COPD except, in very severe cases, lung transplantation (see the Explore More video below).

LUNG CANCER

Lung cancer is a malignant tumor characterized by uncontrolled cell growth in tissues of the lung. The tumor may arise directly from lung tissue (primary lung cancer) or as a result of metastasis from cancer in another part of the body (secondary lung cancer). Primary lung cancer may also metastasize and spread to other parts of the body. Lung cancer develops following genetic damage to DNA that affects the normal functions of the cell. As more damage accumulates, the risk of cancer increases. The most common symptoms of lung cancer include coughing (especially coughing up blood), wheezing, shortness of breath, chest pain, and weight loss.

The major cause of primary lung cancer is tobacco smoking, which accounts for about 85 percent of cases. Cigarette smoke contains numerous cancer-causing chemicals. Besides smoking, other potential causes of lung cancer include exposure to radon gas, asbestos, secondhand smoke, or other air pollutants. When tobacco smoking is combined with other risk factors such as exposure to radon or asbestos, the risk of lung cancer is heightened. People who have close biological relatives with lung cancer are also at increased risk of developing the disease.

Most cases of lung cancer cannot be cured. In many people, cancer has already spread beyond the original site by the time they have symptoms and seek medical attention. About 10 percent of people with lung cancer do not have symptoms when they are diagnosed, and the cancers are found when they have a chest X-ray for another problem. In part because of its typically late diagnosis, lung cancer is the most common cause of cancer-related death in men and the second most common cause in women (after breast cancer). Common treatments for lung cancer include surgical removal of the tumor, radiation therapy, chemotherapy, or some combination of these three types of treatment.

FEATURE: MY HUMAN BODY

Do you — or someone you love — snore? Snoring may be more than just an annoyance. It may also be a sign of a potentially dangerous and common disorder known as sleep apnea. **Sleep apnea** is characterized by pauses in breathing that occur most often because of physical blockage to airflow during sleep. When breathing is paused, carbon dioxide builds up in the bloodstream. The higher-than-normal level of carbon dioxide in the blood causes the respiratory centers in the brain to wake the person enough to start breathing normally. This reduces the carbon dioxide level, and the person falls back asleep. This occurs repeatedly throughout the night, causing serious disruption in sleep. Most people with sleep apnea are unaware that they have the disorder because they don't awake fully enough to remember the repeated awakenings throughout the night. Instead, sleep apnea is more commonly recognized by other people who witness the episodes.

Figure 12.4.5shows how sleep apnea typically occurs. The muscle tone of the body normally relaxes during sleep, allowing the soft tissues in the throat to collapse and block the airway. The relaxation of muscles may be exacerbated by the use of alcohol, tranquilizers, or muscle relaxants. The risk of sleep apnea is greater in people who are overweight, smoke tobacco, or have diabetes. The disorder is also more likely to occur in older people and males. Common symptoms of sleep apnea include loud snoring, restless sleep, and daytime sleepiness and fatigue. Daytime sleepiness, in turn, increases the risk of driving and work-related accidents. Continued sleep deprivation may cause moodiness and belligerence. Lack of adequate oxygen to the body because of sleep apnea may also lead to other health problems including fatty liver diseases and high blood pressure. Symptoms of sleep apnea may be present for years or even decades until (and if) a diagnosis is finally made.

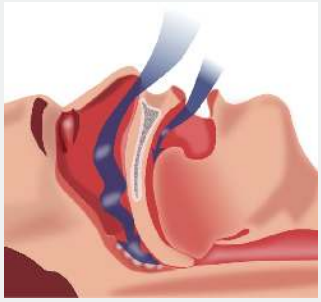


Figure 12.4.5: Sleeping on one's back may increase the risk of the airway becoming temporarily blocked during sleep, resulting in sleep apnea.

Treatment of sleep apnea may include avoiding alcohol, quitting smoking, or losing weight. Elevating the upper body during sleep or sleeping on one's side may help prevent airway collapse in many people with sleep apnea. Another type of treatment is the use of an oral device during sleep that shifts the lower jaw forward to help keep the airway open. The most common treatment for moderate to severe sleep apnea is the use during sleep of CPAP (continuous positive airway pressure), which keeps the airway open by means of pressurized air. In this treatment, the person typically wears a plastic facial mask that is connected by a flexible tube to a small bedside CPAP machine. Although CPAP is effective, long-term compliance is often poor because patients find the mask uncomfortable or they experience unpleasant side effects such as dry mouth and nose. A more extreme form of treatment is surgery to remove some of the tissues — such as the tonsils or part of the soft palate — that tend to collapse and block the airway in people with sleep apnea.

REVIEW

1. What is asthma, and what are its symptoms and causes?
2. Identify common risk factors and triggers of asthma attacks.
3. How can asthma attacks be prevented or controlled?
4. What are the causes and symptoms of pneumonia?
5. How can pneumonia be prevented? How is it treated?
6. Define COPD. How is it related to chronic bronchitis and emphysema?
7. Relate COPD to tobacco smoking.
8. What is the difference between primary and secondary lung cancer?
9. What is the major cause of primary lung cancer?
10. Discuss lung cancer as a cause of death.
11. How is lung cancer treated?
12. Define sleep apnea.
13. What is the difference between how COPD and pneumonia affect the alveoli?

EXPLORE MORE

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12.5: SMOKING AND HEALTH

SURE DEATH

The anti-smoking cartoon in Figure **12.5.1** clearly makes the point that smoking causes death. The cartoon is not using hyperbole, because smoking actually is deadly. It causes about six million deaths each year and is the single greatest cause of preventable death worldwide. As many as half of all people who smoke tobacco die from it. As a result of smoking's deadly effects, the life expectancy of long-term smokers is significantly less than that of non-smokers. In fact, long-term smokers can expect their lifespan to be reduced by as much as 18 years, and they are three times as likely to die before the age of 70 as non-smokers.



Figure **12.5.1**: Have another! Sure death

WHY IS SMOKING DEADLY?

As shown in Figure **12.5.2**, tobacco smoking has adverse effects on just about every bodily system and organ. The detrimental health effects of smoking depend on the number of years that a person smokes and how much the person smokes. Contrary to popular belief, all forms of tobacco smoke — including smoke from cigars and tobacco pipes — have similar health risks as those of cigarette smoke. Smokeless tobacco may be less of a danger to the lungs and heart, but it too has serious health effects. It significantly increases the risk of cancers of the mouth and throat, among other health problems.

Even non-smokers may not be spared the deadly risks of tobacco smoke. If you spend time around smokers either at home or on the job, then you are at risk of the dangers of secondhand smoke. **Secondhand smoke** enters the air directly from burning cigarettes (and cigars and pipes) and indirectly from the lungs of smokers. This smoke may linger in indoor air for hours and increase the risk of a wide range of adverse health effects. For example, non-smokers who are exposed to secondhand smoke may have as much as a 30 percent increase in their risk of lung cancer and heart disease. The 2014 U.S. Surgeon General's Report concluded that there is no established risk-free level of exposure to secondhand smoke.

Tobacco contains **nicotine,** which is a psychoactive drug. Although nicotine in tobacco smoke does not directly cause cancer or most of the other health risks of smoking, it is a highly addictive drug. In fact, nicotine is even more addictive than cocaine or heroin. The addictive nature of nicotine explains why it is so difficult for smokers to quit the habit even when they know the health risks and really want to stop smoking. The good news is that if someone does stop smoking, his or her risks of smoking-related diseases and death soon start to fall. For example, by one year after quitting, the risk of heart disease drops to only half of that of a continuing smoker.

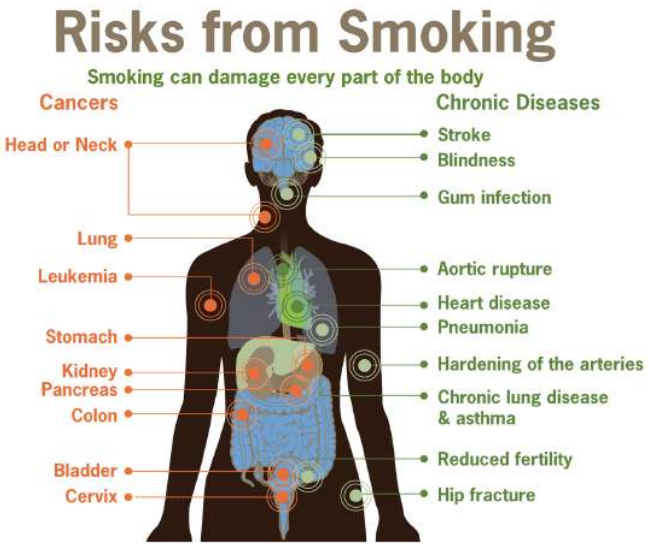


Figure **12.5.2**: Smoking is known to cause many different cancers and chronic diseases such as stroke, blindness, gum infection, aortic rupture, heart disease, pneumonia, hardening of the arteries, chronic lung diseases, reduced fertility, and hip fracture.

SMOKING AND CANCER

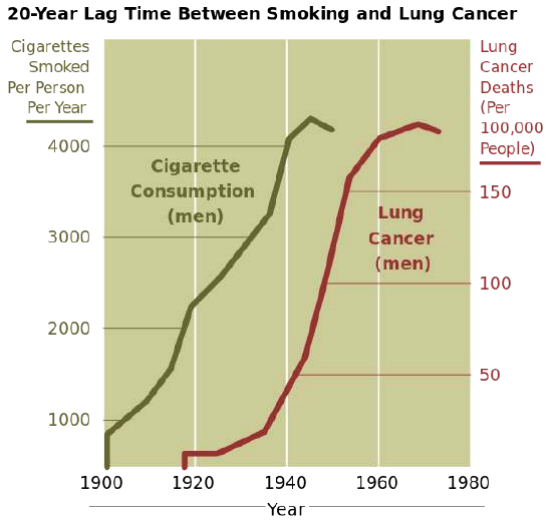


Figure **12.5.3**: Cigarette smoking by men in the U.S. began to decline in the 1950s, but it wasn't until the 1970s — roughly 20 years later — that this was reflected by a concomitant decline in lung cancer deaths in men.

One of the main health risks of smoking is cancer, particularly cancer of the lung. Because of the increased risk of lung cancer with

smoking, the risk of dying from lung cancer before age 85 is more than 20 times higher for a male smoker than for a male non-smoker. As the rate of smoking increases, so does the rate of lung cancer deaths, although the effects of smoking on lung cancer deaths can take up to 20 years to manifest themselves, as shown in Figure **12.5.3**.

Besides lung cancer, several other forms of cancer are also significantly more likely in smokers than non-smokers, including cancers of the kidney, larynx, mouth, lip, tongue, throat, bladder, esophagus, pancreas, and stomach. Unfortunately, many of these cancers have extremely low cure rates.

When you consider the composition of tobacco smoke, it's not surprising that it increases the risk of cancer. Tobacco smoke contains dozens of chemicals that have been proven to be carcinogens or causes of cancer. Many of these chemicals bind to DNA in a smoker's cells and may either kill the cells or cause mutations. If the mutations inhibit programmed cell death, the cells can survive to become cancer cells. Some of the most potent carcinogens in tobacco smoke include benzopyrene, acrolein, and nitrosamines. Other carcinogens in tobacco smoke are radioactive isotopes, including lead-210 and polonium-210.

RESPIRATORY EFFECTS OF SMOKING

Long-term exposure to the compounds found in cigarette smoke, such as carbon monoxide and cyanide, is thought to be responsible for much of the lung damage caused by smoking. These chemicals reduce the elasticity of alveoli, leading to chronic obstructive pulmonary disease (COPD). COPD is a permanent, incurable, and often fatal reduction in the capacity of the lungs, reducing the ability of the lungs to fully exhale air. The chronic inflammation that is also present in COPD is exacerbated by the tobacco smoke carcinogen acrolein and its derivatives. COPD is almost completely preventable simply by not smoking and by also avoiding secondhand smoke.

CARDIOVASCULAR EFFECTS OF SMOKING

Inhalation of tobacco smoke causes several immediate responses in the heart and blood vessels. Within one minute of inhalation of smoke, the heart rate begins to rise, increasing by as much as 30 percent during the first 10 minutes of smoking. Carbon monoxide in tobacco smoke binds with hemoglobin in red blood cells, thereby reducing the blood's ability to carry oxygen. Hemoglobin bound to carbon monoxide forms such a stable complex that it may result in a permanent loss of red blood cell function. Several other chemicals in tobacco smoke lead to the narrowing and weakening of blood vessels and an increase in substances that contribute to blood clotting. These changes increase blood pressure and the chances of a blood clot forming and blocking a vessel, thereby elevating the risk of heart attack and stroke. A recent study found that smokers are five times more likely than non-smokers to have a heart attack before the age of 40.

Smoking has also been shown to have a negative impact on the levels of blood lipids. Total cholesterol levels tend to be higher in smokers than non-smokers. Ratios of "good" cholesterol to "bad" cholesterol tend to be lower in smokers than in non-smokers.

ADDITIONAL ADVERSE HEALTH EFFECTS OF SMOKING

A wide diversity of additional adverse health effects are attributable to smoking. Here are just a few of them:

- Smokers are at a significantly increased risk of developing chronic kidney disease (in addition to kidney cancer). For example, smoking hastens the progression of kidney damage in people with diabetes.
- People who smoke, especially the elderly, have a greater risk of influenza and other infectious diseases than non-smokers. Smoking more than 20 cigarettes a day has been found to increase the risk of infectious diseases by as much as four times the risk in non-smokers. These effects occur because of damage to both the respiratory system and the immune system.
- In addition to oral cancer, smoking causes other oral problems including periodontitis (gum disease). Roughly half of the cases of gum inflammation are attributable to current or former smoking. Such inflammation increases the risk of tooth loss, which is also higher in smokers than non-smokers. In addition, smoking stains the teeth and causes halitosis (bad breath).
- Smoking is a key cause of erectile dysfunction (ED), probably because it leads to narrowing of arteries in the penis as it does elsewhere in the body. The incidence of ED is about 85 percent higher in males who smoke than it is in non-smokers.
- Smoking also has adverse effects on the female reproductive system, potentially causing infertility, in part because it interferes with the body's ability to produce estrogen. Female smokers are about 60 percent more likely to be infertile than non-smokers. Pregnant women who smoke or are exposed to secondhand smoke have a higher risk of miscarriages and low-birth-weight infants.
- Certain therapeutic drugs, including some antidepressants and anticonvulsants, are less effective in smokers than in non-smokers. This occurs because smoking increases levels of liver enzymes that break down the drugs.
- Smoking causes an estimated 10 percent of all deaths due to fires worldwide. Smokers are also at greater risk of dying in motor vehicle crashes and other accidents.
- Smoking leads to an increased risk of bone fractures, especially of the hip. It also leads to slower wound healing after surgery and an increased rate of postoperative complications.

FEATURE: HUMAN BIOLOGY IN THE NEWS

The item in Figure **12.5.4** looks like a regular cigarette, but it's actually an electronic cigarette or e-cigarette. E-cigarettes are battery-powered devices that change flavored liquids and nicotine into a vapor that is inhaled by the user. E-cigarettes are often promoted as being safer than traditional tobacco products and their use is touted as a good way to quit smoking. They are

often not banned in smoke-free areas where it is illegal to smoke tobacco cigarettes.



Figure **12.5.4**: e-cigarette

A study completed in 2015 by researchers at the Harvard School of Public Health and widely reported in the mass media found that e-cigarettes may in fact be very harmful to the user's health. E-cigarettes contain nicotine and cancer-causing chemicals such as formaldehyde. According to the study, about three-quarters of flavored e-cigarettes also contain a chemical named diacetyl that causes an incurable and potentially fatal disorder of the lungs, commonly called "popcorn lung" (bronchiolitis obliterans). In this disorder, the bronchioles compress and narrow due to the formation of scar tissue. This greatly diminishes the breathing capacity of people with the disorder. Popcorn lung gained its common name in 2004 when it was diagnosed in workers at popcorn factories. The buttery flavoring used in the factories contained diacetyl.

Some manufacturers of e-cigarettes and flavorings advertise that their products are now free of diacetyl. However, because e-cigarettes are not currently regulated by the FDA, there is no way of knowing for sure whether the products are actually safe. Equally disturbing is the appeal of flavored e-cigarettes to teens and the attempts of producers to specifically market their products to this age group. Flavors such as "cotton candy," "Katy Perry's cherry," and "alien blood" are obviously marketed to youth. Not surprisingly, the use of e-cigarettes is on the rise in middle and high school students, who are more likely to use them than regular cigarettes. Public health officials fear that e-cigarettes will be a gateway for teens to move on to smoking tobacco cigarettes. Some states have recently passed laws prohibiting minors from buying e-cigarettes. As more questions are raised about their potential negative health effects, it is likely that more laws will be passed to regulate them. Watch the news for updates on this issue.

REVIEW

1. What percentage of people who smoke are likely to die from it?
2. Contrast the life expectancy of long-term smokers and non-smokers.
3. What factors related to smoking determine how smoking affects a smoker's health?
4. What are the two sources of secondhand cigarette smoke? How does exposure to secondhand smoke affect non-smokers?
5. Why is it so difficult for smokers to quit the habit? How is their health likely to be affected by quitting?
6. List five types of cancer that are significantly more likely in smokers than non-smokers.
7. Why does smoking cause cancer?
8. Explain how smoking causes COPD.
9. Identify some of the adverse effects of smoking on the cardiovascular system.
10. Give three examples of additional adverse health effects that are more likely with smoking.
11. Do you think e-cigarettes can be addictive? Explain your reasoning.
12. People who smoke are more likely to get which of these than people who do not smoke.

    A. lung cancer
    B. influenza
    C. kidney disease
    D. All of the above

13. Name three toxic chemicals present in tobacco smoke.
14. *True or False.* Nicotine is more addictive than heroin.
15. *True or False.* Smoking has many negative effects on the respiratory and cardiovascular systems, but not on other systems of the body.

EXPLORE MORE

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12.6: CASE STUDY CONCLUSION- BRONCHITIS AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: COUGH THAT WON'T QUIT

The little child shown in Figure **12.6.1** seems to be enjoying the air coming out of a humidifier. Inhaling the moist air from a humidifier or steamy shower can feel particularly good if you have a respiratory system infection, such as bronchitis. The moist air helps to loosen and thin mucus in the respiratory system, allowing you to breathe easier.



Figure **12.6.1**: Enjoying the Humidifier

At the beginning of this chapter, you learned about Sacheen, who developed acute bronchitis after getting a cold. She had a worsening cough, sore throat due to coughing, and chest congestion. She was also coughing up thick mucus.

Acute bronchitis usually occurs after a cold or flu, usually due to the same viruses that cause cold or flu. Because bronchitis is not usually caused by bacteria (although it can be), antibiotics are not an effective treatment in most cases.

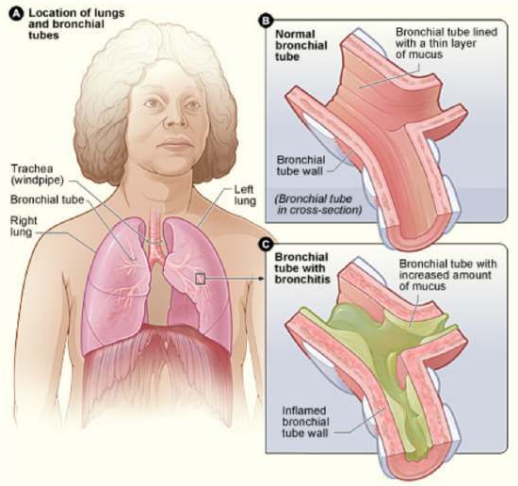


Figure **12.6.2**: Acute Bronchitis

Bronchitis affects the bronchial tubes, which, as you have learned, are air passages in the lower respiratory tract. The main bronchi branch off of the trachea and then branch into smaller bronchi and then bronchioles. In bronchitis, the walls of the bronchi become inflamed, which makes them narrower. Also, there is excessive production of mucus in the bronchi, which further narrows the pathway through which can flow. Figure **12.6.2** shows how bronchitis affects the bronchial tubes.

The function of mucus is to trap pathogens and other potentially dangerous particles that enter the respiratory system from the air. However, when too much mucus is produced in response to an infection (as in the case of bronchitis), it can interfere with normal airflow. The body responds by coughing as it tries to rid itself of the pathogen-laden mucus.

The treatment for most cases of bronchitis involves thinning and loosening the mucus so that it can be effectively coughed out of the airways. This can be done by drinking plenty of fluids, using humidifiers or steam, and in some cases, using over-the-counter medications such as expectorants that are found in some cough medicines. This is why Dr. Tsosie recommended some of these treatments to Sacheen and also warned against using cough suppressants. Cough suppressants work on the nervous system to suppress the cough reflex. When a patient has a “productive” cough —i.e. they are coughing up mucus—doctors generally advise them to not take cough suppressants so that they can cough the mucus out of their bodies.

When Dr. Tsosie was examining Sacheen, she used a pulse oximeter to measure the oxygen level in her blood. Why did she do this? As you have learned, the bronchial tubes branch into bronchioles, which ultimately branch into the alveoli of the lungs. The alveoli are where gas exchange occurs between the air and the blood to take in oxygen and remove carbon dioxide and other wastes. By checking Sacheen’s blood oxygen level, Dr. Tsosie was making sure that her clogged airways were not impacting her level of much-needed oxygen.

Sacheen has acute bronchitis, but you may recall that *chronic* bronchitis was discussed earlier in this chapter as a term that describes the symptoms of chronic obstructive pulmonary disease (COPD). COPD is often due to tobacco smoking and causes damage to the walls of the alveoli, whereas acute bronchitis typically occurs after a cold or flu and involves inflammation and mucus build-up in the bronchial tubes. As implied by the difference in their names, chronic bronchitis is an ongoing, long-term condition, while acute bronchitis is likely to resolve relatively quickly with proper rest and treatment.

However, Sacheen smokes cigarettes, so she is more likely to develop chronic respiratory conditions such as COPD. As you have learned, smoking damages the respiratory system as well as many other systems of the body. Smoking increases the risk of respiratory infections, including bronchitis and flu, due to its damaging effects on the respiratory and immune systems. Dr. Tsosie strongly encouraged Sacheen to quit smoking, not only so that her acute bronchitis resolves, but so that she can avoid future infections and other negative health outcomes associated with smoking, including COPD and lung cancer.

As you have learned in this chapter, the respiratory system is critical to carry out the gas exchange necessary for life’s functions and to

protect the body from pathogens and other potentially harmful substances in the air. But this ability to interface with the outside air has a cost. The respiratory system is prone to infections, as well as damage and other negative effects from allergens, mold, air pollution, and cigarette smoke. Although exposure to most of these things cannot be avoided, not smoking is an important step you can take to protect this organ system—as well as many other systems of your body.

CHAPTER SUMMARY

In this chapter, you learned about the respiratory system. Specifically, you learned that:

- Respiration is the process in which oxygen moves from the outside air into the body and carbon dioxide and other waste gases move from inside the body into the outside air. It involves two subsidiary processes: ventilation and gas exchange.
- The organs of the respiratory system form a continuous system of passages called the respiratory tract. It has two major divisions: the upper respiratory tract and the lower respiratory tract.
    - The upper respiratory tract includes the nasal cavity, pharynx, and larynx. All of these organs are involved in conduction or the movement of air into and out of the body. Incoming air is also cleaned, humidified, and warmed as it passes through the upper respiratory tract. The larynx is also called the voice box because it contains the vocal cords, which are needed to produce vocal sounds.
    - The lower respiratory tract includes the trachea, bronchi and bronchioles, and the lungs. The trachea, bronchi, and bronchioles are involved in conduction. Gas exchange takes place only in the lungs, which are the largest organs of the respiratory tract. Lung tissue consists mainly of tiny air sacs called alveoli, which is where gas exchange takes place between the air in the alveoli and the blood in capillaries surrounding them.
- The respiratory system protects itself from potentially harmful substances in the air by the mucociliary escalator. This includes mucus-producing cells, which trap particles and pathogens in the incoming air. It also includes tiny hair-like cilia that continually move to sweep the mucus and trapped debris away from the lungs and toward the outside of the body.
- The level of carbon dioxide in the blood is monitored by cells in the brain. If the level becomes too high, it triggers a faster rate of breathing, which lowers the level to the normal range. The opposite occurs if the level becomes too low. The respiratory system exchanges gases with the outside air, but it needs the cardiovascular system to carry the gases to and from cells throughout the body.
- Breathing, or ventilation, is the two-step process of drawing air into the lungs (inhaling) and letting the air out of the lungs (exhaling). Inhaling is an active process that results mainly from the contraction of a muscle called the diaphragm. Exhaling is typically a passive process that occurs mainly due to the elasticity of the lungs when the diaphragm relaxes.
    - Breathing is one of the few vital bodily functions that can be controlled consciously as well as unconsciously. Conscious control of breathing is common in many activities, including swimming and singing. However, there are limits on the conscious control of breathing. If you try to hold your breath, for example, you will soon have an irrepressible urge to breathe.
    - Unconscious breathing is controlled by respiratory centers in the medulla and pons of the brainstem. They respond to variations in blood pH by either increasing or decreasing the rate of breathing as needed to return the pH level to the normal range.
    - Nasal breathing is generally considered to be superior to mouth breathing because it does a better job of filtering, warming, and moistening incoming air. It also results in slower emptying of the lungs, which allows more oxygen to be extracted from the air.
- Gas exchange is the biological process through which gases are transferred across cell membranes to either enter or leave the blood. Gas exchange takes place continuously between the blood and cells throughout the body and also between the blood and the air inside the lungs.
    - Gas exchange in the lungs takes place in alveoli. The pulmonary artery carries deoxygenated blood from the heart to the lungs, where it travels through pulmonary capillaries, picking up oxygen, and releasing carbon dioxide. The oxygenated blood then leaves the lungs through pulmonary veins.
    - Gas exchange occurs by diffusion across cell membranes. Gas molecules naturally move down a concentration gradient from an area of higher concentration to an area of lower concentration. This is a passive process that requires no energy.
    - Gas exchange by diffusion depends on the large surface area provided by the hundreds of millions of alveoli in the lungs. It also depends on a steep concentration gradient for oxygen and carbon dioxide. This gradient is maintained by continuous blood flow and constant breathing.
- Asthma is a chronic inflammatory disease of the airways in the lungs, in which the airways periodically become inflamed. This causes swelling and narrowing of the airways, often with excessive mucus production, leading to difficulty breathing and other symptoms. Asthma is thought to be caused by a combination of genetic and environmental factors. Asthma attacks are triggered by allergens, air pollution, or other factors.
- Pneumonia is a common inflammatory disease of the respiratory tract in which inflammation affects primarily the alveoli, which become filled with fluid that inhibits gas exchange. Most cases of pneumonia are caused by viral or bacterial infections.

Vaccines are available to prevent pneumonia; treatment often includes prescription antibiotics.

- Chronic obstructive pulmonary disease (COPD) is a lung disease characterized by chronic poor airflow, which causes shortness of breath and a productive cough. It is caused most often by tobacco smoking, which leads to the breakdown of connective tissues in the lungs. Alveoli are reduced in number and elasticity, making it impossible to fully exhale air from the lungs. There is no cure for COPD, but stopping smoking may reduce the rate at which COPD worsens.
- Lung cancer is a malignant tumor characterized by uncontrolled cell growth in tissues of the lung. It results from accumulated DNA damage, most often caused by tobacco smoking. Lung cancer is typically diagnosed late, so most cases cannot be cured. It may be treated with surgery, chemotherapy, and/or radiation therapy.
- Smoking is the single greatest cause of preventable death worldwide. It has adverse effects on just about every body system and organ. Tobacco smoke affects not only smokers but also non-smokers who are exposed to secondhand smoke. The nicotine in tobacco is highly addictive, making it very difficult to quit smoking.
    - The major health risk of smoking is cancer of the lungs. Smoking also increases the risk of many other types of cancer. Tobacco smoke contains dozens of chemicals that are known carcinogens.
    - Smoking is the primary cause of COPD. Chemicals such as carbon monoxide and cyanide in tobacco smoke reduce the elasticity of alveoli so the lungs can no longer fully exhale air.
    - Smoking damages the cardiovascular system and increases the risk of high blood pressure, blood clots, heart attack, and stroke. Smoking also has a negative impact on levels of blood lipids.
    - A wide diversity of additional adverse health effects are attributable to smoking, such as erectile dysfunction, female infertility, and slow wound healing.

CHAPTER SUMMARY REVIEW

1. Describe the relationship between the bronchi, secondary bronchi, tertiary bronchi, and bronchioles.
2. What is the uppermost structure in the lower respiratory tract?
    A. Bronchus
    B. Lung
    C. Alveolus
    D. Trachea
3. Deoxygenated and oxygenated blood both travel to the lungs. Describe what happens to each there.
4. *True or False.* There are radioactive isotopes in cigarette smoke.
5. *True or False.* The right and left lungs are identical in structure.
6. Explain the difference between ventilation and gas exchange.
7. Which way do oxygen and carbon dioxide flow during a gas exchange in the lungs?
    A. Why does this happen?
    B. Which way do oxygen and carbon dioxide flow during the gas exchange between the blood and the body's cells?
    C. Why does this happen?
8. Why does the body require oxygen and give off carbon dioxide as a waste product?
9. *True or False.* Conduction refers to the movement of gases across cell membranes.
10. *True or False.* Gas exchange does not require energy.
11. What do coughing and sneezing have in common?
12. What is the name of the escalator that protects the respiratory system?
    A. phlegmociliary
    B. mucociliary
    C. mucoflagellar
    D. surfactociliary
13. COPD can lead to too much carbon dioxide in the blood. Answer the following questions about this.
    A. Why can COPD cause there to be too much carbon dioxide in the blood?
    B. What does this do to the blood pH?
    C. How does the body respond to this change in blood pH?
14. From the following list of diseases, choose which one best fits each description. Each disease is used only once. Diseases: asthma, pneumonia, COPD, lung cancer
    A. Alveoli become inflamed and fill with fluid
    B. Can be caused by exposure to inhaled carcinogens
    C. There is a reduction in the number of alveoli
    D. Airways periodically narrow and fill with mucus
15. *True or False.* Pneumonia can be caused by fungi.
16. *True or False.* The diaphragm contracts during exhalation.
17. What are three different types of things that can enter the respiratory system and cause illness or injury? Describe the negative health effects of each in your answer.
18. Where are the respiratory centers of the brain located? What is the main function of the respiratory centers of the brain?
19. Smoking increases the risk of getting influenza, commonly known as the flu. Explain why this could lead to a greater risk of getting pneumonia.
20. If people had a gene that caused them to get asthma, could changes to their environment (such as more frequent cleaning) help their asthma? Why or why not?
21. What does the term *bronchodilator* refer to?
    A. The largest bronchial tube
    B. An area of the brain that increases breathing rate
    C. A medication that opens constricted airways
    D. A medication that clears the nasal cavity
22. Explain why nasal breathing generally stops particles from entering the body at an earlier stage than mouth breathing.

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CHAPTER OVERVIEW

13: DIGESTIVE SYSTEM

This chapter outlines the structure and function of the gastrointestinal tract and accessory organs of digestion. It explains the processes of peristalsis, mechanical and chemical digestion of food, and absorption of nutrients. The chapter also describes several disorders of the gastrointestinal tract.

13.1: Case Study- Food Processing

13.2: Introduction to the Digestive System

13.3: Digestion and Absorption

13.4: Upper Gastrointestinal Tract

13.5: Lower Gastrointestinal Tract

13.6: Accessory Organs of Digestion

13.7: Disorders of the Gastrointestinal Tract

13.8: Case Study Conclusion- Celiac and Chapter Summary

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13.1: CASE STUDY- FOOD PROCESSING

CASE STUDY: PLEASE DON'T PASS THE BREAD

Rania and Tui are college students who met in physics class. They decide to study together for their upcoming midterm, but first, they want to grab some lunch. Rania says there is a particular restaurant she would like to go to because they are able to accommodate her dietary restrictions. Tui agrees and they head to the restaurant.

At lunch, Tui asks Rania what is special about her diet. Rania tells her that she can't eat gluten. Tui says, "Oh yeah, my cousin did that for a while because she heard that gluten is bad for you. But it was too hard for her to not eat bread and pasta, so she gave it up." Rania tells Tui that avoiding gluten isn't optional for her—she has celiac disease. Eating even very small amounts of gluten could damage her digestive system.



Figure **13.1.1**: Gluten Free (Pizzaberg sign)

You have probably heard of gluten—but what is it and why is it harmful to people with celiac disease? Gluten is a protein found in wheat and some other grains such as barley, rye, and oats. Therefore, it is commonly found in foods such as bread, pasta, baked goods, and many packaged foods. In people with celiac disease, eating gluten causes an autoimmune reaction that results in damage to the small, finger-like villi lining the small intestine, causing them to become inflamed and flattened. This damage interferes with the digestive process, which can result in a wide variety of symptoms including diarrhea, anemia, skin rash, bone pain, depression, and anxiety, among others. The degree of damage to the villi can vary from mild to severe, with more severe damage generally resulting in more significant symptoms and complications. Celiac disease can have serious long-term consequences, such as osteoporosis, problems in the nervous and reproductive systems, and the development of certain types of cancers.

How can celiac disease cause so many different types of symptoms and have such significant negative health consequences? As you read this chapter and learn about how the digestive system works, you will see just how important the villi of the small intestine are to the body as a whole. At the end of the chapter, you will learn more about celiac disease, why it can be so serious, and whether it is worth avoiding gluten for people who do not have a diagnosed medical issue with it.

CHAPTER OVERVIEW: DIGESTIVE SYSTEM

In this chapter, you will learn about the digestive system, which processes food so that our bodies can obtain nutrients. Specifically, you will learn about:

- The structures and organs of the gastrointestinal (GI) tract through which food directly passes. This includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine.
- The functions of the GI tract, including mechanical and chemical digestion, absorption of nutrients, and the elimination of solid waste.
- The accessory organs of digestion—the liver, gallbladder, and pancreas—secrete substances needed for digestion into the GI tract, in addition to other important functions.
- Specializations of the tissues of the digestive system that allow it to carry out its functions.
- How different types of nutrients such as carbohydrates, proteins, and fats are digested and absorbed by the body.
- Beneficial bacteria that live in the GI tract and help us digest food, produce vitamins, and protect us from harmful pathogens and toxic substances.
- Disorders of the digestive system, including inflammatory bowel diseases, ulcers, diverticulitis, and gastroenteritis (commonly known as "stomach flu").

As you read this chapter, think about the following questions related to celiac disease:

1. What are the general functions of the small intestine? What do the villi in the small intestine do?
2. Why do you think celiac disease causes so many different types of symptoms and potentially serious complications?
3. What are some other autoimmune diseases that involve the body attacking its own digestive system?

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13.2: INTRODUCTION TO THE DIGESTIVE SYSTEM

YUMMY!

If you're a dessert lover, then just the sight of this flan dish may make your mouth water. The "water" in your mouth is actually saliva, a fluid released by glands that are part of the digestive system. Saliva contains digestive enzymes among other substances important for digestion. When your mouth waters at the sight of a tasty treat, it's a sign that your digestive system is preparing to digest food.



Figure **13.2.1**: Caramel Cream Flan

WHAT IS THE DIGESTIVE SYSTEM?

The **digestive system** consists of organs that break down food, absorb its nutrients, and expel any remaining waste. Organs of the digestive system are shown in Figure **13.2.2**. Most of these organs make up the gastrointestinal (GI) tract. Food actually passes through these organs. The rest of the organs of the digestive system are called accessory organs. These organs secrete enzymes and other substances into the GI tract, but food does not actually pass through them.

FUNCTIONS OF THE DIGESTIVE SYSTEM

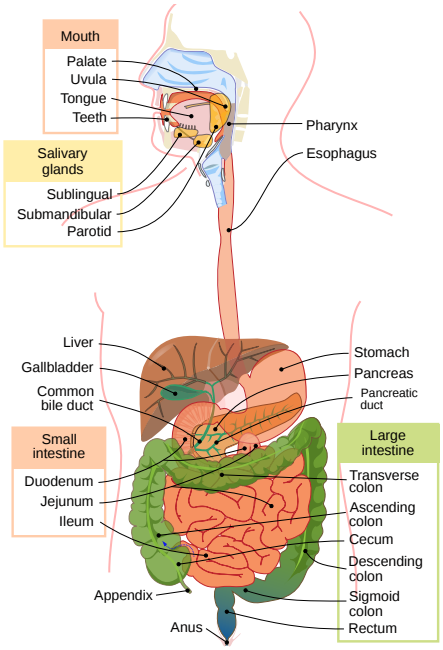


Figure **13.2.2**: The components of the digestive system include the gastrointestinal tract and accessory organs of digestion. The image has labeled parts of the mouth, salivary glands, liver, gallbladder and associated ducts, stomach, pancreas, and small and large intestine parts. Find the organs of the digestive system in this diagram as you read about them in the text.

The digestive system has three main functions relating to food: digestion of food, absorption of nutrients from food, and elimination of solid food waste. Digestion is the process of breaking down food into components the body can absorb. It consists of two types of processes: mechanical digestion and chemical digestion. Mechanical digestion is the physical breakdown of chunks of food into smaller pieces. This type of digestion takes place mainly in the mouth and stomach. Chemical digestion is the chemical breakdown (bonds are broken) of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by body fluids (blood or lymph). This type of digestion begins in the mouth and continues in the stomach but occurs mainly in the small intestine.

After food is digested, the resulting nutrients are absorbed. Absorption is the process in which substances pass into the bloodstream or lymph system to circulate throughout the body. The absorption of nutrients occurs mainly in the small intestine. Any remaining matter from food that is not digested and absorbed passes out of the body through the anus in the process of elimination.

GASTROINTESTINAL TRACT

The **gastrointestinal (GI) tract** is basically a long, continuous tube that connects the mouth with the anus. If it were fully extended, it would be about 9 meters (30 feet) long in adults. It includes the mouth, pharynx, esophagus, stomach, and small and large intestines. Food enters the mouth and then passes through the other organs of the GI tract where it is digested and/or absorbed. Finally, any remaining food waste leaves the body through the anus at the end of the large intestine. It takes up to 50 hours for food or food waste to make the complete trip through the GI tract.

TISSUES OF THE GI TRACT

The walls of the organs of the GI tract consist of four different tissue layers, which are illustrated in Figure **13.2.3**: mucosa, submucosa, muscularis externa, and serosa.

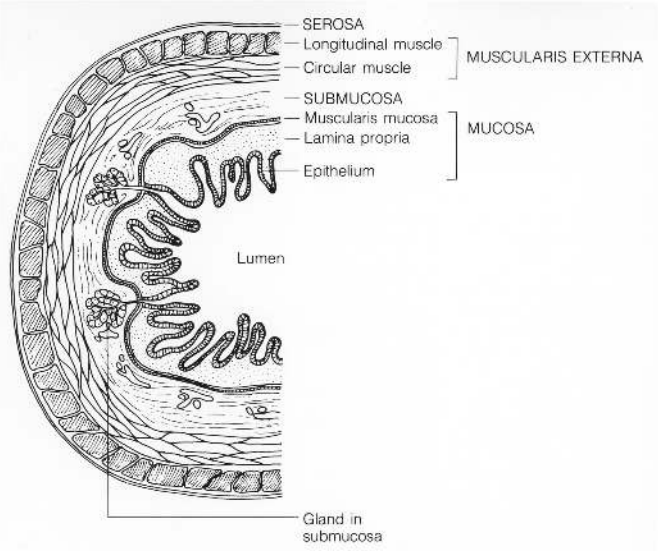


Figure **13.2.3**: This cross-sectional diagram of the wall of a typical GI tract organ shows the layers that comprise it.

1. The mucosa is the innermost layer surrounding the lumen, or open space within the organs of the GI tract. This layer consists mainly of the epithelium with the capacity to secrete and absorb substances. For example, the epithelium can secrete digestive enzymes and mucus, and it can absorb nutrients and water.
2. The submucosa layer consists of connective tissue that contains blood and lymph vessels and also nerves. The vessels are needed to absorb and carry away nutrients after food is digested, and nerves help control the muscles of the GI tract organs.
3. The muscularis externa layer contains two types of smooth muscle: longitudinal muscle and circular muscle. The longitudinal muscle runs the length of the GI tract organs and circular muscle encircles the organs. Both types of muscles contract to keep food moving through the track by the process of peristalsis (Figure **13.2.4**.
4. The serosa layer is the outermost layer of the walls of GI tract organs. This is a thin layer that consists of connective tissue and separates the organs from surrounding cavities and tissues.

PERISTALSIS IN THE GI TRACT

The muscles in the walls of GI tract organs enable peristalsis, which is illustrated in Figure **13.2.4**. Peristalsis is a continuous sequence of involuntary muscle contraction and relaxation that moves rapidly along an organ like a wave, similar to the way a wave moves through a spring toy. Peristalsis in organs of the GI tract propels food through the tract.

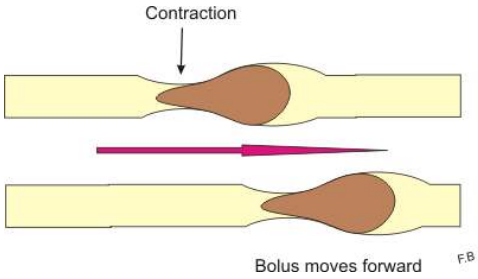


Figure **13.2.4**: Peristalsis pushes food through the GI tract.

DIVISIONS OF THE GI TRACT

The GI tract is often divided into an upper GI tract and a lower GI tract. For medical purposes, the upper GI tract is typically considered to include all the organs from the mouth through the first part of the small intestine, called the duodenum. For instructional purposes, it makes more sense to include the mouth through the stomach in the upper GI tract and all of the small intestine as well as the large intestine in the lower GI tract. The latter approach is followed here. All organs of GI which are discussed in the text are illustrated in Figure **13.2.2**.

UPPER GI TRACT

The mouth is the first digestive organ that food enters. The sight, smell, or taste of food stimulates the release of digestive enzymes and other secretions by salivary glands inside the mouth. The major salivary gland enzyme is amylase. It begins the chemical digestion of carbohydrates by breaking down starches into sugar. The mouth also begins the mechanical digestion of food. When you chew, your teeth break, crush, and grind food into increasingly smaller pieces. Your tongue helps to mix the food with saliva and also helps you swallow.

A lump of swallowed food is called a **bolus.** The bolus passes from the mouth into the pharynx and from the pharynx into the esophagus. The esophagus is a long, narrow tube that carries food from the pharynx to the stomach. It has no other digestive functions. Peristalsis starts at the top of the esophagus when food is swallowed and continues down the esophagus in a single wave, pushing the bolus of food ahead of it.

From the esophagus, food passes into the stomach, where both mechanical and chemical digestion continue. The muscular walls of the stomach churn and mix the food, thus completing mechanical digestion as well as mixing the food with digestive fluids secreted by the stomach. One of these fluids is hydrochloric acid. As well as killing pathogens in food, it gives the stomach the low pH needed by digestive enzymes that work in the stomach. One of these enzymes is pepsin, which chemically digests proteins. The stomach stores the partially digested food until the small intestine is ready to receive it. Food that enters the small intestine from the stomach is in the form of a thick slurry (semi-liquid) called **chyme.**

LOWER GI TRACT

The small intestine is a narrow but very long tubular organ. It may be almost 7 meters (23 feet) long in adults. It is the site of most chemical digestion and virtually all absorption of nutrients. Many digestive enzymes are active in the small intestine, some of which are produced by the small intestine itself, and some of which are produced by the pancreas, an accessory organ of the digestive system. Much of the inner lining of the small intestine is covered by tiny finger-like projections called **villi,** each of which in turn is covered by even tinier projections called **microvilli.** These projections, shown in Figure **13.2.5**, greatly increase the surface area through which nutrients can be absorbed from the small intestine.

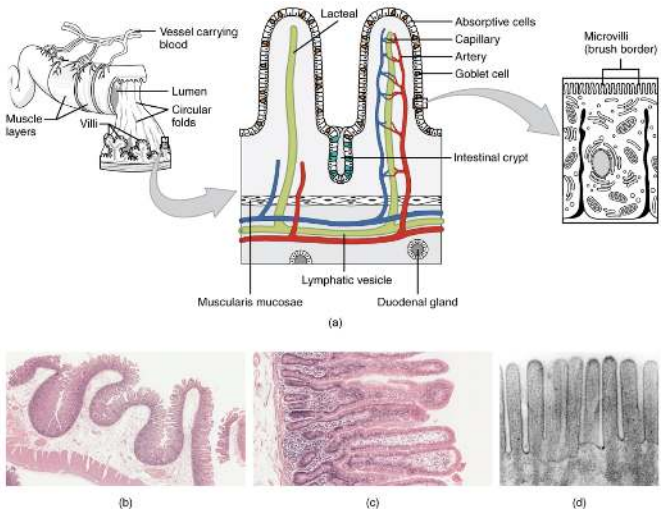


Figure **13.2.5**: The figure above shows three hierarchical small intestine wall modifications that increase the absorptive surface area. The broadest and most gross modification is the projection of mucosa and submucosa called circular folds (b); then, there are projections of mucosa called villi (c); and, finally, the projections of the plasma membrane of absorptive cells called microvilli (d). Microvilli are also referred to as brush border where enzymes reside.

The small intestine is made up of three parts:

1. The duodenum is the first part of the small intestine. It is also the shortest part. This is where most chemical digestion takes place.
2. The jejunum is the second part of the small intestine. This is where most nutrients are absorbed into the blood.
3. The ileum is the last part of the small intestine. A few remaining nutrients are absorbed in the ileum. From the ileum, any remaining food waste passes into the large intestine.

From the small intestine, any remaining nutrients and food waste pass into the large intestine. The large intestine is another tubular organ like the small intestine, but it is wider and shorter than the small intestine. It connects the small intestine and the anus. Waste that enters the large intestine is in a liquid state. As it passes through the large intestine, excess water is absorbed from it. The remaining solid waste, called feces, is eventually eliminated from the body through the anus.

ACCESSORY ORGANS OF THE DIGESTIVE SYSTEM

Accessory organs of the digestive system are not part of the GI tract, so they are not sites where digestion or absorption take place. Instead, these organs secrete or store substances that are needed for the chemical digestion of food. The accessory organs include the liver, gallbladder, and pancreas. They are shown in Figure **13.2.6** and described in the text:

- The liver is an organ that has a multitude of functions. Its main digestive function is producing and secreting a fluid called bile, which reaches the small intestine through a duct. Bile breaks down large globules of lipids into smaller ones that are easier for enzymes to chemically digest. Bile is also needed to reduce the acidity of food entering the small intestine from the highly acidic stomach because enzymes in the small intestine require a less acidic environment in order to work.
- The gallbladder is a small sac below the liver that stores some of the bile from the liver. The gallbladder also concentrates the bile by removing some of the water from it. It then secretes the concentrated bile into the small intestine as needed for fat digestion following a meal.
- The pancreas secretes many digestive enzymes and releases them into the small intestine for the chemical digestion of carbohydrates, proteins, and lipids. The pancreas also helps to lessen the acidity of the small intestine by secreting bicarbonate, a basic substance that neutralizes the acid.

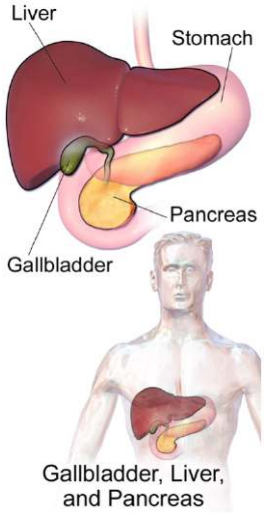


Figure **13.2.6**: This diagram shows the locations of the accessory organs of digestion: the liver, gallbladder, and pancreas.

REVIEW

1. What is the digestive system?
2. What are the three main functions of the digestive system? Define each function.
3. Describe the GI tract.
4. Distinguish between the upper and lower GI tracts.
5. Relate the tissues in the walls of GI tract organs to the functions the organs perform.
6. Identify accessory organs of digestion and their general function in digestion.
7. Identify the points in the GI tract where food becomes a bolus, chyme, and feces, respectively.
8. Does food pass through the pancreas? Why or why not?
9. *True or False.* Absorption mainly occurs in the stomach.
10. *True or False.* Some chemical digestion occurs in the mouth.
11. Most chemical digestion occurs in the _____ .

    A. Gall bladder

    B. Stomach

    C. Small intestine

    D. Large intestine

12. a. Describe one way in which proteins are at least partially chemically digested in the digestive system.

    b. Describe one way in which carbohydrates are at least partially chemically digested in the digestive system.

13. If the villi in your small intestine were damaged and could not function normally, what effect might this have on your body? Explain your reasoning.
14. The esophagus is considered:

    A. An accessory organ of the digestive system

    B. Part of the upper GI tract

    C. Part of the lower GI tract

    D. The longitudinal muscle

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13.3: DIGESTION AND ABSORPTION

INDIGESTION

The process of digestion does not always go as it should. Many people suffer from indigestion, or dyspepsia, a condition of impaired digestion. Symptoms may include upper abdominal fullness or pain, heartburn, nausea, belching, or some combination of these symptoms. The majority of cases of indigestion occur without evidence of an organic disease that is likely to explain the symptoms. Anxiety or certain foods or medications (such as aspirin) may be contributing factors in these cases. In other cases, indigestion is a symptom of an organic disease, most often gastroesophageal reflux disease (GERD) or gastritis. In a small minority of cases, indigestion is a symptom of a peptic ulcer of the stomach or duodenum, usually caused by a bacterial infection. Very rarely, indigestion is a sign of cancer.

An occasional bout of indigestion is usually nothing to worry about, especially in people less than 55 years of age. However, if you suffer frequent or chronic indigestion, it's a good idea to see a doctor. If an underlying disorder such as GERD or an ulcer is causing indigestion, this can and should be treated. If no organic disease is discovered, the doctor can recommend lifestyle changes or treatments to help prevent or soothe the symptoms of acute indigestion. Lifestyle changes might include modifications in eating habits, such as eating more slowly, eating smaller meals, or avoiding fatty foods. You also might be advised to refrain from taking certain medications, especially on an empty stomach. The use of antacids or other medications to relieve symptoms may also be recommended



Figure **13.3.1**: Add for heartburn medicine from 1882.

DIGESTION

Digestion of food is a form of catabolism, in which the food is broken down into small molecules that the body can absorb and use for energy, growth, and repair. Digestion occurs when food is moved through the digestive system. It begins in the mouth and ends in the small intestine. The final products of digestion are absorbed from the digestive tract, primarily in the small intestine. There are two different types of digestion that occur in the digestive system: mechanical digestion and chemical digestion. Figure **13.3.2** summarizes the roles played by different digestive organs in mechanical and chemical digestion, both of which are described in detail in the text.

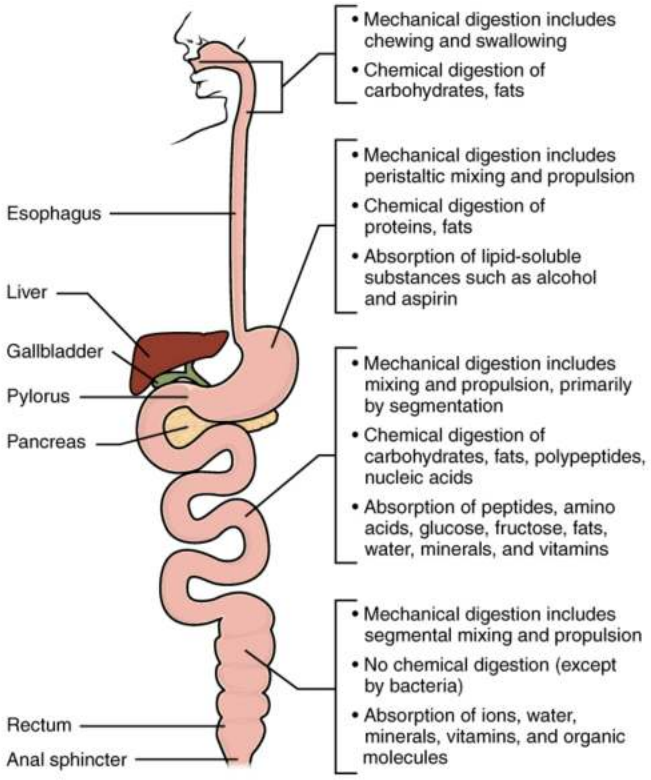


Figure **13.3.2**: Both, mechanical and chemical digestion take place throughout the gastrointestinal tract as indicated in this diagram, but absorption takes place only in the stomach and small and large intestines.

MECHANICAL DIGESTION

Mechanical digestion is a physical process in which food is broken into smaller pieces without becoming changed chemically. It begins with your first bite of food and continues as you chew food with your teeth into smaller pieces. The process of mechanical digestion continues in the stomach. This muscular organ churns and mixes the food it contains, an action that breaks any solid food into still smaller pieces.

Although some mechanical digestion also occurs in the intestines, it is mostly completed by the time food leaves the stomach. At that stage, food in the GI tract has been changed to the thick semi-fluid called chyme. Mechanical digestion is necessary so that chemical digestion can be effective. Mechanical digestion tremendously increases the surface area of food particles so they can be acted upon more effectively by digestive enzymes.

CHEMICAL DIGESTION

Chemical digestion is the biochemical process in which macromolecules in food are changed into smaller molecules that can be absorbed into body fluids and transported to cells throughout the body. Substances in food that must be chemically digested include carbohydrates, proteins, lipids, and nucleic acids. Carbohydrates

must be broken down into simple sugars, proteins into amino acids, lipids into fatty acids and glycerol, and nucleic acids into nitrogen bases and sugars. Some chemical digestion takes place in the mouth and stomach, but most of it occurs in the first part of the small intestine (duodenum).

DIGESTIVE ENZYMES

Chemical digestion could not occur without the help of many different digestive enzymes. Enzymes are proteins that catalyze or speed up biochemical reactions. Digestive enzymes are secreted by exocrine glands or by the mucosal layer of the epithelium lining the gastrointestinal tract. In the mouth, digestive enzymes are secreted by salivary glands. The lining of the stomach secretes enzymes, as does the lining of the small intestine. Many more digestive enzymes are secreted by exocrine cells in the pancreas and carried by ducts to the small intestine. Table **13.3.1** lists several important digestive enzymes, the organs and/or glands that secrete them, and the compounds they digest. You can read more about them in the text.

Table **13.3.1**: Digestive Enzymes

Digestive Enzyme	Organ, Glands That Secretes It	Compound It Digests
Amylase	Salivary Glands, Pancreas	Amylose (Polysaccharide)
Sucrase	Small Intestine	Sucrose (Disaccharide)
Lactase	Small Intestine	Lactose (Disaccharide)
Lipase	Salivary Glands, Pancreas	Lipid
Pepsin	Stomach	Protein
Trypsin	Pancreas	Protein
Chymotrypsin	Pancreas	Protein
Deoxyribonuclease	Pancreas	DNA
Ribonuclease	Pancreas	RNA
Nuclease	Small Intestine	Small Nucleic Acids

CHEMICAL DIGESTION OF CARBOHYDRATES

About 80 percent of digestible carbohydrates in a typical Western diet are in the form of the plant polysaccharide amylose, which consists mainly of long chains of glucose and is one of two major components of starch. Additional dietary carbohydrates include the animal polysaccharide glycogen, along with some sugars, which are mainly disaccharides.

To chemically digest amylose and glycogen, the enzyme amylase is required. The chemical digestion of these polysaccharides begins in the mouth, aided by amylase in saliva. Saliva also contains mucus, which lubricates the food, and hydrogen carbonate, which provides the ideal alkaline conditions for amylase to work. Carbohydrate digestion is completed in the small intestine, with the help of amylase secreted by the pancreas. In the digestive process, polysaccharides are reduced in length by the breaking of bonds between glucose monomers. The macromolecules are broken down to shorter polysaccharides and disaccharides, resulting in progressively shorter chains of glucose. The end result is molecules of the simple sugars glucose and maltose (which consists of two glucose molecules), both of which can be absorbed by the small intestine.

Other sugars are digested with the help of different enzymes produced by the small intestine. For example, sucrose, or table sugar, is a disaccharide that is broken down by the enzyme sucrase to form glucose and fructose, which are readily absorbed by the small intestine. Digestion of the sugar lactose, which is found in milk, requires the enzyme lactase, which breaks down lactose into glucose and galactose, which are then absorbed by the small intestine. Fewer than half of all adults produce sufficient lactase to be able to digest lactose. Those who cannot are said to be lactose intolerant.

CHEMICAL DIGESTION OF PROTEINS

Proteins consist of polypeptides, which must be broken down into their constituent amino acids before they can be absorbed. Protein digestion occurs in the stomach and small intestine through the action of three primary enzymes: pepsin, secreted by the stomach; and trypsin and chymotrypsin secreted by the pancreas. The stomach also secretes hydrochloric acid, making the contents highly acidic, which is required for pepsin to work. Trypsin and chymotrypsin in the small intestine require an alkaline environment to work. Bile from the liver and bicarbonate from the pancreas neutralize the acidic chyme as it empties into the small intestine. After pepsin, trypsin, and chymotrypsin break down proteins into peptides, these are further broken down into amino acids by other enzymes called peptidases, also secreted by the pancreas.

CHEMICAL DIGESTION OF LIPIDS

The chemical digestion of lipids begins in the mouth. The salivary glands secrete the digestive enzyme lipase, which breaks down short-chain lipids into molecules consisting of two fatty acids. A tiny amount of lipid digestion may take place in the stomach, but most lipid digestion occurs in the small intestine.

Digestion of lipids in the small intestine occurs with the help of another lipase enzyme from the pancreas as well as bile secreted by the liver. Bile is required for the digestion of lipids because lipids are oily and do not dissolve in the watery chyme. Bile emulsifies, or breaks up, large globules of food lipids into much smaller ones, called micelles, much as dish detergent breaks up grease. The micelles provide a great deal more surface area to be acted upon by lipase and also point the hydrophilic (“water-loving”) heads of the fatty acids outward into the watery chyme. Lipase can then access and break down the micelles into individual fatty acid molecules.

CHEMICAL DIGESTION OF NUCLEIC ACIDS

Nucleic acids (DNA and RNA) in foods are digested in the small intestine with the help of both pancreatic enzymes and enzymes produced by the small intestine itself. Pancreatic enzymes called ribonuclease and deoxyribonuclease break down RNA and DNA, respectively, into smaller nucleic acids. These, in turn, are further broken down into nitrogen bases and sugars by small intestine enzymes called nucleases.

CHEMICAL DIGESTION BY GUT FLORA

The human gastrointestinal tract is normally inhabited by trillions of bacteria, some of which contribute to digestion. Here are just two of

dozens of examples:

1. The most common carbohydrate in plants, which is cellulose, cannot be digested by the human digestive system. However, tiny amounts of cellulose are digested by bacteria in the large intestine.
2. Certain bacteria in the small intestine help digest lactose, which many adults cannot otherwise digest. As a byproduct of this process, the bacteria produce lactic acid, which increases the release of digestive enzymes and the absorption of minerals such as calcium and iron.

ABSORPTION

When digestion is finished, it results in many simple nutrient molecules that must go through the process of **absorption** from the GI tract by blood or lymph so they can be used by cells throughout the body. A few substances are absorbed in the stomach and large intestine. For example, water is absorbed in both of these organs, and some minerals and vitamins are also absorbed in the large intestine. However, about 95 percent of nutrient molecules are absorbed in the small intestine. The absorption of the majority of these molecules takes place in the second part of the small intestine, called the jejunum. However, there are a few exceptions. For example, iron is absorbed in the duodenum, and vitamin B12 is absorbed in the last part of the small intestine, called the ileum. After being absorbed in the small intestine, nutrient molecules are transported to other parts of the body for storage or further chemical modification. For example, amino acids are transported to the liver to be used for protein synthesis.

The epithelial tissue lining the small intestine is specialized for absorption. It has many wrinkles and is covered with villi and microvilli, creating an enormous surface area for absorption. As shown in Figure **13.3.3**, each villus also has a network of blood capillaries and fine lymphatic vessels called lacteals close to its surface. The thin surface layer of epithelial cells of the villi transports nutrients from the lumen of the small intestine into these capillaries and lacteals. Blood in the capillaries absorbs most of the molecules, including simple sugars, amino acids, glycerol, salts, and water-soluble vitamins (vitamin C and the many B vitamins). Lymph in the lacteals absorbs fatty acids and fat-soluble vitamins (vitamins A, D, E, and K).

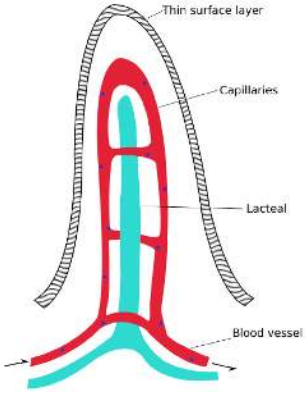


Figure **13.3.3**: This highly simplified drawing of an intestinal villus (plural villi) shows the capillaries and lacteals within it that carry away absorbed substances. Note that each cell in the thin surface layer of the villus is actually covered with microvilli that greatly increase the surface area for absorption.

FEATURE: MY HUMAN BODY

The process of digestion does not always go as it should. Many people suffer from indigestion, or dyspepsia, a condition of impaired digestion. Symptoms may include upper abdominal fullness or pain, heartburn, nausea, belching, or some combination of these symptoms. The majority of cases of indigestion occur without evidence of an organic disease that is likely to explain the symptoms. Anxiety or certain foods or medications (such as aspirin) may be contributing factors in these cases. In other cases, indigestion is a symptom of an organic disease, most often gastroesophageal reflux disease (GERD) or gastritis. In a small minority of cases, indigestion is a symptom of a peptic ulcer of the stomach or duodenum, usually caused by a bacterial infection. Very rarely, indigestion is a sign of cancer.

An occasional bout of indigestion is usually nothing to worry about, especially in people less than 55 years of age. However, if you suffer frequent or chronic indigestion, it's a good idea to see a doctor. If an underlying disorder such as GERD or an ulcer is causing indigestion, this can and should be treated. If no organic disease is discovered, the doctor can recommend lifestyle changes or treatments to help prevent or soothe the symptoms of acute indigestion. Lifestyle changes might include modifications in eating habits, such as eating more slowly, eating smaller meals, or avoiding fatty foods. You also might be advised to refrain from taking certain medications, especially on an empty stomach. The use of antacids or other medications to relieve symptoms may also be recommended.

REVIEW

1. Define digestion. Where does it occur?
2. Identify two organ systems that control the process of digestion by the digestive system.
3. What is mechanical digestion? Where does it occur?
4. Describe chemical digestion.

5. What is the role of enzymes in chemical digestion?
6. What is absorption? When does it occur?
7. a. Where does most absorption occur in the digestive system?

   b. Why does most of the absorption occur in this organ and not earlier in the GI tract?
8. Name two digestive enzymes found in saliva and identify which type of molecule they digest.
9. a. Where is bile produced?

   b. What are some functions of bile?
10. *True or False.* Pepsin digests cellulose.
11. *True or False.* Glucose can be absorbed by the body without being further broken down.
12. The pH of the stomach _____ .

    A. is neutral B. is alkaline

    C. is acidic D. depends only on what you eat
13. Lymph absorbs _____ .

    A. fatty acids B. sugars

    C. amino acids D. vitamin C

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13.4: UPPER GASTROINTESTINAL TRACT

HEAD STAND

Did you ever wonder what would happen if you tried to swallow food while standing on your head? Many people think that food travels down the gullet from the mouth by the force of gravity. If that were the case, then the food you swallowed would stay in your throat while you were standing on your head. In reality, your position doesn't have much to do with your ability to swallow. Food will travel from your mouth to your stomach whether you are standing upright or upside down. That's because the tube the food travels through — the esophagus — moves the food along by the muscular contractions is known as peristalsis. The esophagus is one of several organs that make up the upper gastrointestinal tract.



Figure **13.4.1**: Headstand

ORGANS OF THE UPPER GASTROINTESTINAL TRACT

Besides the esophagus, organs of the **upper gastrointestinal (GI) tract** include the mouth, pharynx, and stomach. These hollow organs are all connected to form a tube through which food passes during digestion. The only role in digestion played by the pharynx and esophagus is to move food through the GI tract. The mouth and stomach, in contrast, are organs where digestion, or the breakdown of food, also occurs. In both of these organs, food is broken into smaller pieces (mechanical digestion) as well as broken down chemically (chemical digestion). It should be noted that the first part of the small intestine (duodenum) is considered in some contexts to be part of the upper GI tract, but that practice is not followed here. You can read about the small intestine (and large intestine) in the concept Lower Gastrointestinal Tract.

MOUTH

The mouth is the first organ of the GI tract. Most of the oral cavity is lined with a mucous membrane. This tissue produces mucus, which helps to moisten, soften, and lubricate food. Underlying the mucous membrane is a thin layer of smooth muscle to which the mucous membrane is only loosely connected. This gives the mucous membrane considerable ability to stretch as you eat food. The roof of the mouth, called the palate, separates the oral cavity from the nasal cavity. The front part is the hard palate, consisting of a mucous membrane covering a plate of bone. The back part of the palate is softer and more pliable, consisting of mucous membrane over muscle and connective tissue. The hard surface of the front of the palate allows for the pressure needed in chewing and mixing food. The soft, pliable surface of the back of the palate can move to accommodate the passage of food while swallowing. Muscles at either side of the soft palate contract to create the swallowing action.

Several specific structures in the mouth are specialized for digestion. These include salivary glands, tongue, and teeth.

SALIVARY GLANDS

The mouth contains three pairs of major **salivary glands**, which are shown in Figure **13.4.2**. These three pairs are all exocrine glands that secrete **saliva** into the mouth through ducts.

1. The largest of the three major pairs of salivary glands are the parotid glands, which are located on either side of the mouth in front of the ears.
2. The next largest pair is the submandibular glands, located beneath the lower jaw.
3. The third pair is the sublingual glands, located underneath the tongue.

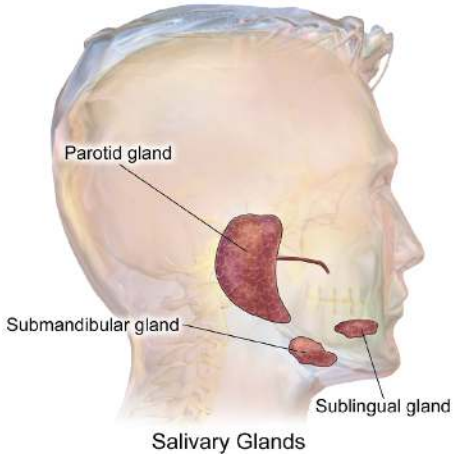


Figure **13.4.2**: Salivary glands in the mouth include the three major pairs of glands shown here. The sublingual gland is under the tongue. The submandibular gland is below the jaw. The parotid gland is the back of the mouth.

In addition to these three pairs of major salivary glands, there are also hundreds of minor salivary glands in the oral mucosa lining the mouth and on the tongue. Along with the major glands, most of the minor glands secrete the digestive enzyme amylase, which begins the chemical digestion of starch and glycogen (polysaccharides). However, the minor salivary glands on the tongue secrete the fat-digesting enzyme lipase, which in the mouth is called lingual lipase (to distinguish it from pancreatic lipase secreted by the pancreas).

The saliva secreted by the salivary glands mainly helps digestion, but it also plays other roles. It helps to maintain dental health by cleaning the teeth, and it contains antibodies that help protect against infection. By keeping the mouth lubricated, saliva also allows the mouth movements needed for speech.

TONGUE

The tongue is a fleshy, muscular organ that is attached to the floor of the mouth by a band of ligaments that gives it great mobility. This is necessary so the tongue can manipulate food for chewing and swallowing. Movements of the tongue are also necessary for speaking. The upper surface of the tongue is covered with tiny projections called papillae, which contain taste buds. The latter are collections of chemoreceptor cells. These sensory cells sense chemicals in food and send the information to the brain via cranial nerves, thus enabling the sense of taste.

TEETH

The teeth are complex structures made of a bone-like material called dentin and covered with enamel, which is the hardest tissue in the body. Adults normally have a total of 32 teeth, with 16 in each jaw. The right and left sides of each jaw are mirror images in terms of the numbers and types of teeth they contain. Teeth have different shapes to suit them for different aspects of mastication (chewing).

PHARYNX

The tube-like pharynx (Figure **13.4.3**) plays a dual role as an organ of both respiration and digestion. As part of the respiratory system, it conducts air between the nasal cavity and larynx. As part of the digestive system, it allows swallowed food to pass from the oral cavity to the esophagus. Anything swallowed has priority over inhaled air when passing through the pharynx. During swallowing, the backward motion of the tongue causes a flap of elastic cartilage, called the epiglottis, to close over the opening to the larynx. This prevents food or drinks from entering the larynx.

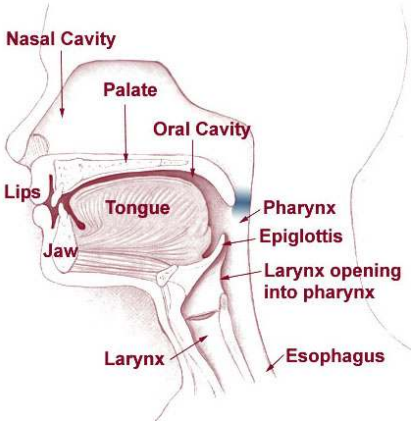


Figure **13.4.3**: The tongue moves backward during swallowing to cause the epiglottis to cover the opening to the larynx so food passes from the pharynx to the esophagus and not into the larynx.

ESOPHAGUS

The **esophagus,** which is shown in Figure **13.4.4**, is a muscular tube through which food is pushed from the pharynx to the stomach. The esophagus passes through an opening in the diaphragm (the large breathing muscle that separates the abdomen from the thorax) before reaching the stomach. In adults, the esophagus averages about 25 cm (10 in.) in length, depending on a person's height. The inner lining of the esophagus consists of a mucous membrane, which provides a smooth, slippery surface for the passage of food. The cells of this membrane are constantly being replaced as they are worn away from the frequent passage of food over them.

When food is not being swallowed, the esophagus is closed at both ends by upper and lower esophageal sphincters. **Sphincters** are rings of muscle that can contract to close off openings between structures. The upper esophageal sphincter is triggered to relax and open by the act of swallowing, allowing a bolus of food to enter the esophagus from the pharynx. Then the esophageal sphincter closes again to prevent food from moving back into the pharynx.

Once in the esophagus, the food bolus travels down to the stomach, pushed along by the rhythmic contraction and relaxation of muscles (peristalsis). The lower esophageal sphincter is located at the junction between the esophagus and the stomach. This sphincter opens when the bolus reaches it, allowing the food to enter the stomach. The sphincter normally remains closed at other times to prevent the contents of the stomach from entering the esophagus. Failure of this sphincter to remain completely closed can lead to heartburn. If it happens chronically, it can lead to gastroesophageal reflux disease (GERD), in which the mucous membrane of the esophagus may become damaged by the highly acidic contents of the stomach.

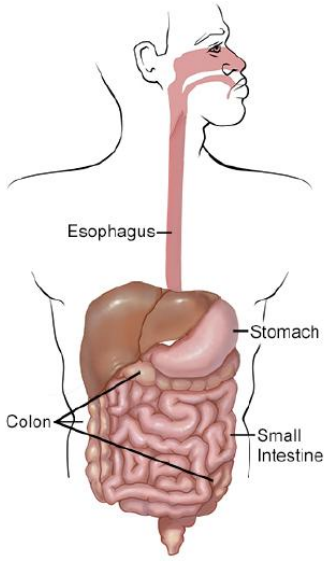


Figure **13.4.4**: The esophagus is located behind the trachea and it connects the pharynx to the stomach. The stomach is connected at the bottom to the small intestine.

STOMACH

The **stomach** (Figure **13.4.4** is a J-shaped organ that is joined to the esophagus at its upper end and to the first part of the small intestine (duodenum) at its lower end. When the stomach is empty of food, it normally has a volume of about 75 mL. However, it can expand to hold up to about a liter of food. Waves of muscle contractions (peristalsis) passing through the muscular walls of the stomach cause the food inside to be mixed and churned. The wall of the stomach has an extra layer of muscle tissue not found in other organs of the

GI tract that helps it squeeze and mix the food. These movements of the stomach wall contribute greatly to mechanical digestion by breaking the food into much smaller pieces. The churning also helps to mix the food with stomach secretions that aid in its chemical digestion.

Secretions of the stomach include gastric acid, which consists mainly of hydrochloric acid. This makes the stomach contents highly acidic, which is necessary so that the enzyme pepsin — also secreted by the stomach — can begin the digestion of protein. Mucus is secreted by the lining of the stomach to provide a slimy protective coating against the otherwise damaging effects of gastric acid. The fat-digesting enzyme lipase is secreted in small amounts in the stomach, but very little fat digestion occurs there.

By the time food has been in the stomach for about an hour, it has become the thick, semi-liquid chyme. When the small intestine is ready to receive chyme, a sphincter between the stomach and duodenum, called the pyloric sphincter, opens to allow the chyme to enter the small intestine for further digestion and absorption.

FEATURE: RELIABLE SOURCES

The ongoing epidemic of obesity has led to the development of several different bariatric surgeries that modify the stomach to help obese patients reduce their food intake and lose weight. Go online to learn more about bariatric surgery. Find sources you judge to be reliable that answer the following questions:

1. Who qualifies for bariatric surgery?
2. Describe the bariatric surgeries commonly called stomach stapling, lap band, and gastric sleeve. How does each type of surgery modify the stomach? How effective is each type in terms of weight loss?
3. What are the major potential risks of bariatric surgery?
4. Besides weight loss, what other benefits have been shown to result from bariatric surgery?

REVIEW

1. List organs of the upper gastrointestinal tract.
2. Identify structures in the mouth that are specialized for digestion.
3. Describe digestion in the mouth.
4. What general role do the pharynx and esophagus play in the digestion of food?
5. How does food travel through the esophagus?
6. Describe digestion in the stomach.
7. In which of the following structures does chemical digestion occur?

   A. Mouth

   B. Esophagus

   C. Stomach

   D. A and C

   E. A, B, and C
8. In which of the following structures does mechanical digestion occur?

   A. Mouth

   B. Pharynx

   C. Stomach

   D. A and C

   E. A, B, and C
9. Describe the differences between how air and food normally move past the pharynx.
10. Name two structures in the mouth that contribute to mechanical digestion.
11. What structure normally keeps stomach contents from backing up into the esophagus?
12. *True or False*. Peristalsis occurs in the esophagus, but not in the stomach.
13. *True or False*. The sense of taste is due to the detection of chemicals by the tongue.
14. Where is most of your food located thirty minutes after you eat a meal? Explain your answer.
15. What are the two roles of mucus in the upper GI tract?

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13.5: LOWER GASTROINTESTINAL TRACT

WHAT IS IT?

Figure **13.5.1** shows some of the cells of what has been called "the last human organ to be discovered." This "organ" weighs about 200 grams (0.44 lb.) and consists of a hundred trillion cells, yet scientists are only now beginning to learn everything it does and how it varies among individuals. What is it? It's the mass of bacteria that live in our lower gastrointestinal tract.



Figure **13.5.1**: Micrograph of *Bacteroides biacutis* - cultured in blood agar medium for 48 hours.

ORGANS OF THE LOWER GASTROINTESTINAL TRACT

Most of the bacteria that normally live in the **lower gastrointestinal (GI) tract** live in the large intestine. They have important and mutually beneficial relationships with the human organism. We provide them with a great place to live, and they provide us with many benefits, some of which you can read about below. Besides the large intestine and its complement of helpful bacteria, the lower GI tract also includes the small intestine. The latter is arguably the most important organ of the digestive system. It is where most chemical digestion and virtually all absorption of nutrients take place.

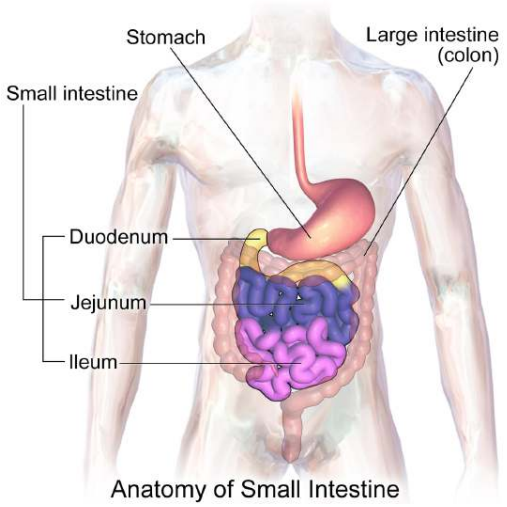


Figure **13.5.2**: The three parts of the small intestine are color-coded in this diagram, with yellow for the duodenum (the first part of the small intestines), blue for the jejunum (the middle), and pink for the ileum (the end of the small intestines).

SMALL INTESTINE

The **small intestine** (also called the small bowel or gut) is the part of the GI tract between the stomach and large intestine. Its average length in adults is 4.6 m (15 ft) in females and 6.9 m (22 ft 8 in.) in males. It is approximately 2.5 to 3.0 cm (1.0 to 1.2 in.) in diameter (it is called "small" because it is much smaller in diameter than the large intestine). The internal surface area of the small intestine totals an average of about 30 m^2 (323 ft^2). Structurally and functionally, the small intestine can be divided into three parts, called the duodenum, jejunum, and ileum, as shown in Figure **13.5.2** and described below.

The mucosa lining the small intestine is very wrinkled and covered with finger-like projections called villi. In fact, each square inch of mucosa contains around 20,000 villi. The individual cells on the surface of the villi also have many finger-like projections, the microvilli shown in Figure **13.5.3**. There are thought to be well over 100 billion microvilli per square inch of intestinal mucosa! All of these wrinkles, villi, and microvilli greatly increase the surface area for chyme to come into contact with digestive enzymes, which coat the microvilli, as well as forming a tremendous surface area for the absorption of nutrients. Inside each of the villi is a network of tiny blood and lymph vessels that receive the absorbed nutrients and carry them away in the blood or lymph circulation. The wrinkles and projections in the intestinal mucosa also slow down the passage of chyme so there is more time for digestion and absorption to take place.

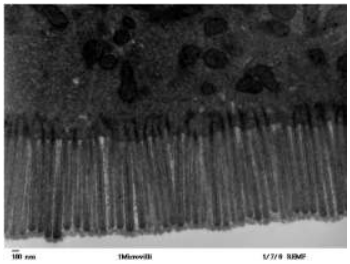


Figure **13.5.3**: The fringe-like structures in this photomicrograph are microvilli lining the inside of the small intestine.

DUODENUM

The **duodenum** is the first part of the small intestine, directly connected to the stomach. It is also the shortest part of the small intestine, averaging only about 25 cm (10 in.) in length in adults. Its main function is chemical digestion, and it is where most of the chemical digestion in the entire GI tract takes place.

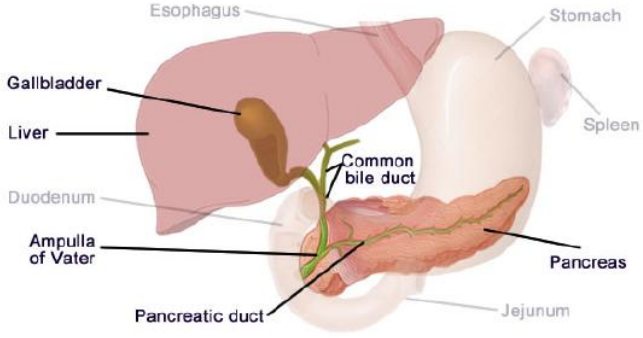


Figure **13.5.1**: This figure shows the liver, gallbladder, and pancreas, along with the ducts that carry their secretions to the duodenum

The duodenum receives partially digested, semi-liquid chyme from the stomach. It receives digestive enzymes and alkaline bicarbonate from the pancreas through the pancreatic duct, and it receives bile from the liver via the gallbladder through the common bile duct (Figure **13.5.4**). In addition, the lining of the duodenum secretes digestive enzymes and contains glands — called Brunner's glands — that secrete mucus and bicarbonate. The bicarbonate from the pancreas and Brunner's glands as well as bile from the liver neutralize the highly acidic chyme after it enters the duodenum from the stomach. This is necessary because the digestive enzymes in the duodenum require a nearly neutral environment in order to work. The three major classes of compounds that undergo chemical digestion in the duodenum are carbohydrates, proteins, and lipids.

DIGESTION OF CARBOHYDRATES IN THE DUODENUM

Complex carbohydrates such as starches are broken down by the digestive enzyme amylase from the pancreas to short-chain molecules consisting of just a few saccharides (that is, simple sugars). Disaccharides, including sucrose and lactose, are broken down into simple sugars by duodenal enzymes: sucrase breaks down sucrose, and lactase (if present) breaks down lactose. Some carbohydrates are not digested in the duodenum and ultimately pass undigested to the large intestine, where they may be digested by intestinal bacteria.

DIGESTION OF PROTEINS IN THE DUODENUM

In the duodenum, the pancreatic enzymes trypsin and chymotrypsin cleave proteins into peptides. Then, these smaller molecules are broken down into amino acids. Their digestion is catalyzed by pancreatic enzymes called peptidases.

DIGESTION OF LIPIDS IN THE DUODENUM

Pancreatic lipase breaks down triglycerides into fatty acids and glycerol. Lipase works with the help of bile secreted by the liver and stored in the gall bladder. Bile salts attach to triglycerides to help them emulsify or form smaller particles (called micelles) that can disperse through the watery contents of the duodenum. This increases the access to the molecules by pancreatic lipase.

JEJUNUM

The **jejunum** is the middle part of the small intestine, connecting the duodenum and the ileum. The jejunum is about 2.5 m (8.2 ft) long. Its main function is the absorption of the products of digestion, including sugars, amino acids, and fatty acids. Absorption occurs by simple diffusion (water and fatty acids), facilitated diffusion (the simple sugar fructose), or active transport (amino acids, small peptides, water-soluble vitamins, and most glucose). All nutrients are absorbed into the blood except for fatty acids and fat-soluble vitamins, which are absorbed into the lymph. Although most nutrients are absorbed in the jejunum, there are a few exceptions:

- Iron is absorbed in the duodenum.
- Vitamin B12 and bile salts are absorbed in the ileum.
- Water and lipids are absorbed throughout the small intestine, including the duodenum and ileum in addition to the jejunum.

ILEUM

The **ileum** is the third and final part of the small intestine, directly connected at its distal end to the large intestine. The ileum is about 3 m (9.8 ft) long. Some cells in the lining of the ileum secrete enzymes that catalyze the final stages of digestion of any undigested protein and carbohydrate molecules. However, the main function of the ileum is to absorb vitamin B12 and bile salts. It also absorbs any other remaining nutrients that were not absorbed in the jejunum. All substances in chyme that remain undigested or unabsorbed by the time they reach the distal end of the ileum pass into the large intestine.

LARGE INTESTINE

The **large intestine**, also called the large bowel, is the last organ of the GI tract. In adults, it averages about 1.5 m (5 ft) in length. It is shorter than the small intestine but at least twice as wide, averaging about 6.5 cm (2.5 in.) in diameter. Water is absorbed from the chyme as it passes through the large intestine, turning the chyme into solid feces. Feces is stored in the large intestine until it leaves the body during defecation.

PARTS OF THE LARGE INTESTINE

Like the small intestine, the large intestine can be divided into several parts, as shown in Figure **13.5.5**. The large intestine begins at the end of the small intestine, where a valve separates the small and large intestines and regulates the movement of chyme into the large intestine. The first part of the large intestine, where chyme enters from the small intestine, is called the cecum. From the cecum, the large intestine continues upward as the ascending colon, travels across the upper abdomen as the transverse colon, and then continues downward as the descending colon. It then becomes a V-shaped region called the sigmoid colon, which is attached to the rectum. The **rectum** stores feces until elimination occurs. It transitions to the final part of the large intestine, called the **anus,** which has an opening to the outside of the body for feces to pass through.

A projection from the cecum of the colon is known as the **appendix.** The function of the appendix is uncertain, but it does not seem to be involved in digestion or absorption. It may play a role in immunity, and in the fetus, it seems to have an endocrine function, releasing hormones needed for homeostasis. Some biologists speculate that the appendix may also store a sample of the colon's normal bacteria. If so, it may be able to repopulate the colon with the bacteria if illness or antibiotic medications deplete these microorganisms. Appendicitis, or infection and inflammation of the appendix, is a fairly common medical problem, typically resolved by surgical removal of the appendix (appendectomy). People who have had their appendix surgically removed do not seem to suffer any ill effects, so the organ is considered to be dispensable. As such, it is often referred to as a vestigial organ, which is a previously useful organ that has been retained over evolutionary time as part of the anatomy, even though it no longer has a function in the body.

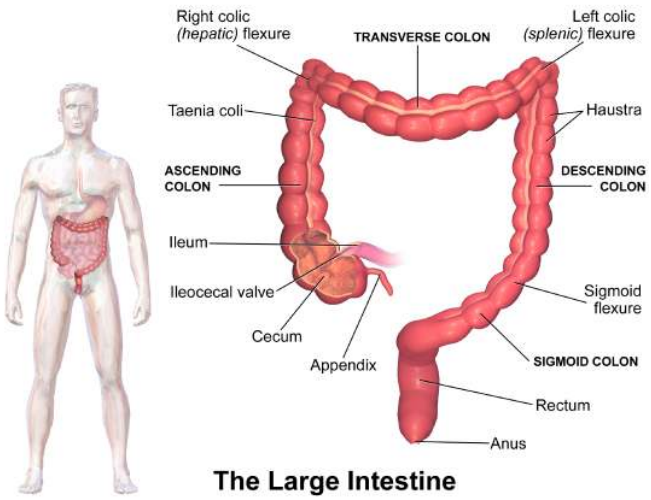


Figure **13.5.5**: The parts of the large intestine include the cecum (just after the small intestines), ascending colon (moving upward), transverse colon (moving across), descending colon (moving downward), sigmoid colon (small S-shaped segment), rectum (connecting to the anus), and anus.

FUNCTIONS OF THE LARGE INTESTINE

The removal of water from chyme to form feces starts in the ascending colon and continues throughout much of the length of the organ. Salts such as sodium are also removed from food wastes in the large intestine before the wastes are eliminated from the body. This allows salts as well as water to be recycled in the body.

The large intestine is also the site where huge numbers of beneficial bacteria ferment many unabsorbed materials in food waste. The bacterial breakdown of undigested polysaccharides produces nitrogen, carbon dioxide, methane, and other gases that are responsible for intestinal gas, or flatulence. These bacteria are particularly prevalent in the descending colon. Some of the bacteria also produce vitamins that are absorbed from the colon. The vitamins include vitamins B_1 (thiamine), B_2 (riboflavin), B_7 (biotin), B_{12}, and K. Another role of bacteria in the colon is immune function. The bacteria may stimulate the immune system to produce antibodies that are effective against similar, but pathogenic, bacteria, thereby preventing infections. Still, other roles played by bacteria in the large intestine include breaking down toxins before they can poison the body, producing substances that help prevent colon cancer, and inhibiting the growth of harmful bacteria.

FEATURE: MY HUMAN BODY

Colorectal cancer, or cancer of the colon or rectum, is the fourth most common cancer in the United States. It is also the second most common cause of cancer deaths in this country. Widespread screening of patients for signs of colorectal cancer has significantly lowered the death rate in recent years. Because early-stage colorectal cancer is usually asymptomatic, routine screening is important for identifying cancer early when chances of a cure are still high.

Screening for colorectal cancer has also become easier and less invasive in recent years. One way to test for colorectal cancer is to examine a sample of stool and look for occult (hidden from the unaided eye) blood in the stool. This test is based on the assumption that blood vessels in cancer are fragile and may be easily damaged by the passage of feces through the colon or rectum. The damaged vessels may bleed into the feces but rarely bleed enough for blood to be visible in the stool. Stool for the occult blood test can be collected by the patient at home with a test kit provided by a doctor. If occult blood is detected in the stool, a different type of follow-up test is generally needed to determine whether cancer is the cause of the bleeding.

A similarly simple and noninvasive but more definitive test for colorectal cancer looks for DNA from cancer cells in the stool. Again, the patient can collect the stool sample at home using a simple test kit and mail the specimen to a lab, which does the analysis. If the test comes back positive, then a direct visual examination of the colon and rectum by colonoscopy is required.

Colonoscopy is the gold standard for the diagnosis of colorectal cancer. Using a tiny camera at the end of a long tube inserted up into the colon, a doctor can directly visualize the lining of the large intestine and spot any suspicious areas that may be cancerous. While a colonoscopy is invasive and requires the patient to prepare for the test for a couple of days by changing his or her diet and drinking special fluids, it reveals more than just cancer. A colonoscopy also reveals any growths called polyps in the colon. Colon polyps are not cancer but often develop into cancerous lesions, so if they are found during a colonoscopy, a surgical instrument inserted with the scope is usually used to remove them. Therefore, a colonoscopy can not only detect cancer in its early stages, but it can even help prevent cancer by enabling the removal of potentially pre-cancerous polyps.

A test similar to colonoscopy may be done in some patients. Called a flexible sigmoidoscopy, it allows a doctor to use a small camera to inspect the rectum and lower third of the colon, where the majority of cases of colorectal cancer occur. However, the rest of the colon cannot be examined with a sigmoidoscopy. Another alternative to a full-blown colonoscopy is a virtual colonoscopy, in which a CT scan of the rectum and colon is used to make detailed cross-sectional images of the organs. The images can then be studied by a specialist to detect cancers or polyps. For both of these colonoscopy alternatives, a follow-up colonoscopy is required if polyps or potentially cancerous lesions are detected.

Unless you have a family history of colorectal cancer or certain other risk factors, you probably do not need to start routine screening for the disease until middle age. Your doctor can tell you the most appropriate starting age for your particular case, given your risk factors and current cancer guidelines. You may be able to be screened with one of the less invasive methods

rather than colonoscopy until you are somewhat older. Again, check with your doctor for specific recommendations. All of the testing methods have pros and cons that should be taken into consideration by a given patient and medical provider.

REVIEW

1. Which organs are included in the lower GI tract?
2. Name the parts of the small intestine.
3. How is the mucosa of the small intestine specialized for digestion and absorption?
4. What digestive substances are secreted into the duodenum, and what compounds in food do they help digest?
5. What is the main function of the jejunum?
6. What roles are played by the ileum?
7. Name the parts of the large intestine.
8. Identify the main functions of the large intestine.
9. How do beneficial bacteria in the large intestine help the human organism?
10. *True or False.* The first part of the large intestine is where most chemical digestion takes place.
11. *True or False.* The small intestine is actually longer than the large intestine.
12. When diarrhea occurs, feces leaves the body in a more liquid state than normal. What part of the digestive system do you think is involved in diarrhea? Explain your answer.
13. Arrange the following parts of the lower GI tract in order of how food passes through them, from earliest to latest. Note that not all parts are listed.

    cecum; duodenum; sigmoid colon; jejunum; rectum; ileum

14. Which enzyme digests proteins?

    A. trypsin

    B. amylase

    C. lipase

    D. lactase

15. What is intestinal gas, or flatulence, due to?

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13.6: ACCESSORY ORGANS OF DIGESTION

JAUNDICED EYES

Did you ever hear of a person looking at something or someone with a "jaundiced eye"? It means to take a negative view, such as envy, maliciousness, or ill will. The expression may be based on the antiquated idea that liver bile is associated with such negative emotions as these, as well as the fact that excessive liver bile causes jaundice or yellowing of the eyes and skin. Jaundice is likely to be a sign of a liver disorder or blockage of the duct that carries bile away from the liver. Bile contains waste products, making the liver an organ of excretion. Bile also has an important role in digestion, making the liver an accessory organ of digestion.



Figure **13.6.1**: Jaundice Eyes

WHAT ARE ACCESSORY ORGANS OF DIGESTION?

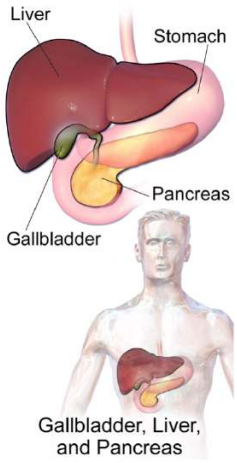


Figure **13.6.2**: The liver, gallbladder, and pancreas are the major accessory organs of digestion. In this figure, the pink tubular structure that starts at the lower stomach and wraps around the pancreas is the duodenum of the small intestine. This is where the accessory organs secrete their digestive substances. The pancreas is just behind the stomach. The liver is above on the right side and the gall bladder is just under the liver.

Accessory organs of digestion are organs that secrete substances needed for the chemical digestion of food but through which food does not actually pass as it is digested. Besides the liver, the major accessory organs of digestion are the gallbladder and pancreas. These organs secrete or store substances that are needed for digestion in the first part of the small intestine, the duodenum, where most chemical digestion takes place. You can see the three organs and their locations in Figure **13.6.2**.

LIVER

The **liver** is a vital organ located in the upper right part of the abdomen. It lies just below the diaphragm to the right of the stomach. The liver plays an important role in digestion by secreting bile. However, the liver has a wide range of additional functions unrelated to digestion. In fact, some estimates put the number of functions of the liver at about 500! A few of them are described below.

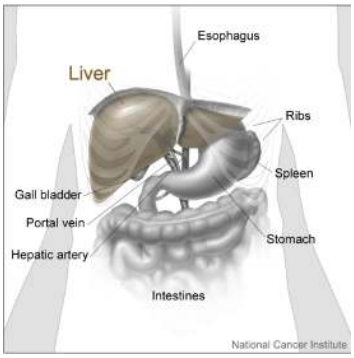


Figure **13.6.3**: The portal vein supplies the liver with wastes filtered out of the blood in the spleen as well as nutrients from the gastrointestinal tract. Oxygen-rich blood enters the liver via the hepatic artery.

STRUCTURE OF THE LIVER

The liver is a reddish-brown, wedge-shaped structure. In adults, the liver normally weighs about 1.5 kg (3.3 lb). It is both the heaviest internal organ and the largest gland in the human body. The liver is divided into four lobes of unequal size and shape. Each lobe, in turn, is made up of lobules, which are the functional units of the liver. Each lobule consists of millions of liver cells, called hepatic cells (or hepatocytes). They are the basic metabolic cells that carry out the various functions of the liver.

As shown in Figure **13.6.3**, the liver is connected to two large blood vessels: the hepatic artery and the portal vein. The hepatic artery carries oxygen-rich blood from the aorta, whereas the portal vein carries blood that is rich in digested nutrients from the GI tract and wastes filtered from the blood by the spleen. The blood vessels subdivide into smaller arteries and capillaries, which lead to the liver lobules. The nutrients from the GI tract are used to build many vital biochemical compounds, and the wastes from the spleen are degraded and excreted.

FUNCTIONS OF THE LIVER

The main digestive function of the liver is the production of bile. **Bile** is a yellowish alkaline liquid that consists of water, electrolytes, bile salts, and cholesterol, among other substances, many of which are waste products. Some of the components of bile are synthesized by hepatocytes; the rest are extracted from the blood.

As shown in the figure below, bile is secreted into small ducts that join together to form larger ducts, with just one large duct carrying bile out of the liver. If bile is needed to digest a meal, it goes directly

to the duodenum through the common bile duct. In the duodenum, the bile neutralizes acidic chyme from the stomach and emulsifies fat globules into smaller particles (called micelles) that are easier to digest chemically by the enzyme lipase. Bile also aids with the absorption of vitamin K. Bile that is secreted when digestion is not taking place goes to the gallbladder for storage until the next meal. In either case, the bile enters the duodenum through the common bile duct shown in Figure **13.6.4**

- The liver synthesizes glycogen from glucose and stores the glycogen as required to help regulate blood sugar levels. It also breaks down the stored glycogen to glucose and releases it back into the blood as needed.
- The liver stores many substances in addition to glycogen, including vitamins A, D, B12, and K. It also stores the minerals iron and copper.
- The liver synthesizes numerous proteins and many of the amino acids needed to make them. These proteins have a wide range of functions. They include fibrinogen, which is needed for blood clotting; insulin-like growth factor (IGF-1), which is important for childhood growth; and albumen, which is the most abundant protein in blood serum and functions to transport fatty acids and steroid hormones in the blood.
- The liver synthesizes many important lipids, including cholesterol, triglycerides, and lipoproteins.
- The liver is responsible for the breakdown of many waste products and toxic substances. The wastes are excreted in bile or travel to the kidneys, which excrete them in the urine.

The liver is clearly a vital organ that supports almost every other organ in the body. Because of its strategic location and diversity of functions, the liver is also prone to many diseases, some of which cause loss of liver function. There is currently no way to compensate for the absence of liver function in the long term, although liver dialysis techniques can be used in the short term. An artificial liver has not yet been developed, so liver transplantation may be the only option for people with liver failure.

GALLBLADDER

The **gallbladder** is a small, hollow, pouch-like organ that lies just under the right side of the liver (Figure **13.6.2** and Figure **13.6.3**). It is about 8 cm (3.1 in.) long and shaped like a tapered sac, with the open end continuous with the cystic duct. The gallbladder stores and concentrates bile from the liver until it is needed in the duodenum to help digest lipids. After the bile leaves the liver, it reaches the gallbladder through the cystic duct. At any given time, the gallbladder may store between 30 and 60 mL (1-2 oz) of bile. A hormone stimulated by the presence of fat in the duodenum signals the gallbladder to contract and force its contents back through the cystic duct and into the common bile duct to drain into the duodenum.

PANCREAS

The **pancreas** is a glandular organ that is part of both the digestive system and the endocrine system. As shown in Figure **13.6.4**, it is located in the abdomen behind the stomach, with the head of the pancreas surrounded by the duodenum of the small intestine. The pancreas is about 15 cm (6 in.) long, and it has two major ducts, the main pancreatic duct, and the accessory pancreatic duct. Both of these ducts drain into the duodenum.

As an endocrine gland, the pancreas secretes several hormones, including insulin and glucagon, which circulate in the blood. The endocrine hormones are secreted by clusters of cells called pancreatic islets (or islets of Langerhans). As a digestive organ, the pancreas secretes many digestive enzymes and also bicarbonate, which helps to neutralize acidic chyme after it enters the duodenum. The pancreas is stimulated to secrete its digestive substances when food in the stomach and duodenum triggers the release of endocrine hormones into the blood that reach the pancreas via the bloodstream. The pancreatic digestive enzymes are secreted by clusters of cells called acini, and they travel through the pancreatic ducts to the duodenum. In the duodenum, they help to chemically break down carbohydrates, proteins, lipids, and nucleic acids in chyme. The pancreatic digestive enzymes include:

- amylase, which helps to digest starch and other carbohydrates.
- trypsin and chymotrypsin, which help to digest proteins.
- lipase, which helps to digest lipids.
- deoxyribonucleases and ribonucleases, which help to digest nucleic acids.

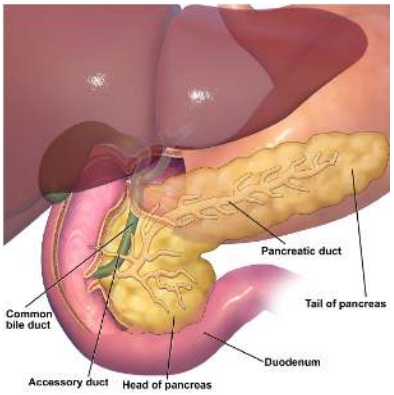


Figure **13.6.4**: Pancreatic digestive enzymes and bicarbonate travel to the duodenum through the pancreatic ducts. The main pancreatic duct joins with the common bile duct before the latter enters the duodenum

REVIEW

1. Name three accessory organs of digestion. How do these organs differ from digestive organs that are part of the GI tract?
2. Describe the liver and its blood supply.
3. Explain the main digestive function of the liver.
4. Besides its role as a digestive organ, what other vital functions does the liver have?
5. What is the gallbladder? How does it aid in digestion in the duodenum?

6. Which two body systems include the pancreas? What type of secretions does the pancreas release as part of each body system?
7. List pancreatic enzymes that work in the duodenum and the substances they help digest.
8. What are two substances produced by accessory organs of digestion that help neutralize chyme in the small intestine, and where are they produced?
9. People who have their gallbladder removed sometimes have digestive problems after eating high-fat meals. Why do you think this happens?
10. *True or False*. The liver is a gland.
11. *True or False*. Substances secreted by the pancreas enter into the duodenum from the common bile duct.
12. *True or False*. Bile contains wastes.
13. Which accessory organ of digestion synthesizes cholesterol?

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13.7: DISORDERS OF THE GASTROINTESTINAL TRACT

CROHN'S RASH

If you had a skin rash like the one in Figure **13.7.1**, you probably wouldn't assume that it was caused by a digestive system disease. However, that's exactly why the individual in the picture has a rash. He has a gastrointestinal (GI) tract disorder called Crohn's disease. This disease is one of a group of GI tract disorders that are known collectively as inflammatory bowel disease. Unlike other inflammatory bowel diseases, signs and symptoms of Crohn's disease may not be confined to the GI tract.

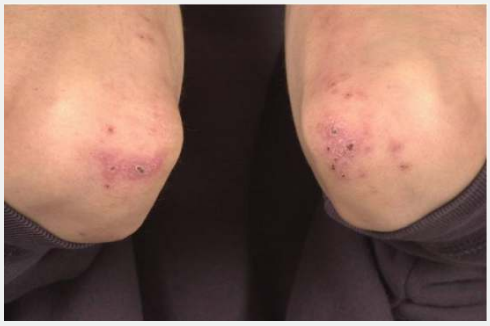


Figure **13.7.1**: Pustules and crusts around the elbows in a patient with Crohn's disease and bowel-associated dermatosis-arthritis syndrome (BADAS).

INFLAMMATORY BOWEL DISEASE

Inflammatory bowel disease is a collection of inflammatory conditions primarily affecting the intestines. The two principal inflammatory bowel diseases are Crohn's disease and ulcerative colitis. Unlike Crohn's disease, which may affect any part of the GI tract and the joints as well as the skin, ulcerative colitis mainly affects just the colon and rectum. Both diseases occur when the body's own immune system attacks the digestive system. Both diseases also typically first appear in the late teens or early twenties and occur equally in all sexes and genders.

CROHN'S DISEASE

Crohn's disease is a type of inflammatory bowel disease that may affect any part of the GI tract from the mouth to the anus, among other body tissues. The most commonly affected region is the ileum, which is the final part of the small intestine. Signs and symptoms of Crohn's disease typically include abdominal pain, diarrhea (with or without blood), fever, and weight loss. Malnutrition because of faulty absorption of nutrients may also occur. Potential complications of Crohn's disease include obstructions and abscesses of the bowel. People with Crohn's disease are also at a slightly greater risk than the general population of developing bowel cancer. Although there is a slight reduction in life expectancy in people with Crohn's disease, if the disease is well managed, affected people can live full and productive lives.

Crohn's disease is caused by a combination of genetic and environmental factors that lead to impairment of the generalized immune response (called innate immunity). The chronic inflammation of Crohn's disease is thought to be the result of the immune system "trying" to compensate for the impairment. Dozens of genes are likely to be involved, only a few of which have been identified. Because of the genetic component, close relatives such as siblings of people with Crohn's disease are many times more likely to develop the disease than people in the general population. Environmental factors that appear to increase the risk of the disease include smoking tobacco and eating a diet high in animal proteins. Crohn's disease is typically diagnosed on the basis of a colonoscopy, which provides a direct visual examination of the inside of the colon and the ileum of the small intestine.

People with Crohn's disease typically experience recurring periods of flare-ups followed by remission. There are no medications or surgical procedures that can cure Crohn's disease, although medications such as anti-inflammatory or immune-suppressing drugs may alleviate symptoms during flare-ups and help maintain remission. Lifestyle changes, such as dietary modifications and smoking cessation, may also help control symptoms and reduce the likelihood of flare-ups. Surgery may be needed to resolve bowel obstructions, abscesses, or other complications of the disease.

ULCERATIVE COLITIS

Ulcerative colitis is an inflammatory bowel disease that causes inflammation and ulcers (sores) in the colon and rectum. Unlike Crohn's disease, other parts of the GI tract are rarely affected in ulcerative colitis. The primary symptoms of the disease are lower abdominal pain and bloody diarrhea. Weight loss, fever, and anemia may also be present. Symptoms typically occur intermittently with periods of no symptoms between flare-ups. People with ulcerative colitis have a considerably increased risk of colon cancer and should be screened for colon cancer more frequently than the general population. However, ulcerative colitis seems to reduce primarily the quality of life and not the lifespan.

The exact cause of ulcerative colitis is not known. Theories about its cause involve immune system dysfunction, genetics, changes in normal gut bacteria, and lifestyle factors such as a diet high in animal protein and the consumption of alcoholic beverages. Genetic involvement is suspected in part because ulcerative colitis tends to "run" in families. It is likely that multiple genes are involved. Diagnosis is typically made on the basis of colonoscopy and tissue biopsies.

Lifestyle changes, such as reducing the consumption of animal protein and alcohol, may improve symptoms of ulcerative colitis. A number of medications are also available to treat symptoms and help prolong remission. These include anti-inflammatory drugs and drugs that suppress the immune system. In cases of severe disease, removal of the colon and rectum may be required and can cure the disease.

DIVERTICULITIS

Diverticulitis is a digestive disease in which tiny pouches in the wall of the large intestine become infected and inflamed. Symptoms typically include lower abdominal pain of sudden onset. There may also be fever, nausea, diarrhea or constipation, and blood in the stool. Having large intestine pouches called diverticula (Figure **13.7.2**) that are not inflamed is called **diverticulosis.** Diverticulosis is thought to be due to a combination of genetic and environmental factors and is more common in people who are obese. Infection and inflammation of the pouches (diverticulitis) occur in about 10 to 25 percent of people with diverticulosis and is more common at older ages. The infection is generally caused by bacteria.



Figure **13.7.2**: Multiple pouches called diverticula in the wall of the large intestine

Diverticulitis can usually be diagnosed with a CT scan. Mild diverticulitis may be treated with oral antibiotics and a short-term liquid diet. For severe cases, intravenous antibiotics, hospitalization, and complete bowel rest (no nourishment via the mouth) may be recommended. Complications such as abscess formation or perforation of the colon require surgery.

PEPTIC ULCER

A **peptic ulcer** is a sore in the lining of the stomach or the duodenum (the first part of the small intestine). If the ulcer occurs in the stomach, it is called a gastric ulcer; if it occurs in the duodenum, it is called a duodenal ulcer. The most common symptoms of peptic ulcers are upper abdominal pain that often occurs at night and improves with eating. Other symptoms may include belching, vomiting, weight loss, and poor appetite. However, many people with peptic ulcers, particularly older people, have no symptoms. Peptic ulcers are relatively common, with about 10 percent of people developing a peptic ulcer at some point in their life.

The most common cause of peptic ulcers is infection with the bacterium *Helicobacter pylori*, which may be transmitted by food, contaminated water, or human saliva (for example, by kissing or sharing eating utensils). Surprisingly, the bacterial cause of peptic ulcers was not discovered until the 1980s. The scientists who made the discovery are Australians Robin Warren and Barry J. Marshall. Although the two scientists eventually won a Nobel Prize for their discovery, their hypothesis was poorly received at first. To demonstrate the validity of their discovery, Marshall used himself in an experiment. He drank a culture of bacteria from a peptic ulcer patient and developed symptoms of peptic ulcer in a matter of days. His symptoms resolved on their own within a couple of weeks, but he took antibiotics to kill any remaining bacteria at his wife's urging (apparently because bad breath is also one of the symptoms of *H. pylori* infection). Marshall's self-experiment was published in the Australian Medical Journal and is among the most cited articles ever published in the journal.

Another relatively common cause of peptic ulcers is the chronic use of non-steroidal anti-inflammatory drugs (NSAIDs), such as aspirin or ibuprofen. Additional contributing factors may include tobacco smoking and stress, although these factors have not been demonstrated conclusively to cause peptic ulcers independent of *H. pylori* infection. Contrary to popular belief, diet does not appear to play a role in either causing or preventing peptic ulcers. Eating spicy foods and drinking coffee and alcohol were once thought to cause peptic ulcers. These lifestyle choices are no longer thought to have much if any effect on the development of peptic ulcers.

Peptic ulcers are typically diagnosed on the basis of symptoms or the presence of *H. pylori* in the GI tract. However, endoscopy (Figure **13.7.3**), which allows direct visualization of the stomach and duodenum with a camera, may be required for a definitive diagnosis. Peptic ulcers are usually treated with antibiotics to kill *H. pylori*, along with medications to temporarily decrease stomach acid and aid in healing. Unfortunately, *H. pylori* have developed resistance to commonly used antibiotics, so treatment is not always effective. If a peptic ulcer has penetrated so deep into the tissues that it causes perforation of the wall of the stomach or duodenum, then emergency surgery is needed to repair the damage.



Figure **13.7.3**: A doctor inserts a tiny camera through a tube (called an endoscope) to examine a patient's upper GI tract for peptic ulcers. He views the image created by the camera on a screen above the patient's head.

GASTROENTERITIS

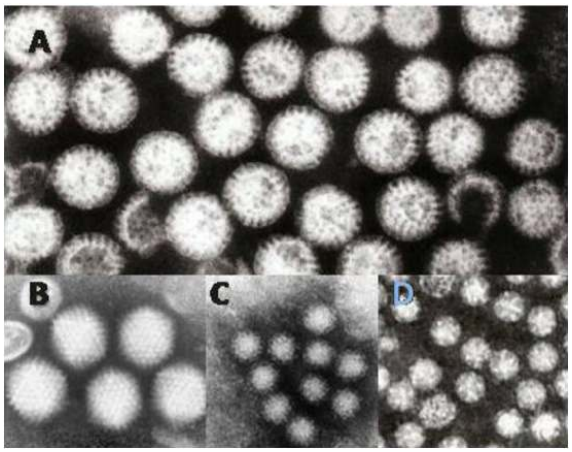


Figure **13.7.4**: These micrographs show four types of viruses that commonly cause gastroenteritis in humans: A. rotavirus, B. adenovirus, C. norovirus, and D. astrovirus.

Gastroenteritis, also known as infectious diarrhea, is an acute and usually self-limiting infection of the GI tract by pathogens. Symptoms typically include some combination of diarrhea, vomiting, and abdominal pain. Fever, lack of energy, and dehydration may also occur. The illness generally lasts less than two weeks, even without treatment, but in young children, it is potentially deadly. Gastroenteritis is very common, especially in poorer nations. Worldwide, up to five billion cases occur each year, resulting in about 1.4 million deaths. In the United States, infectious diarrhea is the second most common type of infection after the common cold.

Commonly called "stomach flu," gastroenteritis is unrelated to the influenza virus, although viruses are the most common cause of the disease (Figure **13.7.4**). In children, rotavirus is most often the cause, whereas norovirus is more likely to be the cause in adults. Besides viruses, other potential causes of gastroenteritis include fungi, protozoa (including *Giardia lamblia*, described below), and bacteria (most often *Escherichia coli* or *Campylobacter jejuni).* Transmission of pathogens may occur due to eating improperly prepared foods or foods left to stand at room temperature, drinking contaminated water, or having close contact with an infected individual.

Gastroenteritis is less common in adults than children, partly because adults have acquired immunity after repeated exposure to the most common infectious agents. Adults also tend to have better hygiene than children. If children have frequently repeated incidents of gastroenteritis, they may suffer from malnutrition, stunted growth, and developmental delays. Many cases of gastroenteritis in children can be avoided by giving them a rotavirus vaccine. Frequent and thorough hand washing can cut down on infections caused by other pathogens.

Treatment of gastroenteritis generally involves increasing fluid intake to replace fluids lost in vomitus or diarrhea. Oral rehydration solution, which is a combination of water, salts, and sugar, is often recommended. In severe cases, intravenous fluids may be needed. Antibiotics are not usually prescribed because they are ineffective against viruses that cause most cases of gastroenteritis.

GIARDIASIS



Figure **13.7.5**: Giardia lamblia is a single-celled organism that parasitizes the GI tract of humans as well as many other animal species. It is a eukaryotic cell with tentacle-like extensions.

Giardiasis, popularly known as beaver fever, is a type of gastroenteritis caused by a GI tract parasite, the single-celled protozoan *Giardia lamblia* (Figure **13.7.5**). The parasite inhabits the digestive tract of a wide variety of domestic and wild animal species in addition to human beings, including cows, rodents, and sheep as well as beavers (hence its popular name). Giardiasis is one of the most common parasitic infections in people the world over, with hundreds of millions of people infected worldwide each year.

Transmission of *G. lamblia* is via a fecal-oral route. Those at greatest risk include travelers to countries where giardiasis is common, people who work in child-care settings, backpackers and campers who drink untreated water from lakes or rivers, and people who have close contact with infected people or animals in other settings. In the United States, giardiasis occurs more often during the summer than in other seasons, probably because people spend more time outdoors and in wild settings at that time of year.

Symptoms of giardiasis can vary widely. About a third of people with the infection have no symptoms, whereas others have severe diarrhea with poor absorption of nutrients. Problems with absorption occur because the parasites inhibit intestinal digestive enzyme production, cause detrimental changes in microvilli lining the small intestine, and kill off small intestinal epithelial cells. The illness can result in weakness, loss of appetite, stomach cramps, vomiting, and excessive gas. Without treatment, symptoms may continue for several weeks. Treatment with an antibiotic may be needed if symptoms persist longer or are particularly severe.

REVIEW

1. What is inflammatory bowel disease?
2. Describe typical symptoms of inflammatory bowel disease.
3. Compare and contrast Crohn's disease and ulcerative colitis.
4. What is diverticulosis? How is it related to diverticulitis?
5. Identify the locations and causes of peptic ulcers.
6. Define and describe gastroenteritis.
7. Identify the cause of giardiasis. Why may it cause malabsorption?
8. Which of the following does not normally affect the small intestine?

A. Peptic ulcers

B. Crohn's disease

C. Giardiasis

D. Ulcerative colitis

9. Name three disorders of the GI tract that can be due to bacteria.
10. *True or False.* A colonoscopy can be used to examine the small intestine.
11. *True or False.* Peptic ulcers are mainly due to diet.
12. Name one disorder of the GI tract that can be *helped* by anti-inflammatory medications and one that can be *caused* by chronic use of anti-inflammatory medications.
13. People with ulcerative colitis should be frequently screened for _____ cancer.
14. Describe one reason why it can be dangerous to drink untreated water.
15. Do you think the “stomach flu” can be prevented by an influenza vaccine? Why or why not?

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13.8: CASE STUDY CONCLUSION- CELIAC AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: PLEASE DON'T PASS THE BREAD

The garlic bread stuffed with spaghetti shown in Figure **13.8.1** may or may not look appetizing to you, but for people with celiac disease, it is certainly off-limits. Bread and pasta are traditionally made with wheat, which contains proteins called gluten. As you learned in the beginning of the chapter, even trace amounts of gluten can damage the digestive system of people with celiac disease. When Rania and Tui met for lunch, Rania chose a restaurant that she knew could provide her with gluten-free food because she has this disease.



Figure **13.8.1**: Spaghetti Stuffed Garlic Bread

When people with celiac disease eat gluten, it causes an autoimmune reaction that results in inflammation and flattening of the villi of the small intestine. What do you think happens if the villi are inflamed and flattened? Think about what you have learned about the functions of the villi and small intestine. The small intestine is where most chemical digestion and absorption of nutrients occurs in the body. The villi increase the surface area in the small intestine to maximize the digestion of food and absorption of nutrients into the blood and lymph. If the villi are inflamed and flattened, there is less surface area where digestion and absorption can occur. Therefore, damage from celiac disease can result in inadequate absorption of nutrients, called malabsorption.

Malabsorption explains why there can be so many different types of symptoms of celiac disease, ranging from diarrhea and other forms of digestive distress to anemia, nutritional deficiencies, skin rashes, osteoporosis, bone pain, depression, anxiety, and rarer but potentially serious complications such as cancer. Our bodies need to digest and absorb adequate amounts of nutrients in order to function properly and stay healthy. Lack of nutrients can affect and damage cells, tissues, and organs throughout the body, sometimes seriously and irreversibly. A person with celiac disease can limit and often heal intestinal damage just by not eating gluten. In fact, eliminating all gluten from the diet is the main treatment for celiac disease. In some people with celiac disease, a gluten-free diet may not be enough, and steroids and other medications may be used to reduce the inflammation in the small intestine.

Celiac disease is an autoimmune disorder in which the body's immune system attacks its own tissues. It is thought to be caused by the presence of particular genes in combination with exposure to gluten. What are some other autoimmune disorders that you read about in this chapter that affect the digestive system? The two main inflammatory bowel diseases, Crohn's disease and ulcerative colitis are both due to the body's immune system attacking the digestive system, resulting in inflammation. Crohn's disease can affect any part of the GI tract, most commonly the ileum of the small intestine, while ulcerative colitis mainly affects the colon and rectum. Similar to celiac disease, treatments for these diseases also focus on reducing GI tract damage through lifestyle changes and medications.

Gluten is clearly dangerous for people with celiac disease, but should people who do not have celiac disease or other diagnosed medical problems with gluten also eliminate gluten from their diet? Many medical experts say no; because gluten-free diets are so restrictive, they may cause nutritional deficiencies without providing any proven health benefits. They can also be expensive and, as Tui's cousin found out, difficult to maintain given that gluten is present in so many foods. It is estimated that only 1% of the population has celiac disease. Most people should enjoy a varied diet and consult with their doctor if they are concerned about celiac disease, other types of gluten intolerance, or food allergies.

CHAPTER SUMMARY

In this chapter, you learned about the digestive system, which allows the body to obtain needed nutrients from food. Specifically, you learned that:

- The digestive system consists of organs that break down food, absorb its nutrients, and expel any remaining food waste.
- Most digestive organs form a long, continuous tube through which food passes, called the gastrointestinal (GI) tract. It starts at the mouth, which is followed by the pharynx, esophagus, stomach, small intestine, and large intestine.
- Organs of the GI tract have walls that consist of several tissue layers that enable them to carry out digestion and/or absorption. For example, the inner mucosa has cells that secrete digestive enzymes and other digestive substances and also cells that absorb nutrients. The muscle layer of the organs enables them to contract and relax in waves of peristalsis to move food through the GI tract.
- Digestion is a form of catabolism, in which food is broken down into small molecules that the body can absorb and use for energy, growth, and repair. Digestion occurs when food moves through the GI tract. The digestive process is controlled by both hormones and nerves.
    - Mechanical digestion is a physical process in which food is broken into smaller pieces without becoming chemically changed. It occurs mainly in the mouth and stomach.
    - Chemical digestion is a chemical process in which macromolecules including carbohydrates, proteins, lipids, and nucleic acids in food are changed into simple nutrient

molecules that can be absorbed into body fluids. Carbohydrates are chemically digested to sugars, proteins to amino acids, lipids to fatty acids, and nucleic acids to individual nucleotides. Chemical digestion requires digestive enzymes. Gut flora carries out additional chemical digestion.

- Absorption occurs when the simple nutrient molecules that result from digestion are absorbed into blood or lymph. They are then circulated through the body.
- Organs of the upper gastrointestinal (GI) tract include the mouth, pharynx, esophagus, and stomach.
  - The mouth is the first organ of the GI tract. It has several structures that are specialized for digestion, including salivary glands, tongue, and teeth. Both mechanical digestion and chemical digestion of carbohydrates and fats begin in the mouth.
  - The pharynx and esophagus move food from the mouth to the stomach but are not directly involved in the process of digestion or absorption. Food moves through the esophagus by peristalsis.
  - Mechanical and chemical digestion continue in the stomach. Acid and digestive enzymes secreted by the stomach start the chemical digestion of proteins. The stomach turns masticated food into a semi-fluid mixture called chyme.
- The lower GI tract includes the small intestine and large intestine. The small intestine is where most chemical digestion and virtually all absorption of nutrients occur. The large intestine contains huge numbers of beneficial bacteria and removes water and salts from food waste before it is eliminated.
  - The small intestine consists of three parts: the duodenum, jejunum, and ileum. All three parts of the small intestine are lined with mucosa that is very wrinkled and covered with villi and microvilli, giving the small intestine a huge surface area for digestion and absorption.
    - The ileum carries out any remaining digestion and absorption of nutrients, but its main function is to absorb vitamin B12 and bile salts.
    - The jejunum carries out most of the absorption of nutrients in the small intestine, including the absorption of simple sugars, amino acids, fatty acids, and many vitamins.
    - The duodenum secretes digestive enzymes and also receives bile from the liver or gallbladder and digestive enzymes and bicarbonate from the pancreas. These digestive substances neutralize acidic chyme and allow for the chemical digestion of carbohydrates, proteins, lipids, and nucleic acids in the duodenum.
- The large intestine consists of the colon (which in turn includes the cecum, ascending colon, transverse colon, descending colon, and sigmoid colon), rectum, and anus. The vestigial organ called the appendix is attached to the cecum of the colon.
  - The main function of the large intestine is to remove water and salts from chyme for recycling within the body and eliminating the remaining solid feces from the body through the anus. The large intestine is also the site where trillions of bacteria help digest certain compounds, produce vitamins, stimulate the immune system, and break down toxins, among other important functions.
- Accessory organs of digestion are organs that secrete substances needed for the chemical digestion of food, but through which food does not actually pass as it is digested. The accessory organs include the liver, gallbladder, and pancreas. These organs secrete or store substances that are carried to the duodenum of the small intestine as needed for digestion.
  - The liver is a large organ in the abdomen that is divided into lobes and smaller lobules, which consist of metabolic cells called hepatic cells, or hepatocytes. The liver receives oxygen in the blood from the aorta through the hepatic artery. It receives nutrients in blood from the GI tract and wastes in blood from the spleen through the portal vein.
    - The main digestive function of the liver is the production of the alkaline liquid called bile. Bile is carried directly to the duodenum by the common bile duct or to the gallbladder first for storage. Bile neutralizes acidic chyme that enters the duodenum from the stomach and also emulsifies fat globules into smaller particles (micelles) that are easier to digest chemically.
    - Other vital functions of the liver include regulating blood sugar levels by storing excess sugar as glycogen, storing many vitamins and minerals, synthesizing numerous proteins and lipids, and breaking down waste products and toxic substances.
- The gallbladder is a small, pouch-like organ near the liver. It stores and concentrates bile from the liver until it is needed in the duodenum to neutralize chyme and help digest lipids.
- The pancreas is a glandular organ that secretes both endocrine hormones and digestive enzymes. As an endocrine gland, the pancreas secretes insulin and glucagon to regulate blood sugar. As a digestive organ, the pancreas secretes digestive enzymes into the duodenum through ducts. Pancreatic digestive enzymes include amylase (starches); trypsin and chymotrypsin (proteins); lipase (lipids); and ribonucleases and deoxyribonucleases (RNA and DNA).
- Inflammatory bowel disease is a collection of inflammatory conditions primarily affecting the intestines. The diseases involve the immune system attacking the GI tract, and they have multiple genetic and environmental causes. Typical symptoms include abdominal pain and diarrhea, which show a pattern of repeated flare-ups interrupted by periods of remission. Lifestyle changes and medications may control flare-ups and extend remission. Surgery is sometimes required.
- The two principal inflammatory bowel diseases are Crohn's disease and ulcerative colitis. Crohn's disease may affect any part of the GI tract from the mouth to the anus, among other body tissues. Ulcerative colitis affects the colon and/or rectum.

- Some people have little pouches, called diverticula, in the lining of their large intestine, a condition called diverticulosis. People with diverticulosis may develop diverticulitis, in which one or more of the diverticula become infected and inflamed. Diverticulitis is generally treated with antibiotics and bowel rest; sometimes surgery is required.
- A peptic ulcer is a sore in the lining of the stomach (gastric ulcer) or duodenum (duodenal ulcer). The most common cause is infection with the bacterium *Helicobacter pylori*. NSAIDs such as aspirin can also cause peptic ulcers, and some lifestyle factors may play contributing roles. Antibiotics and acid reducers are typically prescribed; surgery is not often needed.
- Gastroenteritis, or infectious diarrhea, is an acute and usually self-limiting infection of the GI tract by pathogens, most often viruses. Symptoms typically include diarrhea, vomiting, and/or abdominal pain. Treatment includes replacing lost fluids; antibiotics are not usually effective.
- Giardiasis is a type of gastroenteritis caused by infection of the GI tract with the protozoa parasite *Giardia lamblia*. It may cause malnutrition. It is generally self-limiting, but severe or long-lasting cases may require antibiotics.

CHAPTER SUMMARY REVIEW

1. Explain how the accessory organs of digestion interact with the GI tract.
2. In which of the following organs is food actually digested?
   A. Pancreas
   B. Small intestine
   C. Gallbladder
   D. A and B
3. *True or False.* Bile is one of the digestive fluids secreted in the stomach.
4. *True or False.* The smell of food can stimulate the release of digestive enzymes.
5. If the pH in the duodenum was too low (acidic), what effect do you think this would have on the processes of the digestive system?
6. Is the stomach involved in chemical digestion, mechanical digestion, or both? Explain your answer.
7. Absorption of most nutrients occurs in the:
   A. Duodenum
   B. Ileum
   C. Cecum
   D. Jejunum
8. Is food passing through the GI tract generally more solid in the small intestine or the large intestine? Explain your answer.
9. What is another name for the colon?
10. Discuss whether digestion occurs in the large intestine.
11. The appendix is attached to:
    A. The large intestine
    B. The small intestine
    C. The pancreas
    D. The liver
12. What is lacteal? In your answer, be sure to describe both its location and function in the digestive system.
13. Lipids are digested at different points in the digestive system. Describe how lipids are digested at two of these points.
14. Describe two different functions of stomach acid.
15. *True or False*. Proteins are only digested in the stomach.
16. *True or False*. A peptic ulcer can occur in the small intestine.
17. Match each of the following organs of the digestive system with the description that best fits it. Each organ is used only once: Organs: pancreas; liver; gallbladder
    A. A small, pouch-like organ that stores and concentrates bile produced by a different organ.
    B. Produces insulin as well as digestive enzymes and other needed substances.
    C. Processes wastes in addition to aiding in digestive functions.
18. What is the name of the rhythmic muscle contractions that move food through the GI tract?
19. What are the major roles of the upper GI tract?
20. Diverticulitis causes infected and inflamed pouches in the:
    A. stomach
    B. small intestine
    C. jejunum
    D. large intestine
21. What is the physiological cause of heartburn?
22. Which disease most commonly affects the ileum of the small intestine?
    A. Crohn's disease
    B. Peptic ulcer
    C. Ulcerative colitis
    D. Gastroenteritis
23. *True or False.* Smoking does not contribute to digestive system disorders.
24. *True or False.* In addition to obtaining nutrients, the digestive system plays a role in protecting the body from pathogens.
25. What are two ways in which the tongue participates in digestion?
26. Where is the epiglottis located?
27. If the epiglottis were to not close properly, what might happen?
28. The GI tract goes from the mouth to which structure?

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CHAPTER OVERVIEW

14: URINARY SYSTEM

This chapter discusses the concept of excretion and explains the excretory functions of the skin, liver, large intestine, lungs, and kidneys. It also describes the other organs of the urinary system and several urinary system disorders.

14.1: Case Study- Waste Management

14.2: Introduction to the Urinary System

14.3: Kidneys

14.4: Ureters, Urinary Bladder, and Urethra

14.5: Disorders of the Urinary System

14.6: Case Study Conclusion- Alcohol and Chapter Summary

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14.1: CASE STUDY- WASTE MANAGEMENT

CASE STUDY: DRINK AND FLUSH

"Wow, this line for the restroom is long!" Bintou says to Maeva, anxiously bobbing from side to side to ease the pressure in her bladder. Maeva nods and says, "It's always like this at parties. It's the alcohol."

Bintou and Maeva are 21-year-old college students at a party. They and many other people have been drinking alcoholic beverages over the course of the evening. As the night has gotten later, the line for the restroom has gotten longer and longer. You may have noticed this phenomenon if you have been to places where large numbers of people are drinking alcohol, like at the ballpark below.



Figure **14.1.1**: A line stretching out of a restroom door at a ballpark.

Bintou says, "I wonder why alcohol makes you have to pee?" Maeva learned about this in her Human Biology class and tells Bintou that alcohol inhibits a hormone that helps you retain water. So instead of your body retaining water, you urinate more out. This could lead to dehydration, so she suggests that after their trip to the restroom, they start drinking water instead of alcohol.

For people who drink occasionally or moderately, this effect of alcohol on the excretory system—the system that removes wastes such as urine—is usually temporary. However, in people who drink excessively, alcohol can have serious, long-term effects on the excretory system. For example, heavy drinking on a regular basis can cause liver and kidney disease.

As you will learn in this chapter, the liver and kidneys are important organs of the excretory system, and impairment of the functioning of these organs can cause serious health consequences. At the end of the chapter, you will learn which hormone Maeva was referring to, and some of the ways alcohol can affect the excretory system, both after the occasional drink and in cases of excessive alcohol use and abuse.

CHAPTER OVERVIEW: EXCRETORY SYSTEM

In this chapter, you will learn about the excretory system, which rids the body of toxic waste products and helps maintain homeostasis. Specifically, you will learn about:

- The organs of the excretory system, which include the skin, liver, large intestine, lungs, and kidneys, eliminate waste and excess water from the body.
- How wastes are eliminated through sweat, feces, urine, and exhaled gases; and how toxic substances in the blood are broken down by the liver.
- The urinary system, which includes the kidneys, ureters, bladder, and urethra.
- The main function of the urinary system, which is to filter the blood and eliminate wastes, mineral ions, and excess water from the body in the form of urine.
- How the kidneys filter the blood, retain needed substances, produce urine, and help maintain homeostasis, such as proper ion and water balance.
- How urine is stored, transported, and released from the body.
- Disorders of the urinary system, including bladder infections, kidney stones, polycystic kidney disease, urinary incontinence, and kidney damage due to factors such as uncontrolled diabetes and high blood pressure.

As you read the chapter, think about the following questions:

1. Which hormone do you think Maeva was referring to? Remember that this hormone causes the urinary system to retain water and excrete less water out in the urine.
2. How and where does this hormone work?
3. Long-term, excessive use of alcohol can affect the liver and kidneys. How do these two organs of excretion interact and work together?

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14.2: INTRODUCTION TO THE URINARY SYSTEM

SCULPTURE GARDEN

In Figure **14.2.1**, this interesting outdoor art installation can be viewed at the Hague in the Netherlands. It's a colorful piece with an unusual subject. The wrinkled structures on each side of the sculpture represent the kidneys, and the striped structure in the distance represents the urinary bladder. The red and blue tubes are blood vessels, and the tan tubes are ureters. In short, the installation is a three-dimensional depiction of the human urinary system. Only one urinary system organ is not visible in the photo. Do you know what it is?



Figure **14.2.1**: Nier met blaas (Kidney with bladder)

The actual human **urinary system**, also known as the renal system, is shown in Figure **14.2.2**. The system consists of the kidneys, ureters, bladder, and urethra, which is the only structure not visible in the sculpture above. The main function of the urinary system is to eliminate the waste products of metabolism from the body by forming and excreting **urine.** Between 1 and 2 liters of urine are normally produced every day in a healthy individual.

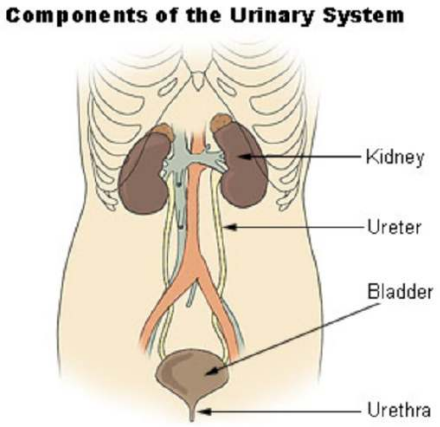


Figure **14.2.2**: The components of the urinary system include the two kidneys which lead to two tubes called ureters which lead to a holding structure called the bladder which leads to a tube called the urethra.

ORGANS OF THE URINARY SYSTEM

The urinary system is all about urine. It includes organs that form urine and also those that transport, store, or excrete urine.

KIDNEYS

Urine is formed by the kidneys, which filter many substances out of blood, allow the blood to reabsorb needed materials, and use the remaining materials to form urine. The human body normally has two paired kidneys, although it is possible to get by quite well with just one kidney. The anatomy and function of the kidney are discussed in detail in the next section.

URETERS, BLADDER, URETHRA

After urine forms in the kidneys, it is transported through the ureters (one per kidney) to the sac-like bladder, which stores the urine until urination. During urination, the urine is released from the bladder and transported by the urethra to be excreted outside the body through the external urethral opening.

FUNCTIONS OF THE URINARY SYSTEM

Waste products removed from the body with the formation and elimination of urine include many water-soluble metabolic products. The main waste products are urea, a by-product of protein catabolism, and uric acid, a by-product of nucleic acid catabolism. Excess water and mineral ions are also eliminated in urine.

Besides the elimination of waste products such as these, the urinary system has several other vital functions. These include:

- maintaining homeostasis of mineral ions in extracellular fluid. These ions are either excreted in urine or returned to the blood as needed to maintain the proper balance.
- regulating the acid-base balance in the body. For example, when pH is too low (blood is too acidic), the kidneys excrete less bicarbonate (which is basic) in the urine. When pH is too high (blood is too basic), the opposite occurs and more bicarbonate is excreted in the urine.
- controlling the volume of extracellular fluids, including the blood, which helps maintain blood pressure. The kidneys control fluid volume and blood pressure by excreting more or less salt and water in urine.

CONTROL OF THE URINARY SYSTEM

The formation of urine must be closely regulated to maintain body-wide homeostasis. Several endocrine hormones help control this function of the urinary system, including antidiuretic hormone, parathyroid hormone, and aldosterone.

- Antidiuretic hormone, also called vasopressin, is secreted by the hypothalamus. One of its main roles is conserving body water. It is released when the body is dehydrated and causes the kidneys to excrete less water in urine.
- Parathyroid hormone is secreted by the parathyroid glands. It works to regulate the balance of mineral ions in the body through its effects on several organs, including the kidneys. Parathyroid hormone stimulates the kidneys to excrete less calcium and more phosphorus in the urine.

- Aldosterone is secreted by the cortex of the adrenal glands, which rest atop the kidneys, as shown in Figure **14.2.3**. It plays a central role in regulating blood pressure through its effects on the kidneys. It causes the kidneys to excrete less sodium and water in urine.

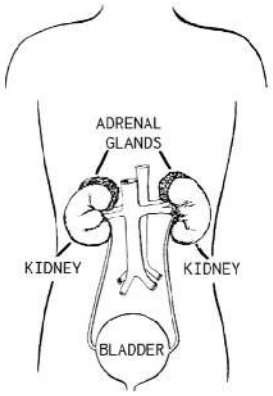


Figure **14.2.3**: The adrenal glands are located on top of the kidneys. They secrete aldosterone into the bloodstream, which carries it to the kidneys.

Once urine forms, it is excreted from the body in the process of urination. This process is controlled by both the autonomic and the somatic nervous systems. As the bladder fills with urine, it causes the autonomic nervous system to signal a muscle in the bladder wall to contract and the sphincter between the bladder and urethra to relax and open. This forces urine out of the bladder and through the urethra. Another sphincter at the distal end of the urethra is under voluntary control. When it relaxes under the influence of the somatic nervous system, it allows urine to leave the body through the external urethral opening.

REVIEW

1. What organs make up the urinary system?
2. State the main function of the urinary system.
3. What is the primary function of the kidneys?
4. Describe how blood enters and leaves the kidneys.
5. What are nephrons?
6. What happens to urine after it forms in the kidneys?
7. Identify the functions of the urinary system besides the elimination of waste products.
8. How is the formation of urine regulated?
9. Explain how the process of urination is controlled.
10. What function do the adrenal glands carry out that is related to urine?

    A. They form urine and transport it to the kidneys

    B. They excrete concentrated urine into the ureters

    C. They secrete a hormone that affects the composition of urine

    D. They store urine when water and salts need to be retained by the body
11. Explain why it is important to have voluntary control over the sphincter at the end of the urethra.
12. Compare the aldosterone to antidiuretic hormones in terms of how they affect the kidneys.
13. If your body needed to retain more calcium, which of the hormones described in this concept is the most likely to rise in the level? Explain your reasoning.
14. *True or False.* Urine is composed of water, urea, and minerals only.
15. *True or False.* The renal artery contains blood that was filtered by the kidney.

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14.3: KIDNEYS

KIDNEYS ON THE MENU

Pictured here amidst a bed of mixed veggies are a steak and kidney pudding. More often made into a pie, this savory dish is a British favorite. Kidneys on the menu typically come from sheep, pigs, or cows. In these animals as in the human animal, kidneys are the main organs of excretion.



Figure **14.3.1**: Steak and kidney pudding

LOCATION OF THE KIDNEYS

The two bean-shaped **kidneys** are located high in the back of the abdominal cavity, one on each side of the spine. Both kidneys sit just below the diaphragm, the large breathing muscle that separates the abdominal and thoracic cavities. As you can see in Figure **14.3.2**, the right kidney is slightly smaller and lower than the left kidney. The right kidney is behind the liver, and the left kidney is behind the spleen. The location of the liver explains why the right kidney is smaller and lower than the left.

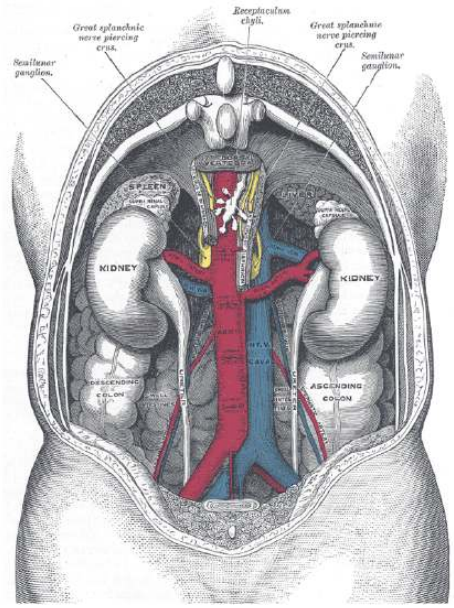


Figure **14.3.2**: This classic illustration of the abdominal cavity provides a view of the internal organs from the back of the body. It clearly shows the locations of the right and left kidney, as well as the large blood vessels that connect the kidneys to the body's main artery (aorta) and vein (inferior vena cava). The ureter exiting each kidney is also shown in the diagram.

KIDNEY ANATOMY

The shape of each kidney gives it a convex side and a concave side. You can see this clearly in the detailed diagram of kidney anatomy shown in Figure **14.3.3**. The concave side is where the renal artery enters the kidney and the renal vein and ureter leave the kidney. This area of the kidney is called the hilum. The entire kidney is surrounded by tough fibrous tissue, called the renal capsule, which in turn is surrounded by two layers of protective, cushioning fat.

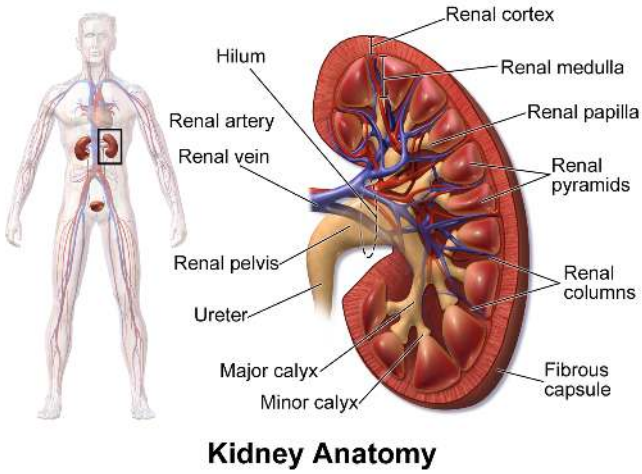


Figure **14.3.3**: This diagram shows the location and relative size of the two kidneys as well as the internal structure of each kidney.

Internally, each kidney is divided into two major layers: the outer renal cortex and the inner renal medulla (see Figure **14.3.3**). These layers take the shape of many cone-shaped renal lobules, each containing a renal cortex surrounding a portion of the medulla called a renal pyramid. Within the renal pyramids are the structural and functional units of the kidneys, the tiny nephrons. Between the renal pyramids are projections of cortex called renal columns. The tip or papilla of each pyramid empties urine into a minor calyx (chamber). Several minor calyces empty into a major calyx, and the latter empties into the funnel-shaped cavity called the renal pelvis, which becomes the ureter as it leaves the kidney.

RENAL CIRCULATION

The renal circulation is an important part of the kidney's main function of filtering waste products from the blood. Blood is supplied to the kidneys via the renal arteries. The right renal artery supplies the right kidney, and the left renal artery supplies the left kidney. These two arteries branch directly from the aorta, which is the largest artery in the body. Each kidney is only about 11 cm (4.4 in.) long and has a mass of just 150 grams (5.3 oz), yet it receives about 10 percent of the total output of blood from the heart. Blood is filtered through the kidneys about 20 times each hour, 24 hours a day, day after day.

As indicated in Figure **14.3.4**, each renal artery carries blood with waste products into the kidney. Within the kidney, the renal artery branches into increasingly smaller arteries that extend through the

renal columns between the renal pyramids. These arteries, in turn, branch into arterioles that penetrate the renal pyramids. Blood in the arterioles passes through nephrons, the structures that actually filter the blood. After blood passes through the nephrons and is filtered, the clean blood moves through a network of venules that converge into small veins. Small veins merge into increasingly larger ones and ultimately into the renal vein, which carries clean blood away from the kidney to the inferior *vena cava*.

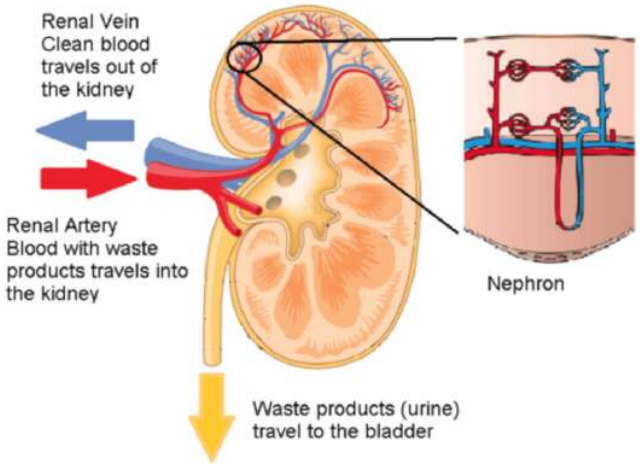


Figure **14.3.4**: The renal artery and renal vein carry blood to and from the kidney, respectively. As blood passes through the capillaries surrounding nephrons within the kidney, it is filtered and substances filtered from the blood are eventually excreted via ureter to the bladder.

NEPHRON STRUCTURE AND FUNCTION

The illustration above gives an indication of the complex structure of a nephron. The **nephron** is the basic structural and functional unit of the kidney, and each kidney typically contains at least a million of them. As blood flows through a nephron, many materials are filtered out of the blood, needed materials are returned to the blood, and the remaining materials form urine. Most of the waste products removed from the blood and excreted in the urine are byproducts of metabolism. At last half of the waste is urea, a waste product produced by protein catabolism. Another important waste is uric acid, produced in nucleic acid catabolism.

COMPONENTS OF A NEPHRON

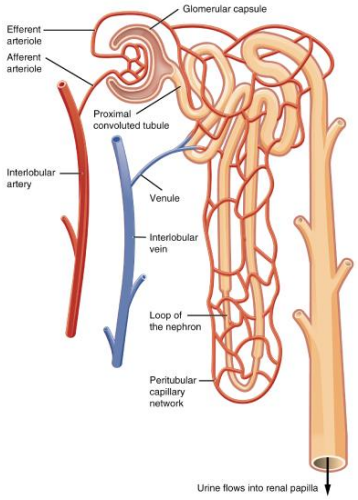


Figure **14.3.5**: This model of an individual nephron shows each of the structures that are involved in filtering blood, returning needed materials to blood, or excreting wastes that form urine. The arrows indicate the direction in which fluids flow through the nephron.

The diagram in Figure **14.3.5** shows in greater detail the components of a nephron. The renal corpuscle is a filtering structure that is consists of a network of capillaries called the glomerulus (plural, glomeruli) and the Bowman's capsule, a space surrounding the glomerulus. Bowman's capsule is the initial structure of a nephron. Extending from Bowman's capsule is the renal tubule. The proximal end (nearest Bowman's capsule) of the renal tubule is called the proximal convoluted (coiled) tubule. From here, the renal tubule continues as a loop (known as the loop of Henle), which in turn becomes the distal convoluted tubule. The latter finally joins with a collecting duct. As you can see in the diagram, peritubular capillaries surround the total length of the renal tubule.

THE FUNCTION OF A NEPHRON

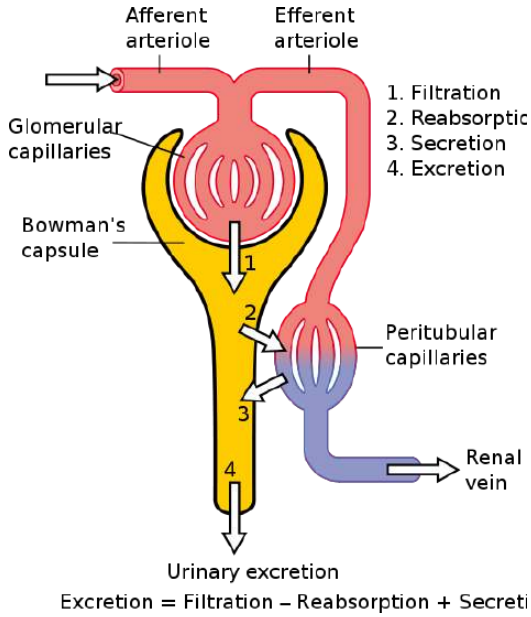


Figure **14.3.6**: This diagram of a nephron shows the parts of the nephron where different stages of nephron function take place. Filtration (1) occurs in the Renal corpuscle, Reabsorption (2) occurs in the proximal tubule, Secretion (3) occurs in the distal tubule, and Excretion (4) occurs in the collecting duct.

The simplified diagram of a nephron in Figure **14.3.6** shows how the nephron functions. Blood enters the nephron through an arteriole called the afferent arteriole. Some of the blood next passes through the capillaries of the glomerulus. Any blood that doesn't pass through the glomerulus, as well as blood after it passes through the glomerular capillaries, continues on through an arteriole called the efferent arteriole. The efferent arteriole follows the renal tubule of the nephron, where it continues to play roles in nephron functioning.

FILTRATION

As blood from the afferent arteriole flows through the glomerular capillaries, it is under pressure. Because of the pressure, water and solutes are filtered out of the blood and into the space made by Bowman's capsule. This is the filtration stage of nephron function. The filtered substances, called filtrate, pass into Bowman's capsule and from there into the proximal end of the renal tubule. At this stage, filtrate includes water, salts, organic solids such as nutrients, and waste products of metabolism such as urea.

REABSORPTION AND SECRETION

As filtrate moves through the renal tubule, some of the substances it contains are reabsorbed from the filtrate back into the blood in the efferent arteriole (via peritubular capillaries). This is the reabsorption stage of nephron function. About two-thirds of the filtered salts and water and all of the filtered organic solutes (mainly glucose and amino acids) are reabsorbed from the filtrate by the blood in the peritubular capillaries. Reabsorption occurs mainly in the proximal convoluted tubule and the loop of Henle.

At the distal end of the renal tubule, some additional reabsorption generally occurs. This is also the region of the tubule where other substances from the blood are added to the filtrate in the tubule. The addition of other substances to the filtrate from the blood is called secretion. Both reabsorption and secretion in the distal convoluted tubule are largely under the control of endocrine hormones that maintain homeostasis of water and mineral salts in the blood. These hormones work by controlling what is reabsorbed into the blood from the filtrate and what is secreted from the blood into the filtrate to become urine. For example, the parathyroid hormone causes more calcium to be reabsorbed into the blood and more phosphorus to be secreted into the filtrate.

COLLECTION OF URINE AND EXCRETION

By the time the filtrate has passed through the entire renal tubule, it has become the liquid waste known as urine. Urine empties from the distal end of the renal tubule into a **collecting duct**. From there, the urine flows into increasingly larger collecting ducts. As urine flows through the system of collecting ducts, more water may be reabsorbed from it. This will occur in the presence of antidiuretic hormone from the hypothalamus. This hormone makes the collecting ducts permeable to water, allowing water molecules to pass through them into capillaries by osmosis while preventing the passage of ions or other solutes. As much as three-fourths of the water may be reabsorbed from urine in the collecting ducts, making the urine more concentrated.

Urine finally exits the largest collecting ducts through the renal papillae. It empties into the renal calyces and finally into the renal pelvis (see Figure **14.3.3**. From there, it travels through the ureter to the urinary bladder for eventual excretion from the body. An average of about 1.5 liters of urine is excreted each day. Normally, urine is yellow or amber in color (Figure **14.3.7**). The darker the color, generally the more concentrated the urine is.



Figure **14.3.7**: Fresh urine is typically yellow or amber in color.

OTHER FUNCTIONS OF THE KIDNEYS

Besides filtering blood and forming urine for the excretion of soluble wastes, the kidneys have several vital functions in maintaining body-wide homeostasis. Most of these functions are related to the composition or volume of urine formed by the kidneys. These functions include maintaining the proper balance of water and salts in the body, normal blood pressure, and the correct range of blood pH. Through the processes of absorption and secretion by nephrons, more or less water, salt ions, acids, or bases are returned to the blood or excreted in urine as needed to maintain homeostasis.

KIDNEY HORMONES

- **Aldosterone** is secreted by the adrenal cortex. Aldosterone causes the kidneys to increase the reabsorption of sodium ions and water from the filtrate into the blood. This returns the

concentration of sodium ions in the blood to normal. The increased water in the blood also increases blood volume and blood pressure.

- **Calcitriol** is secreted by the kidneys in response to low levels of calcium in the blood. This hormone stimulates the uptake of calcium by the intestine, thus raising blood levels of calcium.
- **Erythropoietin** is secreted by the kidneys in response to low levels of oxygen in the blood. This hormone stimulates **erythropoiesis**, which is the production of red blood cells in the bone marrow. Extra red blood cells increase the level of oxygen carried in the blood.

FEATURE: HUMAN BIOLOGY IN THE NEWS

Kidney failure is a complication of common disorders including diabetes mellitus and hypertension. Almost half a million Americans have end-stage kidney disease and need to either receive a donated kidney or have frequent hemodialysis, a medical procedure in which the blood is artificially filtered through a machine. Transplant generally has better outcomes than hemodialysis but demand for organs far outstrips the supply. At any given time, more than 100,000 people in the U.S. are on a waiting list for a kidney transplant, but each year fewer than 20,000 receive them. Every day, 13 Americans die while waiting for a donor's kidney.

For the past decade, Dr. William Fissell, a kidney specialist at Vanderbilt University, has been working to create an implantable part-biological and part-artificial kidney. Using microchips like those used in computers, he has produced an artificial kidney small enough to implant in the patient's body in place of the failed kidney. According to Dr. Fissell, the artificial kidney is "... a bio-hybrid device that can mimic a kidney to remove enough waste products, salt, and water to keep a patient off [hemo]dialysis."

The filtration system in the artificial kidney consists of a stack of 15 microchips. Tiny pores in the microchips act as a scaffold for the growth of living kidney cells that can mimic the natural functions of the kidney. The living cells form a membrane to filter the patient's blood as a biological kidney would, but with less risk of rejection by the patient's immune system because they are embedded within the device. The new kidney doesn't need a power source because it uses the natural pressure of blood flowing through arteries to push the blood through the filtration system. A major part of the design of the artificial organ was devoted to fine-tuning the fluid dynamics so blood flows through the device without clotting.

The implantable kidney was given fast-track approval for testing in people by the U.S. Food and Drug Administration because of the potentially life-saving benefits of the device. The artificial kidney is expected to be tested in pilot trials by 2018. Dr. Fissell says he has a long list of patients eager to volunteer for the trials.

REVIEW

1. Where are the kidneys located?
2. Contrast the renal artery and renal vein.
3. Describe the structure of the kidney.
4. Identify the functions of a nephron.
5. Describe in detail what happens to fluids (blood, filtrate, and urine) as they pass through the parts of a nephron.
6. Use the example of the renin-angiotensin-aldosterone system to illustrate how the kidneys control homeostasis with the help of endocrine hormones.
7. Identify two endocrine hormones secreted by the kidneys and the functions they control.
8. Put the following structures in order of how urine flows out of the kidney, from the earliest to the latest:

   collecting ducts; renal tubule; renal pelvis; renal calyces
9. Name two regions in the kidney where water is reabsorbed.
10. *True or False.* Once the filtrate enters the renal tubule, no substances are added to it.
11. *True or False.* Some substances are reabsorbed in the distal end of the renal tubule.
12. Is the blood in the glomerular capillaries more or less filtered than the blood in the peritubular capillaries? Explain your answer.
13. How many nephrons are there per kidney?

    A. One

    B. Thirteen

    C. At least one thousand

    D. At least one million
14. If blood flow to the kidneys is blocked, what do you think would happen?
15. The loop of Henle is part of the:

    A. glomerulus

    B. renal tubule

    C. collecting duct

    D. ureter

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14.4: URETERS, URINARY BLADDER, AND URETHRA

COMMUNICATING WITH URINE

Why do dogs urinate on fire hydrants? Besides "having to go," they are marking their territory with chemicals called pheromones in their urine. It's a form of communication, in which they are "saying" with odors that the yard is theirs and other dogs should stay away. Dogs may urinate on fence posts, trees, car tires, and many other objects in addition to fire hydrants. Urination in dogs, as in people, is usually a voluntary process controlled by the brain. The process of forming urine, which occurs in the kidneys, occurs constantly and is not under voluntary control. What happens to all the urine that forms in the kidneys? It passes from the kidneys through the other organs of the urinary system, starting with the ureters.



Figure **14.4.1**: Dog urinating on hydrant

URETERS

As shown in Figure **14.4.2**, ureters are tube-like structures that connect the kidneys with the urinary bladder. They are paired structures, with one ureter for each kidney. In adults, ureters are between 25 and 30 cm (10 to 12 in.) long and about 3 to 4 mm (about 1/8 in.) in diameter.

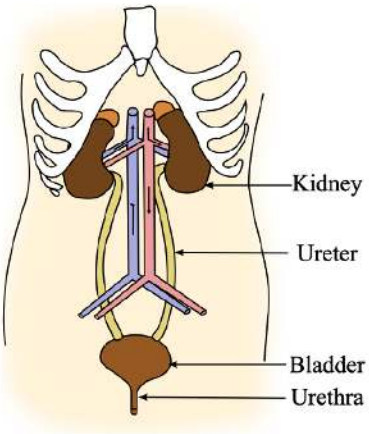


Figure **14.4.2**: Besides the kidneys, the urinary system includes two ureters, the urinary bladder, and the urethra.

Each ureter arises in the pelvis of a kidney (Figure **14.4.3**). It then passes down the side of the kidney and finally enters the back of the bladder.

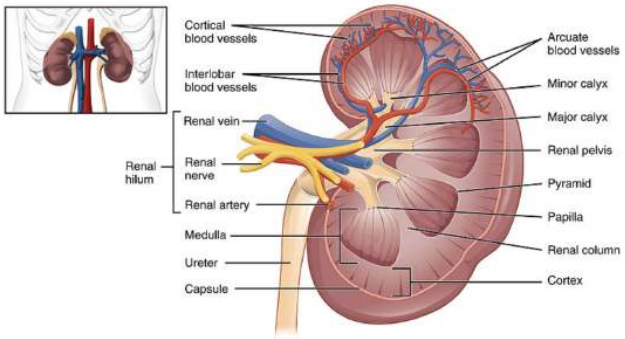


Figure **14.4.3**: Urine collects in the renal pelvis which is continuous with the ureter. The ureter then carries the urine from the kidney to the urinary bladder.

The walls of the ureters are composed of multiple layers of different types of tissues. You can see the layers in Figure **14.4.4**. The innermost layer is a special type of epithelium, called the transitional epithelium. Unlike the epithelium lining most organs, the transitional epithelium is capable of flattening and distending and does not produce mucus. It lines much of the urinary system, including the renal pelvis, bladder, and much of the urethra in addition to the ureters. Transitional epithelium allows these organs to stretch and expand as they fill with urine or allow urine to pass through. The next layer of the ureter walls is made up of loose connective tissue containing elastic fibers, nerves, and blood and lymphatic vessels. After this layer are two layers of smooth muscles, an inner circular layer, and an outer longitudinal layer. The smooth muscle layers can contract in waves of peristalsis to propel urine down the ureters from the kidneys to the urinary bladder. The outermost layer of the ureter walls consists of fibrous tissue.

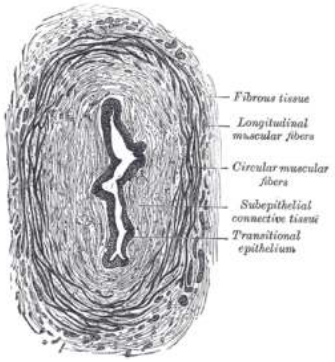


Figure **14.4.4**: This illustration shows a cross-section of a ureter. The white space inside is the lumen through which urine passes. From the lumen outward, the layers of the ureter wall include transitional epithelium, connective tissue, two layers of muscle fibers, and an outer layer of fibrous tissue.

URINARY BLADDER

The **urinary bladder** is a hollow, muscular, and stretchy organ that rests on the pelvic floor. It collects and stores urine from the kidneys before the urine is eliminated through urination. As shown in Figure **14.4.5**, urine enters the urinary bladder from the ureters through two ureteral openings on either side of the back wall of the bladder.

Urine leaves the bladder through a sphincter called the internal urethral sphincter. When the sphincter relaxes and opens, it allows urine to flow out of the bladder and into the urethra.

Like the ureters, the bladder is lined with transitional epithelium, which can flatten out and stretch as needed as the bladder fills with urine. The next layer (lamina propria) is a layer of loose connective tissue, nerves, and blood and lymphatic vessels. This is followed by a submucosa layer, which connects the lining of the bladder with the detrusor muscle in the walls of the bladder. The outer covering of the bladder is the peritoneum, which is a smooth layer of epithelial cells that lines the abdominal cavity and covers most abdominal organs.

The detrusor muscle in the wall of the bladder is made of smooth muscle fibers that are controlled by both the autonomic and somatic nervous systems. As the bladder fills, the detrusor muscle automatically relaxes to allow it to hold more urine. When the bladder is about half full, the stretching of the walls triggers the sensation of needing to urinate. When the individual is ready to void, conscious nervous signals cause the detrusor muscle to contract and the internal urethral sphincter to relax and open. As a result, urine is forcefully expelled out of the bladder and into the urethra.

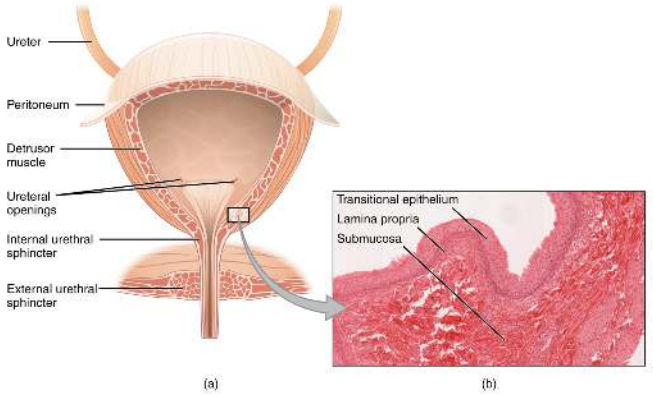


Figure **14.4.5**: This diagram of the urinary bladder shows (a) a cross-sectional drawing of the entire bladder and (b) a microscopic cross-section of the tissues in the wall of the bladder.

URETHRA

The **urethra** is a tube that connects the urinary bladder to the external urethral orifice, which is the opening of the urethra on the surface of the body. As shown in Figure **14.4.6**, the urethra in a person with XY chromosomes (anatomically male) travels through the penis, so it is much longer than the urethra in a person with XX chromosomes (anatomically female). In a genetically male person, the urethra averages about 20 cm (8 in.) long, whereas, in a genetically female individual, it averages only about 4.8 cm (1.9 in.) long. In an XY individual, the urethra carries semen as well as urine, but in the XX individual, it carries only urine.

Like the ureters and bladder, the proximal (closer to the bladder) two-thirds of the urethra are lined with transitional epithelium. The distal (farther from the bladder) third of the urethra is lined with mucus-secreting epithelium. The mucus helps protect the epithelium from urine, which is corrosive. Below the epithelium is loose connective tissue, and below that are layers of smooth muscle that are continuous with the muscle layers of the urinary bladder. When the bladder contracts to forcefully expel urine, the smooth muscle of the urethra relaxes to allow the urine to pass through.

In order for urine to leave the body through the external urethral orifice, the external urethral sphincter must relax and open. This sphincter is a striated muscle that is controlled by the somatic nervous system, so it is under conscious, voluntary control in most people (exceptions are infants, some elderly people, and patients with certain injuries or disorders). The muscle can be held in a contracted state and hold in the urine until the person is ready to urinate. Following urination, the smooth muscle lining the urethra automatically contracts to re-establish muscle tone, and the individual consciously contracts the external urethral sphincter to close the external urethral opening.

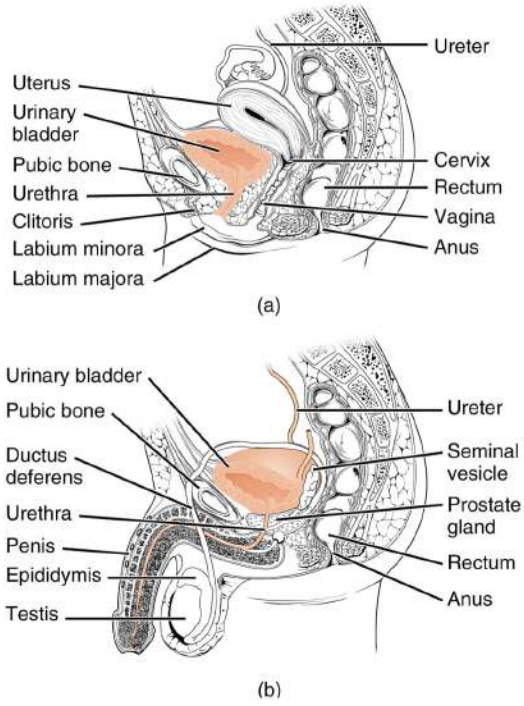


Figure **14.4.6**: The urinary bladder and urethra are colored brown to illustrate them in (a) female anatomy and (b) male anatomy. Notice how much longer the male urethra is because it travels through the length of the penis to reach the external urethral orifice.

REVIEW

1. What are ureters?
2. Describe the location of the ureters relative to other urinary tract organs.
3. Identify layers in the walls of a ureter and how they contribute to the ureter's function.
4. Describe the urinary bladder.
5. What is the function of the urinary bladder?
6. How does the nervous system control the urinary bladder?
7. What is the urethra?
8. How does the nervous system control urination?

9. Identify the sphincters that are located along the pathway from the ureters to the external urethral orifice.
10. What are two differences between the male and female urethra?
11. *True or False.* Urine travels through the urinary system due solely to the force of gravity.
12. *True or False.* Urination refers to the process that occurs from the formation of urine in the kidneys to the elimination of urine from the body.
13. When the bladder muscle contracts, the smooth muscle in the walls of the urethra _____ .
14. Transitional epithelium lines the:

    A. bladder

    B. ureters

    C. renal pelvis

    D. All of the above

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14.5: DISORDERS OF THE URINARY SYSTEM

AWARENESS RIBBON

Awareness ribbons are symbols meant to show support or raise consciousness for a cause. Different colors are associated with different issues, often relating to health problems. The first ribbon to gain familiarity for a health issue was the red ribbon for HIV/AIDS, created in 1991. The pink ribbon for breast cancer awareness is probably the best known today. Do you know what a green ribbon like the one pictured in Figure **14.5.1** represents? Among several other health problems, a green ribbon is meant to show support or raise awareness for kidney disorders.



Figure **14.5.1**: Kidney disorder awareness ribbon

The kidneys play such vital roles in eliminating wastes and toxins and maintaining body-wide homeostasis that disorders of the kidneys may be life-threatening. The gradual loss of normal kidney function commonly occurs with a number of disorders, including diabetes mellitus and high blood pressure. Other disorders of the kidneys are caused by faulty genes that are inherited. Loss of kidney function may eventually progress to kidney failure.

DIABETIC NEPHROPATHY

Diabetic nephropathy is a progressive kidney disease caused by damage to the capillaries in the glomeruli of the kidneys due to long-standing diabetes mellitus (see Figure **14.5.2**). It is not fully understood how diabetes leads to damage of glomerular capillaries, but it is thought that high levels of glucose in the blood are involved. In people with diabetes, nephropathy is more likely if their blood glucose is poorly controlled. Having high blood pressure, a history of cigarette smoking and a family history of kidney problems are additional risk factors. Diabetic nephropathy often has no symptoms at first. In fact, it may take up to a decade after kidney damage begins for symptoms to appear. When they do appear, they typically include severe tiredness, headaches, nausea, frequent urination, and itchy skin.

Proteins are large molecules that usually are not filtered out of blood in the glomeruli. When the glomerular capillaries are damaged, it allows proteins such as albumin to leak into the filtrate from the blood. As a result, albumin ends up being excreted in the urine. Finding a high level of albumin in the urine is one indicator of diabetic nephropathy and helps to diagnose the disorder. Drugs may be prescribed to reduce protein levels in the urine. Controlling high blood sugar levels and hypertension (high blood pressure) is also important to help slow kidney damage, as is a reduction of sodium intake.

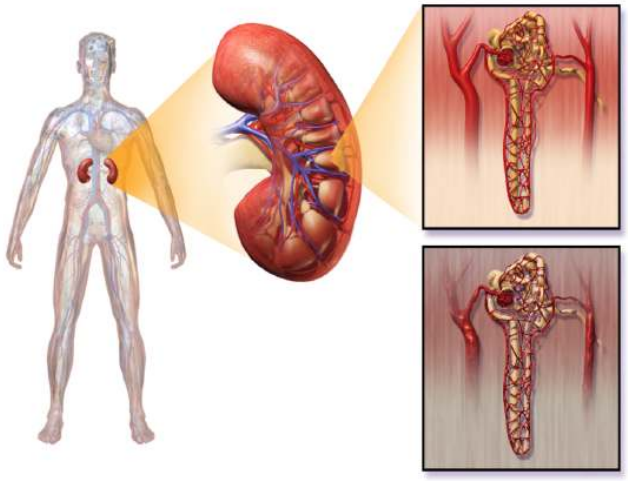


Figure **14.5.2**: Diabetic nephropathy is characterized by damage to the capillaries in the glomeruli of the kidneys, represented by the lower of the two inset diagrams.

POLYCYSTIC KIDNEY DISEASE

Polycystic kidney disease (PKD) is a genetic disorder in which multiple abnormal cysts develop and grow in the kidneys. Figure **14.5.3** shows a pair of kidneys that are riddled with cysts from PKD. In people who inherit PKD, the cysts may start to form at any point in life from infancy through adulthood. Typically, both kidneys are affected. Symptoms of the disorder may include high blood pressure, headaches, abdominal pain, blood in the urine, and excessive urination.



Figure **14.5.3**: In polycystic kidney disease, the kidneys are injured by the formation of multiple cysts, which may grow to be quite large.

There are two types of PKD. The more common type is caused by an autosomal dominant allele, and the less common type is caused by an autosomal recessive allele. Both types collectively make PKD one of the most common hereditary diseases in the United States, affecting more than half a million people. There is little or no difference in the rate of occurrence of PKD between genders or ethnic groups. There is no known cure for this disease other than a kidney transplant.

KIDNEY FAILURE

Both diabetic nephropathy and PKD may lead to **kidney** (or renal) **failure** (classified as end-stage kidney disease), in which the kidneys are no longer able to adequately filter metabolic wastes from the blood. Long-term, uncontrolled high blood pressure is another common cause of kidney failure. Symptoms of kidney failure may include nausea, more or less frequent urination, blood in the urine, muscle cramps, anemia, swelling of the extremities, and shortness of breath due to the accumulation of fluid in the lungs. If kidney function drops below the level needed to sustain life, then the only treatment option is kidney transplantation or some means of artificial filtration of the blood, such as by hemodialysis.

Hemodialysis is a medical procedure in which blood is filtered externally through a machine. You can see how it works in the simplified diagram in Figure **14.5.4**. During dialysis, waste products such as urea as well as excess water are removed from the patient's blood before the blood is returned to the patient. Hemodialysis is typically done on an outpatient basis in a hospital or special dialysis clinic. Less frequently, it is done in the patient's home. Depending on the patient's size, among other factors, the blood is filtered for 3 to 4 hours about 3 times a week. Because the treatment is needed so frequently, hemodialysis is one of the most common procedures performed in U.S. hospitals.

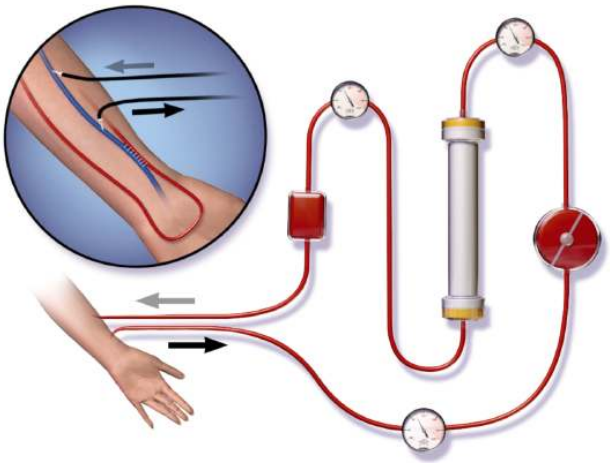


Figure **14.5.4**: This simple diagram shows the general process by which blood is filtered externally in the process of hemodialysis. Blood is taken from a patient, run through a filtration machine, and then returned.

KIDNEY STONES

A **kidney stone**, also known as a renal calculus, is a solid crystal that forms in a kidney from minerals in urine (see Figure **14.5.5**). The majority of kidney stones consist of crystals of calcium salts. Kidney stones typically leave the body in the urine stream. A small stone may pass through the ureters and other urinary tract organs without causing symptoms and go undetected. A larger stone may cause pain when it passes through the urinary tract. If a kidney stone grows large enough, it may block the ureter. Blockage of a ureter may cause a decrease in kidney function and damage to the kidney.

A kidney stone that causes pain is generally treated with pain medication until it passes through the urinary tract. A stone that causes a blockage may be treated with lithotripsy. This is a medical procedure in which high-intensity ultrasound pulses are applied externally to cause fragmentation of the stone into pieces small enough to pass easily through the urinary tract. Although lithotripsy is noninvasive, it can cause damage to the kidneys. An alternative treatment for a stone that blocks urine flow is to insert a stent into the ureter to expand it and allow both urine and the stone to pass. In some cases, surgery may be required to physically remove a large stone from the ureter.

A combination of lifestyle and genetic factors seem to predispose certain people to develop kidney stones. Risk factors include high consumption of cola soft drinks, eating a diet high in animal protein, being overweight, and not drinking enough fluids. Preventive measures are obvious. They include limiting cola consumption, eating less animal protein, losing weight, and increasing fluid intake.

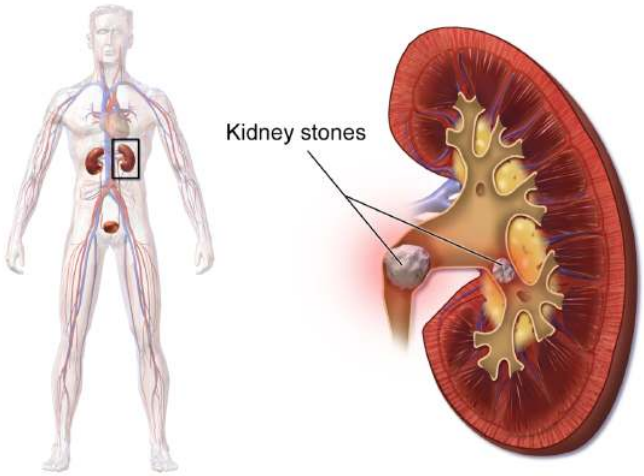


Figure **14.5.5**: Kidney stones form in the kidney and may grow large enough to block the major calyx or ureter.

OTHER URINARY SYSTEM DISORDERS

Although disorders of the kidneys are generally the most serious urinary system disorders, problems that affect other organs of the urinary tract are generally more common. They include bladder infections and urinary incontinence.

BLADDER INFECTION

A **bladder infection**, also called cystitis, is a very common type of urinary tract infection in which the urinary bladder becomes infected by bacteria (typically *Escherichia coli*), rarely by fungi. Symptoms of bladder infections may include pain with urination, frequent urination, and feeling the need to urinate despite having an empty bladder. In some cases, there may be blood in the urine. A much less common type of urinary tract infection is pyelonephritis, in which the kidney becomes infected. If a kidney infection occurs, it is generally because of an untreated bladder infection. Bladder infections are treated mainly with antibiotics.



Figure **14.5.6**: Using a diaphragm like this one as a barrier method of birth control may increase the risk of a woman developing a bladder infection following sexual intercourse

Risk factors for urinary bladder infections include sexual intercourse (especially when spermicide or a diaphragm, as shown in Figure **14.5.6**, is used for contraception), diabetes, obesity, and most importantly, female sex. Bladder infections are four times more common in women than in men. In fact, in women, they are the most common type of bacterial infection, and as many as 1 in 10 women has a bladder infection in any given year. Female anatomy explains the sex difference in the incidence of bladder infections. The urethra is much shorter and closer to the anus in females than in males, so contamination of the urethra and then the bladder with GI tract bacteria is more likely in females than in males. Once the bacteria reach the bladder, they can attach to the bladder wall and form a biofilm that resists the body's immune response.

URINARY INCONTINENCE

Urinary incontinence is a chronic problem of uncontrolled leakage of urine. It is very common, especially at older ages and especially in women. Sometimes urinary incontinence is a sign of another health problem, such as diabetes or obesity. Regardless of the underlying cause, the symptoms of urinary incontinence alone may have a large impact on the quality of life, frequently causing inconvenience, embarrassment, and distress.

In a person with male anatomy, urinary incontinence is most commonly caused by an enlarged prostate gland or treatment for prostate cancer. In genetically female individuals, there are two common types of urinary incontinence with different causes: stress incontinence and urge incontinence.

- Stress urinary incontinence is caused by loss of support of the urethra, usually due to stretching of pelvic floor muscles during childbirth. It is characterized by leakage of small amounts of urine with activities that increase abdominal pressure, such as coughing, sneezing, or lifting. Treatment of stress urinary incontinence may include Kegel exercises to strengthen the pelvic muscles (see Explore More below). More serious cases may call for surgery to improve support for the bladder.
- Urge urinary incontinence (commonly called "overactive bladder") is caused by uncontrolled contractions of the detrusor muscle in the wall of the bladder. This causes the bladder to empty unexpectedly. Urge incontinence is characterized by leakage of large amounts of urine in association with an insufficient warning to get to the bathroom in time. Treatment of urge incontinence may include taking medication to relax the detrusor muscle.

FEATURE: MY HUMAN BODY

You probably have had to "donate" a urine specimen for analysis in conjunction with a medical visit. A thorough medical exam often includes clinical tests for urine. Understanding what your urine may reveal about your health may help you appreciate the need for such tests.

The most common urine test is called a urinalysis. In a routine urinalysis, a urine sample may be analyzed by sight and smell and with simple urine test strips. If a particular disorder is suspected, urinalysis may be more extensive. For example, the urine may be analyzed with specific tests or viewed under a microscope to identify abnormal substances in the urine. If a bacterial infection is suspected, a sample of urine may be cultured in the lab to see if it grows bacteria and which type of bacteria grow. Knowing the type of bacteria is important for deciding which class of antibiotics is likely to be most effective in treating the infection.

The color and clarity of urine may be obvious first indicators of disorders or other abnormalities. Normal urine is yellow to amber in color and looks clear. If urine is nearly colorless, it could be a sign of excessive fluid intake, or it might be a sign of diabetes. Very dark urine may indicate dehydration, but it could also be caused by taking certain medications or ingesting some other substances. If the urine has a reddish tinge, it is often a sign of blood in the urine, which could be due to a urinary tract infection, kidney stone, or even cancer. If the urine appears cloudy instead of clear, it could be due to white blood cells in the urine, which may be another sign of a urinary tract infection.

Normal urine may have virtually no odor if it is very dilute. It will have a stronger odor if it is concentrated. Brief changes in the normal odor of urine often occur due to the ingestion of certain foods or medications. For example, after eating asparagus, urine may have a peculiar and distinctive odor for several hours. More significant is urine that has a sweet smell, because this may indicate sugar in the urine, which is a sign of diabetes.

Urine test strips, much like the familiar litmus test strips used to detect acids and bases in a chemistry lab, are used to identify abnormal levels of certain components in the urine. For example, urine test strips can detect and quantify the presence of nitrites in urine, which is usually a sign of infection with certain types of bacteria. Urine test strips can also be used to identify proteins such as albumin in urine, which may be a sign of a kidney infection or of kidney failure. Levels of sodium in urine can also be measured with test strips, and higher-than-normal levels may be another indication of kidney failure. In

addition, test strips can identify and quantify the presence of white blood cells and blood in a urine specimen, both of which are likely to be a sign of a urinary tract infection or some other urinary system disorder.

Besides the use of urine test strips, other simple urine tests that are often performed include Benedict's test, which is a test for the presence and quantity of glucose in urine. If the level is high, it is likely to indicate diabetes. The test is so simple that it may even be done in the home by the patient to monitor how well sugar levels are being controlled. Testing for some other substances in urine requires the patient to collect urine over a 24-hour period. This is the case, for example, when testing for the adrenal hormone cortisol in urine. When urine cortisol levels are higher than normal it may indicate Cushing's syndrome, and when the levels are lower than normal it may indicate Addison's disease.

REVIEW

1. What is diabetic nephropathy and what causes it?
2. Describe polycystic kidney disease (PKD).
3. Define kidney failure.
4. What are potential treatments for kidney failure when kidney function drops below the level needed to sustain life?
5. Describe hemodialysis.
6. What are kidney stones?
7. How may a large kidney stone be removed from the body?
8. How are bladder infections usually treated?
9. Why are bladder infections much more common in females than in males?
10. Define urinary incontinence.
11. Compare and contrast stress incontinence and urge incontinence.
12. Why is the presence of a protein such as albumin in the urine a cause for concern?
13. Patients undergoing hemodialysis usually have to do this procedure a few times a week. Why does it have to be done so frequently?
14. Which of the following is considered a genetic disorder?
    A. Polycystic kidney disease
    B. Diabetic nephropathy
    C. Kidney failure
    D. Urinary incontinence
15. What is the most common cause of a kidney infection?

EXPLORE MORE

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3. Polycystic kidneys by CDC/ Dr. Edwin P. Ewing, Jr., Public Domain, via Wikimedia Commons
4. Hemodialysis by Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". *WikiJournal of Medicine* **1** (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. CC BY 3.0 via Wikimedia Commons
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14.6: CASE STUDY CONCLUSION- ALCOHOL AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: DRINK AND FLUSH

You are probably aware that drinking alcohol can cause visual disturbances, slurred speech, drowsiness, impaired judgment, and loss of coordination because of its effects on the brain. Although it may be less obvious, alcohol also can have serious effects on the functioning of the excretory system.



Figure **14.6.1**: Alcohol bottles

As you learned in the beginning of the chapter from the conversation between Maeva and Bintou, who were in line for the restroom, consumption of alcohol inhibits a hormone that causes our bodies to retain water. The result is that more water is released in urine, increasing the frequency of restroom trips as well as the risk of dehydration.

Which hormone discussed in this chapter does this? If you answered antidiuretic hormone (ADH; also called vasopressin)—you are correct! ADH is secreted by the hypothalamus of the brain and acts on the kidneys. As you have learned, the kidneys filter the blood, reabsorb needed substances, and produce urine. ADH helps the body conserve water by influencing this process. ADH makes the collecting ducts in the kidneys permeable to water, allowing water molecules to be reabsorbed from the urine back into the blood through osmosis into capillaries.

Alcohol is thought to produce more dilute urine by inhibiting the release of ADH. This causes the collecting ducts to be more impermeable to water, so less water can be reabsorbed and more is excreted in the urine. Because the volume of urine is increased, the bladder fills up more quickly, and the urge to urinate occurs more frequently. This is part of the reason why you often see a long line for the restroom in situations where many people are drinking alcohol. In addition to producing more dilute urine, simply consuming many beverages can also increase urine output.

In most cases, moderate drinking causes only a minor and temporary effect on kidney function. However, when people consume a large quantity of alcohol in a short period of time or abuse alcohol over long time periods, there can be serious effects on the kidney. For example, binge drinking (i.e. consuming about four to five drinks in two hours), can cause a condition called "acute kidney injury," serious and sudden impairment of kidney function that requires immediate medical attention. As with other cases of kidney failure that you learned about in this chapter, the treatment is to artificially filter the blood using hemodialysis. While normal kidney function may eventually return, acute kidney injury can sometimes cause long-term damage to the kidneys.

In cases where people abuse alcohol, particularly for an extended period of time, there can be many serious effects on the kidneys and other parts of the excretory system. The dehydrating effect of alcohol on the body can impair the function of many organs, including the kidneys themselves. Additionally, because of alcohol's effect on kidney function and water and ion balance, chronic alcohol consumption can cause abnormalities in blood ion concentration and acid-base balance, which can be very dangerous.

Additionally, drinking more than two alcoholic beverages a day can increase your risk of high blood pressure. As you have learned, high blood pressure is a risk factor for some kidney disorders and a common cause of kidney failure. Therefore, drinking too much alcohol can damage the kidneys by raising blood pressure.

Finally, chronic excessive consumption of alcohol can cause liver disease. As you know, the liver is an important organ of the excretory system that breaks down toxic substances in the blood. The liver and kidneys work together to remove wastes from the bloodstream. For example, as you have learned, the liver transforms ammonia into urea, which is then filtered and excreted by the kidneys. When the liver is not functioning normally, it puts added strain on the kidneys, which can result in kidney dysfunction. This association between alcohol, liver disease, and kidney dysfunction is so strong that most of the patients in the United States with both liver disease and related kidney dysfunction are alcoholics.

As you have learned, the excretory system is essential to remove toxic wastes from the body and regulate homeostasis. Having an occasional drink can temporarily alter these functions, but excessive alcohol exposure can seriously and permanently damage this system in many ways. Limiting alcohol consumption can help preserve the normal functioning of the excretory system so that it can protect your health.

CHAPTER SUMMARY

In this chapter, you learned about the excretory system. Specifically, you learned that:

- Excretion is the process of removing wastes and excess water from the body. It is an essential process in all living things and a major way the human body maintains homeostasis.
- Organs of the excretory system include the skin, liver, large intestine, lungs, and kidneys.
- The skin plays a role in excretion through the production of sweat by sweat glands. Sweating eliminates excess water and

salts and also a small amount of urea, a byproduct of protein catabolism.

- The liver is a very important organ of excretion. The liver breaks down many substances in the blood, including toxins. The liver also excretes bilirubin, a waste product of hemoglobin catabolism, in bile. Bile then travels to the small intestine and is eventually excreted in feces by the large intestine.
- The main excretory function of the large intestine is to eliminate solid waste that remains after food is digested and water is extracted from the indigestible matter. The large intestine also collects and excretes wastes from throughout the body.
- The lungs are responsible for the excretion of gaseous wastes, primarily carbon dioxide from cellular respiration in cells throughout the body. Exhaled air also contains water vapor and trace levels of some other waste gases.
- The paired kidneys are often considered to be the main organs of excretion. Their primary function is the elimination of excess water and wastes from the bloodstream by the production of urine. The kidneys filter many substances out of blood, allow the blood to reabsorb needed materials, and use the remaining materials to form urine.
- The two bean-shaped kidneys are located high in the back of the abdominal cavity on either side of the spine. A renal artery connects each kidney with the aorta and transports unfiltered blood to the kidney. A renal vein connects each kidney with the inferior vena cava and transports filtered blood back to the circulation.
- The kidney has two main layers involved in the filtration of blood and formation of urine: the outer cortex and inner medulla. At least a million nephrons, which are the tiny functional units of the kidney, span the cortex and medulla. The entire kidney is surrounded by a fibrous capsule and protective fat layers.
- As blood flows through a nephron, many materials are filtered out of the blood, needed materials are returned to the blood, and the remaining materials are used to form urine.
    - In each nephron, the glomerulus and the surrounding Bowman's capsule form the unit that filters blood. From Bowman's capsule, the material filtered from the blood, called filtrate, passes through the long renal tubule. As it does, some substances are reabsorbed into the blood and other substances are secreted from the blood into the filtrate, finally forming urine. The urine empties into collecting ducts, where more water may be reabsorbed.
- The kidneys are part of the urinary system, which also includes the ureters, urinary bladder, and urethra. The main function of the urinary system is to eliminate the waste products of metabolism from the body by forming and excreting urine. After urine forms in the kidneys, it is transported through the ureters to the bladder. The bladder stores the urine until urination, when urine is transported by the urethra to be excreted outside the body.
- Besides the elimination of waste products such as urea, uric acid, excess water, and mineral ions, the urinary system has other vital functions. These include maintaining homeostasis of mineral ions in extracellular fluid, regulating acid-base balance in the blood, regulating the volume of extracellular fluids, and controlling blood pressure.
- The formation of urine must be closely regulated to maintain body-wide homeostasis. Several endocrine hormones help control this function of the urinary system, including antidiuretic hormone from the hypothalamus, parathyroid hormone from the parathyroid glands, and aldosterone from the adrenal glands. For example, the kidneys are part of the renin-angiotensin-aldosterone system that regulates the concentration of sodium in the blood to control blood pressure. In this system, the enzyme renin secreted by the kidneys works with hormones from the liver and adrenal gland to stimulate nephrons to reabsorb more sodium and water from urine.
- The kidneys also secrete endocrine hormones, including calcitriol, which helps control the level of calcium in the blood; and erythropoietin, which stimulates the bone marrow to produce red blood cells.
- The process of urination is controlled by both the autonomic and the somatic nervous systems. The autonomic system causes the detrusor muscle in the bladder wall to relax as the bladder fills with urine, but the conscious contraction of the detrusor muscle expels urine from the bladder during urination.
- Ureters are tube-like structures that connect the kidneys with the urinary bladder. Each ureter arises at the renal pelvis of a kidney and travels down through the abdomen to the urinary bladder. The walls of the ureter contain smooth muscle that can contract to push urine through the ureter by peristalsis. The walls are lined with transitional epithelium that can expand and stretch.
- The urinary bladder is a hollow, muscular organ that rests on the pelvic floor. It is also lined with transitional epithelium. The function of the bladder is to collect and store urine from the kidneys before the urine is eliminated through urination. Filling of the bladder triggers the autonomic nervous system to stimulate the detrusor muscle in the bladder wall to contract. This forces urine out of the bladder and into the urethra.
- The urethra is a tube that connects the urinary bladder to the external urethral orifice. Somatic nerves control the sphincter at the distal end of the urethra. This allows the opening of the sphincter for urination to be under voluntary control.
- Diabetic nephropathy is a progressive kidney disease caused by damage to the capillaries in the glomeruli of the kidneys due to long-standing diabetes mellitus. Years of capillary damage may occur before symptoms first appear.
- Polycystic kidney disease (PKD) is a genetic disorder (autosomal dominant or recessive) in which multiple abnormal cysts grow in the kidneys.
- Diabetic nephropathy, PKD, or chronic hypertension may lead to kidney failure, in which the kidneys are no longer able to adequately filter metabolic wastes from the blood. Kidneys may fail to such a degree that kidney transplantation or repeated, frequent hemodialysis is needed to support life. In hemodialysis,

the patient's blood is filtered artificially through a machine and then returned to the patient's circulation.

- A kidney stone is a solid crystal that forms in a kidney from minerals in the urine. A small stone may pass undetected through the ureters and the rest of the urinary tract. A larger stone may cause pain when it passes or be too large to pass so it blocks a ureter. Large kidney stones may be shattered with high-intensity ultrasound into pieces small enough to pass through the urinary tract, or they may be removed surgically.
- A bladder infection is generally caused by bacteria that reach the bladder from the GI tract and multiply. Bladder infections are much more common in females than males because the female urethra is much shorter and closer to the anus. Treatment generally includes antibiotic drugs.
- Urinary incontinence is a chronic problem of uncontrolled leakage of urine. It is very common, especially at older ages and in women. In men, urinary incontinence is usually caused by an enlarged prostate gland. In women, it is usually caused by stretching of pelvic floor muscles during childbirth (stress incontinence) or by an "overactive bladder" that empties without warning (urge incontinence).

You have learned that the excretory system protects your body through the removal of toxic wastes and the maintenance of homeostasis. But how does your body protect itself against pathogens and other threats? Read the next chapter on the immune system to find out.

CHAPTER SUMMARY REVIEW

1. Match each organ of the excretory system with the description that best fits it. Each organ is used only once. Organs: lungs, skin, kidneys, liver, large intestine
   A. Excretes solid wastes from food
   B. Cools the body while it eliminates water and other wastes
   C. Part of the urinary system
   D. Produces bile and breaks down toxins in the blood
   E. Eliminates waste gases
2. In what ways can the alveoli of the lungs be considered analogous to the nephrons of the kidney?
3. What is urea? Where is urea produced and what is it produced from? How is urea excreted from the body?
4. *True or False.* The lungs help excrete excess water, in addition to carbon dioxide.
5. *True or False.* There are two kidneys in the human body, and both are the same size and shape.
6. *True or False.* The renal pelvis is a bone that surrounds the kidneys.
7. If a person has a large kidney stone that prevents urine that has left the kidney from reaching the bladder, where do you think this kidney stone is located? Explain your answer.
8. Match each of the following structures with the description that best fits it. Each structure is used only once. Structures: urethra; nephron; ureters; urinary bladder
   A. Produces urine
   B. Stores relatively large quantities of urine
   C. Releases urine to the outside of the body
   D. Transports urine between where it is produced and where it is stored
9. Explain what is meant by "Excretion = Filtration – Reabsorption + Secretion" regarding the production of urine.
10. Which disease discussed in the chapter specifically affects the glomerular capillaries of the kidneys? Where are the glomerular capillaries located within the kidneys, and what is their function?
11. Describe one way in which the excretory system helps maintain homeostasis in the body.
12. Secretion in a nephron occurs:
    A. before filtration, and goes from the filtrate into the blood
    B. after filtration, and goes from the filtrate into the blood
    C. before filtration, and goes from the blood into the filtrate
    D. after filtration, and goes from the blood into the filtrate
13. High blood pressure can both contribute to the development of kidney disorders and be a symptom of kidney disorders. What is a kidney disorder that can be caused by high blood pressure? What is a kidney disorder that has high blood pressure as a symptom? How does blood pressure generally relate to the function of the kidney?
14. If the body is dehydrated, what do the kidneys do? What does this do to the appearance of the urine produced?
15. Which of the following contain filtered blood in the kidney?
    A. Arteries
    B. Venules
    C. Veins
    D. B and C
16. *True or False.* Hormones influence the functions of the kidney, but the kidney itself does not produce hormones.
17. *True or False.* Both the lungs and the kidneys help maintain the pH of the blood.
18. Identify three risk factors for the development of kidney stones.

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CHAPTER OVERVIEW

15: REPRODUCTIVE SYSTEM

Please note there are not only two genders in the human population. When male or female is mentioned in this chapter, it only refers to the biological male and female sexes. This chapter outlines the structures and functions of the male and female reproductive systems, explains how fertilization occurs, and discusses the menstrual cycle's role. The chapter describes the causes of and treatments for male and female reproductive system disorders, infertility, and contraception methods.

15.1: Case Study- Making Babies
15.2: Introduction to the Reproductive System
15.3: Structures of the Male Reproductive System
15.4: Functions of the Male Reproductive System
15.5: Disorders of the Male Reproductive System
15.6: Structures of the Female Reproductive System
15.7: Menstrual Cycle
15.8: Functions of the Female Reproductive System
15.9: Disorders of the Female Reproductive System
15.10: Infertility
15.11: Contraception
15.12: Case Study Conclusion- Trying to Conceive and Chapter Summary

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15.1: CASE STUDY- MAKING BABIES

CASE STUDY: TRYING TO CONCEIVE

Isabella, 28, and Omar, 30, have been together for three years. A year ago, they decided they wanted to have a baby, and they stopped using birth control. At first, they did not pay attention to the timing of their sexual activity in relation to Isabella's menstrual cycle, but after six months passed without Isabella becoming pregnant, they decided to try to maximize their efforts.



Figure **15.1.1**: Couples holding hands

They knew that in order for a woman to become pregnant, the man's sperm must encounter the woman's egg, which is typically released once a month through a process called ovulation. They had also heard that for the average woman, ovulation occurs around day 14 of the menstrual cycle. To maximize their chances of conception, they tried to have sexual intercourse on day 14 of Isabella's menstrual cycle each month.



Figure **15.1.2**: Monitoring body temperature before getting out of bed in the morning can often help tell if and when a woman is ovulating. Usually, a special, highly sensitive thermometer is used.

After several months of trying this method, Isabella is still not pregnant. She is concerned that she may not be ovulating on a regular basis because her menstrual cycles are irregular and often longer than the average 28 days. Omar is also concerned about his own fertility. He had some injuries to his testicles (testes) when he was younger, and wonders if that may have caused a problem with his sperm.

Isabella calls her doctor for advice. Dr. Bashir recommends that she try taking her temperature each morning before she gets out of bed. This temperature is called basal body temperature (BBT), and recording BBT throughout a woman's menstrual cycle can sometimes help identify if and when they ovulate. Additionally, Dr. Bashir recommends she try using a home ovulation predictor kit, which predicts ovulation by measuring the level of **luteinizing hormone (LH)** in the urine. In the meantime, Dr. Bashir sets up an appointment for Omar to give a semen sample, so that his sperm may be examined with a microscope.

As you read this chapter, you will learn about the male and female reproductive systems, how sperm and eggs are produced, and how they meet each other to ultimately produce a baby. You will learn how these complex processes are regulated, and how they can be susceptible to problems along the way. Problems in either the male or female reproductive systems can result in infertility, or difficulty in achieving a successful pregnancy. As you read the chapter, you will understand exactly how BBT and LH relate to ovulation, why Dr. Bashir recommended that Isabella monitor these variables, and the types of problems she will look for in Omar's semen. At the end of the chapter, you will find out the results of Isabella and Omar's fertility assessments, steps they can take to increase their chances of conception, and whether they are ultimately able to get pregnant.

LGBTQ +

Most of the information in this chapter is in terms of cis-gendered individuals because there is a lack of data on lesbian, gay, bisexual, transgender, and queer (LGBTQ) individuals. About 3.5% of Americans identify themselves as lesbian, gay, or bisexual, and 0.3% identify themselves as transgender. The acronym LGBTQIA+ is an umbrella term that includes a number of groups: lesbian (homosexual woman), gay (homosexual man or woman), bisexual (person who is attracted to both genders), transgender (person who identifies their gender as different from their biological one), queer (a synonym for gay; some people prefer to identify themselves as queer to empower themselves and take their identity "back from the bullies"), questioning (people who are unsure about their gender identity/sexuality), intersex (people with two sets of genitalia), asexual (people who are not sexually attracted to anyone and who don't identify with any orientation), allies (the loving supporters of the community, though not necessarily part of it), two spirits (a tradition in many First Nations that considers sexual minorities to have both male and female spirits), and pansexual (person sexually attracted to others of any sex or gender).

CHAPTER OVERVIEW: REPRODUCTIVE SYSTEM

In this chapter, you will learn about the male and female reproductive systems. Specifically, you will learn about:

- The functions of the reproductive system, which include the production and fertilization of gametes (eggs and sperm), the production of sex hormones by the gonads (testes and ovaries), and, in females, the carrying of a fetus
- How the male and female reproductive systems differentiate in the embryo and fetus, and how they mature during puberty
- The structures of the male reproductive system, including the testes, epididymis, vas deferens, ejaculatory ducts, seminal

vesicles, prostate gland, bulbourethral glands, and the penis
- How sperm are produced, matured, stored, and deposited into the female
- The fluids in semen that protect and nourish sperm, and where those fluids are produced
- Disorders of the male reproductive system, including erectile dysfunction, epididymitis, prostate cancer, and testicular cancer —some of which predominantly affect younger men
- The structures of the female reproductive system, including the ovaries, fallopian tubes, uterus, cervix, vagina, and external structures of the vulva
- How eggs are produced in the female fetus, and how they then mature after puberty through the process of ovulation
- The menstrual cycle, its purpose, and the hormones that control it
- How fertilization and implantation occur, the stages of pregnancy and childbirth, and how the mother's body produces milk to feed the baby
- Disorders of the female reproductive system, including cervical cancer, endometriosis, and vaginitis (which includes yeast infections)
- Some causes and treatments of male and female infertility
- Forms of contraception (birth control), including barrier methods (such as condoms), hormonal methods (such as the birth control pill), behavioral methods, intrauterine devices, and sterilization

As you read the chapter, think about the following questions:

1. Why might sexual intercourse on day 14 of Isabella's menstrual cycle not necessarily be optimal timing to achieve a pregnancy?
2. Why is Isabella concerned about her irregular and long menstrual cycles? How could tracking her BBT and LH level help identify if she is ovulating and when?
3. Why do you think Omar is concerned about past injuries to his testes? How might an analysis of his semen help assess whether he has a fertility issue—and, if so, the type of issue?

ATTRIBUTIONS

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3. Some text is adapted from Health Care Disparities Among Lesbian, Gay, Bisexual, and Transgender Youth: A Literature Review; Hudaisa Hafeez, Muhammad Zeshan, Muhammad A Tahir, Nusrat Jahan, and Sadiq Naveed; Cureus. 2017 Apr; 9(4): e1184. Published online 2017 Apr 20. doi: 10.7759/cureus.1184; CC BY 4.0.
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15.2: INTRODUCTION TO THE REPRODUCTIVE SYSTEM

IT'S ALL ABOUT SEX

A tiny sperm breaks through the surface of a huge egg. Voilà! In nine months, a new baby will be born. Like most other multicellular organisms, human beings reproduce sexually. In human sexual reproduction, individuals with testes produce sperm, and individuals with ovaries produce eggs, and a new offspring forms when a sperm unites with an egg. How do sperm and eggs form? And how do they arrive together at the right place and time so they can unite to form a new offspring? These are functions of the reproductive system.

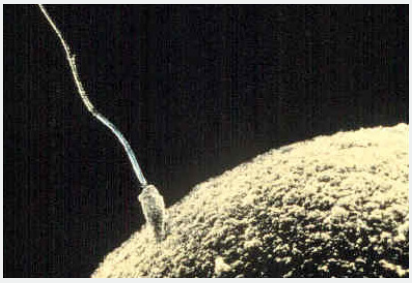


Figure **15.2.1**: A sperm cell fertilizing an egg cell

WHAT IS THE REPRODUCTIVE SYSTEM?

The **reproductive system** is the human organ system responsible for the production and fertilization of gametes (sperm or eggs) and carrying of a fetus. Both both sexes **gonads** produce gametes. A **gamete** is a haploid cell that combines with another haploid gamete during fertilization, forming a single diploid cell called a zygote. Besides producing gametes, the gonads also produce sex hormones. **Sex hormones** are endocrine hormones that control the development of sex organs before birth, sexual maturation at puberty, and reproduction once sexual maturation has occurred. Other reproductive system organs have various functions, such as maturing gametes, delivering gametes to the site of fertilization, and providing an environment for the development and growth of offspring.

SEX DIFFERENCES IN THE REPRODUCTIVE SYSTEM

The reproductive system is the only human organ system that is significantly different between males and females. Embryonic structures that will develop into the reproductive system start out the same in males and females, but by birth, the reproductive systems have differentiated. How does this happen?

SEX DIFFERENTIATION

Starting around the seventh week after conception in genetically male (XY) embryos, a gene called SRY on the Y chromosome (Figure **15.2.2**) initiates the production of multiple proteins. These proteins cause undifferentiated gonadal tissue to develop into testes. Testes secrete hormones — including testosterone — that trigger other changes in the developing offspring (now called a fetus), causing it to develop a complete male reproductive system. Without a Y chromosome, an embryo will develop ovaries, that will produce estrogen. Estrogen, in turn, will lead to the formation of the other organs of a female reproductive system.

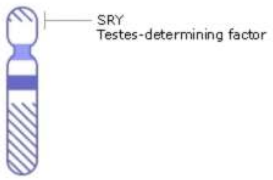


Figure **15.2.2**: The SRY gene on the short arm of the Y chromosome causes the undifferentiated gonads of an embryo to develop into testes. Otherwise, the gonads develop into ovaries.

HOMOLOGOUS STRUCTURES

Undifferentiated embryonic tissues develop into different structures in male and female fetuses. Structures that arise from the same tissues in males and females are called **homologous structures**. The testes and ovaries, for example, are homologous structures that develop from the undifferentiated gonads of the embryo. Likewise, the penis and clitoris are homologous structures that develop from the same embryonic tissues.

SEX HORMONES AND MATURATION

Male and female reproductive systems are different at birth, but they are immature and incapable of producing gametes or sex hormones. Maturation of the reproductive system occurs during puberty when hormones from the hypothalamus and pituitary gland stimulate the testes or ovaries to start producing sex hormones again. The main sex hormones are **testosterone** and **estrogen**. Sex hormones, in turn, lead to the growth and maturation of the reproductive organs, rapid body growth, and the development of **secondary sex characteristics**, such as body and facial hair and breasts.

ROLE OF SEX HORMONES IN TRANSGENDER TREATMENT

Feminizing or masculinizing hormone therapy is the administration of exogenous endocrine agents to induce changes in physical appearance. Since hormone therapy is inexpensive relative to surgery and highly effective in the development of secondary sex characteristics (e.g., facial and body hair in female-to-male [FTM] individuals or breast tissue in male-to-females [MTFs]), hormone therapy is often the first, and sometimes only, medical gender affirmation intervention accessed by transgender individuals looking to develop masculine or feminine characteristics consistent with their gender identity. In some cases, hormone therapy may be required before surgical interventions can be conducted. Trans-females are prescribed estrogen and anti-testosterone medication, such as cyproterone acetate and spironolactone. Trans-men are prescribed testosterone.

MALE REPRODUCTIVE SYSTEM

The main structures of the male reproductive system are external to the body and illustrated in Figure **15.2.3**. The two testes (singular, testis) hang between the thighs in a sac of skin called the scrotum. The testes produce both sperm and testosterone. Resting atop each testis is a coiled structure called the epididymis (plural, epididymes). The function of the epididymes is to mature and store sperm. The penis is a tubular organ that contains the urethra and has the ability to stiffen during sexual arousal. Sperm passes out of the body through the urethra during a sexual climax (orgasm). This release of sperm is called ejaculation.

In addition to these organs, there are several ducts and glands that are internal to the body. The ducts, which include the vas deferens (also called the ductus deferens), transport sperm from the epididymis to the urethra. The glands, which include the prostate gland and seminal vesicles, produce fluids that become part of semen. Semen is the fluid that carries sperm through the urethra and out of the body. It contains substances that control pH and provide sperm with nutrients for energy.

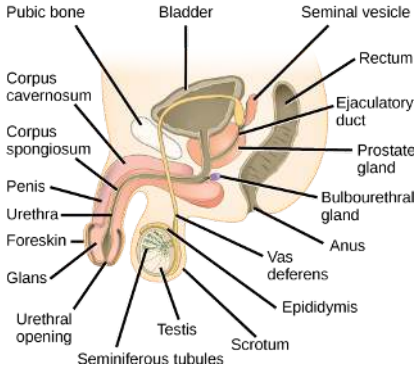
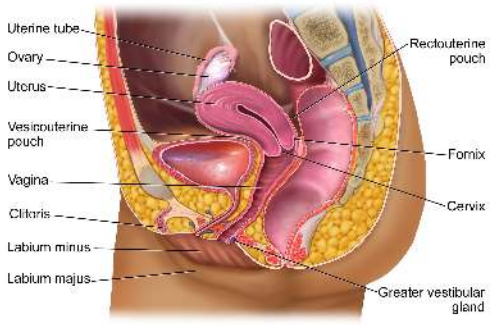


Figure **15.2.3**: The main organs of the male reproductive system. Focus on the seminiferous tubules, testis, scrotum, epididymis, vas deferens, urethra, penis, and the glands that produce semen.

FEMALE REPRODUCTIVE SYSTEM



The Female Reproductive System

Figure **15.2.4**: The main organs of the female reproductive system lie within the abdominal cavity. Pay attention to ovaries, uterine tube, uterus, cervix, and vagina.

The main structures of the female reproductive system are internal to the body and shown in Figure **15.2.4**. They include the paired ovaries, which are small, oval structures that produce eggs and secrete estrogen. The two Fallopian tubes (aka uterine tubes) start near the ovaries and end at the uterus. Their function is to transport eggs from the ovaries to the uterus. If an egg is fertilized, it usually occurs while it is traveling through a Fallopian tube. The uterus is a pear-shaped muscular organ that functions to carry a fetus until birth. It can expand greatly to accommodate a growing fetus, and its muscular walls can contract forcefully during labor to push the baby into the vagina. The vagina is a tubular tract connecting the uterus to the outside of the body. The vagina is where sperm are usually deposited during sexual intercourse and ejaculation. The vagina is also called the birth canal because a baby travels through the vagina to leave the body during birth.

The external structures of the female reproductive system are referred to collectively as the vulva. They include the clitoris, which is homologous to the male penis. They also include two pairs of labia (singular, labium), which surround and protect the openings of the urethra and vagina.

REVIEW

1. What is the reproductive system?
2. Define gonad.
3. What are sex hormones? What are their general functions?
4. Distinguish between male and female sex hormones.
5. How does the differentiation of the reproductive system occur in males and females?
6. In the context of the human male and female reproductive systems, what are homologous structures?
7. When and how does the human reproductive system mature?
8. List the organs of the male reproductive system.
9. List the organs of the female reproductive system.
10. What are female gametes called? What are male gametes called?
11. *True or False:* The vagina is the homologous structure to the penis.
12. *rue or False:* In the absence of a Y chromosome in humans, ovaries will develop.
13. Which are secondary sex characteristics?
    A. Fallopian tubes
    B. ovaries
    C. breasts
    D. all of the above
14. Fertilization usually occurs in which of these structures?
    A. ovary
    B. Fallopian tube
    C. uterus
    D. vagina
15. Explain the difference between the vulva and the vagina.

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15.3: STRUCTURES OF THE MALE REPRODUCTIVE SYSTEM

ROCKY MOUNTAIN OYSTERS

First, they are peeled and pounded flat. Then, they are coated in flour, seasoned with salt and pepper, and deep-fried. What are they? They are often called Rocky Mountain oysters, but they don't come from the sea. They may also be known as Montana tendergroin, cowboy caviar, or swinging beef — all names that hint at their origins. Here's another hint: they are harvested only from male animals, such as bulls or sheep. What are they? In a word: testes.



Figure **15.3.1**: Lamb fries are fried lamb testicles

TESTES AND SCROTUM

The two **testes** (singular, testis) are sperm- and testosterone-producing gonads in male mammals, including male humans. These and other organs of the human male reproductive system are shown in Figure **15.3.2**. The testes are contained within the **scrotum,** a pouch made of skin and smooth muscle that hangs down behind the penis.

TESTES STRUCTURE

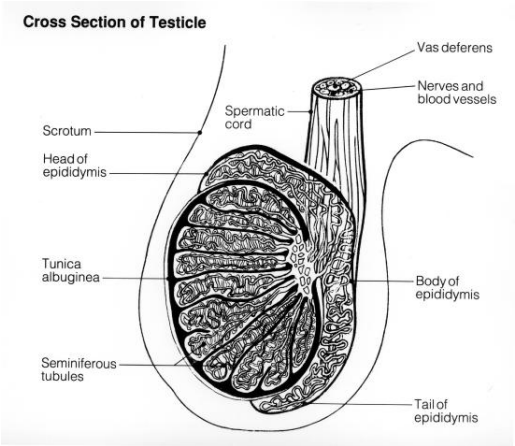


Figure **15.3.2**: This drawing includes a testis, epididymis, and vas (or ductus) deference. The three structures are connected to create a tract through which sperm can travel. Testes are composed of microscopic tubes called Seminiferous tubues where spersm are produced. Sperm is stored in epididymis after maturation until it is ejeculated via vas derernes.

The testes are filled with hundreds of tiny tubes, called **seminiferous tubules**, which are the functional units of the testes. The seminiferous tubules are coiled and tightly packed within divisions of the testis called lobules. Lobules are separated from one another by internal walls (or septa).

One or more seminiferous tubules are tightly coiled within each of the hundreds of lobules in the testis. A single testis normally contains a total of about 30 m (90 ft) of these tightly packed tubules! As shown in the cross-sectional drawing of a seminiferous tubule in Figure **15.3.2**, the tubule contains sperm in several different stages of development

OTHER SCROTAL STRUCTURES

Besides the two testes, the scrotum also contains a pair of organs called epididymes (singular, epididymis) and part of each of the paired vas deferens (or ducti deferens). Both structures play important functions in the production or transport of sperm.

EPIDIDYMIS

The seminiferous tubules within each testis join together to form ducts (called efferent ducts) that transport immature sperm to the epididymis associated with that testis. Each **epididymis** (plural, epididymes) consists of a tightly coiled tubule with a total length of about 6 m (20 ft). As shown in Figure **15.3.2** the epididymis is generally divided into three parts: the head (which rests on top of the testis), the body (which drapes down the side of the testis), and the tail (which joins with the vas deferens near the bottom of the testis). The functions of the two epididymes are to mature sperm, and then to store that mature sperm until they leave the body during an ejaculation when they pass the sperm on to the vas deferens.

VAS DEFERENS

The **vas deferens,** also known as sperm ducts, are a pair of thin tubes, each about 30 cm (1 ft) long, which begin at the epididymis in the scrotum and continue up into the pelvic cavity. They are composed of ciliated epithelium and smooth muscle. These structures help the vas deferens fulfill their function of transporting sperm from the epididymes to the ejaculatory ducts, which are accessory structures of the male reproductive system.

ACCESSORY STRUCTURES

In addition to the structures within the scrotum, the male reproductive system includes several internal accessory structures. They include the ejaculatory ducts, seminal vesicles, and the prostate and bulbourethral (Cowper's) glands. See Figure **15.3.3**. The major reproductive structures represented in this figure are explained below.

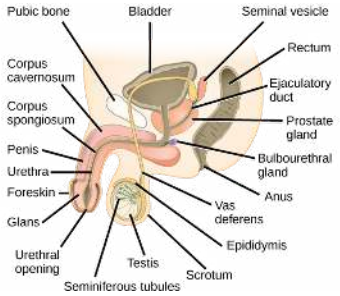


Figure **15.3.3**: The figure shows the ejaculatory duct, seminal vesicles, and the bulbourethral gland that produce semen. The figure also shows the other major structures of the male reproductive system.

SEMINAL VESICLES

The **seminal vesicles** are a pair of glands that each consist of a single tube, which is folded and coiled upon itself. Each vesicle is about 5 cm (2 in.) long and has an excretory duct that merges with the vas deferens to form one of the two ejaculatory ducts. Fluid secreted by the seminal vesicles into the ducts makes up about 70 percent of the total volume of **semen,** which is the sperm-containing fluid that leaves the penis during an ejaculation. The fluid from the seminal vesicles is alkaline, so it gives semen a basic pH that helps prolong the lifespan of sperm after it enters the acidic secretions inside the female vagina. Fluid from the seminal vesicles also contains proteins, fructose (a simple sugar), and other substances that help nourish sperm.

EJACULATORY DUCTS

The **ejaculatory ducts** form where the vas deferens join with the ducts of the seminal vesicles in the prostate gland. They connect the vas deferens with the urethra. The ejaculatory ducts carry sperm from the vas deferens, as well as secretions from the seminal vesicles and the prostate gland that together form semen. The substances secreted into semen by the glands as it passes through the ejaculatory ducts control its pH and provide nutrients to sperm, among other functions. The fluid itself provides sperm with a medium in which to “swim.”

PROSTATE GLAND

The **prostate gland** is located just below the seminal vesicles. It is a walnut-sized organ that surrounds the urethra and its junction with the two ejaculatory ducts. The function of the prostate gland is to secrete a slightly alkaline fluid that constitutes close to 30 percent of the total volume of semen. The prostate fluid contains small quantities of proteins, such as enzymes. In addition, it has a very high concentration of zinc, which is an important nutrient for maintaining sperm quality and motility.

BULBOURETHRAL GLANDS

Also called Cowper’s glands, the two **bulbourethral glands** are each about the size of a pea and located just below the prostate gland. The bulbourethral glands secrete a clear, alkaline fluid that is rich in proteins. Each of the glands has a short duct that carries the secretions into the urethra, where they make up a tiny percentage of the total volume of semen. The function of the bulbourethral secretions is to help lubricate the urethra and neutralize any urine (which is acidic) that may remain in the urethra.

PENIS

The **penis** is the external male organ that has the reproductive function of delivering sperm to the female reproductive tract. This function is called intromission. The penis also serves as the organ that excretes urine.

STRUCTURE OF THE PENIS

The structure of the penis and its location relative to other reproductive organs are shown in Figure **15.3.4**. The part of the penis that is located inside the body and out of sight is called the root of the penis. The shaft of the penis is the part of the penis that is outside the body. The enlarged, bulbous end of the shaft is called the glans penis.

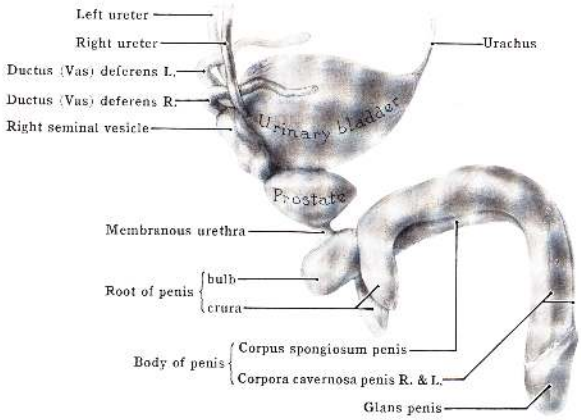


Figure **15.3.4**: This section shows the internal anatomy of the penis and related structures. The penis is composed of glans pernis, shaft, root of pernis. The corpus spongiosum is the column of erectile tissue that contains the urethra. The corpora cavernosa are the other two columns that erect the penis.

URETHRA

The urethra passes through the penis to carry urine from the bladder — or semen from the ejaculatory ducts — through the penis and out of the body. After leaving the urinary bladder, the urethra passes through the prostate gland, where the urethra is joined by the ejaculatory ducts. From there, the urethra passes through the penis to its external opening at the tip of the glans penis. Called the external urethral orifice, this opening provides a way for urine or semen to leave the body.

TISSUES OF THE PENIS

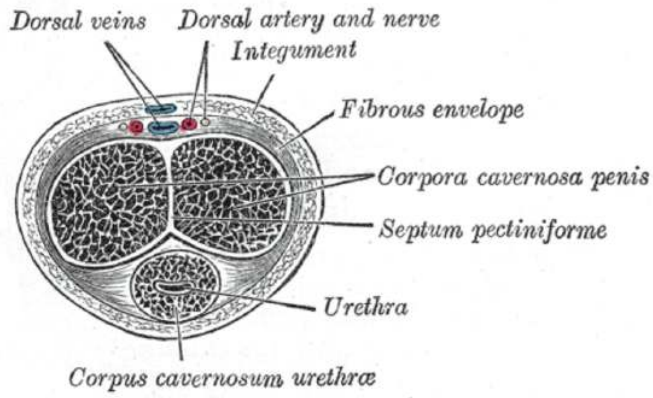


Figure 15.3.5: Cross-section of the penis: The penis consists mostly of spongy tissues that can fill with blood, stiffening the organ. The corpus cavernosum urethrae are now called corpus spongiosum. You can see the urethra in the center of the corpus spongiosum.

The penis is covered with skin (epithelium) that is unattached and free to move over the body of the penis. In an uncircumcised male, the glans penis is also mainly covered by epithelium, which (in this location) is called the foreskin, and below which is a layer of the mucous membrane. The foreskin is attached to the penis at an area on the underside of the penis called the frenulum.

As shown in Figure 15.3.5, the interior of the penis consists of three columns of spongy tissue that can fill with blood and swell in size, allowing the penis to become erect. This spongy tissue is called corpus cavernosum (plural, corpora cavernosa). Two columns of this tissue run side by side along the top of the shaft, and one column runs along the bottom of the shaft. The urethra runs through this bottom column of spongy tissue, which is sometimes called corpus spongiosum. The glans penis also consists mostly of spongy erectile tissue. Veins and arteries run along the top of the penis, allowing blood circulation through the spongy tissues.

FEATURE: HUMAN BIOLOGY IN THE NEWS

Lung, heart, kidney, and other organ transplants have become relatively commonplace, so when they occur, they are unlikely to make the news. However, when the nation's first penis transplant took place, it was considered very newsworthy.

In 2016, Massachusetts General Hospital in Boston announced that a team of its surgeons had performed the first penis transplant in the United States. The patient who received the donated penis was a 64-year-old cancer patient. During the 15-hour procedure, the intricate network of nerves and blood vessels of the donor penis were connected with those of the penis recipient. The surgery went well, but doctors reported it would be a few weeks until they would know if normal urination would be possible, and even longer before they would know if sexual functioning would be possible. At the time that news of the surgery was reported in the media, the patient had not shown any signs of rejecting the donated organ. The surgeons also reported they were hopeful that such transplants would become relatively common, and that patient populations would expand to include wounded warriors and transgender males seeking to transition.

The 2016 Massachusetts operation was not the first penis transplant ever undertaken. The world's first successful penis transplant was actually performed in 2014 in Cape Town, South Africa. A young man who had lost his penis from complications of a botched circumcision at age 18 was given a donor penis three years later. That surgery lasted nine hours and was highly successful. The young man made a full recovery and regained both urinary and sexual functions in the transplanted organ.

In 2005, a man in China also received a donated penis in a technically successful operation. However, the patient asked doctors to reverse the procedure just two weeks later, because of psychological problems associated with the transplanted organ for both himself and his wife.

REVIEW

1. What are the testes? Where are they located?
2. Describe the structure of a testis.
3. Identify the epididymis and its functions.
4. What are the vas deferens? What do they do?
5. Where are the seminal vesicles located? What is their reproductive role?
6. Which parts of the male reproductive system are connected by the ejaculatory ducts? What fluids enter and leave the ejaculatory ducts?
7. Identify the location of the prostate gland relative to other male reproductive organs. What is the prostate's function?
8. Where are the bulbourethral glands? What is their function?
9. Relate the structure of the penis to its two basic functions.
10. For each of the descriptions below, match the part of the male reproductive system from the list that best fits it. Each part is used only once. Parts of the male reproductive system: *urethra*, *seminal vesicle*, *epididymis*, *testes*
    A. Sperm are produced here.
    B. Sperm mature here.
    C. Sperm are transported through the penis in this structure.
    D. This is a gland that produces fluid that is a major component of semen.
11. A vasectomy is a form of birth control for men that is performed by surgically cutting or blocking the vas deferens so that sperm cannot be ejaculated out of the body. Do you think men who have a vasectomy emit semen when they ejaculate? Why or why not?
12. Which of the following structures are located internally within the body? Choose all that apply.
    A. testes
    B. seminal vesicles
    C. epididymis
    D. prostate
    E. glans penis

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15.4: FUNCTIONS OF THE MALE REPRODUCTIVE SYSTEM

COLORFUL SPERM

The false-color image in Figure **15.4.1** shows real human sperm. The tiny gametes are obviously greatly magnified in the picture because they are actually the smallest of all human cells. In fact, human sperm cells are small, even when compared with sperm cells of other animals. Mice sperm are about *twice* the length of human sperm! Human sperm may be small in size, but in a normal, healthy man, huge numbers of them are usually released during each ejaculation. There may be hundreds of millions of sperm cells in a single teaspoon of semen. Producing sperm is one of the major functions of the male reproductive system.

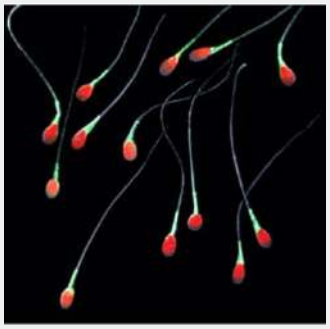


Figure **15.4.1**: Human spermatozoa (sperm cells)

SPERM ANATOMY

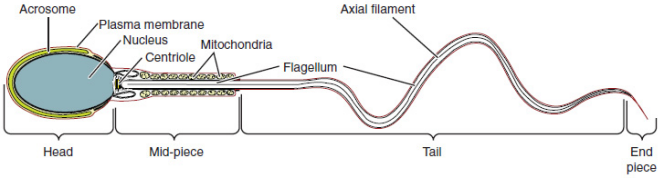


Figure **15.4.2**: Each normal mature sperm cell has the structures labeled in this image. The acrosome is at the front end, just behind the nucleus. The midpiece connects the nucleus to the tail.

A mature sperm cell has several structures that help it reach and penetrate an egg. These are labeled in the drawing of a sperm shown in Figure **15.4.2**.

- The **head** is the part of the sperm that contains the nucleus — and not much else. The nucleus, in turn, contains tightly coiled DNA that is the male parent's contribution to the genetic makeup of a zygote (if one forms). Each sperm is a haploid cell, containing half the chromosomal complement of a normal, diploid body cell.
- The front of the head is an area called the **acrosome**. The acrosome contains enzymes that help the sperm penetrate an egg (if it reaches one).
- The **midpiece** is the part of the sperm between the head and the flagellum tail. The midpiece is packed with mitochondria that produce the energy needed to move the flagellum.
- The **flagellum** (also called the tail) can rotate like a propeller, allowing the sperm to "swim" through the female reproductive tract to reach an egg if one is present.

SPERMATOGENESIS

The process of producing sperm is known as **spermatogenesis.** Spermatogenesis normally starts when a boy reaches puberty, and it usually continues uninterrupted until death, although a decrease in sperm production generally occurs at older ages. A young, healthy male may produce hundreds of millions of sperm a day! Only about half of these, however, are likely to become viable, mature sperm.

WHERE SPERM ARE PRODUCED

Spermatogenesis occurs in the seminiferous tubules in the testes. Spermatogenesis requires high concentrations of testosterone. Testosterone is secreted by Leydig cells, which are adjacent to the seminiferous tubules in the testes.

Sperm production in the seminiferous tubules is very sensitive to temperature. This may be the most important reason the testes are located outside the body in the scrotum. The temperature inside the scrotum is generally about 2 degrees Celsius (almost 4 degrees Fahrenheit) cooler than core body temperature. This lower temperature is optimal for spermatogenesis. The scrotum regulates its internal temperature as needed by contractions of the smooth muscles lining the scrotum. When the temperature inside the scrotum becomes too low, the scrotal muscles contract. The contraction of the muscles pulls the scrotum higher against the body, where the temperature is warmer. The opposite occurs when the temperature inside the scrotum becomes too high.

EVENTS OF SPERMATOGENESIS

Figure **15.4.3** summarizes of the main cellular events that occur in the process of spermatogenesis. The process begins with a diploid stem cell called a **spermatogonium** (plural, spermatogonia), and involves several cell divisions. The entire process takes at least ten weeks to complete, including maturation in the epididymis.

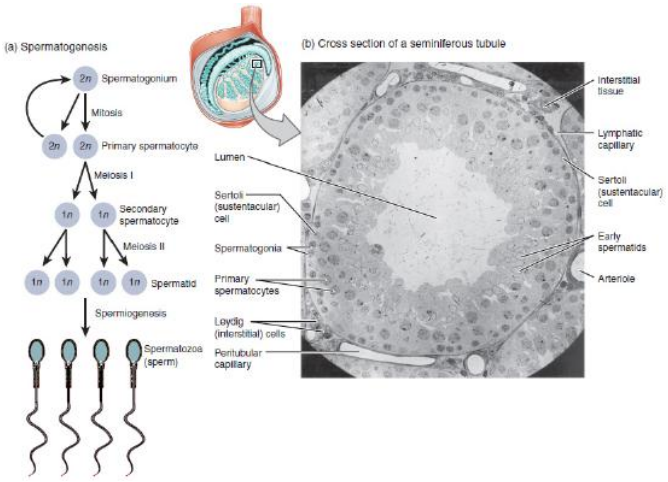


Figure **15.4.3**: Spermatogenesis includes one mitotic division and two meiotic divisions. Also on the right, the cross-section of the seminiferous tubule shows the locations of the lumen, cells of spermatogenesis, Sertoli, and Leydig cells in the tube.

1. A spermatogonium undergoes mitosis to produce two diploid cells called primary spermatocytes. One of the primary spermatocytes goes on to produce sperm. The other replenishes the reserve of spermatogonia.
2. The primary spermatocyte undergoes meiosis I to produce two haploid daughter cells called secondary spermatocytes.
3. The secondary spermatocytes rapidly undergo meiosis II to produce a total of four haploid daughter cells called spermatids.
4. The spermatids begin to form a tail, and their DNA becomes highly condensed. Unnecessary cytoplasm and organelles are removed from the cells, and they form a head, midpiece, and flagellum. The resulting cells are sperm (spermatozoa).

As shown in Figure **15.4.3**, the events of spermatogenesis begin near the wall of the seminiferous tubule — where spermatogonia are located — and continue inward toward the lumen of the tubule. Sertoli cells extend from the wall of the seminiferous tubule inward toward the lumen, so they are in contact with developing sperm at all stages of spermatogenesis. Sertoli cells play several roles in spermatogenesis:

- They secrete endocrine hormones that help regulate spermatogenesis.
- They secrete substances that initiate meiosis.
- They concentrate testosterone (from Leydig cells), which is needed at high levels to maintain spermatogenesis.
- They phagocytize the extra cytoplasm that is shed from developing sperm cells.
- They secrete a testicular fluid that helps carry sperm into the epididymis.
- They maintain a blood-testis barrier, so immune system cells cannot reach and attack the sperm

MATURATION IN THE EPIDIDYMIS

Although the sperm produced in the testes have tails, they are not yet motile (able to “swim”). The non-motile sperms are transported to the epididymis in the testicular fluid that is secreted by Sertoli cells with the help of peristaltic contractions. In the epididymis, the sperms gain motility, so they are capable of swimming up the female genital tract and reaching an egg. The mature sperms are stored in the epididymis until ejaculation occurs.

EJACULATION

Sperms are released from the body during **ejaculation,** which typically occurs during orgasm. Hundreds of millions of mature sperm — contained within a small amount of thick, whitish fluid called semen — are propelled from the penis during a normal ejaculation.

HOW EJACULATION OCCURS

Ejaculation occurs when peristalsis of the muscle layers of the vas deferens and other accessory structures propel sperm from the epididymes, where mature sperm are stored. The muscle contractions force the sperm through the vas deferens and the ejaculatory ducts, and then out of the penis through the urethra. Due to the peristaltic action of the muscles, the ejaculation occurs in a series of spurts.

THE ROLE OF SEMEN

As sperms travel through the ejaculatory ducts during ejaculation, they mix with secretions from the seminal vesicles, prostate gland, and bulbourethral glands to form semen (Figure **15.4.4**). The average amount of semen per ejaculate is about 3.7 mL, which is a little less than a teaspoonful. Most of this volume of semen consists of glandular secretions, with the hundreds of millions of sperm cells actually contributing relatively little to the total volume.



Figure **15.4.4**: This petri dish shows normal human semen in a typical ejaculate.

The secretions in semen are important for the survival and motility of sperm. They provide a medium through which sperm can swim. They also include sperm-sustaining substances, such as high concentrations of the sugar fructose, which is the main source of energy for sperm. In addition, semen contains many alkaline substances that help neutralize the acidic environment in the female vagina. This protects the DNA in sperm from being denatured by the acid and prolongs the life of sperm in the female reproductive tract.

ERECTION

Besides providing a way for sperm to leave the body, the main role of the penis in reproduction is **intromission** or depositing sperm in the vagina of the female reproductive tract. Intromission depends on the ability of the penis to become stiff and erect, a state referred to as an **erection.** The human penis, unlike that of most other mammals, contains no erectile bone. Instead, in order to reach its erect state, it relies entirely on engorgement with the blood of its columns of spongy tissue. During sexual arousal, the arteries that supply blood

to the penis dilate, allowing more blood to fill the spongy tissue. The now-engorged spongy tissue presses against and constricts the veins that carry blood away from the penis. As a result, more blood enters than leaves the penis, until a constant erectile size is achieved.

In addition to sperm, the penis also transports urine out of the body. These two functions cannot occur simultaneously. During an erection, the sphincters that prevent urine from leaving the bladder are controlled by centers in the brain so they cannot relax and allow urine to enter the urethra.

TESTOSTERONE PRODUCTION

The final major function of the male reproductive system is the production of the male sex hormone testosterone. In mature males, this occurs mainly in the testes. Testosterone production is under the control of luteinizing hormone (LH) from the pituitary gland. LH stimulates Leydig cells in the testes to secrete testosterone.

Testosterone is important for male sexual development at puberty. It stimulates maturation of the male reproductive organs, as well as the development of secondary male sex characteristics (such as facial hair). Testosterone is also needed in mature males for normal spermatogenesis to be maintained in the testes. Follicle stimulating hormone (FSH) from the pituitary gland is also needed for spermatogenesis to occur, in part because it helps Sertoli cells in the testes concentrate testosterone to high enough levels to maintain sperm production. Testosterone is also needed for the proper functioning of the prostate gland. In addition, testosterone plays a role in erection, allowing sperm to be deposited within the female reproductive tract.

FEATURE: MY HUMAN BODY

If you're a man and you use a laptop computer on your lap for long periods of time, you may be decreasing your fertility. The reason? A laptop computer generates considerable heat, and its proximity to the scrotum during typical use results in a significant rise in temperature inside the scrotum. Spermatogenesis is very sensitive to high temperatures, so it may be adversely affected by laptop computer use. If you want to avoid the potentially fertility-depressing effect of laptop computer use, you might want to consider using your laptop computer on a table or other surface rather than on your lap — at least when you log on for long computer sessions. Other activities that raise scrotal temperature and have the potential to reduce spermatogenesis including soaking in hot tubs, wearing tight clothing, and biking. Although the effects of short-term scrotal heating on fertility seem to be temporary, years of such heat exposure may cause irreversible effects on sperm production.



Figure **15.4.5**: A male with a laptop on his lap

REVIEW

1. List parts of mature sperm.
2. What is spermatogenesis? When does it occur?
3. Where does spermatogenesis take place? State one role of Sertoli cells in spermatogenesis.
4. Summarize the steps of sperm production, naming the cells and processes involved.
5. What must happen to sperm before they are able to "swim"?
6. What is ejaculation?
7. Describe semen and its components.
8. Define intromission. How is it related to erection?
9. Explain how an erection occurs.
10. What cells secrete testosterone? What controls this process?
11. Identify the functions of testosterone in males.
12. Which of the following cells are haploid? Choose all that apply.
    1. spermatids
    2. spermatogonia
    3. primary spermatocytes
    4. secondary spermatocytes
    5. mature sperm
13. Describe one way in which Leydig and Sertoli cells work together to maintain spermatogenesis.
14. *True or False:* When it is cold outside the body, the scrotal muscles relax.
15. *True or False:* During an erection, the arteries and veins of the penis dilate.

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15.5: DISORDERS OF THE MALE REPRODUCTIVE SYSTEM

OFFERING TO THE GODS

The marble penis and scrotum depicted in Figure **15.5.1** comes from ancient Rome, during the period from about 200 BCE to 400 CE. During that time, offerings like this were commonly given to the gods by people with health problems, either in the hopes of a cure or as thanks for receiving one. The offerings were generally made in the shape of the afflicted body part. Scholars think this marble penis and scrotum may have been an offering given in hopes of — or thanks for — a cure for impotence, known medically today as erectile dysfunction.



Figure **15.5.1**: Votive male genitalia, Roman, 200 BCE-400 CE

ERECTILE DYSFUNCTION

Erectile dysfunction (ED) is sexual dysfunction characterized by the regular and repeated inability of a sexually mature individual to obtain or maintain an erection. It is a common disorder that affects about 40 percent of people with penises.

CAUSES OF ERECTILE DYSFUNCTION

The penis normally stiffens and becomes erect when the columns of spongy tissue within the shaft of the penis (the corpora cavernosa and corpus spongiosum) become engorged with blood. Anything that hampers normal blood flow to the penis may, therefore, interfere with its potential to fill with blood and become erect. The normal nervous control of sexual arousal or penile engorgement may also fail and lead to problems obtaining or maintaining an erection

Specific causes of ED include both physiological and psychological causes. Physiological causes include the use of therapeutic drugs (such as antidepressants), aging, kidney failure, diseases (such as diabetes or multiple sclerosis), tobacco smoking, and treatments for other disorders (such as prostate cancer). Psychological causes are less common but may include stress, performance anxiety, or mental disorders. The risk of ED may also be greater in people with obesity, cardiovascular disease, poor dietary habits, and overall poor physical health. Having an untreated hernia in the groin may also lead to ED.

TREATMENTS FOR ERECTILE DYSFUNCTION

Treatment of ED depends on its cause or contributing factors. For example, for tobacco smokers, smoking cessation may bring significant improvement in ED. Improving overall physical health by losing weight and exercising regularly may also be beneficial. The most common first-line treatment for ED, however, is the use of oral prescription drugs, known by brand names such as Viagra® and Cialis®. These drugs help ED by increasing blood flow to the penis. Other potential treatments include topical creams applied to the penis, injection of drugs into the penis, or the use of a vacuum pump that helps draw blood into the penis by applying negative pressure. More invasive approaches may be used as a last resort if other treatments fail. These usually involve surgery to implant inflatable tubes or rigid rods into the penis.

Ironically, the world's most venomous spider —the Brazilian wandering spider (Figure **15.5.2**) — may offer a new treatment for ED. The venom of this spider is known to cause priapism in humans. Priapism is a prolonged erection that may damage the reproductive organs and lead to infertility if it continues too long. Researchers are investigating one of the components of the spider's venom as a possible treatment for ED if taken in minute quantities.



Figure **15.5.2**: The venom of a Brazilian wandering spider may be deadly, but one of its components might lead to a new treatment for ED.

EPIDIDYMITIS

Epididymitis is inflammation of the epididymis. The epididymis is one of the paired organs within the scrotum where sperm mature and are stored. Discomfort or pain and swelling in the scrotum are typical symptoms of epididymitis, which is a relatively common condition, especially in young individuals. In the U.S. alone, more than half a million cases of epididymitis are diagnosed annually between the ages of 18 and 35.

ACUTE VS. CHRONIC EPIDIDYMITIS

Epididymitis may be acute or chronic. Acute diseases are generally short-term conditions, whereas chronic diseases may last years or even a lifetime.

ACUTE EPIDIDYMITIS

Acute epididymitis generally has a fairly rapid onset and is most often caused by a bacterial infection. Bacteria in the urethra can

backflow through the urinary and reproductive structures to the epididymis. In sexually active individuals, many cases of acute epididymitis are caused by sexually transmitted bacteria. Besides pain and swelling, common symptoms of acute epididymitis include redness, warmth in the scrotum, and a fever. There may also be a urethral discharge.

CHRONIC EPIDIDYMITIS

Chronic epididymitis is epididymitis that lasts for more than three months. In some, the condition may last for years. It may occur with or without a bacterial infection being diagnosed. Sometimes, it is associated with lower back pain after an activity that stresses the lower back, such as heavy lifting or a long time spent driving a vehicle.

TREATMENT OF EPIDIDYMITIS

If a bacterial infection is suspected, acute and chronic epididymitis are generally treated with antibiotics. Antibiotic treatment may be prescribed for chronic epididymitis for four to six weeks to ensure the complete eradication of any possible bacteria. Additional treatments often include anti-inflammatory drugs to reduce inflammation of the tissues and painkillers to control the pain, which may be severe. Physically supporting the scrotum and applying cold compresses may also be recommended to help relieve swelling and pain.

Regardless of symptoms, treatment is important for both acute and chronic epididymitis because major complications may occur otherwise. Untreated acute epididymitis may lead to an abscess—a buildup of pus—or to the infection spreading to other organs. Untreated chronic epididymitis may lead to permanent damage to the epididymis and testis, and it may even cause infertility.

MALE REPRODUCTIVE CANCERS

Why does the Brazilian hospital pictured in Figure **15.5.3** have a huge blue mustache on its "face"? The mustache is a symbol of "Movember." This is an international campaign to raise awareness of prostate cancer, as well as money to fund prostate cancer research.



Figure **15.5.3**: The mustache is a symbol for "Movember," a campaign against prostate cancer.

PROSTATE CANCER

The prostate gland is an organ located in the male pelvis. The urethra passes through the prostate gland after it leaves the bladder and before it reaches the penis. The function of the prostate is to secrete zinc and other substances into semen during ejaculation. In the United States, **prostate cancer** is the most common type of cancer and the second leading cause of cancer death in people carrying prostate gland. About 80 percent of American individuals with the prostate will have cancerous cells in their prostate gland by the age of 80.

HOW PROSTATE CANCER OCCURS

Prostate cancer occurs when glandular cells of the prostate mutate into tumor cells. Eventually, the tumor, if undetected, may invade nearby structures, such as the seminal vesicles. Tumor cells may also metastasize and travel in the bloodstream or lymphatic system to organs elsewhere in the body. Prostate cancer most commonly metastasizes to the bones, lymph nodes, rectum, or lower urinary tract organs.

SYMPTOMS OF PROSTATE CANCER

Early in the course of prostate cancer, there may be no symptoms. When symptoms *do* occur, they mainly involve urination, because the urethra passes through the prostate gland. The symptoms typically include frequent urination, difficulty starting and maintaining a steady stream of urine, blood in the urine, and painful urination. Prostate cancer may also cause problems with sexual function, such as difficulty achieving an erection or painful ejaculation.

RISK FACTORS FOR PROSTATE CANCER

Some factors that increase the risk of prostate cancer can be changed, and others cannot.

- Risk factors that *can* be changed include a diet high in meat, a sedentary lifestyle, obesity, and high blood pressure.
- Older age, a family history of prostate cancer, and African ancestry are risk factors that cannot be changed. Family history is an important risk factor, so genes are involved. Many different genes have been implicated.

DIAGNOSING PROSTATE CANCER

The only definitive test to confirm a diagnosis of prostate cancer is a biopsy. In this procedure, a small piece of the prostate gland is surgically removed and then examined microscopically. A biopsy is done only after less invasive tests have found evidence that a patient may have prostate cancer.

A routine exam by a doctor may find a lump on the prostate, which might be followed by a blood test that detects an elevated level of prostate-specific antigen (PSA). PSA is a protein secreted by the prostate that normally circulates in the blood. Higher-than-normal levels of PSA can be caused by prostate cancer, but they may also have other causes. Ultrasound or magnetic resonance imaging (MRI) might also be undertaken to provide images of the prostate gland and additional cancer information.

TREATMENT OF PROSTATE CANCER

The average age at which men are diagnosed with prostate cancer is 70. Prostate cancer is typically such a slow-growing cancer that elderly patients may not require treatment. Instead, the patients are

watched carefully over the subsequent years to make sure the cancer isn't growing and posing an immediate threat — an approach that is called active surveillance. It is used for at least 50 percent of patients who are expected to die from other causes before their prostate cancer causes symptoms.

Treatment of younger patients — or those with more aggressively growing tumors — may include surgery to remove the prostate, chemotherapy, and/or radiation therapy (such as brachytherapy, see Figure **15.5.4**). All of these treatment options can have significant side effects, such as erectile dysfunction or urinary incontinence. Patients should learn the risks and benefits of the different treatments, and discuss them with their healthcare provider to decide on the best treatment options for their particular case.

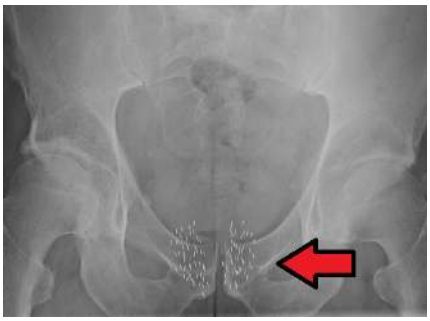


Figure **15.5.4**: Brachytherapy is a form of radiation therapy for prostate cancer. Radioactive "seeds" like the ones shown here are inserted into the prostate gland. The seeds give off radiation that kills cancer cells.

TESTICULAR CANCER

Reproductive cancer, which is rare and most commonly affects young individuals, is **testicular cancer**. The testes are the paired reproductive organs in the scrotum that produce sperm and secrete testosterone. The risk of testicular cancer is about four to five times greater in individuals of European than African ancestry. The cause of this difference is unknown.

SIGNS AND SYMPTOMS OF TESTICULAR CANCER

One of the first signs of testicular cancer is often a lump or swelling in one of the two testes. The lump may or may not be painful. If pain is present, it may occur as a sharp pain or a dull ache in the lower abdomen or scrotum. Some people with testicular cancer report a feeling of heaviness in the scrotum. Testicular cancer does not commonly spread beyond the testis, but if it does, it most often spreads to the lungs, where it may cause shortness of breath or a cough.

DIAGNOSIS OF TESTICULAR CANCER

The main way testicular cancer is diagnosed is by detecting a lump in the testis. Further diagnostic tests will likely follow this. An ultrasound may be done to determine the exact location, size, and characteristics of the lump. Blood tests may be done to identify and measure tumor-marker proteins in the blood that are specific to testicular cancer. CT scans may also be done to determine whether the disease has spread beyond the testis. However, unlike the case with prostate cancer, a biopsy is not recommended because it increases the risk of cancer cells spreading into the scrotum.

TREATMENT OF TESTICULAR CANCER

Testicular cancer has one of the highest cure rates of all cancers. Three basic types of treatment for testicular cancer are surgery, radiation therapy, and/or chemotherapy. Generally, the initial treatment is surgery to remove the affected testis. If the cancer is caught at an early stage, the surgery is likely to cure the cancer and has nearly a 100 percent five-year survival rate. When just one testis is removed, the remaining (if healthy) is adequate to maintain fertility, hormone production, and other normal functions. Radiation therapy and/or chemotherapy may follow surgery to kill any tumor cells that might exist outside the affected testis, even when there is no indication that cancer has spread. In many cases, however, surgery is followed by surveillance instead of additional treatments.

REVIEW

1. What is erectile dysfunction? When does it occur?
2. Underlying causes of erectile dysfunction may include physiological and/or psychological factors. Identify some of these factors.
3. Discuss types of treatment for erectile dysfunction.
4. Define epididymitis. What is its most common cause?
5. Identify possible treatments for epididymitis. Why is treatment important, even when there are no symptoms?
6. Rank prostate cancer as a cause of cancer and a cause of cancer death in men. What are some of the symptoms of prostate cancer?
7. List the risk factors for prostate cancer.
8. How is prostate cancer detected?
9. In many cases, treatment for prostate cancer is unnecessary. Why? When is treatment necessary, and what are the treatment options?
10. Testicular cancer is generally rare, but it is the most common cancer in one age group. What age group is it?
11. Identify possible signs and symptoms of testicular cancer.
12. How can testicular cancer be diagnosed?
13. Describe how testicular cancer is typically treated.
14. Which of the following is common in younger individuals (i.e., under age 39)?

    A. prostate cancer
    B. testicular cancer
    C. epididymitis
    D. B and C

15. A biopsy is important in cases of suspected:

    A. epididymitis
    B. testicular cancer
    C. prostate cancer
    D. B and C

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15.6: STRUCTURES OF THE FEMALE REPRODUCTIVE SYSTEM

FERTILITY SYMBOL

The geometric design on this ancient stone carving represents a powerful symbol of fertility: the vagina. The symbol is called yoni in Hindu, and it reflects the value placed by Hindu culture on the ability to give birth. The vagina is one of several organs in the female reproductive system.



Figure **15.6.1**: A stone yoni found in Cát Tiên sanctuary, Lam Dong, Vietnam.

FEMALE REPRODUCTIVE ORGANS

The female reproductive system is made up of internal and external organs that function to produce haploid gametes called eggs (or oocytes), secrete sex hormones (such as estrogen), and carry and give birth to a fetus. As shown in Figure **15.6.2**, the internal reproductive organs include the vagina, uterus, Fallopian (uterine) tubes, and ovaries. The external organs — collectively called the vulva — include the clitoris and labia.

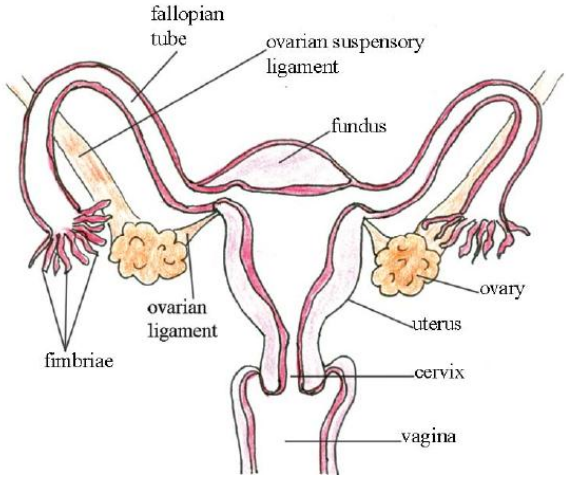


Figure **15.6.2**: Structures of the internal female reproductive organs.

The **vagina** is an elastic, muscular canal leading from its opening in the vulva to the neck of the uterus, called the cervix. It is about 7.5 cm (3.0 in.) long at the front, and about 9 cm (3.5 in.) long at the back. The vagina accommodates the penis and is the site where sperm are usually ejaculated during sexual intercourse. In the context of pregnancy and natural (vaginal) childbirth, the vagina is also referred to as the birth canal. In addition, it channels the flow of menstrual blood from the uterus.

STRUCTURE OF THE VAGINA

The **vagina**, shown at the bottom of Figure **15.6.2**, is a muscular canal (approximately 10 cm long) that serves as the entrance to the reproductive tract. It also serves as the exit from the uterus during menses and childbirth. The outer walls of the anterior and posterior vagina are formed into longitudinal columns or ridges, and the superior portion of the vagina—called the fornix—meets the protruding uterine cervix. The walls of the vagina are lined with an outer, fibrous adventitia; a middle layer of smooth muscle; and an inner mucous membrane with transverse folds called **rugae**. Together, the middle and inner layers allow the expansion of the vagina to accommodate intercourse and childbirth. The thin, perforated hymen can partially surround the opening to the vaginal orifice. The hymen can be ruptured with strenuous physical exercise, penile-vaginal intercourse, and childbirth. The Bartholin's glands and the lesser vestibular glands (located near the clitoris) secrete mucus, which keeps the vestibular area moist.

The vagina is home to a normal population of microorganisms that help to protect against infection by pathogenic bacteria, yeast, or other organisms that can enter the vagina. In a healthy individual, the most predominant type of vaginal bacteria is from the genus *Lactobacillus*. This family of beneficial bacterial flora secretes lactic acid, and thus protects the vagina by maintaining an acidic pH (below 4.5). Potential pathogens are less likely to survive in these acidic conditions. Lactic acid, in combination with other vaginal secretions, makes the vagina a self-cleaning organ. However, douching—or washing out the vagina with fluid—can disrupt the normal balance of healthy microorganisms, and actually increase the risk for infections and irritation. Indeed, the American College of Obstetricians and Gynecologists recommend that people do not douche and that they allow the vagina to maintain its normal healthy population of protective microbial flora.

UTERUS

The **uterus** (commonly called the womb) is a pear-shaped, muscular organ that is about 7.6 cm (3 in.) long. It is located above the vagina and behind the bladder in the center of the pelvis. The position of the uterus in the pelvis is stabilized by several ligaments and bands of supportive tissue. The uterus is where a fetus develops during gestation, and the organ provides mechanical protection and support for the developing offspring. Contractions of the muscular wall of the uterus are responsible for pushing the fetus out of the uterus during childbirth.

PARTS OF THE UTERUS

As shown in Figure **15.6.3**, the lower end of the uterus forms the **cervix,** which is also called the neck of the uterus. The cervix is about 2.5 cm (1 in.) long and protrudes downward into the vagina. A

small canal runs the length of the cervix, connecting the uterine cavity with the lumen of the vagina. This allows semen deposited in the vagina to enter the uterus, and a baby to pass from the uterus into the vagina during birth. Glands in the cervix secrete mucus that varies in water content and thickness, so it can function either as a barrier to keep microorganisms out of the uterus during pregnancy or as a transport medium to help sperm enter the uterus around the time of ovulation. The rest of the uterus above the cervix is called the body of the uterus. The upper end of the uterus is connected with the two Fallopian tubes.

TISSUES OF THE UTERUS

As indicated in Figure **15.6.3**, the uterus consists of three tissue layers, called the endometrium, myometrium, and perimetrium.

- The **endometrium** is the innermost tissue layer of the uterus. It consists of epithelial tissue, including mucous membranes. This layer thickens during each menstrual cycle and, unless an egg is fertilized, sloughs off during the following menstrual period. If an egg is fertilized, the thickened endometrium is maintained by hormones and provides nourishment to the embryo. As gestation progresses, the endometrium develops into the maternal portion of the placenta. The **placenta** is a temporary organ that consists of a mass of maternal and fetal blood vessels through which the mother's and fetus's blood exchange substances.
- The **myometrium** is the middle layer of the uterus. It consists mostly of a thick layer of smooth muscle tissue. Powerful contractions of the smooth muscle allow the uterus to contract and expel an infant during childbirth.
- The **perimetrium** is the outermost layer of the uterus. It covers the outer surface of the uterus. This layer actually consists of two layers of epithelium that secrete fluid into the space between them. The fluid allows for small movements of the uterus within the pelvis, without causing it to rub against other organs.

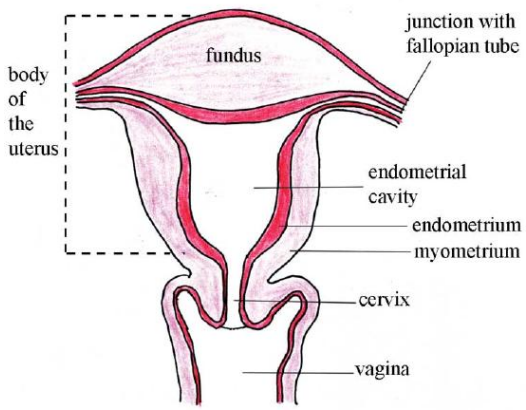


Figure **15.6.3**: The cervix of uterus connects it to vagina. The thick walls of the uterus are composed of layers of tissues known as endometrium, myometrium, and perimetrium.

FALLOPIAN TUBES

The **Fallopian tubes** (Figure **15.6.2**) are two thin tubes that lie between the ovaries and the uterus. The Fallopian tubes are not attached to the ovaries, but their broad upper ends — called infundibula — lie very close to the ovaries. The infundibula also have fringe-like extensions called fimbriae that move in a waving motion to help guide eggs from the ovaries into the Fallopian tubes. The lower ends of the Fallopian tubes are attached to the upper part of the body of the uterus on either side of the body. They open into the uterus. Egg is fertilized in the fallopian tubes.

OVARIES

The **ovaries** are the gonads. Paired ovals, they are each about 2 to 3 cm in length, about the size of an almond. The ovaries are located within the pelvic cavity and are supported by many ligaments. The ovaries are the ovum-producing organs of the internal reproductive system. The ovary is an ovum-producing reproductive organ, typically found in pairs. Ovaries are analogous to testes in that both are gonads and endocrine glands. Ovaries secrete both estrogen and progesterone. Estrogen is responsible for the appearance of secondary sex characteristics of females at puberty and for the maturation and maintenance of the reproductive organs in their mature functional state. Progesterone functions with estrogen by promoting menstrual cycle changes in the endometrium.

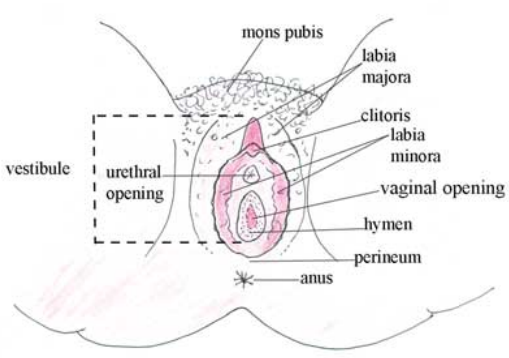


Figure **15.6.4**: External female genitalia (vulva)

VULVA

The external reproductive structures are referred to collectively as the **vulva** (Figure **15.6.4**). The **mons pubis** is a pad of fat that is located at the anterior, over the pubic bone. After puberty, it becomes covered in pubic hair. The **labia majora** (labia = "lips"; majora = "larger") are folds of hair-covered skin that begin just posterior to the mons pubis. The thinner and more pigmented **labia minora** (labia = "lips"; minora = "smaller") extend medially to the labia majora. Although they naturally vary in shape and size, the labia minora serve to protect the urethra and the entrance to the reproductive tract.

The superior, anterior portions of the labia minora come together to encircle the **clitoris** (or glans clitoris), an organ that originates from the same cells as the glans penis and has abundant nerves that make it important in sexual sensation and orgasm. The **hymen** is a thin membrane that sometimes partially covers the entrance to the vagina. An intact hymen cannot be used as an indication of "virginity"; even at birth, this is only a partial membrane, as menstrual fluid and other secretions must be able to exit the body,

regardless of penile-vaginal intercourse. The vaginal opening is located between the opening of the urethra and the anus. It is flanked by outlets to the **Bartholin's glands** (or greater vestibular glands).

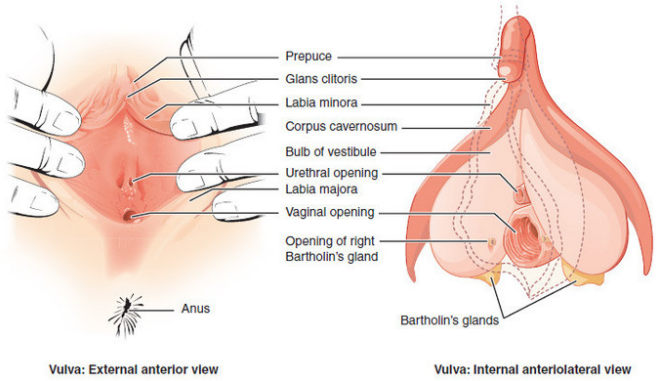


Figure **15.6.5**: External and internal view of a vulva

BREASTS

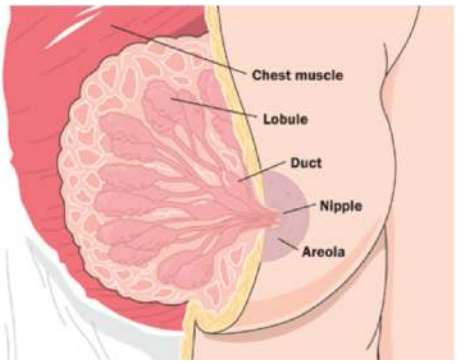


Figure **15.6.6**: The breasts are not really reproductive organs, but they play a reproductive role as mammary glands that can produce milk to feed an infant. Milk is produced in the glands of the lobules. Then the milk is created through ducts when the infant suks on the nipples.

The breasts are not directly involved in reproduction, but because they contain **mammary glands,** they can provide nourishment to an infant after birth. The breasts overlay major muscles in the chest from which they project outward in a conical shape. The two main types of tissues in the breast are adipose (fat) tissue and glandular tissue that produces milk. As shown in Figure **15.6.6**, each mature breast contains many lobules, where milk is produced and stored during pregnancy.

During nursing (or lactation), the milk drains into ducts and sacs, which in turn converge at the nipple. Milk exits the breast through the nipple in response to the suckling action of an infant. The nipple is surrounded by a more darkly pigmented area called the areola. The areola contains glands that secrete an oily fluid, which lubricates and protects the nipple during breastfeeding.

In 2018, during a survey, the respondents mentioned about two protocols of lactation induction in a trans woman, Zil Goldstein and Newman-Goldfarb protocols, which was initially designed for a cis woman to nurse a baby born to a surrogate mother. The Zil Goldstein protocol starts with 10 mg domperidone (a drug) three times daily while the Newman-Goldfarb protocol recommends 10 mg domperidone four times daily. Both regimens subsequently increase the dose to 20 mg four times daily. Since domperidone is not approved by the Food and Drug Administration, the patients obtain the drug elsewhere. Both regimens also utilize estradiol and progesterone sex hormones. Subsequently, the physical stimulation of the nipples is recommended for milk production. Informal reports of trans women who induced lactation have emerged recently. However, there are no data to support any of the other reports. There is a critical gap in evidence-based medicine for this population.

REVIEW

1. State the general functions of the female reproductive system.
2. Describe the vagina and its reproductive functions.
3. Outline the structure and basic functions of the uterus.
4. What is the endometrium? How does it change during the monthly cycle?
5. Relate features of the Fallopian tubes to the functions of these structures.
6. Define ovary.
7. Identify the functional units of the ovaries.
8. Discuss the timing of egg production and ovulation in the context of a female's lifetime.
9. What is the vulva? What structures does it include?
10. Why are breasts included in discussions of reproduction, if they are not organs of the female reproductive system?
11. What is the function of the folds in the mucous membrane lining of the vagina?
12. What are two ways in which the female reproductive system protects itself from pathogens?
13. *True or False:* The fallopian tube runs through the cervix and allows sperm to enter the uterus.
14. *True or False:* The nipple and the areola are not the same things.
15. Immature eggs are located in _____, which are located within _____ .

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15.7: MENSTRUAL CYCLE

TABOO TOPIC

The banner in Figure **15.7.1** was carried in a 2014 march in Uganda as part of the celebration of Menstrual Hygiene Day. Menstrual Hygiene Day is an awareness day on May 28 of each year that aims to raise awareness worldwide about menstruation and menstrual hygiene. Maintaining good menstrual hygiene is difficult in developing countries like Uganda because of taboos on discussing menstruation and the lack of availability of menstrual hygiene products. Poor menstrual hygiene, in turn, can lead to embarrassment, degradation, and reproductive health problems in females. May 28 was chosen as Menstrual Hygiene Day because of its symbolism. May is the fifth month of the year that symbolizes the five days of bleeding during menstruation each month. The 28th day was chosen because the menstrual cycle averages about 28 days.



Figure **15.7.1**: Water for People Uganda celebration of Menstrual Hygiene Day in 2014

WHAT IS THE MENSTRUAL CYCLE?

The **menstrual cycle** refers to natural changes that occur in the female reproductive system each month during the reproductive years. The cycle is necessary for the production of eggs and the preparation of the uterus for pregnancy. It involves changes in both the ovaries and the uterus and is controlled by pituitary and ovarian hormones. Day 1 of the cycle is the first day of the menstrual period**,** when bleeding from the uterus begins as the built-up endometrium lining the uterus is shed. The endometrium builds up again during the remainder of the cycle, only to be shed again during the beginning of the next cycle if pregnancy does not occur. In the ovaries, the menstrual cycle includes the development of a follicle, ovulation of a secondary oocyte, and the degeneration of the follicle if pregnancy does not occur. Both uterine and ovarian changes during the menstrual cycle are generally divided into three phases, although the phases are not the same in the two organs.

MENARCHE AND MENOPAUSE

The female reproductive years are delineated by the start and stop of the menstrual cycle. The first menstrual period usually occurs around 12 or 13 years of age, an event that is known as **menarche.** There is considerable variation among individuals in the age of menarche. It may occasionally occur as early as eight years of age or as late as 16 years of age and still be considered normal. The average age is generally later in the developing world, and earlier in the developed world. This variation is thought to be largely attributable to nutritional differences.

The cessation of menstrual cycles at the end of a woman's reproductive years is termed **menopause.** The average age of menopause is 52 years, but it may occur normally at any age between about 45 and 55 years of age. The age of menopause varies due to a variety of biological and environmental factors. It may occur earlier as a result of certain illnesses or medical treatments.

VARIATION IN THE MENSTRUAL CYCLE

The length of the menstrual cycle — as well as its phases — may vary considerably, not only among different individuals but also from month to month for a given person. The average length of time between the first day of one menstrual period and the first day of the next menstrual period is 28 days, but it may range from 21 days to 45 days. Cycles are considered regular when a woman's longest and shortest cycles differ by less than eight days. The menstrual period itself is usually about five days long, but it may vary in length from about two days to seven days.

OVARIAN CYCLE

The events of the menstrual cycle that take place in the ovaries make up the **ovarian cycle.** It consists of changes that occur in the follicles of one of the ovaries. The ovarian cycle is divided into the following three phases: the follicular phase, ovulation, and luteal phase. These phases are illustrated in Figure **15.7.2**.

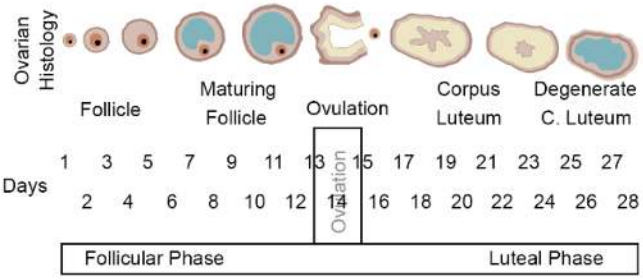


Figure **15.7.2**: The diagram shows the maturation of follicles in the ovary, ovulation, and formation of corpus luteum during follicular and luteal phases of ovaries. The phases and days of the ovarian cycle are shown in this diagram. The ovarian cycle depicted in the diagram represents a cycle in which fertilization does not occur so the corpus luteum degenerates during the luteal phase.

FOLLICULAR PHASE

The **follicular phase** is the first phase of the ovarian cycle. It generally lasts about 12 to 14 days for a 28-day menstrual cycle. During this phase, several ovarian follicles are stimulated to begin maturing, but usually only one — called the Graafian follicle — matures completely so it is ready to release an egg. The other maturing follicles stop growing and disintegrate. Follicular development occurs because of a rise in the blood level of follicle-stimulating hormone (FSH), which is secreted by the pituitary gland. The maturing follicle releases estrogen, the level of which rises throughout the follicular phase. You can see these and other changes in hormone levels that occur during the menstrual cycle in the chart in Figure **15.7.3**.

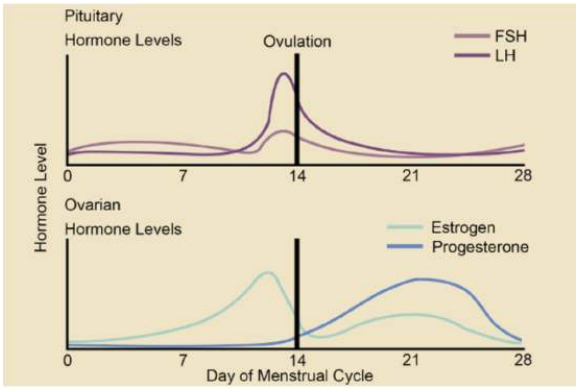


Figure **15.7.3**: Pituitary and ovarian hormone levels. FSH in the pituitary and estrogen in the ovaries increase during the first half of the menstrual cycle. LH in the pituitary surges shortly before ovulation occurs due to the rise in estrogen in the ovaries. After ovulation, the level of progesterone and estrogen increases in ovaries due to the formation of the corpus luteum if pregnancy does not occur.

OVULATION

Ovulation is the second phase of the ovarian cycle. It usually occurs around day 14 of a 28-day menstrual cycle. During this phase, the Graafian follicle ruptures and releases its egg. Ovulation is stimulated by a sudden rise in the blood level of luteinizing hormone (LH) from the pituitary gland. This is called the LH surge. You can see the LH surge in the top hormone graph above. The LH surge generally starts around day 12 of the cycle and lasts for a day or two. The surge in LH is triggered by a continued rise in estrogen from the maturing follicle in the ovary. During the follicular phase, the rising estrogen level actually suppresses LH secretion by the pituitary. However, by the time the follicular phase is nearing its end, the level of estrogen reaches a threshold level above which this effect is reversed, and estrogen stimulates the release of a large amount of LH. The surge in LH matures the egg and weakens the wall of the follicle, causing the fully developed follicle to release its secondary oocyte.

LUTEAL PHASE

The **luteal phase** is the third and final phase of the ovarian cycle. It typically lasts about 14 days in a 28-day menstrual cycle. At the beginning of the luteal phase, FSH and LH cause the Graafian follicle that ovulated the egg to transform into a structure called a corpus luteum. The corpus luteum secretes progesterone, which in turn suppresses FSH and LH production by the pituitary and stimulates the continued buildup of the endometrium in the uterus. How this phase ends depends on whether or not the egg has been fertilized.

- If fertilization has not occurred, the falling levels of FSH and LH during the luteal phase cause the corpus luteum to atrophy, so its production of progesterone declines. Without a high level of progesterone to maintain it, the endometrium starts to break down. By the end of the luteal phase, the endometrium can no longer be maintained, and the next menstrual cycle begins with the shedding of the endometrium (menses).
- If fertilization has occurred so a zygote forms and then divides to become a blastocyst, the outer layer of the blastocyst produces a hormone called human chorionic gonadotropin. This hormone is very similar to LH and preserves the corpus luteum. The corpus luteum can then continue to secrete progesterone to maintain the new pregnancy.

UTERINE CYCLE

The events of the menstrual cycle that take place in the uterus make up the **uterine cycle**. This cycle consists of changes that occur mainly in the endometrium, which is the layer of tissue that lines the uterus. The uterine cycle is divided into the following three phases: menstruation, proliferative phase, and secretory phase. These phases are illustrated in Figure **15.7.4**.

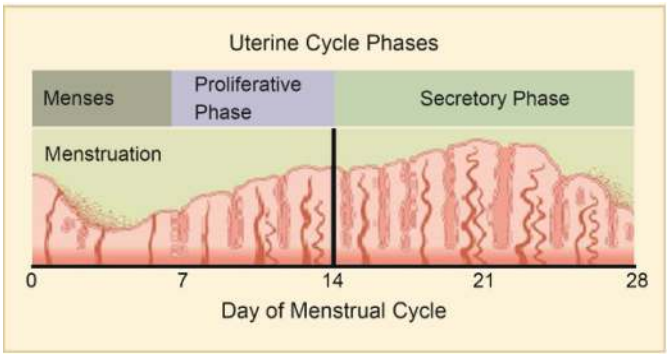


Figure **15.7.4**: The uterine cycle begins with menstruation, which starts on day 1 of the cycle. The proliferative phase ranges from day 7 to 14. The secretory phase laster for the second half of the uterine cycle.

MENSTRUATION

Menstruation (also called the menstrual period or menses) is the first phase of the uterine cycle. It occurs if fertilization has not taken place during the preceding menstrual cycle. During menstruation, the endometrium of the uterus, which has built up during the preceding cycle, degenerates and is shed from the uterus. The average loss of blood during menstruation is about 35 mL. The flow of blood is often accompanied by uterine cramps, which may be severe in some people.

PROLIFERATIVE PHASE

The **proliferative phase** is the second phase of the uterine cycle. During this phase, estrogen secreted by cells of the maturing ovarian follicle causes the lining of the uterus to grow, or proliferate. Estrogen also stimulates the cervix of the uterus to secrete larger amounts of thinner mucus that can help sperm swim through the cervix and into the uterus, making fertilization more likely.

SECRETORY PHASE

The **secretory phase** is the third and final phase of the uterine cycle. During this phase, progesterone produced by the corpus luteum in the ovary stimulates further changes in the endometrium so it is more receptive to implantation of a blastocyst. For example, progesterone increases blood flow to the uterus and promotes uterine secretions. It also decreases the contractility of smooth muscle tissue in the uterine wall.

MY BODY: MENSTRUATORS, NOT MENSTRUATING WOMEN

Within the field of critical menstruation studies, we must pay attention to our depictions of menstruation and menstruators, and the knowledge we produce in the pursuit to de-stigmatize menstruation. Not all women menstruate, for example, trans women, postmenopausal women, pregnant women, and those experiencing amenorrhea, and not all who menstruate are women, for example, transmen. Experiences of menstruating later in life vary among menstruators as well. Some do not suffer from their periods in direct relation to their gender identity. Others do, as they disidentify with the body as a whole and/or with certain body parts such as the genitalia or the uterus, or with the bodily function of menstruation. This suffering is sometimes related to gender dysphoria. Testosterone treatments are a method adopted by some trans menstruators to get rid of unwanted bleeding. Preventing the menstrual period is not necessarily the main reason for using testosterone, but it can be one among several desired outcomes. Menstruators *are* of a variety of gender identities (far beyond those who identify as trans) and, hence, menstruation cannot be equated singularly with cis/womanhood.

REVIEW

1. What is the menstrual cycle?
2. Why is the menstrual cycle necessary in order for pregnancy to occur?
3. What organs are involved in the menstrual cycle? What hormones control the cycle?
4. Identify the two major events that mark the beginning and end of the reproductive period in females. When do these events typically occur?
5. Discuss the average length of the menstrual cycle and menstruation, as well as variations that are considered normal.
6. Define the ovarian cycle.
7. Summarize the phases of the ovarian cycle.
8. Compare and contrast events that occur in the ovaries and uterus, depending on whether or not an egg is fertilized during the menstrual cycle.
9. Define the uterine cycle.
10. Give an overview of the phases of the uterine cycle.
11. If the LH surge did not occur in a menstrual cycle, what do you think would happen? Explain your answer.
12. Give one reason why FSH and LH levels drop in the luteal phase of the menstrual cycle.
13. What does the follicle that housed the ovulated egg become in the luteal phase of the menstrual cycle?
14. *True or False:* Day 1 of the menstrual cycle is when the secondary oocyte is released from its follicle.
15. *True or False:* The secretory phase of the uterine cycle generally aligns with the luteal phase of the ovarian cycle.

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15.8: FUNCTIONS OF THE FEMALE REPRODUCTIVE SYSTEM

WAITING EXPECTANTLY

A mother-to-be waits patiently for her fetus to grow as her belly swells. Reproduction is all about making babies, and the female reproductive system is specialized for this purpose. Its functions include producing gametes called eggs, secreting sex hormones (such as estrogen), providing a site for fertilization, gestating a fetus if fertilization occurs, giving birth to a baby, and breastfeeding a baby after birth. The only thing missing is sperm.



Figure **15.8.1**: Pregnant woman

EGG PRODUCTION

At birth, ovaries contain all the eggs that will ever be produced, which may include a million or more eggs. The eggs don't start to mature, however, until a female enters puberty and attains sexual maturity. After that, one egg typically matures each month and is released from an ovary. This continues until menopause (cessation of monthly periods), typically by age 52. By then, viable eggs may be almost depleted, and hormone levels can no longer support the monthly cycle. During the reproductive years, which of the two ovaries releases an egg in a given month seems to be a matter of chance. Occasionally, both ovaries will release an egg at the same time. If both eggs are fertilized, the offspring are fraternal twins (dizygotic, or "two-zygote," twins), and they are no more alike genetically than non-twin siblings.

OOGENESIS

The process of producing eggs in the ovaries of a fetus carrying XX chromosomes is called **oogenesis.** Eggs are haploid gametes, and their production occurs in several steps that involve different types of cells, as summarized in Figure 15.8.2. Oogenesis is completed long before birth. It occurs when diploid germ cells called **oogonia** (singular, oogonium) undergo mitosis. Each such cell division produces two diploid cells. One is called the primary oocyte, and the other is retained to help maintain a reserve of oogonia. The primary oocyte, in turn, starts to go through the first cell division of meiosis (meiosis I). However, it does not complete meiosis I until puberty.

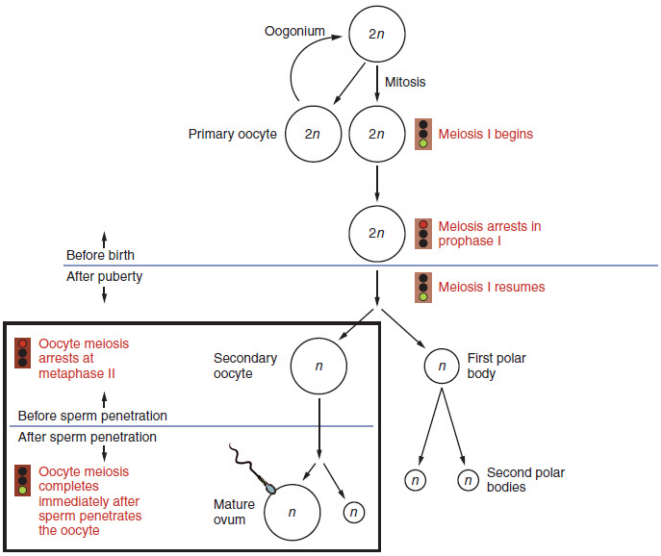


Figure **15.8.2**: Formation of a secondary oocyte that may become a zygote begins with the mitosis of an oogonium. Two meiotic cell divisions follow this. The first polar body does not undergo the second meiotic division in humans. The secondary oocyte completes meiosis II after the penetration of sperm.

MATURATION OF A FOLLICLE

Beginning in puberty, about once a month, one of the follicles in an ovary undergoes maturation, and an egg is released. As the follicle matures, it goes through changes in the numbers and types of its cells. The primary oocyte within the follicle also resumes meiosis. It completes meiosis I, which began long before birth, to form a secondary oocyte and a smaller cell, called the first polar body. Both the secondary oocyte and the first polar body are haploid cells. The secondary oocyte has most of the cytoplasm from the primary oocyte and is much larger than the first polar body, which soon disintegrates and disappears. The secondary oocyte begins meiosis II, but only completes it if the egg is fertilized.

RELEASE OF AN EGG

It typically takes 12 to 14 days for a follicle to mature in an ovary and for the secondary oocyte to form. Then, the follicle bursts open and the ovary ruptures, releasing the secondary oocyte from the ovary. This event is called **ovulation.** The now-empty follicle starts to change into a structure called a **corpus luteum.** The expelled secondary oocyte is usually swept into the nearby Fallopian tube by its waving, fingerlike fimbriae.

UTERINE CHANGES

While the follicle matures in the ovary, the uterus also changes to prepare it for an embryo if fertilization occurs. For example, the endometrium gets thicker and becomes more vascular. Around ovulation, the cervix undergoes changes that help sperm reach the oocyte to fertilize it. The cervical canal widens, and the cervical

mucus becomes thinner and more alkaline. These changes help promote the passage of sperm from the vagina into the uterus and make the environment more hospitable to sperm.

FERTILIZATION — OR NOT

Fertilization of an egg by a sperm normally occurs in a Fallopian tube, most often in the part of the tube that passes above the ovary (Figure **15.8.3**). In order for fertilization to occur, sperm must "swim" from the vagina where they are deposited, through the cervical canal to the uterus and then through the body of the uterus to one of the Fallopian tubes. Once sperm enter a Fallopian tube, tubular fluids help carry them through the tube toward the secondary oocyte at the other end. The secondary oocyte also functions to promote fertilization. It releases molecules that guide the sperm and allow the surface of the egg to attach to the surface of the sperm. The egg can then absorb the sperm, allowing fertilization to occur.

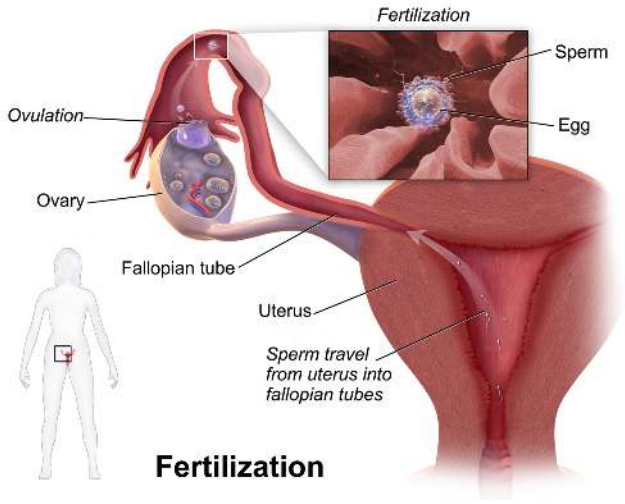


Figure **15.8.3**: The Fimbriae of the fallopian tube sweep the egg into the fallopian tube. Sperm travels through the cervix and uterus and enters the fallopian tube, fertilizing the egg. The embryo, then, travels towards the uterus.

IF FERTILIZATION OCCURS

If the secondary oocyte is fertilized by a sperm as it passes through the Fallopian tube, the secondary oocyte quickly completes meiosis II, forming a diploid zygote and another polar body. (This second polar body, like the first, normally breaks down and disappears.) The zygote then continues the journey through the fallopian tube to the uterus, during which it undergoes several mitotic cell divisions. When it reaches the uterus, up to five days after fertilization, it consists of a ball of cells called a blastocyst. Within another day or two, the blastocyst implants itself in the endometrium lining the uterus, and gestation begins.

IF FERTILIZATION DOES NOT OCCUR

What happens if the secondary oocyte is not fertilized by a sperm as it passes through the Fallopian tube? It continues on its way to the uterus without ever completing meiosis II. It is likely to disintegrate within a few days while still in the Fallopian tube. Any remaining material will be shed from the woman's body during the next menstrual period.

PREGNANCY

Pregnancy is the carrying of one or more offspring from fertilization until birth. This is one of the major functions of the female reproductive system. It involves virtually every other body system, including the cardiovascular, urinary, and respiratory systems, to name just three. The maternal organism plays a critical role in the development of the offspring. They must provide all the nutrients and other substances needed for the normal growth and development of the offspring and remove the wastes excreted by the offspring. Most nutrients are needed in greater amounts by a pregnant individual to meet fetal needs, but some are especially important, including folic acid, calcium, iron, and omega-3 fatty acids. A healthy diet and prenatal vitamin supplements are recommended for the best pregnancy outcome. A pregnant person should also avoid ingesting substances (such as alcohol) that can damage the developing offspring, especially early in the pregnancy when all of the major organs and organ systems are forming.

When counted from the first day of the last menstrual period, the average duration of pregnancy is about 40 weeks (38 weeks when counted from the time of fertilization). However, a pregnancy that lasts between 37 and 42 weeks is still considered within the normal range. From the point of view of the maternal organism, the total duration of pregnancy is typically divided into three periods, called **trimesters,** each of which lasts about three months. This division of the total period of gestation is useful for summarizing the typical changes during pregnancy. From the point of view of the developing offspring, however, the major divisions are different. They are the embryonic and fetal stages. The offspring is called an embryo from the time it implants in the uterus through the first eight weeks of life. After that, it is called a fetus for the duration of the pregnancy.

FIRST TRIMESTER

The first trimester begins at the time of fertilization and lasts for the next 12 weeks. Even before a pregnant person knows they are pregnant, they may experience signs and symptoms of pregnancy. They may notice a missed menstrual period, and they may also experience a tender nipple area, increased appetite, and more frequent urination. Many individuals also experience nausea and vomiting in the first trimester. This is often called "morning sickness" because it commonly occurs in the morning but may occur at any time of day. Some lose weight during the first trimester because of morning sickness.

SECOND TRIMESTER

The second trimester occurs during weeks 13 to 28 of pregnancy. A pregnant person may feel more energized during this trimester. If she experienced nausea and vomiting during the first trimester, these symptoms often subside during the second trimester. Weight gain starts occurring during this trimester, as well. By about week 20, the fetus is getting large enough that the mother can feel its movements. The photo on the left in Figure **15.8.4** shows a pregnant woman at

week 26, toward the end of the second trimester. (For comparison, the same woman is shown on the right of Figure **15.8.4** at the end of the third trimester.)

THIRD TRIMESTER

The third trimester occurs during weeks 29 through birth (at about 40 weeks). During this trimester, the uterus expands rapidly, making up a larger and larger portion of the woman's abdomen. Weight gain is also more rapid. During the third trimester, the movements of the fetus become stronger and more frequent, and they may become disruptive to the mother. As the fetus grows larger, its weight and the space it takes up may lead to symptoms in the mother such as back pain, swelling of the lower extremities, more frequent urination, varicose veins, and heartburn. By the end of the third trimester, the woman's abdomen often will transform in shape as it drops, due to the fetus turning to a downward position before birth so its head rests on the cervix. This relieves pressure on the upper abdomen, but reduces bladder capacity and increases pressure on the pelvic floor and rectum.



Figure **15.8.4**: The same woman is shown in both photos: on the left at week 26 of the pregnancy, and on the right at week 40 of the pregnancy

CHILDBIRTH

Near the time of birth, the amniotic sac — a fluid-filled membrane that encloses the fetus within the uterus — breaks in a gush of fluid. This is commonly called “breaking water.” Labor usually begins within a day of this event, although it may begin prior to it. **Labor** is the general term for the process of childbirth in which regular uterine contractions push the fetus and placenta out of the body. Labor can be divided into three stages, which are illustrated in Figure **15.8.5**: dilation, birth, and after birth.

1. During the dilation stage of labor, uterine contractions begin and become increasingly frequent and intense. The contractions push the baby’s head (most often) against the cervix, causing the cervical canal to dilate, or become wider. This lasts until the cervical canal has dilated to about 10 cm (3.9 in.) in width, which may take 12 to 20 hours — or even longer. The cervical canal must be dilated to this extent in order for the baby’s head to fit through it.
2. During birth, the baby descends (usually headfirst) through the cervical canal and vagina, and into the world outside. This is the stage when the mother generally starts bearing down during the contractions to help push out the fetus. The fetus exits the vagina with its face facing the mother's posterior. It takes a 90-degree turn as the shoulders are delivered. This stage may last from about 20 minutes to two hours or more. Usually, within a minute or less of birth, the umbilical cord is cut, so the baby is no longer connected to the placenta.
3. During the afterbirth stage, the placenta is delivered. This stage may last from a few minutes to a half hour.

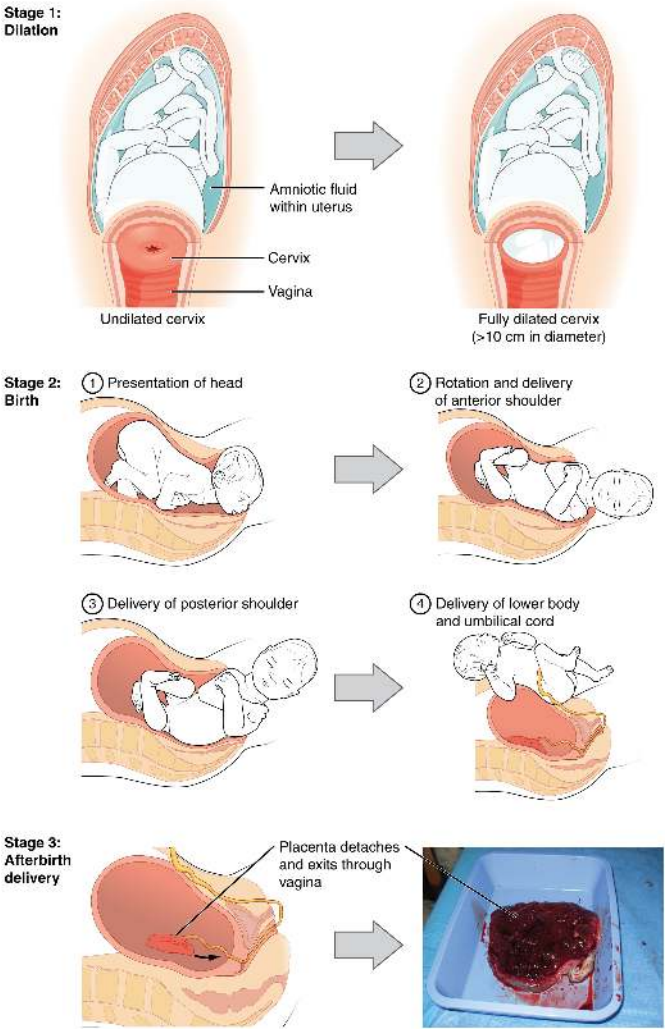


Figure **15.8.5**: The three stages of labor are dilation of the cervix, the birth of the baby, and the delivery of the afterbirth (placenta)

Delivery is a matter of concern for all individuals. However, additional concerns arise for individuals with disabilities. According to a study done by Lipson and Rogers, delivery decisions for disabled individuals are made arbitrarily without their consent. They are forced to deliver via cesarean section because they think that a disabled person wouldn't be able to handle the process.

FEATURE: MYTH VS. REALITY

There are many myths associated with pregnancy. Most are harmless, but some may put the pregnant woman or fetus at risk. As always, knowledge is power.

Myth: You should avoid petting your cat during pregnancy.

Reality: Cat feces may be contaminated with microscopic parasites that can cause a disease called toxoplasmosis. Pregnant women who contract this disease are at risk of stillbirth, miscarriage, or giving birth to an infant with serious health problems. Pregnant women should not have contact with a cat's litter box or feces, but petting a cat poses no real risk of infection.

Myth: You should not dye your hair during pregnancy, because the chemicals can harm the fetus.

Reality: Whereas some chemicals (such as certain pesticides) have been shown to be associated with birth defects, there is no evidence that using hair dye during pregnancy increases this risk.

Myth: A pregnant woman needs to eat for two, so she should double her pre-pregnancy caloric intake.

Reality: Throughout a typical pregnancy, a person needs only about 300 extra calories per day, on average, to support her growing fetus. Most of the extra calories are needed during the last trimester when the fetus is growing most rapidly. Doubling her caloric intake during pregnancy is likely to cause too much weight gain, which can be detrimental to her baby. Babies that weigh much more than the average 7.5 pounds at birth are more likely to develop diabetes and obesity in later life.

Myth: Women who are pregnant have strange food cravings, such as ice cream with pickles.

Reality: Some women do have food cravings during pregnancy, but they are not necessarily cravings for strange foods or unusual food combinations. For example, a pregnant woman might crave starchy foods for a few weeks, or she may be put off by certain foods that she loved before pregnancy.

Myth: A pregnant woman has skin that glows.

Reality: Pregnancy can actually be hard on the skin and its appearance. Besides stretch marks on the abdomen and breasts, pregnancy may lead to spider veins, varicose veins, new freckles, darkening of moles, and acne flare-ups. In addition, as many as 75 percent of pregnant women experience chloasma, which is the emergence of blotchy brown patches of skin on the face due to high estrogen levels. Chloasma is often referred to as the "mask of pregnancy."

Myth: Men cannot carry a baby.

Reality: Transgender men can get pregnant using alternative methods.

REVIEW

1. What is oogenesis? How does it occur?
2. Describe the maturation of an ovarian follicle.
3. Define ovulation.
4. What is happening in the uterus while a follicle in the ovary is maturing?
5. After a secondary oocyte is ovulated from the ovary, it may or may not be fertilized. Contrast what happens next in each of these different outcomes.
6. What is pregnancy, and what is the role of the maternal organism in pregnancy?
7. What is the average duration of pregnancy? Identify the trimesters of pregnancy.
8. Define labor. What event is often a sign that labor will soon begin?
9. Identify the stages of labor.
10. Describe the physiological function of female breasts. How is this function controlled?
11. Identify the functions of the female sex hormones estrogen and progesterone.
12. *True or False:* All of the developing gametes in an ovary complete meiosis I at the time of puberty.
13. *True or False:* After fertilization, meiosis II is completed, and then mitosis occurs.
14. A fertilized egg that has not yet implanted in the uterus is called a(n) _____.

A. embryo

B. zygote

C. fetus

D. secondary oocyte

15. Describe the roles of the cervix in fertilization and childbirth.

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15.9: DISORDERS OF THE FEMALE REPRODUCTIVE SYSTEM

VACCINATING AGAINST CANCER

Can a vaccine prevent cancer? In the case of cervical cancer, it *can*. Cervical cancer is one of three disorders of the female reproductive system described in detail in this concept. Of the three, only cervical cancer can be prevented with a vaccine.



Figure **15.9.1**: Getting a vaccine

CERVICAL CANCER

Cervical cancer occurs when cells of the cervix (neck of the uterus) grow abnormally and develop the ability to invade nearby tissues or spread to other parts of the body, such as the abdomen or lungs. Figure **15.9.2** shows the location of the cervix and the appearance of normal and abnormal cervical cells when examined with a microscope.

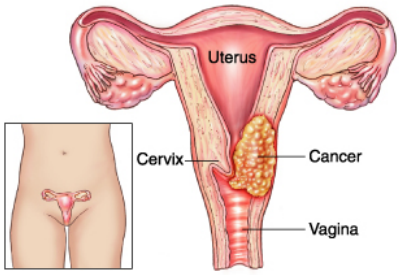


Figure **15.9.2**: Cancer of the cervix

CERVICAL CANCER PREVALENCE AND DEATH RATES

Worldwide, cervical cancer is the second most common type of cancer (after breast cancer) and the fourth most common cause of cancer death. In the United States and other high-income nations, the widespread use of cervical cancer screening has detected many cases of precancerous cervical changes and has dramatically reduced rates of cervical cancer deaths. About three-quarters of cervical cancer cases occur in developing countries, where routine screening is less likely because of cost and other factors. Cervical cancer is also the most common cause of cancer death in low-income countries.

SYMPTOMS OF CERVICAL CANCER

Early in the development of cervical cancer, there are typically no symptoms. As the disease progresses, however, symptoms are likely to occur. The symptoms may include abnormal vaginal bleeding, pelvic pain, or pain during sexual intercourse. Unfortunately, by the time symptoms start to occur, cervical cancer has typically progressed to a stage at which treatment is less likely to be successful.

CERVICAL CANCER CAUSES AND RISK FACTORS

More than 90 percent of cases of cervical cancer are caused at least in part by human papillomavirus **(HPV)**, which is a sexually transmitted virus that also causes genital warts. HPV infection can cause cervical cancer by interfering with a normal cell division. When HPV is not present, cervical cells containing mutations are not allowed to divide, so the cervix remains healthy. When HPV is present, however, cervical cells with mutations may be allowed to divide, leading to uncontrolled growth of mutated cells and the formation of a tumor.

Other risk factors for cervical cancer include smoking, a weakened immune system (for example, due to HIV infection), use of birth control pills, becoming sexually active at a young age, and having many sexual partners. However, these risk factors are less important than HPV infection. Instead, the risk factors are more likely to increase the risk of cervical cancer in individuals who are *already* infected with HPV. For example, among HPV-infected, current and former smokers have roughly two to three times the incidence of cervical cancer as non-smokers. Passive smoking is also associated with an increased risk of cervical cancer but to a lesser extent.

DIAGNOSIS OF CERVICAL CANCER

Diagnosis of cervical cancer is typically made by looking for microscopic abnormal cervical cells in a smear of cells scraped off the cervix. This is called a **Pap smear.** If cancerous cells are detected or suspected in the smear, this test is usually followed up with a biopsy to confirm the Pap smear results. Medical imaging (by CT scan or MRI, for example) is also likely to be done to provide more information, such as whether the cancer has spread.

PREVENTION OF CERVICAL CANCER

It is now possible to prevent HPV infection with a vaccine. The first HPV vaccine was approved by the U.S. Food and Drug Administration in 2006. The vaccine protects against the strains of HPV that have the greatest risk of causing cervical cancer. It is thought that widespread use of the vaccine will prevent up to 90 percent of cervical cancer cases. Current recommendations are to be given the vaccine between the ages of nine and 26. (All sexes should be vaccinated against HPV, because the virus may also cause cancer of the penis and certain other cancers.) The vaccine is effective only if it is given *before* HPV infection has occurred. Using condoms during sexual intercourse can also help prevent HPV infection and cervical cancer, in addition to preventing pregnancy and sexually transmitted infections (such as HIV).

Even for those who have received the HPV vaccine, there is still a small risk of developing cervical cancer. Therefore, it is

recommended that individuals with cervix continue to be examined with regular Pap smears.

TREATMENT OF CERVICAL CANCER

Treatment of cervical cancer generally depends on the stage at which the cancer is diagnosed, but it is likely to include some combination of surgery, radiation therapy, and/or chemotherapy. Outcomes of treatment depend largely on how early the cancer is diagnosed and treated. For surgery to cure cervical cancer, the entire tumor must be removed with no cancerous cells found at the margins of the removed tissue on microscopic examination. If cancer is found and treated very early when it is still in the microscopic stage, the five-year survival rate is virtually 100 percent.

VAGINITIS

Vaginitis is inflammation of the vagina — and sometimes the vulva, as well. Symptoms may include a discharge that is yellow, gray, or green; itching; pain; and a burning sensation. There may also be a foul vaginal odor and pain or irritation with sexual intercourse.



Figure **15.9.3**: The yeast *Candida albicans* — shown here growing on a culture plate — is one of the most common causes of vaginitis.

CAUSES OF VAGINITIS

About 90 percent of cases of vaginitis are caused by infection with microorganisms. Most commonly, vaginal infections are caused by the yeast *Candida albicans* (Figure **15.9.3**). Such infections are referred to as vaginal **candidiasis.** Other possible causes of vaginal infections include bacteria, especially *Gardnerella vaginalis*, and some single-celled parasites, notably the protist parasite *Trichomonas vaginalis*, which is usually transmitted through vaginal intercourse. The risk of vaginal infections may be greater in those who wear tight clothing, are taking antibiotics for another condition, use birth control pills, or have improper hygiene. Poor hygiene allows organisms that are normally present in the stool (such as yeast) to contaminate the vagina. Most of the remaining cases of vaginitis are due to irritation by — or allergic reactions to — various products. These irritants may include condoms, spermicides, soaps, douches, lubricants, and even semen. Using tampons or soaking in hot tubs may be additional causes of this type of vaginitis.

DIAGNOSIS OF VAGINITIS

Diagnosis of vaginitis typically begins with symptoms reported by the patient. This may be followed by a microscopic examination or culture of the vaginal discharge in order to identify the specific cause. The color, consistency, acidity, and other characteristics of the discharge may be predictive of the causative agent. For example, infection with *Candida albicans* may cause a cottage cheese-like discharge with a low pH, whereas infection with *Gardnerella vaginalis* may cause a discharge with a fish-like odor and a high pH.

PREVENTION OF VAGINITIS

Prevention of vaginitis includes wearing loose cotton underwear that helps keep the vulva dry. Yeasts and bacteria that may cause vaginitis tend to grow best in a moist environment. It is also important to avoid the use of perfumed soaps, personal hygiene sprays, and douches, all of which may upset the normal pH and bacterial balance in the vagina. To help avoid vaginitis caused by infection with *Trichomonas vaginalis*, the use of condoms during sexual intercourse is advised.

TREATMENT OF VAGINITIS

The appropriate treatment of vaginitis depends on the cause. In many cases of vaginitis, there is more than one cause, and all of the causes must be treated to ensure a cure.

- Yeast infections of the vagina are typically treated with topical anti-fungal medications, which are available over the counter. The medications may be in the form of tablets or creams that are inserted into the vagina. Depending on the particular medication used, treatment may involve one, three, or seven days of application.
- Bacterial infections of the vagina are usually treated with antibiotics. These may be taken orally as pills or applied topically to the vagina in creams.
- *Trichomonas vaginalis* infections of the vagina are generally treated with a single dose of an oral antibiotic. Sexual partners should be treated at the same time, and intercourse should be avoided for at least a week until both partners have completed treatment and been followed up by a physician.

ENDOMETRIOSIS

Endometriosis is a disease in which endometrial tissue, which normally grows inside the uterus, grows outside of the uterus (Figure **15.9.4**). Most often, the endometrial tissue grows around the ovaries, Fallopian tubes, and uterus. In rare instances, the tissue may grow elsewhere in the body. The areas of endometriosis typically bleed each month during the menstrual period, and this often results in inflammation, pain, and scarring. An estimated six to ten percent of individuals with a uterus are believed to have endometriosis. It is most common in their thirties and forties, and only rarely occurs before menarche or after menopause.

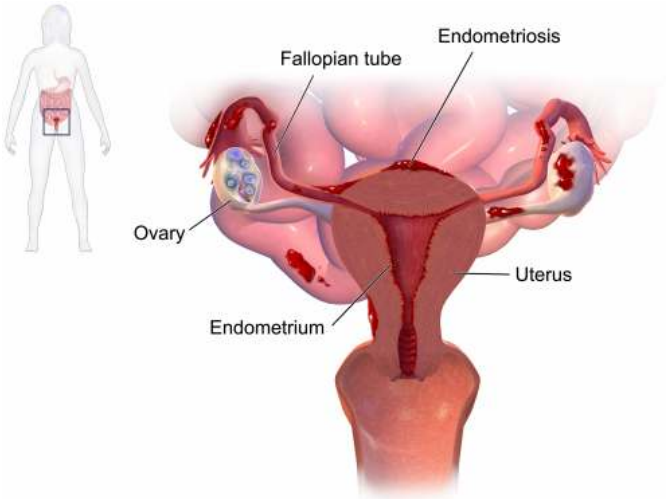


Figure 15.9.4: In endometriosis, endometrial tissue may grow outside the uterus and cause health problems such as pain, bleeding, scarring, and infertility. Here the endometrial tissue is growing in the fallopian tubes, ovaries, and on the outside of the fallopian tube and uterus.

SIGNS AND SYMPTOMS OF ENDOMETRIOSIS

The main symptom of endometriosis is pelvic pain, which may range from mild to severe. There appears to be little or no relationship between the amount of endometrial tissue growing outside the uterus and the severity of the pain. For many with the disease, the pain occurs mainly during menstruation. However, nearly half of those affected have chronic pelvic pain. The pain of endometriosis may be caused by bleeding in the pelvis, which triggers inflammation. Pain can also occur from internal scar tissue that binds internal organs to each other.

Another problem often associated with endometriosis is infertility, or the inability to conceive or bear children. Among patients with endometriosis, up to half may experience infertility. Infertility can be related to scar formation or to anatomical distortions due to abnormal endometrial tissue. Other possible symptoms of endometriosis may include diarrhea or constipation, chronic fatigue, nausea and vomiting, headaches, and heavy or irregular menstrual bleeding.

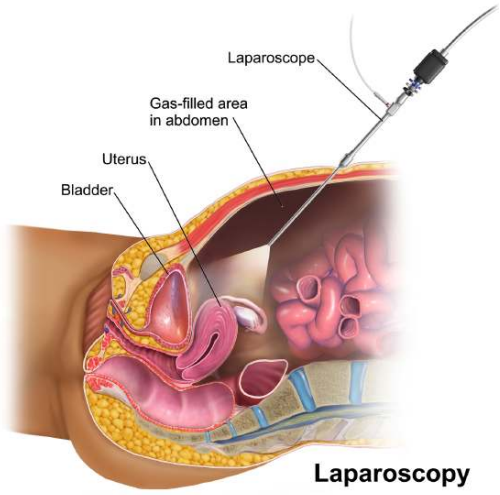


Figure 15.9.5: Laparoscopy: visually inspecting the abdomen for endometrial growth is the most reliable way to diagnose endometriosis. the camera is inserted through the abdominal wall.

CAUSES OF ENDOMETRIOSIS

The causes of endometriosis are not known for certain, but several risk factors have been identified, including a family history of endometriosis. People who have a genetic relationship with a person with endometriosis have about six times the normal risk of developing the disease themselves. It has been suggested that endometriosis results from mutations in several genes. It is likely that endometriosis is multifactorial, involving the interplay of several factors.

At the physiological level, the predominant idea for how endometriosis comes about is retrograde menstruation. This happens when some of the endometrial debris from a menstrual flow exits the uterus through the Fallopian tubes, rather than through the vagina. The debris then attaches itself to the outside of organs in the abdominal cavity, or to the lining of the abdominal cavity itself. Retrograde menstruation, however, does not explain all cases of endometriosis, so other factors are apparently involved. Suggestions include environmental toxins and autoimmune responses.

DIAGNOSIS OF ENDOMETRIOSIS

Diagnosis of endometriosis is usually based on self-reported symptoms and a physical examination by a doctor, often combined with medical imaging, such as ultrasonography. The only way to definitively diagnose endometriosis, however, is through visual inspection of the endometrial tissue. This can be done with a surgical procedure called **laparoscopy**, in which a tiny camera is inserted into the abdomen through a small incision (Figure 15.9.5). The camera allows the physician to visually inspect the area where endometrial tissue is suspected.

TREATMENT OF ENDOMETRIOSIS

The most common treatments for endometriosis are medications to control the pain, and surgery to remove the abnormal tissue. Frequently used pain medications are non-steroidal inflammatory drugs (NSAIDS), such as naproxen. Opiates may be used in cases of

severe pain. Laparoscopy can be used to surgically treat endometriosis, as well as to diagnose the condition. In this type of surgery, an additional small incision is made to insert instruments that the surgeon can manipulate externally in order to burn (cauterize) or cut away the endometrial growths. In younger patients who want to have children, surgery is conservative to keep the reproductive organs intact and functional. However, with conservative surgery, endometriosis recurs in 20 to 40 percent of cases within five years of the surgery. In older patients who have completed childbearing, hysterectomy may be undertaken to remove all or part of the internal reproductive organs. This is the only procedure that is likely to cure endometriosis and prevent relapses.

FEATURE: MY HUMAN BODY

A Pap smear is a method of cervical cancer screening used to detect potentially pre-cancerous and cancerous cells in the cervix. It is the most widely used screening test for this type of cancer, and it is very effective. The test may also detect vaginal infections and abnormal endometrial cells, but it is not designed for these purposes.

If you are sexually active, you should start receiving routine Pap smears by age 21. Because most cases of cervical cancer are caused by infection with human papillomavirus (HPV), which is a sexually transmitted infection, there is little or no benefit to screening people who have not had vaginal intercourse. Starting at age 21, general guidelines are for Pap smears to be repeated every three years until age 50, and then every five years until age 65. Screening may be discontinued after age 65 if the last three Pap smears were normal. If a person has a complete hysterectomy so they no longer have a cervix, there is also no need for further Pap smears. On the other hand, if a person has had a history of abnormal Pap smears or cancer, they will likely be screened more frequently. Pap smears can be done safely during the first several months of pregnancy and resumed about three months after childbirth. Generally, better results are obtained if Pap smears are not done during menstruation.

If you've never had a Pap smear, knowing what to expect may help prepare you for the procedure. The patient lies on the examining table with their feet in "stirrups" to hold the legs up and apart. An instrument called a speculum is inserted into the vagina to hold back the vaginal walls and give access to the cervix. A tiny amount of tissue is brushed off the cervix and smeared onto a microscope slide. The speculum is then removed, and the procedure is over. The slide is later examined under a microscope for abnormal cells. Some people experience light spotting or mild diarrhea after a Pap smear, but most have no lasting effects.

Pap smears are uncomfortable and may be somewhat painful for some people. there may also be a pelvic exam where doctors insert their fingers into the vagina during the Pap smear test. If you experience pain during a Pap smear, tell your health care provider. Many steps can be taken to minimize the pain, which might include using a smaller speculum, using warm instruments and a lubricant, and applying a topical anesthetic such as lidocaine to the cervix before obtaining the smear. Any pain is generally very brief, and the potential reward is worth it. Pap tests are estimated to reduce up to 80 percent of cervical cancer deaths. One of the lives saved could be your own.

REVIEW

1. What is cervical cancer? Worldwide, how prevalent is it, and how does it rank as a cause of cancer deaths?
2. Identify the symptoms of cervical cancer.
3. What are the causes of — and risk factors for — cervical cancer?
4. What roles can Pap smears and HPV vaccines play in preventing cervical cancer cases and cervical cancer deaths?
5. How is cervical cancer treated?
6. Define vaginitis and identify its symptoms.
7. What are some of the causes of vaginitis? Which cause is responsible for most of the cases?
8. How is vaginitis diagnosed and treated?
9. What is endometriosis, and what are its symptoms?
10. Discuss possible causes of endometriosis.
11. How is endometriosis treated? Which treatment is most likely to prevent the recurrence of the disorder?
12. Which disorder below is the most likely to cause symptoms, specifically during menstruation?

    A. endometriosis
    B. cervical cancer
    C. HPV infection
    D. vaginitis

13. *True or False:* Yeast infections are normally treated with antibiotics.
14. *True or False:* In the absence of HPV, there are no mutated cells in the cervix.
15. In the case of infection with *Trichomonas vaginalis*, why is the woman's sexual partner usually treated at the same time?

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15.10: INFERTILITY

FAMILY PORTRAIT

This family portrait in Figure **15.10.1** shows that human societies value having children. Indeed, for most people, parenthood is an important life goal. Unfortunately, some people are unable to achieve that goal because of infertility.



Figure **15.10.1**: Family portrait

WHAT IS INFERTILITY?

Infertility is the inability of a sexually mature adult to reproduce by natural means. For scientific and medical purposes, infertility is generally defined as the failure to achieve a successful pregnancy after at least one year of regular, unprotected sexual intercourse. Infertility may be primary or secondary. Primary infertility applies to cases in which an individual has never achieved a successful pregnancy. Secondary infertility applies to cases in which an individual has had at least one successful pregnancy, but fails to achieve another after trying for at least a year. Infertility is a common problem. About ten percent (6.1 million) of U.S. women aged 15 to 44 have difficulty getting or staying pregnant.

CAUSES OF INFERTILITY

Pregnancy is the result of a multi-step process. In order for a normal pregnancy to occur, an egg must be released from one of the ovaries, the egg must go through a Fallopian tube, a sperm must fertilize the egg as it passes through the Fallopian tube, and then the fertilized egg must implant in the uterus. If there is a problem with any of these steps, infertility can result.

CAUSES OF MALE INFERTILITY

Male infertility occurs when there are no or too few sperms, or when the sperms are not healthy and motile and cannot travel through the female reproductive tract to fertilize an egg. A common cause of inadequate numbers or motility of sperm is varicocele, which is an enlargement of blood vessels in the scrotum. This may raise the temperature of the testes and adversely affect sperm production. In other cases, there is no problem with the sperm, but there is a blockage in the male reproductive tract that prevents the sperm from being ejaculated.

Factors that increase a man's risk of infertility include heavy alcohol use, drug abuse, cigarette smoking, exposure to environmental toxins (such as pesticides or lead), certain medications, serious diseases (such as kidney disease), and radiation or chemotherapy for cancer. Another risk factor is advancing age. Male fertility normally peaks in the mid-twenties and gradually declines after about age 40, although it may never actually drop to zero.

CAUSES OF FEMALE INFERTILITY

Female infertility generally occurs due to one of two problems: failure to produce viable eggs by the ovaries, or structural problems in the Fallopian tubes or uterus. The most common cause of female infertility is a problem with ovulation. Without ovulation, there are no eggs to be fertilized. Anovulatory cycles (menstrual cycles in which ovulation does not occur) may be associated with no or irregular menstrual periods, but even regular menstrual periods may be anovulatory for a variety of reasons. The most common cause of anovulatory cycles is polycystic ovary syndrome (PCOS), which causes hormone imbalances that can interfere with normal ovulation. Another relatively common cause of anovulation is primary ovarian insufficiency. In this condition, the ovaries stop working normally and producing viable eggs at a relatively early age, generally before the age of 40.

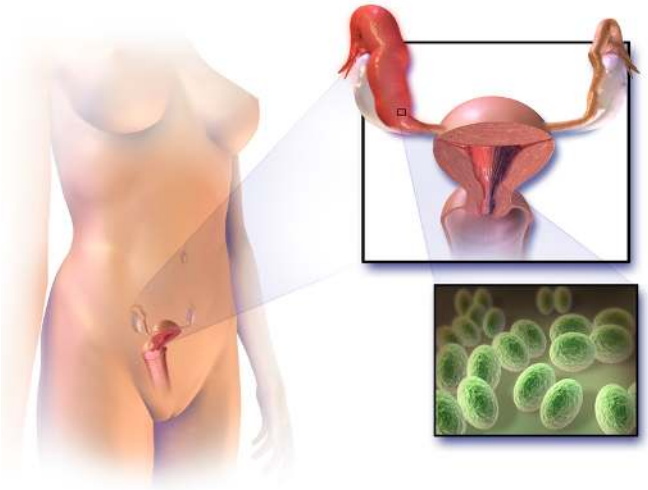


Figure **15.10.2**: An infection of the Fallopian tubes may cause scarring and blockage of the tubes, so sperm cannot reach eggs for fertilization.

Structural problems with the Fallopian tubes or uterus are less common causes of infertility. The Fallopian tubes may be blocked as a result of endometriosis. Another possible cause is a pelvic inflammatory disease, which occurs when sexually transmitted

infections spread to the Fallopian tubes or other female reproductive organs (Figure 15.10.2). The infection may lead to scarring and blockage of the Fallopian tubes. If an egg is produced and the Fallopian tubes are functioning — and a woman has a condition such as uterine fibroids — implantation in the uterus may not be possible. Uterine fibroids are non-cancerous clumps of tissue and muscle that form on the walls of the uterus.

Factors that increase a woman's risk of infertility include tobacco smoking, excessive use of alcohol, stress, poor diet, strenuous athletic training, and being overweight or underweight. Advanced age is even more problematic for females than males. Female fertility normally peaks in the mid-twenties, and continuously declines after age 30 and until menopause around the age of 52, after which the ovary no longer releases eggs. About one-third of couples in which the woman is over age 35 have fertility problems. In older women, more cycles are likely to be anovulatory, and the eggs may not be as healthy.

DIAGNOSING CAUSES OF INFERTILITY

Diagnosing the cause(s) of a couple's infertility often requires testing both partners for potential problems. The semen is likely to be examined for the number, shape, and motility of sperm. If problems are found with sperm, further studies are likely to be done, such as medical imaging to look for structural problems with the testes or ducts.

In individuals with ovaries and uterus, the first step is most often determining whether ovulation is occurring. This can be done at home by carefully monitoring body temperature (it rises slightly around the time of ovulation) or using a home ovulation test kit, which is available over the counter at most drugstores. Whether or not ovulation is occurring can also be detected with blood tests or ultrasound imaging of the ovaries. If ovulation is occurring normally, then the next step may be an X-ray of the Fallopian tubes and uterus to see if there are any blockages or other structural problems. Another approach to examining the reproductive tract for potential problems is laparoscopy. In this surgical procedure, a tiny camera is inserted into the abdomen through a small incision. This allows the doctor to directly inspect the reproductive organs.

TREATING INFERTILITY

Infertility often can be treated successfully. The type of treatment depends on the cause of infertility.

TREATING MALE INFERTILITY

Medical problems that interfere with sperm production may be treated with medications or other interventions that may lead to the resumption of normal sperm production. If, for example, if an infection is interfering with sperm production, antibiotics may resolve the problem. If there is a blockage in the ejaculation of sperm, surgery may be able to remove the blockage. Alternatively, the sperm may be removed from his body and then used for the artificial insemination of their partner. In this procedure, the sperms are injected into the uterus.

TREATING FEMALE INFERTILITY

It is possible to correct blocked Fallopian tubes or uterine fibroids with surgery. Ovulation problems, on the other hand, are usually treated with hormones that act either on the pituitary gland or on the ovaries. Hormonal treatments that stimulate ovulation often result in more than one egg being ovulated at a time, thus increasing the chances of a person conceiving with twins, triplets, or even higher multiple births. Multiple fetuses are at greater risk of being born too early or having health and developmental problems. The mother is also at greater risk of complications arising during pregnancy. Therefore, the possibility of multiple fetuses should be weighed in making a decision about this type of infertility treatment.

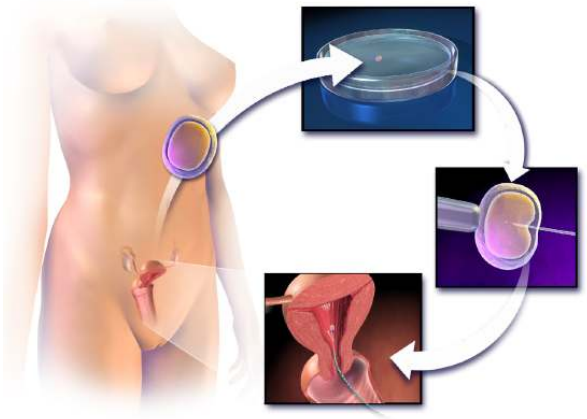


Figure 15.10.3: This figure shows one way ART procedures may be used to treat infertility. An egg is removed from the female reproductive tract, injected with sperm from her partner, and allowed to develop into an embryo in the lab. Then, the embryo is placed inside the woman's uterus for implantation and development during the remainder of gestation.

ASSISTED REPRODUCTIVE TECHNOLOGY

Some cases of infertility are treated with **assisted reproductive technology (ART)**. This is a collection of medical procedures in which eggs and sperms are removed to be manipulated in ways that increase the chances of fertilization occurring. The eggs and sperm may be injected into one of the Fallopian tubes for fertilization to take place *in vivo* (in the body). More commonly, however, the eggs and sperm are mixed together outside the body so fertilization takes place *in vitro* (in a test tube or dish in a lab). The latter approach is illustrated in Figure 15.10.3. With *in vitro* fertilization, the fertilized eggs may be allowed to develop into embryos before being placed in the woman's uterus.

ART has about a 40 percent chance of leading to a live birth in women under the age of 35, but only about a 20 percent chance of success after the age of 35. Some studies have found a higher-than-average risk of birth defects in children produced by ART procedures, but this may be due to the generally higher ages of the parent — not the technologies used. Same-sex couples take advantage of the ART process to expand their family.

OTHER APPROACHES

Other approaches for certain causes of infertility and same-sex couples include the use of a surrogate mother, a gestational carrier, or sperm donation.

- A **surrogate mother** is a woman who agrees to become pregnant using the man's sperm and her own egg. The child, who will be the biological offspring of the surrogate and the male partner, is given up at birth for adoption by the couple. Surrogacy might be selected by women with no eggs or unhealthy eggs. A woman who carries a mutant gene for a serious genetic disorder might choose this option to ensure that the defective gene is not passed on to the offspring.
- A **gestational carrier** is a woman who agrees to receive a transplanted embryo from a couple and carry it to term. The child, who will be the biological offspring of the couple, is given to the parents at birth. A gestational carrier might be used by women who have normal ovulation but no uterus, or who cannot safely carry a fetus to term because of a serious health problem (such as kidney disease or cancer). This method is commonly used by gay men couples.
- **Sperm donation** is the use of sperm from a fertile man (generally through artificial insemination) for cases in which the male partner in a couple is infertile, or in which a woman seeks to become pregnant without a male partner. A lesbian couple may use donated sperm to enable one of them to become pregnant and have a child. Sperm can be obtained from a sperm bank, which buys and stores sperm for artificial insemination, or a male friend or another individual may donate sperm to a specific woman.

FEATURE: HUMAN BIOLOGY IN THE NEWS

More than 14 million people in the United States have polycystic ovary syndrome (PCOS), an endocrine disorder with a genetic basis that is the most common cause of infertility. Most patients with PCOS grow many small cysts on their ovaries. The cysts are not usually harmful, but they lead to hormone imbalances, such as higher-than-normal levels of testosterone in affected individuals. The hormonal imbalances are the primary cause of infertility associated with PCOS. The disorder also increases the risk of a whole slew of other serious health problems, including endometrial cancer, heart disease, high blood pressure, type 2 diabetes, asthma, obesity, depression, and anxiety.

Despite the prevalence of PCOS and its serious potential effects, until recently, its cause was poorly understood. There were also no effective early diagnostic or treatment strategies for it. All that appears to be changing now. A review of the research literature on PCOS published in 2016 provides new insights into causes, diagnosis, and treatment for the disorder.

Among the research cited in the review is promising new work on nonhuman animal models, including monkeys and mice. One line of research suggests that PCOS may be programmed into a fetus during the second trimester of pregnancy. Another line of research indicates that hair taken from an infant can be analyzed for early risk factors for PCOS, even though PCOS symptoms do not show up until puberty. In addition, the research is helping scientists identify a constellation of genes that are suspected to play a role in PCOS.

The new research on PCOS is important for those who suffer from the disorder and its consequences, including infertility and life-threatening chronic conditions (such as heart disease and diabetes). The hope is that such research will lead to new ways of diagnosing PCOS at an early age, when medical interventions and lifestyle choices may be used to head off the more serious complications. It is likely that the research will also eventually lead to new and more effective treatment options for the millions of people who battle PCOS.

REVIEW

1. What is infertility? How is infertility defined scientifically and medically?
2. What percentage of infertility in couples is due to male infertility? What percentage is due to female infertility?
3. Identify causes of and risk factors for male infertility.
4. Identify causes of and risk factors for female infertility.
5. How are the causes of infertility in couples diagnosed?
6. How is infertility treated?
7. Discuss some of the social and ethical issues associated with infertility or its treatment.
8. Why is infertility an under-appreciated problem in developing countries?
9. Describe two similarities between the causes of male and female infertility.
10. *True or False:* A person who already has a biological child can suffer from infertility.
11. *True or False:* ART always involves fertilization outside of the body.
12. Explain the difference between males and females in terms of how age affects fertility.
13. If a woman has no viable eggs, which method below is the most likely to help her and her partner have a baby?

    A. gestational carrier
    B. surrogate mother
    C. *in vitro* fertilization
    D. *in vivo* fertilization

14. Do you think that taking medication to stimulate ovulation is likely to improve fertility in cases where infertility is due to endometriosis? Explain your answer.
15. If a semen sample shows no sperm, what is a possible cause?

    A. blockage in the male reproductive tract
    B. lack of spermatogenesis
    C. PCOS
    D. A and B

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3. Assisted Reproductive Technology by Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. CC BY 3.0 via Wikimedia Commons
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15.11: CONTRACEPTION

FAMILY PLANNING PIONEER

Her name was Marie Stopes, and she was a British author and paleobotanist who lived from 1880 to 1958. She is pictured here in her lab next to her microscope. Stopes made significant contributions to science and was the first woman on the faculty of the University of Manchester in England. Her primary claim to fame was her work as a family planning pioneer.



Figure **15.11.1**: Marie Stopes in her laboratory in 1904

Along with her husband, Stopes founded the first birth control clinic in Britain. She also edited a newsletter called *Birth Control News*, which gave explicit practical advice on how to avoid unwanted pregnancies. In 1918, she published a sex manual titled *Married Love. The book was* controversial and influential, bringing the subject of contraception into wide public discourse for the first time.

TYPES OF CONTRACEPTION AND THEIR EFFECTIVENESS

Types of birth control methods include barrier methods, hormonal methods, intrauterine devices, behavioral methods, and sterilization. With the exception of sterilization, all of these methods are reversible. Examples of each type of birth control method and their failure rates with typical use are described below.

BARRIER METHODS

Barrier methods are devices that are used to physically block sperm from entering the uterus. They include condoms and diaphragms. Eighteen out of 100 individuals who use this method may get pregnant.

CONDOMS

Condoms are the most commonly used method of birth control globally. There are condoms for vaginas and penises, but penis condoms are more widely used, less expensive, and more readily available. Both types of condoms are pictured in Figure **15.11.2**.

WHAT IS CONTRACEPTION?

About a century after *Married Love*, more than half of all fertile married couples worldwide use some form of contraception. **Contraception,** also known as birth control, is any method or device used to prevent pregnancy. Birth control methods have been used for centuries, but safe and effective methods only became available in the 20th century, in part because of the work of people like Marie Stopes.

Many different birth control methods are currently available, but they differ considerably in their effectiveness at preventing pregnancy. The effectiveness of contraception is generally expressed as the failure rate, which is the percentage of women who become pregnant using a given method during the first year of use. Virtually no one uses any method of birth control perfectly, so the failure rate with typical use is almost always higher — and often much higher — than the failure rate *with* perfect use. For example, with perfect use, a birth control method might have a failure rate of just one percent, whereas, with typical use, the failure rate might be 25 percent. For comparison, there is an average one-year pregnancy rate of 85 percent if no contraception is used.

All methods of birth control have potential adverse effects, but their health risks are less than the health risks associated with pregnancy. Using contraception to space the children in a family is also good for the children's health and development, as well as for the health of the mother.

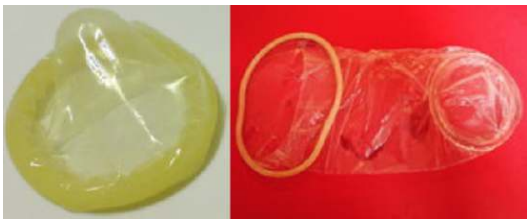


Figure **15.11.2**: (left) Rolled up penis condom. (right) An unrolled vagina condom

Whichever type of condom is used, it must be put in place before sexual intercourse occurs. Condoms work by physically blocking ejaculated sperm from entering the vagina of the sexual partner. With typical use, penis condoms have an 18 percent failure rate, and vagina condoms have a 21 percent failure rate. Unlike virtually all other birth control methods, condoms also help prevent the spread of sexually transmitted infections (STIs), in addition to helping to prevent pregnancy.

DIAPHRAGMS

Diaphragms, like the one in Figure **15.11.3**, ideally prevent sperm from passing through the cervical canal and into the uterus. A diaphragm is inserted vaginally before sexual intercourse occurs and must be placed over the cervix to be effective. It is usually recommended that a diaphragm be covered with spermicide before insertion for extra protection. It is also recommended that the diaphragm be left in place for at least six hours after intercourse. The

failure rate of diaphragms with typical use is about 12 percent, which is about half that of condoms. However, diaphragms do not help prevent the spread of STIs, and their use is also associated with an increased frequency of urinary tract infections.



Figure 15.11.3: A diaphragm is pictured here beside a U.S. quarter coin for size comparison. The diaphragm should fit snugly over the cervix so it blocks sperm from entering the cervical canal.

HORMONAL METHODS

Hormonal contraception is the administration of hormones to prevent ovulation. Hormones can be taken orally in birth control pills, implanted under the skin, injected into a muscle, or received transdermally from a skin patch. Six to twelve pregnancies in hundred individuals who use this method may occur.

Hormonal methods are currently available only for individuals with uterus and ovaries. Birth control pills are the most common form of hormonal contraception. There are two types of pills: the combined pill (which contains both estrogen and progesterone) and the progesterone-only pill. Both types of pills inhibit ovulation and thicken cervical mucus. The failure rate of birth control pills is only about one percent or less if used perfectly. However, the failure rate rises to about ten percent with typical use, because individuals do not always remember to take the pill at the same time every day. The combined pill is associated with a slightly increased risk of blood clots, but a reduced risk of ovarian and endometrial cancers. The progesterone-only pill does not increase the risk of blood clots, but it may cause irregular menstrual periods. It may take a few weeks or even months for fertility to return to normal after the long-term use of birth control pills.

INTRAUTERINE DEVICES

An **intrauterine device (IUD)** is a T-shaped or coiled plastic structure that is inserted into the uterus via the vagina and cervix that contains either copper or a hormone. You can see an IUD in the uterus in the drawing in Figure 15.11.4. An IUD is inserted by a physician and may be left in place for months or even years. A physician also must remove an IUD, using the strings attached to the device. The copper in copper IUDs prevents pregnancy by interfering with the movement of sperm so they cannot reach and fertilize an egg. The copper may also prevent implantation in the unlikely circumstance of a sperm managing to reach and fertilize an egg. Almost no one gets pregnant who uses this method.

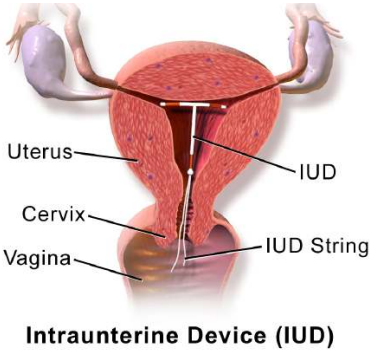


Figure 15.11.4: An IUD is a T-shaped structure. two ends of the IUD block the openings of the two fallopian tubes and the third end contains IUD string that hangs out of the cervix into the vagina.

The hormones in hormonal IUDs prevent pregnancy by thickening cervical mucus and trapping sperm. The hormones may also interfere with ovulation, so there is no egg to fertilize. For both types of IUDs, the failure rates are less than one percent, and failure rates with typical use are virtually the same as failure rates with perfect use. Their effectiveness is one reason that IUDs are among the most widely used forms of reversible contraception. Once removed, even after long-term use, fertility returns to normal immediately. On the other hand, IUDs do have a risk of complications, including increased menstrual bleeding and more painful menstrual cramps. IUDs are also occasionally expelled from the uterus, and there is a slight risk of perforation of the uterus by the IUD.

BEHAVIORAL METHODS

The least effective methods of contraception are behavioral methods. They involve regulating the timing or method of intercourse to prevent the introduction of sperm into the uterus, either altogether or when an egg may be present. Behavioral methods include fertility awareness methods and withdrawal. Abstinence from sexual activity, or at least from vaginal intercourse, is sometimes considered a behavioral method, as well — but it is unlikely to be practiced consistently enough by most people to prevent pregnancy. Even teens who receive abstinence-only sex education do not have reduced rates of pregnancy. Abstinence is also ineffective in cases of non-consensual sex.

FERTILITY AWARENESS METHODS

Fertility awareness methods involve estimating the most fertile days of the menstrual cycle and then avoiding unprotected vaginal intercourse on those days. The most fertile days are generally a few days before ovulation occurs, the day of ovulation, and another day or two after that. Unless unprotected sex occurs on those days, pregnancy is unlikely. Techniques for estimating the most fertile days include monitoring and detecting minor changes in basal body temperature or cervical secretions. This requires daily motivation and diligence, so it is not surprising that typical-use failure rates of these methods are at least 20 to 25 percent, and for some individuals may be as high as using no contraception at all (85 percent).

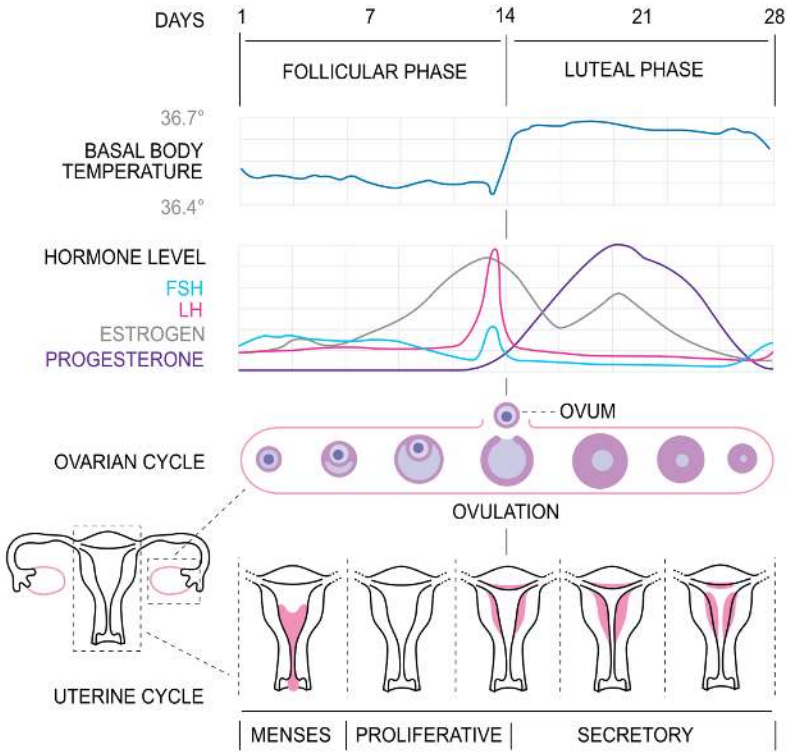


Figure **15.11.5**: A woman's basal body temperature rises slightly when ovulation occurs and stays slightly elevated until the start of the next menstrual period. The follicular phase of the ovaries lasts from day 1 to 14 of the menstrual cycle. After ovulation, the luteal phase lasts from day 14 to day 28. During ovulation, the levels of follicle stimulating, luteinizing, and estrogen hormones increase. The level of progesterone increases after ovulation that builds and prepares the endometrium for implantation.

Basal body temperature is the lowest body temperature when the body is at rest (usually during sleep). It is most often estimated by a temperature measurement taken immediately upon awakening in the morning and before any physical activity has occurred. Basal body temperature normally rises after ovulation occurs, as shown in Figure **15.11.5**. The increase in temperature is small but consistent and may be used to determine when ovulation occurs, around which time unprotected intercourse should be avoided to prevent pregnancy. However, basal body temperature only shows when ovulation has already occurred, and it cannot predict in advance when ovulation will occur. Sperm can live for up to a week in the female reproductive tract, so determining the occurrence of ovulation only after the fact is a major drawback of this method.

Monitoring cervical mucus has the potential for being more effective than monitoring basal body temperature because it can predict ovulation ahead of time. As ovulation approaches, cervical secretions usually increase in the amount and become thinner (which helps sperm swim through the cervical canal). By recognizing the changing characteristics of cervical mucus, ovulation timing can be predicted. From this information, it can be determined when to avoid unprotected sex to prevent pregnancy.

WITHDRAWAL

Withdrawal (also called coitus interruptus) is the practice of withdrawing the penis from the vagina before ejaculation occurs. The main risk of the withdrawal method is that penis is not withdrawn in a timely manner. The fluid typically released from the penis before ejaculation occurs may also contain some sperm. In addition, if sperms are ejaculated just outside of the vagina, there is a chance they will be able to enter the vagina and travel up to fertilize an egg. For all these reasons, the withdrawal method has a relatively high failure rate of about 22 percent with typical use.

STERILIZATION

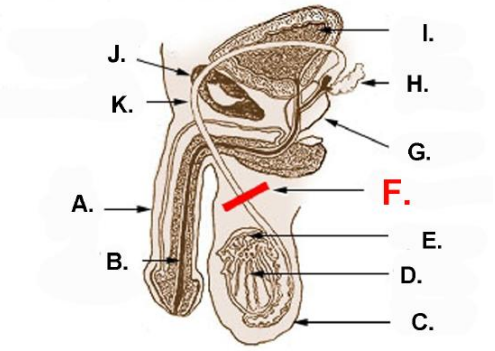


Figure **15.11.6**: The red line (F in the upper portion of the scrotum) shows where each vas deferens (K) is clamped or cut in a vasectomy. The other structures are A. penis, B. urethra, C. scrotum, D. testis, E. epididymis, G. prostate, H. seminal vesicle, I. bladder, J. pubic bone

The most effective contraceptive method is **sterilization.** In both sexes, sterilization generally involves surgical procedures that are considered irreversible. Additional surgery may be able to reverse a sterilization procedure, but there are no guarantees. Male

sterilization is generally less invasive and less risky than female sterilization.

MALE STERILIZATION

Male sterilization is usually achieved with a **vasectomy**. In this surgery, the vas deferens from each testis is clamped, cut, or otherwise sealed (Figure **15.11.6**). This prevents sperm from traveling from the epididymis to the ejaculatory ducts and being ejaculated from the penis. The same amount of semen will still be ejaculated, but it will not contain any sperm, making fertilization impossible. After a vasectomy, the testes continue to produce sperm, but the sperms are reabsorbed. It usually takes several months after a vasectomy for all remaining sperm to be ejaculated or reabsorbed. In the meantime, another method of birth control should be used.

FEMALE STERILIZATION

The procedure undertaken for female sterilization is usually **tubal ligation.** The Fallopian tubes may be tied or cut in a surgical procedure, which permanently blocks the tubes. Alternatively, tiny metal implants may be inserted into the Fallopian tubes in a nonsurgical procedure. Over time, scar tissue grows around the implants and permanently blocks the tubes. Either method stops eggs from traveling from the ovaries through the Fallopian tubes, where fertilization usually takes place.

EMERGENCY CONTRACEPTION

Emergency contraception is any form of contraception that is used after unprotected vaginal intercourse. One method is the so-called “morning-after” pill. This is essentially a high-dose birth control pill that helps prevent pregnancy by temporarily preventing ovulation. It works only if ovulation has not already occurred, and when taken within five days after unprotected sex. The sooner the pill is taken, the more likely it is to work. Another method of emergency contraception is the IUD. An IUD that is inserted up to five days after unprotected sex can prevent nearly 100 percent of pregnancies. It keeps sperm from reaching and fertilizing an egg or inhibits implantation if an egg has already been fertilized. The IUD can then be left in place to prevent future pregnancies.

REVIEW

1. Define contraception. Globally, how prevalent is the use of contraception by fertile married couples?
2. How is the effectiveness of contraceptive methods typically measured?
3. List five different types of birth control methods. Which (if any) methods are reversible? Which (if any) methods can prevent the spread of sexually transmitted infections, as well as pregnancies?
4. What are barrier methods? Give two examples.
5. Describe hormonal contraception. What is the most commonly used form of hormonal contraception?
6. What is an IUD?
7. Generally, describe behavioral methods of contraception, and identify two specific behavioral methods.
8. Discuss sterilization as a birth control method. How is sterilization typically achieved in males? In females?
9. What is emergency contraception? When is it used? What are the two forms of emergency contraception?
10. How does the thickness of cervical mucus relate to fertility? How do two methods of contraception take advantage of this relationship?
11. Arrange the following methods of contraception in order of typical effectiveness, from the least effective to most effective: *birth control pill; fertility awareness method; IUD; male condom*
12. If a newly developed method of contraception had a 35 percent failure rate, would you consider this to be an effective method? Explain your answer.
13. Which method of contraception prevents ovulation?\
    A. female condom
    B. tubal ligation
    C. birth control pill
    D. fertility awareness method
14. *True or False:* A vasectomy prevents the production of sperm.
15. *True or False:* If a man and woman have unprotected intercourse four days before ovulation occurs, the woman cannot get pregnant.

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15.12: CASE STUDY CONCLUSION- TRYING TO CONCEIVE AND CHAPTER SUMMARY

CASE STUDY CONCLUSION: TRYING TO CONCEIVE

The person in Figure **15.12.1** is holding a home pregnancy test. The two pink lines in the middle are the type of result that Isabella and Omar are desperately hoping to see themselves one day—a positive pregnancy test. At the beginning of the chapter, you learned that Isabella and Omar have been actively trying to get pregnant for a year, which, as you now know, is the timeframe necessary for infertility to be diagnosed.



Figure **15.12.1**: Pregnancy test

Isabella and Omar tried having sexual intercourse on day 14 of her menstrual cycle to optimize their chances of having his sperm meet her egg. Why might this not be successful, even if they do *not* have fertility problems? As you have learned, although the average menstrual cycle is 28 days, with ovulation occurring around day 14, many women vary widely from these averages (either consistently or variably) from month to month. Recall, for example, that menstrual cycles may vary from 21 to 45 days in length, and a woman's cycle is considered to be regular if it varies within as many as eight days from shortest to longest cycle. This variability means that ovulation often does not occur on or around day 14, particularly if the woman has significantly shorter, longer, or irregular cycles—as Isabella does. Therefore, by aiming for day 14 without knowing when Isabella is actually ovulating, they may not be successful in helping Omar's sperm encounter Isabella's egg.

Lack of ovulation entirely can also cause variability in menstrual cycle length. As you have learned, the regulation of the menstrual cycle depends on an interplay of hormones from the pituitary and ovary, including FSH and LH from the pituitary and estrogen and progesterone from the ovary—specifically from the follicle which surrounds the maturing egg and becomes the corpus luteum after ovulation. Shifts in these hormones and processes can affect ovulation and menstrual cycle length. This is why Isabella was concerned about her long and irregular menstrual cycles. If there is a sign that she is not ovulating, that could be the reason why she is having trouble getting pregnant.

In order to get a better idea of whether Isabella is ovulating, Dr. Bashir recommended that she take her basal body temperature (BBT) each morning before getting out of bed, and track it throughout her menstrual cycle. As you have learned, BBT typically rises slightly and stays high after ovulation. While tracking BBT is not a particularly effective form of contraception, since the temperature rise occurs only after ovulation, it can be a good way to see whether a person is ovulating at all. Although not every individual will see a clear shift in BBT after ovulation, it is a relatively easy way to start assessing fertility and is used as part of a more comprehensive fertility assessment by some physicians.

Dr. Bashir also recommended that Isabella use a home ovulation predictor kit. This is another relatively cheap and easy way to assess ovulation. Most ovulation predictor kits work by detecting the hormone LH in urine using test strips, like the ones shown in Figure **15.12.2**. Why can this predict ovulation? Think about what you have learned about how ovulation is triggered. Rising levels of estrogen from the maturing follicle in the ovary causes a surge in the level of LH secreted from the pituitary gland, which triggers ovulation. This surge in LH can be detected by the home kit, which compares the level of LH in urine to that of a control on the strip. After the LH surge is detected, ovulation will typically occur within one to two days.



Figure **15.12.2**: Ovulation test strips. The pink line towards the right in both strips is the control line that is used as a comparison to the test line that detects LH in the woman's urine, located to the left of the control line. In the top strip, the test line is barely visible, indicating that LH levels are low. In the bottom strip, the light pink line on the left indicates that the level of LH is starting to increase. When the test line is equal in intensity to, or darker than, the control line, the LH surge is likely occurring.

By tracking her BBT and using the ovulation predictor kit, Isabella has learned that she is most likely ovulating—but not in every cycle, and sometimes she ovulates much later than day 14. Because frequent anovulatory cycles can be a sign of an underlying hormonal disorder, such as polycystic ovary syndrome (PCOS) or problems with the pituitary or other glands that regulate the reproductive system, Dr. Bashir orders blood tests for Isabella and sets up an appointment for a physical exam.

But because Isabella is sometimes ovulating, the problem may not lie solely with her. Recall that infertility occurs in equal proportions in all sexes, and can be due to problems in both partners. This is why it is generally recommended that both partners get assessed for fertility issues when they are having trouble getting pregnant after a year of trying.

Therefore, Omar proceeds with the semen analysis that Dr. Bashir recommended. In this process, the man provides a semen sample by ejaculating into a cup or special condom, and the semen is then

examined under a microscope. As you have learned, the semen is then checked for sperm number, shape, and motility. Sperm with an abnormal shape or trouble moving will likely have trouble reaching and fertilizing an egg. A low amount of sperm will also reduce the chances of conception. In this way, a semen analysis can provide insight into the possible underlying causes of infertility. For instance, a low sperm count could indicate problems in sperm production or a blockage that is preventing sperm from being emitted from the penis. Further testing would have to be done to dissociate between these two possible causes.

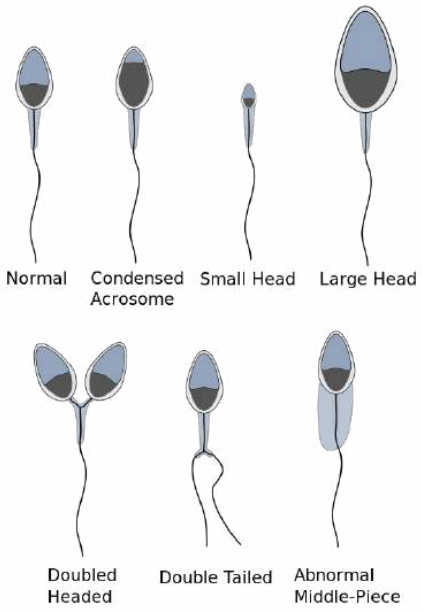


Figure 15.12.3: The image compares normal sperm to malformed sperm

Omar had been worried that past injuries to his testes may have affected his fertility. As you have learned, the testes are where sperm are produced, and because they are external to the body, they are vulnerable to injury. In addition to physical damage to the testes and other parts of the male reproductive tract, a testicular injury could potentially cause the creation of antibodies against a person's own sperm. As you have learned, Sertoli cells lining the seminiferous tubules are tightly packed so that the developing sperm are normally well-separated from the body's immune system. However, in the case of an injury, this barrier can be breached, which can cause the creation of anti-sperm antibodies. These antibodies can hamper fertility by killing the sperm or otherwise interfering with their ability to move or fertilize an egg. When infertility is due to such antibodies, it is called "immune infertility."

However, Omar's semen analysis shows that he has normal numbers of healthy sperm. Dr. Bashir recommends that while they investigate whether Isabella has an underlying medical issue, she continues to track her BBT and use ovulation predictor kits to try to pinpoint when she is ovulating. She recommends that once Isabella sees an LH surge, the couple try to have intercourse within three days to maximize their chances of conception. If Isabella is found to have a medical problem that is inhibiting ovulation, depending on what it is, they may either address the problem directly, or she can take medication that stimulates ovulation, such as clomiphene citrate (often sold under the brand name Clomid). This medication works by increasing the amount of FSH secreted by the pituitary.

Fortunately, tracking ovulation at home and timing intercourse appropriately was all Isabella and Omar needed to do to finally get pregnant! After their experience, they, like you, now have a much deeper understanding of the intricacies of the reproductive system and the complex biology that is involved in the making of a new human organism.

CHAPTER SUMMARY

In this chapter, you learned about the male and female reproductive systems. Specifically, you learned that:

- The reproductive system is the human organ system responsible for the production and fertilization of gametes and the carrying of a fetus.
- Both male and female reproductive systems have organs called gonads (testes in males, ovaries in females) that produce gametes (sperm or eggs) and sex hormones (such as testosterone and estrogen). Sex hormones are endocrine hormones that control the prenatal development of sex organs, sexual maturation at puberty, and reproduction after puberty.
- The reproductive system is the only organ system that is significantly different between male and female sexes. A Y-chromosome gene called SRY is responsible for undifferentiated embryonic tissues developing into a male reproductive system. Without a Y chromosome, the undifferentiated embryonic tissues develop into a female reproductive system.
- Male and female reproductive systems are different at birth but immature and nonfunctioning. Maturation of the reproductive system occurs during puberty when hormones from the hypothalamus and pituitary gland stimulate the gonads to produce sex hormones again. The sex hormones, in turn, cause the changes of puberty.
- Male reproductive system organs include the testes, epididymis, penis, vas deferens, prostate gland, and seminal vesicles.
    - The two testes are sperm- and testosterone-producing male gonads. They are contained within the scrotum, a pouch that hangs down behind the penis. The testes are filled with hundreds of tiny, tightly coiled seminiferous tubules, where sperm are produced. The tubules contain sperm in different stages of development, as well as Sertoli cells, which secrete substances needed for sperm production. Between the tubules are Leydig cells, which secrete testosterone.
    - The two epididymes are contained within the scrotum. Each epididymis is a tightly coiled tubule where sperms mature and are stored until they leave the body during an ejaculation.
    - The two vas deferens are long, thin tubes that run from the scrotum up into the pelvis. During ejaculation, each vas deferens carries sperm from one of the epididymes to one of the pair of ejaculatory ducts.

- The two seminal vesicles are glands within the pelvis that secrete fluid through ducts into the junction of each vas deferens and ejaculatory duct. This alkaline fluid makes up about 70 percent of semen, the sperm-containing fluid that leaves the penis during ejaculation. Semen contains substances and nutrients that sperm need to survive and "swim" in the female reproductive tract.
- The prostate gland is located just below the seminal vesicles and surrounds the urethra and its junction with the ejaculatory ducts. The prostate secretes an alkaline fluid that makes up close to 30 percent of semen. The prostatic fluid contains a high concentration of zinc, which sperm need to be healthy and motile.
- The ejaculatory ducts form where the vas deferens joins with the ducts of the seminal vesicles in the prostate gland. They connect the vas deferens with the urethra. The ejaculatory ducts carry sperm from the vas deferens whereas the secretions from the seminal vesicles and prostate gland form semen.
- The paired bulbourethral glands are located just below the prostate gland. They secrete a tiny amount of fluid into semen. The secretions help lubricate the urethra and neutralize any acidic urine it may contain.
- The penis is the external male organ that has the reproductive function of intromission, which is delivering sperm to the female reproductive tract. The penis also serves as the organ that excretes urine. The urethra passes through the penis and carries urine or semen out of the body. Internally, the penis consists largely of columns of spongy tissue that can fill with blood and make the penis stiff and erect. This is necessary for sexual intercourse so intromission can occur.

- Parts of a mature sperm include the head, acrosome, midpiece, and flagellum. The process of producing sperm is called spermatogenesis. This normally starts during puberty and continues uninterrupted until death.
  - Spermatogenesis occurs in the seminiferous tubules in the testes and requires high concentrations of testosterone. Sertoli cells in the testes play many roles in spermatogenesis, including concentrating testosterone under the influence of follicle-stimulating hormone (FSH) from the pituitary gland.
  - Spermatogenesis begins with a diploid stem cell called a spermatogonium, which undergoes mitosis to produce a primary spermatocyte. The primary spermatocyte undergoes meiosis I to produce haploid secondary spermatocytes, and these cells in-turn, undergo meiosis II to produce spermatids. After the spermatids grow a tail and undergo other changes, they become sperm.
  - Before sperms are able to "swim," they must mature in the epididymis. The mature sperms are then stored in the epididymis until ejaculation occurs.
- Ejaculation is the process in which semen is propelled by peristalsis in the vas deferens and ejaculatory ducts from the urethra in the penis.
- Leydig cells in the testes secrete testosterone under the control of luteinizing hormone (LH) from the pituitary gland. Testosterone is needed for male sexual development and to maintain normal spermatogenesis after puberty. It also plays a role in the prostatatic function and the ability of the penis to become erect.
- Disorders of the male reproductive system include erectile dysfunction (ED), epididymitis, prostate cancer, and testicular cancer.
  - ED is a disorder characterized by the regular and repeated inability of a sexually mature male to obtain and maintain an erection. ED is a common disorder that occurs when normal blood flow to the penis is disturbed or there are problems with the nervous control of penile engorgement or arousal.
    - Possible physiological causes of ED include aging, illness, drug use, tobacco smoking, and obesity, among others. Possible psychological causes of ED include stress, performance anxiety, and mental disorders.
    - Treatments for ED may include lifestyle changes, such as stopping smoking and adopting a healthier diet and regular exercise. However, the first-line treatment is prescription drugs such as Viagra® or Cialis® that increase blood flow to the penis. Vacuum pumps or penile implants may be used to treat ED if other types of treatment fail.
  - Epididymitis is inflammation of the epididymis. It is a common disorder, especially in young men. It may be acute or chronic and is often caused by a bacterial infection. Treatments may include antibiotics, anti-inflammatory drugs, and painkillers. Treatment is important to prevent the possible spread of infection, permanent damage to the epididymis or testes, and even infertility.
  - Prostate cancer is the most common type of cancer in men and the second leading cause of cancer death in men. If there are symptoms, they typically involve urination, such as frequent or painful urination. Risk factors for prostate cancer include older age, family history, high-meat diet, and sedentary lifestyle, among others.
    - Prostate cancer may be detected by a physical exam or a high level of prostate-specific antigen (PSA) in the blood, but a biopsy is required for a definitive diagnosis. Prostate cancer is typically diagnosed relatively late in life and is usually slow growing, so no treatment may be necessary. In younger patients or those with faster-growing tumors, treatment is likely to include surgery to remove the prostate, followed by chemotherapy and/or radiation therapy.
  - Testicular cancer, or cancer of the testes, is the most common cancer in males between the ages of 20 and 39 years. It is more common in males of European than African ancestry. A lump or swelling in one testis, fluid in the scrotum, and testicular pain or tenderness are possible signs and symptoms of testicular cancer.

        - Testicular cancer can be diagnosed by a physical exam and diagnostic tests, such as ultrasound or blood tests. Testicular cancer has one of the highest cure rates of all cancers. It is typically treated with surgery to remove the affected testis, and this may be followed by radiation therapy, and/or chemotherapy. Normal male reproductive functions are still possible after one testis is removed if the remaining testis is healthy.
- The female reproductive system is made up of internal and external organs that function to produce haploid female gametes called eggs, secrete female sex hormones (such as estrogen), and carry and give birth to a fetus.
- Female reproductive system organs include the ovaries, Fallopian tubes, uterus, vagina, clitoris, and labia.
    - The vagina is an elastic, muscular canal that can accommodate the penis. It is where sperm are usually ejaculated during sexual intercourse. The vagina is also the birth canal, and it channels the flow of menstrual blood from the uterus. A healthy vagina has a balance of symbiotic bacteria and an acidic pH.
    - The uterus is a muscular organ above the vagina where a fetus develops. Its muscular walls contract to push out the fetus during childbirth. The cervix is the neck of the uterus that extends down into the vagina. It contains a canal connecting the vagina and uterus for sperm or an infant to pass through. The innermost layer of the uterus, the endometrium, thickens each month in preparation for an embryo but is shed in the following menstrual period if fertilization does not occur.
    - The Fallopian tubes extend from the uterus to the ovaries. Waving fimbriae at the ovary ends of the Fallopian tubes guide ovulated eggs into the tubes where fertilization may occur as the eggs travel to the uterus. Cilia and peristalsis help eggs move through the tubes. Tubular fluid helps nourish sperm as they swim up the tubes toward eggs.
    - The ovaries are gonads that produce eggs and secrete sex hormones including estrogen. Nests of cells called follicles in the ovarian cortex are the functional units of ovaries. Each follicle surrounds an immature egg. At birth, a baby girl's ovaries contain at least a million eggs, and they will not produce any more during her lifetime. One egg matures and is typically ovulated each month during a woman's reproductive years.
    - The vulva is a general term for external female reproductive organs. The vulva includes the clitoris, two pairs of labia, and openings for the urethra and vagina. Secretions from Bartholin's glands near the vaginal opening lubricate the vulva.
    - The breasts are technically not reproductive organs, but their mammary glands produce milk to feed an infant after birth. Milk drains through ducts and sacs and out through the nipple when a baby sucks.
- Oogenesis is the process of producing eggs in the ovaries of a female fetus. Oogenesis begins when a diploid oogonium divides by mitosis to produce a diploid primary oocyte. The primary oocyte begins meiosis I and then remains at this stage in an immature ovarian follicle until after birth.
- After puberty, one follicle a month matures and its primary oocyte completes meiosis I to produce a secondary oocyte, which begins meiosis II. During ovulation, the mature follicle bursts open and the secondary oocyte leaves the ovary and enters a Fallopian tube.
- While a follicle is maturing in an ovary each month, the endometrium in the uterus is building up to prepare for an embryo. Around the time of ovulation, cervical mucus becomes thinner and more alkaline to help sperm reach the secondary oocyte.
- If the secondary oocyte is fertilized by a sperm, it quickly completes meiosis II and forms a diploid zygote, which will continue through the Fallopian tube. The zygote will go through multiple cell divisions before reaching and implanting in the uterus. If the secondary oocyte is not fertilized, it will not complete meiosis II, and will soon disintegrate.
- Pregnancy is the carrying of one or more offspring from fertilization until birth. The maternal organism must provide all the nutrients and other substances needed by the developing offspring, and also remove its wastes. She should also avoid exposures that could potentially damage the offspring, especially early in the pregnancy when organ systems are developing.
    - The average duration of pregnancy is 40 weeks (from the first day of the last menstrual period) and is divided into three trimesters of about three months each. Each trimester is associated with certain events and conditions that a pregnant woman may expect, such as morning sickness during the first trimester, feeling fetal movements for the first time during the second trimester, and rapid weight gain in both fetus and mother during the third trimester.
    - Labor, which is the general term for the birth process, usually begins around the time the amniotic sac breaks and its fluid leaks out. Labor occurs in three stages: dilation of the cervix, the birth of the baby, and delivery of the placenta (afterbirth).
- The physiological function of female breasts is lactation or the production of breastmilk to feed an infant. Sucking on the breast by the infant stimulates the release of the hypothalamic hormone oxytocin from the posterior pituitary, which causes the flow of milk. The release of milk stimulates the baby to continue sucking, which in turn keeps the milk flowing. This is one of the few examples of positive feedback in the human organism.
- The ovaries produce female sex hormones, including estrogen and progesterone. Estrogen is responsible for sexual maturation and secondary sex characteristics at puberty. It is also needed to help regulate the menstrual cycle and ovulation after puberty until menopause. Progesterone prepares the uterus for pregnancy each month during the menstrual cycle and helps maintain the pregnancy if fertilization occurs.

- The menstrual cycle refers to natural changes that occur in the female reproductive system each month during the reproductive years, except when a woman is pregnant. The cycle is necessary for the production of eggs and the preparation of the uterus for pregnancy. It involves changes in both the ovaries and uterus and is controlled by pituitary hormones (FSH and LH) and ovarian hormones (estrogen and progesterone).
  - The female reproductive period is delineated by menarche, or the first menstrual period, which usually occurs around age 12 or 13; and by menopause, or the cessation of menstrual periods, which typically occurs around age 52. A typical menstrual cycle averages 28 days in length but may vary normally from 21 to 45 days. The average menstrual period is five days long but may vary normally from two to seven days. These variations in the menstrual cycle may occur both between women and within individual women from month to month.
  - The events of the menstrual cycle that take place in the ovaries make up the ovarian cycle. It includes the follicular phase, when a follicle and its egg mature due to rising levels of FSH; ovulation, when the egg is released from the ovary due to a rise in estrogen and a surge in LH; and the luteal phase, when the follicle is transformed into a structure called a corpus luteum that secretes progesterone. In a 28-day menstrual cycle, the follicular and luteal phases typically average about two weeks in length, with ovulation generally occurring around day 14 of the cycle.
  - The events of the menstrual cycle that take place in the uterus make up the uterine cycle. It includes menstruation, which generally occurs on days 1 to 5 of the cycle and involves shedding of endometrial tissue that built up during the preceding cycle; the proliferative phase, during which the endometrium builds up again until ovulation occurs; and the secretory phase, which follows ovulation and during which the endometrium secretes substances and undergoes other changes that prepare it to receive an embryo.
- Disorders of the female reproductive system include cervical cancer, vaginitis, and endometriosis.
  - Cervical cancer occurs when cells of the cervix grow abnormally and develop the ability to invade nearby tissues, or spread to other parts of the body. Worldwide, cervical cancer is the second-most common type of cancer in females and the fourth-most common cause of cancer death in females. Early on, cervical cancer often has no symptoms; later, symptoms such as abnormal vaginal bleeding and pain are likely.
    - Most cases of cervical cancer occur because of infection with human papillomavirus (HPV), so the HPV vaccine is expected to greatly reduce the incidence of the disease. Other risk factors include smoking and a weakened immune system. A Pap smear can diagnose cervical cancer at an early stage. Where Pap smears are done routinely, cervical cancer death rates have fallen dramatically. Treatment of cervical cancer generally includes surgery, which may be followed by radiation therapy or chemotherapy.
  - Vaginitis is an inflammation of the vagina. A discharge is likely, and there may be itching and pain. About 90 percent of cases of vaginitis is caused by infection with microorganisms, typically by the yeast *Candida albicans*. A minority of cases are caused by irritants or allergens in products such as soaps, spermicides, or douches.
    - Diagnosis of vaginitis may be based on characteristics of the discharge, which can be examined microscopically or cultured. Treatment of vaginitis depends on the cause and is usually an oral or topical anti-fungal or antibiotic medication.
  - Endometriosis is a disease in which endometrial tissue grows outside the uterus. This tissue may bleed during the menstrual period and cause inflammation, pain, and scarring. The main symptom of endometriosis is pelvic pain, which may be severe. Endometriosis may also lead to infertility.
    - Endometriosis is thought to have multiple causes, including genetic mutations. Retrograde menstruation may be the immediate cause of endometrial tissue escaping the uterus and entering the pelvic cavity. Endometriosis is usually treated with surgery to remove the abnormal tissue and medication for pain. If surgery is more conservative than hysterectomy, endometriosis may recur.
- Infertility is the inability of a sexually mature adult to reproduce by natural means. It is defined scientifically and medically as the failure to achieve a successful pregnancy after at least one year of regular, unprotected sexual intercourse.
- About 30 percent of infertility in couples is due to female infertility, and another 30 percent is due to male infertility. In the remaining cases, a couple's infertility is due to problems in both partners or to unknown causes.
- Male infertility occurs when there are no or too few healthy, motile sperm. This may be caused by problems with spermatogenesis or by blockage of the male reproductive tract that prevents sperm from being ejaculated. Risk factors for male infertility include heavy alcohol use, smoking, certain medications, and advancing age, to name just a few.
- Female infertility occurs due to failure to produce viable eggs by the ovaries or structural problems in the Fallopian tubes or uterus. Polycystic ovary syndrome is the most common cause of failure to produce viable eggs. Endometriosis and uterine fibroids are possible causes of structural problems in the Fallopian tubes and uterus. Risk factors for female infertility include smoking, stress, poor diet, and older age, among others.
- Diagnosing the cause(s) of a couple's infertility generally requires testing both the man and the woman for potential problems. For men, semen is likely to be examined for adequate

numbers of healthy, motile sperm. For women, signs of ovulation are monitored, for example, with an ovulation test kit or ultrasound of the ovaries. For both partners, the reproductive tract may be medically imaged to look for blockages or other abnormalities.

  - Treatments for infertility depend on the cause. For example, if a medical problem is interfering with sperm production, medication may resolve the underlying problem so sperm production is restored. Blockages in either the male or the female reproductive tract can often be treated surgically. If there are problems with ovulation, hormonal treatments may stimulate ovulation.
  - Some cases of infertility are treated with assisted reproductive technology (ART). This is a collection of medical procedures in which eggs and sperm are taken from the couple and manipulated in a lab to increase the chances of fertilization occurring and an embryo forming. Other approaches for certain causes of infertility include the use of a surrogate mother, gestational carrier, or sperm donation.
- Infertility can negatively impact a couple socially and psychologically, and it may be a major cause of marital friction or even divorce. Infertility treatments may raise ethical issues relating to the costs of the procedures and the status of embryos that are created *in vitro* but not used for pregnancy. Infertility is an under-appreciated problem in developing countries where birth rates are high and children have high economic as well as a social value. In these countries, poor health care is likely to lead to more problems with infertility and fewer options for treatment.
- More than half of all fertile couples worldwide use contraception (birth control), which is any method or device used to prevent pregnancy. Different methods of contraception vary in their effectiveness, typically expressed as the failure rate, or the percentage of women who become pregnant using a given method during the first year of use. For most methods, the failure rate with typical use is much higher than the failure rate with perfect use.
- Types of birth control methods include barrier methods, hormonal methods, intrauterine devices, behavioral methods, and sterilization. Except for sterilization, all of the methods are reversible.
  - Barrier methods are devices that block sperm from entering the uterus. They include condoms and diaphragms. Of all birth control methods, only condoms can also prevent the spread of sexually transmitted infections.
  - Hormonal methods involve the administration of hormones to prevent ovulation. Hormones can be administered in various ways, such as in an injection, through a skin patch, or, most commonly, in birth control pills. There are two types of birth control pills: those that contain estrogen and progesterone, and those that contain only progesterone. Both types are equally effective, but they have different potential side effects.
  - An intrauterine device (IUD) is a small T-shaped plastic structure containing copper or a hormone that is inserted into the uterus by a physician and left in place for months or even years. It is highly effective even with typical use, but it does have some risks, such as increased menstrual bleeding and, rarely, perforation of the uterus.
  - Behavioral methods involve regulating the timing or method of intercourse to prevent the introduction of sperm into the female reproductive tract, either altogether or when an egg may be present. In the fertility awareness methods, unprotected intercourse is avoided during the most fertile days of the cycle as estimated by basal body temperature or the characteristics of cervical mucus. In withdrawal, the penis is withdrawn from the vagina before ejaculation occurs. Behavioral methods are the least effective methods of contraception.
  - Sterilization is the most effective contraceptive method, but it requires a surgical procedure and may be irreversible. Male sterility is usually achieved with a vasectomy, in which the vas deferens are clamped or cut to prevent sperm from being ejaculated in semen. Female sterility is usually achieved with a tubal ligation, in which the Fallopian tubes are clamped or cut to prevent sperm from reaching and fertilizing eggs.
  - Emergency contraception is any form of contraception that is used after unprotected vaginal intercourse. One method is the “morning after” pill, which is a high-dose birth control pill that can be taken up to five days after unprotected sex. Another method is an IUD, which can be inserted up to five days after unprotected sex.

In this chapter, you learned how the male and female reproductive systems work together to produce a zygote. In the next chapter, you will learn about how the human organism grows and develops throughout life—from a zygote all the way through old age.

CHAPTER SUMMARY REVIEW

1. Which glands produce semen? What is the rough percentage of each fluid in semen?
2. What is one reason why semen's alkalinity assists in reproduction?
3. *True or False:* The hormones FSH and LH are involved in regulating the female reproductive system, but not the male reproductive system.
4. *True or False:* A majority of American males have some cancerous cells in their prostate gland by age 80.
5. *True or False:* The secretory phase of the menstrual cycle is when menstruation occurs.
6. Menarche is:
   A. the part of the menstrual cycle known as a period
   B. the first menstrual period
   C. the conclusion of menstrual periods when a woman is around 50
   D. an anovulatory menstrual cycle

7. Where are sperm located when they develop tails?
    A. the testes
    B. the epididymis
    C. the vas deferens
    D. the seminal vesicles
8. For each of the descriptions below, choose whether it applies to the male or female reproductive systems.
    A. The gametes are present at birth.
    B. Gametogenesis begins at puberty.
    C. The gametes complete meiosis II upon fertilization.
    D. The mature gametes have a reduced amount of cytoplasm.
9. What are three things that pass through the cervical canal of females, going in either direction?
10. If a man and a woman have unprotected vaginal intercourse, what are the structures of the female reproductive tract, in order, that sperm would move through? (Assume that these sperm do not die prematurely before they reach their final destination.)
11. Other than where the cancer originates, what is one difference between the prostate and testicular cancer?
12. Progesterone is relatively high...
    A. in the follicular phase of the menstrual cycle
    B. in the luteal phase of the menstrual cycle
    C. during pregnancy
    D. B and C
13. If a woman is checking her basal body temperature each morning as a form of contraception, and today is day 12 of her menstrual cycle and her basal body temperature is still low, is it safe for her to have unprotected sexual intercourse today? Why or why not?
14. *True or False:* If a young woman does not get pregnant after nine months of regular, unprotected intercourse, the couple will be diagnosed with infertility.
15. *True or False:* In the developing male fetus, the gonads start out as ovaries, but then differentiate into testes because of the Y chromosome.
16. *True or False:* A cause of endometriosis can be retrograde menstruation, where some of the endometrial tissue flows backward from the uterus out through the Fallopian tubes.
17. Where are sperm produced?
    A. the seminal vesicles
    B. the spermatogonium
    C. the epididymis
    D. the seminiferous tubules
18. Which of the following methods of contraception is the most effective, while also being reversible? A. withdrawal B. tubal ligation C. intrauterine device D. condoms
19. Where is a diaphragm placed? How does it work to prevent pregnancy?
20. Why are the testes located outside of the body?
21. Why is it important to properly diagnose the causative agent when a woman has vaginitis?
22. *True or False:* When a baby nurses, the stimulation negatively feeds back to decrease milk flow to the nipple.
23. *True or False:* Part of the penis is located inside of the male body.
24. What is the best description of what occurs at menopause?
    A. Eggs stop maturing in the ovaries on a monthly basis.
    B. Oogenesis stops occurring.
    C. Ovulated eggs cannot be fertilized, so they are automatically reabsorbed.
    D. The endometrium can no longer support a fetus, so fertilized eggs cannot implant.
25. The transition from spermatid to sperm involves
    A. mitosis
    B. meiosis I
    C. meiosis II
    D. no cell division
26. Describe two ways in which sperm can move through the male and/or female reproductive tracts.

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Index

A

abdominopelvic cavity
1.7: Anatomical Terminology
abductor
5.4: Naming Skeletal Muscle
ABO blood group
9.7: Blood Typing
accessory organs of digestion
13.6: Accessory Organs of Digestion
acne
3.6: Diseases, Disorders, and Injuries of the Integumentary System
actin
2.5: Cytoplasm and Cytoskeleton
action potential
6.4: Nerve Impulses
active transport
2.8: Active Transport and Homeostasis
adaptive immune system
11.5: Adaptive Immune System
addiction
6.7: Psychoactive Drugs
Addison's disease
8.7: Adrenal Glands
adductor
5.4: Naming Skeletal Muscle
ADH
14.6: Case Study Conclusion- Alcohol and Chapter Summary
adrenal cortex
8.7: Adrenal Glands
adrenal gland
8.7: Adrenal Glands
adrenal medulla
8.7: Adrenal Glands
adrenaline
8.7: Adrenal Glands
aerobic exercise
5.7: Physical Exercise
agglutination
9.7: Blood Typing
agonist
6.7: Psychoactive Drugs
agranular leukocytes
9.5: Leukocytes and Platelets
albinism
3.3: Layers of the Skin
albumin
9.2: An Overview of Blood
allergen
11.6: Disorders of the Immune System
allergy
11.6: Disorders of the Immune System
alpha tubulin
2.5: Cytoplasm and Cytoskeleton
Alzheimer's disease
6.8: Case Study Conclusion- Memory and Chapter Summary
anabolism
1.4: Functions of Human Life
anaerobic exercise
5.7: Physical Exercise
anagen
3.4: Accessory Structures of the Skin
anaphylaxis
11.6: Disorders of the Immune System
anatomical position
1.7: Anatomical Terminology
anatomy
1.2: Overview of Anatomy and Physiology
androgen
8.7: Adrenal Glands
anemia
9.4: Erythrocytes
angina
10.7: Cardiovascular Disease
antagonists
6.7: Psychoactive Drugs
anterior
1.7: Anatomical Terminology
Anterior Cavity
1.7: Anatomical Terminology
anterior pituitary
8.4: Pituitary Gland and Hypothalamus
antibodies
9.2: An Overview of Blood
anticoagulant
9.6: Hemostasis
antithrombin
9.6: Hemostasis
anus
13.5: Lower Gastrointestinal Tract
apocrine sweat gland
3.4: Accessory Structures of the Skin
appendicular skeleton
4.3: Divisions of the Skeletal System
appendix
13.5: Lower Gastrointestinal Tract
areoler connective tissue
2.10: Human Cells and Tissues
arrector pili
3.4: Accessory Structures of the Skin
arteries
10.6: Blood Vessels
artificial pacemaker
10.4: Cardiac Cycle and Electrical Activity
assisted reproductive technology
15.10: Infertility
atherosclerosis
10.7: Cardiovascular Disease
ATP
2.6: Cell Organelles
atrioventricular (AV) node
10.4: Cardiac Cycle and Electrical Activity
atrioventricular bundle
10.4: Cardiac Cycle and Electrical Activity
atrioventricular bundle branches
10.4: Cardiac Cycle and Electrical Activity
atrium
10.3: Heart
atrophy
5.2: Introduction to the Muscular System
autonomic nervous system
6.6: Peripheral Nervous System
autorhythmicity
10.4: Cardiac Cycle and Electrical Activity
axial skeleton
4.3: Divisions of the Skeletal System
axon
6.3: Neurons

B

B cell
11.5: Adaptive Immune System
B lymphocytes
9.5: Leukocytes and Platelets
Bachmann's bundle
10.4: Cardiac Cycle and Electrical Activity
basal cell
3.3: Layers of the Skin
basal cell carcinoma
3.6: Diseases, Disorders, and Injuries of the Integumentary System
3.7: Case Study Conclusion- Skin Cancer and Chapter Summary
basophils
9.5: Leukocytes and Platelets
bedsore
3.6: Diseases, Disorders, and Injuries of the Integumentary System
Beta tubulin
2.5: Cytoplasm and Cytoskeleton
bi
5.4: Naming Skeletal Muscle
bile
13.6: Accessory Organs of Digestion
bilirubin
9.4: Erythrocytes
biliverdin
9.4: Erythrocytes
biopsy
3.7: Case Study Conclusion- Skin Cancer and Chapter Summary
bladder infection
14.5: Disorders of the Urinary System
blood
2.10: Human Cells and Tissues
9.2: An Overview of Blood
blood vessels
10.6: Blood Vessels
bone
2.10: Human Cells and Tissues
bone fracture
4.5: Bone Growth, Remodeling, and Repair
bone marrow
4.4: Structure of Bone
bone marrow biopsy
9.3: Production of the Formed Elements
bone marrow transplant
9.3: Production of the Formed Elements
bone remodeling
4.5: Bone Growth, Remodeling, and Repair

bone tissue
4.4: Structure of Bone
botulism
5.9: Case Study Conclusion- Needing to Relax and Chapter Summary
Bowman’s capsule
14.3: Kidneys
brain
6.1: Case Study- The Control Center of Your Body
6.5: Central Nervous System
brainstem
6.5: Central Nervous System
breathing
12.3: Breathing
brevis
5.4: Naming Skeletal Muscle
bronchi
12.2: Structure and Function of the Respiratory System
bronchitis
12.6: Case Study Conclusion- Bronchitis and Chapter Summary
buffy coat
9.2: An Overview of Blood
bulbourethral glands
15.3: Structures of the Male Reproductive System
bundle of His
10.4: Cardiac Cycle and Electrical Activity

C

callus
3.6: Diseases, Disorders, and Injuries of the Integumentary System
carbaminohemoglobin
9.4: Erythrocytes
cardiac cycle
10.5: Cardiac Cycle
cardiac muscle
2.10: Human Cells and Tissues
cardiovascular disease
10.7: Cardiovascular Disease
cardiovascular system
10: Cardiovascular System- Heart and Blood Vessels
10.2: Introduction to the Cardiovascular System
carpel tunnel syndrome
5.8: Disorders of the Muscular System
carrier protein
2.7: Cell Transport
cartilage
2.10: Human Cells and Tissues
4.2: Introduction to the Skeletal System
cartilaginous joint
4.6: Joints
catabolism
1.4: Functions of Human Life
catagen
3.4: Accessory Structures of the Skin
catecholamines
8.7: Adrenal Glands
Caudal
1.7: Anatomical Terminology
celiac disease
13.8: Case Study Conclusion- Celiac and Chapter Summary
cell
1.3: Structural Organization of the Human Body
2.2: Discovery of Cells and Cell Theory
2.11: Case Study Conclusion- Tired and Chapter Summary
cell body
6.3: Neurons
Cell size
2.3: Variation in Cells
cell theory
2.2: Discovery of Cells and Cell Theory
cells
2.1: Cells Introduction- Case Study- The Importance of Cells
central nervous system
6.5: Central Nervous System
centriole
2.6: Cell Organelles
cerebellum
6.5: Central Nervous System
cerebral cortex
6.5: Central Nervous System
cerebrum
6.5: Central Nervous System
cervical cancer
15.9: Disorders of the Female Reproductive System
chemical digestion
13.3: Digestion and Absorption
chronic obstructive pulmonary disease
12.4: Disorders of the Respiratory System
chyme
13.2: Introduction to the Digestive System
cilia
2.4: Plasma Membrane
cisternae
2.6: Cell Organelles
clitoris
15.6: Structures of the Female Reproductive System
clotting factors
9.6: Hemostasis
coagulation
9.6: Hemostasis
collagen fibers
2.10: Human Cells and Tissues
collecting duct
14.3: Kidneys
colon
13.5: Lower Gastrointestinal Tract
common pathway
9.6: Hemostasis
complement system
11.4: Innate Immune System
concentration gradient
2.7: Cell Transport
connective tissue
2.10: Human Cells and Tissues
contraception
15.11: Contraception
control center
1.6: Homeostasis
corn
3.6: Diseases, Disorders, and Injuries of the Integumentary System
coronary artery
10.3: Heart
cortex
3.4: Accessory Structures of the Skin
14.2: Introduction to the Urinary System
corticosteroid
8.7: Adrenal Glands
cortisol
8.7: Adrenal Glands
Cranial
1.7: Anatomical Terminology
cranial cavity
1.7: Anatomical Terminology
cranium
4.3: Divisions of the Skeletal System
Crohn's disease
13.7: Disorders of the Gastrointestinal Tract
cross matching
9.7: Blood Typing
crossbridge cycling
5.6: Muscle Contraction
Cushing’s disease
8.7: Adrenal Glands
cuticle
3.4: Accessory Structures of the Skin
cytokine
11.4: Innate Immune System
cytokines
9.3: Production of the Formed Elements
cytoplasm
2.2: Discovery of Cells and Cell Theory
2.5: Cytoplasm and Cytoskeleton
cytoskeleton
2.5: Cytoplasm and Cytoskeleton
cytosol
2.5: Cytoplasm and Cytoskeleton

D

Deep
1.7: Anatomical Terminology
deep vein thrombosis
10.1: Case Study- Your Body's Transportation System
10.8: Case Study Conclusion- Flight and Chapter Summary
defensins
9.5: Leukocytes and Platelets
dendrites
6.3: Neurons
dense connective tissue proper
2.10: Human Cells and Tissues
dense irregular connective tissue
2.10: Human Cells and Tissues
dense regular connective tissue
2.10: Human Cells and Tissues
deoxyhemoglobin
9.4: Erythrocytes
dependence
6.7: Psychoactive Drugs
dermal papilla
3.3: Layers of the Skin
dermis
3.3: Layers of the Skin

desmin
2.5: Cytoplasm and Cytoskeleton
desmosome
3.3: Layers of the Skin
development
1.4: Functions of Human Life
diabetic nephropathy
14.5: Disorders of the Urinary System
diapedesis
9.5: Leukocytes and Platelets
diaphragm
12.3: Breathing
diastole
10.3: Heart
10.5: Cardiac Cycle
differentiation
1.4: Functions of Human Life
diffusion
2.7: Cell Transport
digestion
13.3: Digestion and Absorption
digestive system
13: Digestive System
13.1: Case Study- Food Processing
13.2: Introduction to the Digestive System
Distal
1.7: Anatomical Terminology
Diverticulitis
13.7: Disorders of the Gastrointestinal Tract
Diverticulosis
13.7: Disorders of the Gastrointestinal Tract
DNA
2.2: Discovery of Cells and Cell Theory
Dorsal
1.7: Anatomical Terminology
dorsal cavity
1.7: Anatomical Terminology
Down Syndrome
2.9: Cell Reproduction- Mitosis and Meiosis
dynamic equilibrium
2.7: Cell Transport

E

eccrine sweat gland
3.4: Accessory Structures of the Skin
eczema
3.6: Diseases, Disorders, and Injuries of the Integumentary System
effector
1.6: Homeostasis
Ejaculation
15.4: Functions of the Male Reproductive System
ejaculatory ducts
15.3: Structures of the Male Reproductive System
elastic cartilage
2.10: Human Cells and Tissues
elastic connective tissue
2.10: Human Cells and Tissues
elastic fiber
2.10: Human Cells and Tissues
elastin fibers
3.3: Layers of the Skin
electrocardiogram (ECG)
10.4: Cardiac Cycle and Electrical Activity
eleiden
3.3: Layers of the Skin
embolus
9.6: Hemostasis
emigration
9.5: Leukocytes and Platelets
end diastolic volume (EDV)
10.5: Cardiac Cycle
end systolic volume (ESV)
10.5: Cardiac Cycle
endocrine gland
8.2: Introduction to the Endocrine System
endocrine hormones
8.3: Endocrine Hormones
endocrine system
8.1: Case Study- Hormones and Health
8.2: Introduction to the Endocrine System
endocytosis
2.8: Active Transport and Homeostasis
Endometriosis
15.9: Disorders of the Female Reproductive System
endometrium
15.6: Structures of the Female Reproductive System
15.7: Menstrual Cycle
endomysium
5.3: Types of Muscle Tissue
endoplasmic reticulum
2.6: Cell Organelles
eosinophils
9.5: Leukocytes and Platelets
epidermis
3.3: Layers of the Skin
epididymis
15.3: Structures of the Male Reproductive System
epididymitis
15.5: Disorders of the Male Reproductive System
epimysium
5.3: Types of Muscle Tissue
epithelial tissue
2.10: Human Cells and Tissues
eponychium
3.4: Accessory Structures of the Skin
erectile dysfunction
15.5: Disorders of the Male Reproductive System
erthropoiesis
14.3: Kidneys
erythrocyte
9.4: Erythrocytes
erythropoietin (EPO)
9.3: Production of the Formed Elements
esophagus
13.4: Upper Gastrointestinal Tract
estrogen
15.2: Introduction to the Reproductive System
15.8: Functions of the Female Reproductive System
eukaryotes
2.3: Variation in Cells
eukaryotic cells
2.3: Variation in Cells
Excretory System
14: Urinary System
14.1: Case Study- Waste Management
exocrine glands
8.2: Introduction to the Endocrine System
exocytosis
2.8: Active Transport and Homeostasis
extensor
5.4: Naming Skeletal Muscle
external root sheath
3.4: Accessory Structures of the Skin
extrinsic pathway
9.6: Hemostasis

F

facilitated diffusion
2.7: Cell Transport
Fallopian tubes
15.6: Structures of the Female Reproductive System
ferritin
9.4: Erythrocytes
fibrin
9.6: Hemostasis
fibrinogen
9.2: An Overview of Blood
fibrinolysis
9.6: Hemostasis
fibroblast cells
2.10: Human Cells and Tissues
fibrocartilage
2.10: Human Cells and Tissues
fibrous joint
4.6: Joints
flagella
2.4: Plasma Membrane
flexibility exercise
5.7: Physical Exercise
flexor
5.4: Naming Skeletal Muscle
follicle
8.5: Thyroid Gland
formed elements
9.2: An Overview of Blood
frontal lobe
6.5: Central Nervous System
Frontal Plane
1.7: Anatomical Terminology

G

gallbladder
13.6: Accessory Organs of Digestion
gamete
15.2: Introduction to the Reproductive System
Ganglia
2.10: Human Cells and Tissues
gas exchange
12.3: Breathing
gastroenteritis
13.7: Disorders of the Gastrointestinal Tract
gastrointestinal tract
13.2: Introduction to the Digestive System
gestational carrier
15.10: Infertility
GI Tract
13.2: Introduction to the Digestive System
giardiasis
13.7: Disorders of the Gastrointestinal Tract

glassy membrane
3.4: Accessory Structures of the Skin
glial cells
6.2: Introduction to the Nervous System
globin
9.4: Erythrocytes
globulins
9.2: An Overview of Blood
Glomerulus
14.3: Kidneys
goiter
8.5: Thyroid Gland
Golgi apparatus
2.6: Cell Organelles
gonads
15.2: Introduction to the Reproductive System
granular leukocytes
9.5: Leukocytes and Platelets
Graves disease
8.5: Thyroid Gland
gray matter
2.10: Human Cells and Tissues
growth
1.4: Functions of Human Life

H

hair
3.4: Accessory Structures of the Skin
hair bulb
3.4: Accessory Structures of the Skin
hair follicle
3.4: Accessory Structures of the Skin
hair matrix
3.4: Accessory Structures of the Skin
hair papilla
3.4: Accessory Structures of the Skin
hair root
3.4: Accessory Structures of the Skin
hair shaft
3.4: Accessory Structures of the Skin
Hashimoto thyroiditis
8.5: Thyroid Gland
heart
10.3: Heart
heart block
10.4: Cardiac Cycle and Electrical Activity
heart failure
5.6: Muscle Contraction
heart sounds
10.5: Cardiac Cycle
hematocrit
9.2: An Overview of Blood
hematopoiesis
4.2: Introduction to the Skeletal System
9.3: Production of the Formed Elements
heme
9.4: Erythrocytes
hemispheres'
6.5: Central Nervous System
hemocytoblast
9.3: Production of the Formed Elements
hemodialysis
14.5: Disorders of the Urinary System
hemoglobin
9.4: Erythrocytes
hemolysis
9.7: Blood Typing
hemolytic disease of the newborn (HDN)
9.7: Blood Typing
hemophilia
9.6: Hemostasis
hemopoiesis
9.3: Production of the Formed Elements
hemopoietic growth factors
9.3: Production of the Formed Elements
hemopoietic stem cell
9.3: Production of the Formed Elements
hemorrhage
9.6: Hemostasis
hemosiderin
9.4: Erythrocytes
hemostasis
9.6: Hemostasis
heparin
9.6: Hemostasis
histamine
11.4: Innate Immune System
HIV
11.6: Disorders of the Immune System
homeostasis
1.2: Overview of Anatomy and Physiology
homologus structures
15.2: Introduction to the Reproductive System
hormonal contraception
15.11: Contraception
hormone
8.9: Case Study Conclusion- Hormonal and Chapter Summary
humanpapillomavirus
15.9: Disorders of the Female Reproductive System
hyaline cartilage
2.10: Human Cells and Tissues
hyperparathyroidism
8.6: Parathyroid Glands
hypersecretion
8.2: Introduction to the Endocrine System
hypertension
10.7: Cardiovascular Disease
hyperthyroidism
8.5: Thyroid Gland
hypertonic
2.7: Cell Transport
hyperventilating
12.3: Breathing
hypodermis
3.3: Layers of the Skin
hyponychium
3.4: Accessory Structures of the Skin
hypoparathyroidism
8.6: Parathyroid Glands
hyposecretion
8.2: Introduction to the Endocrine System
hypothalamus
6.5: Central Nervous System
hypothyroidism
8.5: Thyroid Gland
hypotonic
2.7: Cell Transport
hypoxemia
9.4: Erythrocytes

I

Ileum
13.5: Lower Gastrointestinal Tract
immune surveillance
11.2: Introduction to the Immune System
immune system
11: Lymphatic and Immune Systems
11.1: Case Study- Your Defense System
11.2: Introduction to the Immune System
immunity
11.5: Adaptive Immune System
immunization
11.5: Adaptive Immune System
immunodeficiency
11.6: Disorders of the Immune System
immunoglobulins
9.2: An Overview of Blood
immunotherapy
11.6: Disorders of the Immune System
11.8: Case Study Conclusion- Lymphoma and Chapter Summary
inferior
1.7: Anatomical Terminology
inferior vena cava
10.6: Blood Vessels
infertility
15.10: Infertility
inflammation
11.4: Innate Immune System
inflammatory bowel disease
13.7: Disorders of the Gastrointestinal Tract
infundibulum
8.4: Pituitary Gland and Hypothalamus
innate immune system
11.4: Innate Immune System
integumentary system
3.3: Layers of the Skin
interatrial band
10.4: Cardiac Cycle and Electrical Activity
intercalated disc
10.4: Cardiac Cycle and Electrical Activity
intergumentary system
3.2: Introduction to the Integumentary System
interleukins
9.3: Production of the Formed Elements
intermediate filaments
2.5: Cytoplasm and Cytoskeleton
internal root sheath
3.4: Accessory Structures of the Skin
Interneurons
6.3: Neurons
internodal pathways
10.4: Cardiac Cycle and Electrical Activity
intrauterine device
15.11: Contraception
intrinsic pathway
9.6: Hemostasis
isometric
5.6: Muscle Contraction

isotonic
2.7: Cell Transport
5.6: Muscle Contraction
isovolumic contraction
10.5: Cardiac Cycle
isovolumic ventricular relaxation phase
10.5: Cardiac Cycle

J
jaundiced eye
13.6: Accessory Organs of Digestion
jejunum
13.5: Lower Gastrointestinal Tract
joint hypermobility
4.6: Joints
joints
4.6: Joints

K
karyotype
2.9: Cell Reproduction- Mitosis and Meiosis
keratin
2.5: Cytoplasm and Cytoskeleton
3.3: Layers of the Skin
keratinocyte
3.3: Layers of the Skin
keratinocytes
3.2: Introduction to the Integumentary System
keratins
3.2: Introduction to the Integumentary System
keratohyalin
3.3: Layers of the Skin
kidney
14.3: Kidneys
kidney failure
14.5: Disorders of the Urinary System
kidney stone
14.5: Disorders of the Urinary System
kinetic energy
2.7: Cell Transport
Klinefelter's syndrome
2.9: Cell Reproduction- Mitosis and Meiosis

L
labia
15.6: Structures of the Female Reproductive System
lactation
15.8: Functions of the Female Reproductive System
lamin
2.5: Cytoplasm and Cytoskeleton
Langerhans cell
3.3: Layers of the Skin
large intestine
13.5: Lower Gastrointestinal Tract
larynx
12.2: Structure and Function of the Respiratory System
lateral
1.7: Anatomical Terminology
lateralis
5.4: Naming Skeletal Muscle
lateralization
6.5: Central Nervous System
leukemia
9.5: Leukocytes and Platelets
leukocyte
9.5: Leukocytes and Platelets
leukocytosis
9.5: Leukocytes and Platelets
leukopenia
9.5: Leukocytes and Platelets
ligaments
4.2: Introduction to the Skeletal System
liver
13.6: Accessory Organs of Digestion
longus
5.4: Naming Skeletal Muscle
loose connective tissue proper
2.10: Human Cells and Tissues
lower gastrointestinal tract
13.5: Lower Gastrointestinal Tract
lung
12.2: Structure and Function of the Respiratory System
lung cancer
12.4: Disorders of the Respiratory System
lunula
3.4: Accessory Structures of the Skin
lymph
11.3: Lymphatic System
lymph node
11.3: Lymphatic System
lymphatic system
11.3: Lymphatic System
lymphocytes
9.5: Leukocytes and Platelets
lymphoid stem cells
9.3: Production of the Formed Elements
lymphoma
9.5: Leukocytes and Platelets
11.8: Case Study Conclusion- Lymphoma and Chapter Summary
Lysozyme
9.5: Leukocytes and Platelets

M
macrophage
9.4: Erythrocytes
major histocompatibility complex
11.2: Introduction to the Immune System
mandible
4.3: Divisions of the Skeletal System
Marie Stopes
15.11: Contraception
maxillae
4.3: Divisions of the Skeletal System
maximus
5.4: Naming Skeletal Muscle
mechanical digestion
13.3: Digestion and Absorption
medial
1.7: Anatomical Terminology
medialis
5.4: Naming Skeletal Muscle
medius
5.4: Naming Skeletal Muscle
medulla
3.4: Accessory Structures of the Skin
14.2: Introduction to the Urinary System
medulla oblongata
6.5: Central Nervous System
megakaryocyte
9.5: Leukocytes and Platelets
Meissner corpuscle
3.5: Functions of the Integumentary System
melanin
3.3: Layers of the Skin
melanocyte
3.3: Layers of the Skin
melanoma
3.6: Diseases, Disorders, and Injuries of the Integumentary System
3.7: Case Study Conclusion- Skin Cancer and Chapter Summary
melanosome
3.3: Layers of the Skin
membrane
2.7: Cell Transport
memory cell
9.5: Leukocytes and Platelets
menarche
15.7: Menstrual Cycle
menopause
15.7: Menstrual Cycle
menstrual cycle
15.7: Menstrual Cycle
Merkel cell
3.3: Layers of the Skin
metabolism
1.4: Functions of Human Life
metastasis
3.6: Diseases, Disorders, and Injuries of the Integumentary System
3.7: Case Study Conclusion- Skin Cancer and Chapter Summary
microbiome
11.7: Human Microbiome
microscope
2.2: Discovery of Cells and Cell Theory
Microscopic Anatomy
1.2: Overview of Anatomy and Physiology
microtubules
2.5: Cytoplasm and Cytoskeleton
microvilli
2.5: Cytoplasm and Cytoskeleton
13.2: Introduction to the Digestive System
midbrain
6.5: Central Nervous System
minimus
5.4: Naming Skeletal Muscle
mitochondria
2.1: Cells Introduction- Case Study- The Importance of Cells
2.6: Cell Organelles
mixed nerves
6.6: Peripheral Nervous System
monocytes
9.5: Leukocytes and Platelets
motor nerves
6.6: Peripheral Nervous System

motor neurons
6.3: Neurons
mucous membrane
2.10: Human Cells and Tissues
mucus
2.10: Human Cells and Tissues
murmur
10.5: Cardiac Cycle
muscle
5.1: Case Study- Muscles and Movement
muscle contraction
5.6: Muscle Contraction
muscle fascicles
5.3: Types of Muscle Tissue
muscle fibers
5.2: Introduction to the Muscular System
muscle strain
5.8: Disorders of the Muscular System
muscle tissue
2.10: Human Cells and Tissues
5.3: Types of Muscle Tissue
muscular dystrophy
5.8: Disorders of the Muscular System
muscular system
5.2: Introduction to the Muscular System
Musculoskeletal System
5.8: Disorders of the Muscular System
Myasthenia gravis
5.8: Disorders of the Muscular System
myelin sheath
6.3: Neurons
myeloid stem cells
9.3: Production of the Formed Elements
myocardial conducting cells
10.4: Cardiac Cycle and Electrical Activity
myocardial contractile cells
10.4: Cardiac Cycle and Electrical Activity
myocyte
5.2: Introduction to the Muscular System
5.3: Types of Muscle Tissue
myofibril
5.6: Muscle Contraction
myokines
5.7: Physical Exercise
myometrium
15.6: Structures of the Female Reproductive System

N

nail bed
3.4: Accessory Structures of the Skin
nail body
3.4: Accessory Structures of the Skin
nail cuticle
3.4: Accessory Structures of the Skin
nail fold
3.4: Accessory Structures of the Skin
nail root
3.4: Accessory Structures of the Skin
nasal cavity
12.2: Structure and Function of the Respiratory System
natural killer (NK) cells
9.5: Leukocytes and Platelets
negative feedback
1.6: Homeostasis
nephron
14.2: Introduction to the Urinary System
nephrons
14.2: Introduction to the Urinary System
nerve impulse
6.4: Nerve Impulses
nerves
2.10: Human Cells and Tissues
nervous system
6.1: Case Study- The Control Center of Your Body
6.2: Introduction to the Nervous System
nervous tissue
2.10: Human Cells and Tissues
neurogenesis
6.3: Neurons
neuroimmune system
11.2: Introduction to the Immune System
neuromuscular disorders
5.8: Disorders of the Muscular System
neuromuscular junction
5.6: Muscle Contraction
neurons
6.3: Neurons
neurotransmitter
6.4: Nerve Impulses
neutrophils
9.5: Leukocytes and Platelets
nicotine
12.5: Smoking and Health
nodes of Ranvier
6.3: Neurons
nondisjunction
2.9: Cell Reproduction- Mitosis and Meiosis
Normal Range
1.6: Homeostasis
nucleoplasm
2.5: Cytoplasm and Cytoskeleton
nucleus
2.6: Cell Organelles
nutrient
1.5: Requirements for Human Life

O

oblique
5.4: Naming Skeletal Muscle
occipital lobe
6.5: Central Nervous System
oogenesis
15.8: Functions of the Female Reproductive System
oogonia
15.8: Functions of the Female Reproductive System
opioids
6.7: Psychoactive Drugs
organ
1.3: Structural Organization of the Human Body
organ system
1.3: Structural Organization of the Human Body
organelle
2.3: Variation in Cells
2.6: Cell Organelles
organelles
2.2: Discovery of Cells and Cell Theory
organism
1.3: Structural Organization of the Human Body
osmosis
2.7: Cell Transport
ossification
4.5: Bone Growth, Remodeling, and Repair
osteoarthritis
4.7: Disorders of the Skeletal System
osteoblast
4.4: Structure of Bone
osteoblasts
2.10: Human Cells and Tissues
4.5: Bone Growth, Remodeling, and Repair
osteocalcin
4.2: Introduction to the Skeletal System
osteoclast
4.4: Structure of Bone
osteocyte
4.4: Structure of Bone
osteogenic cells
4.4: Structure of Bone
osteon
2.10: Human Cells and Tissues
osteoporosis
4.7: Disorders of the Skeletal System
ovulation
15.8: Functions of the Female Reproductive System
oxyhemoglobin
9.4: Erythrocytes
oxytocin
8.4: Pituitary Gland and Hypothalamus

P

P wave
10.4: Cardiac Cycle and Electrical Activity
pacemaker
10.3: Heart
10.4: Cardiac Cycle and Electrical Activity
Pacinian corpuscle
3.5: Functions of the Integumentary System
packed cell volume (PCV)
9.2: An Overview of Blood
pancreas
8.8: Pancreas
13.6: Accessory Organs of Digestion
pancreatic islet
8.8: Pancreas
Pancreatitis
8.8: Pancreas
Pap smear
15.9: Disorders of the Female Reproductive System
papillary layer
3.3: Layers of the Skin
paralysis
6.5: Central Nervous System
parathyroid glands
8.6: Parathyroid Glands
parietal lobe
6.5: Central Nervous System
Parkinson’s disease
5.8: Disorders of the Muscular System

passive immunity
11.5: Adaptive Immune System
passive transport
2.7: Cell Transport
pathogen
11.2: Introduction to the Immune System
pelvic girdle
4.3: Divisions of the Skeletal System
penis
15.3: Structures of the Male Reproductive System
peptic ulcers
13.7: Disorders of the Gastrointestinal Tract
pericardium
1.7: Anatomical Terminology
perimetrium
15.6: Structures of the Female Reproductive System
perimysium
5.3: Types of Muscle Tissue
Peripheral artery disease
10.7: Cardiovascular Disease
peripheral immune system
11.2: Introduction to the Immune System
peripheral nervous system
6.2: Introduction to the Nervous System
6.6: Peripheral Nervous System
peristalsis
5.2: Introduction to the Muscular System
peritoneum
1.7: Anatomical Terminology
phagocytosis
2.8: Active Transport and Homeostasis
pharynx
12.2: Structure and Function of the Respiratory System
phospholipid bilayer
2.4: Plasma Membrane
phospholipids
2.4: Plasma Membrane
physiology
1.2: Overview of Anatomy and Physiology
pinocytosis
2.8: Active Transport and Homeostasis
pituitary gland
8.4: Pituitary Gland and Hypothalamus
placenta
15.6: Structures of the Female Reproductive System
Plane
1.7: Anatomical Terminology
plasma
9.2: An Overview of Blood
plasma membrane
2.2: Discovery of Cells and Cell Theory
2.4: Plasma Membrane
plasmin
9.6: Hemostasis
platelet plug
9.6: Hemostasis
platelets
9.2: An Overview of Blood
pleura
1.7: Anatomical Terminology
pluripotent stem cell
9.3: Production of the Formed Elements
pneumonia
12.4: Disorders of the Respiratory System
polycystic kidney disease
14.5: Disorders of the Urinary System
polycythemia
9.4: Erythrocytes
polymorphonuclear
9.5: Leukocytes and Platelets
pons
6.5: Central Nervous System
positive chemotaxis
9.5: Leukocytes and Platelets
positive feedback
1.6: Homeostasis
posterior
1.7: Anatomical Terminology
Posterior Cavity
1.7: Anatomical Terminology
posterior pituitary
8.4: Pituitary Gland and Hypothalamus
preload
10.5: Cardiac Cycle
prepotential depolarization
10.4: Cardiac Cycle and Electrical Activity
pressure
1.5: Requirements for Human Life
primary active transport
2.8: Active Transport and Homeostasis
probiotic
11.7: Human Microbiome
progesterone
15.8: Functions of the Female Reproductive System
prokaryote
2.3: Variation in Cells
prokaryotic cell
2.3: Variation in Cells
prolactin
8.4: Pituitary Gland and Hypothalamus
Prone
1.7: Anatomical Terminology
prostate cancer
15.5: Disorders of the Male Reproductive System
prostate gland
15.3: Structures of the Male Reproductive System
proximal
1.7: Anatomical Terminology
Psychoactive Drugs
6.7: Psychoactive Drugs
pulmonary circulation
10.2: Introduction to the Cardiovascular System
pump
2.8: Active Transport and Homeostasis
Purkinje fibers
10.4: Cardiac Cycle and Electrical Activity

Q

QRS complex
10.4: Cardiac Cycle and Electrical Activity

R

receptor mediated endocytosis
2.8: Active Transport and Homeostasis
rectum
13.5: Lower Gastrointestinal Tract
rectus
5.4: Naming Skeletal Muscle
red blood cells (RBCs)
9.2: An Overview of Blood
reflexes
6.5: Central Nervous System
regional anatomy
1.2: Overview of Anatomy and Physiology
renal pelvis
14.2: Introduction to the Urinary System
renal tubule
14.3: Kidneys
reproduction
1.4: Functions of Human Life
reproductive system
15.1: Case Study- Making Babies
15.12: Case Study Conclusion- Trying to Conceive and Chapter Summary
respiration
12.2: Structure and Function of the Respiratory System
respiratory center
12.3: Breathing
respiratory system
12.1: Case Study- Respiratory System and Gas Exchange
respiratory tract
12.2: Structure and Function of the Respiratory System
Responsiveness
1.4: Functions of Human Life
Resting Potential
6.4: Nerve Impulses
reticular connective tissue
2.10: Human Cells and Tissues
reticular fibers
2.10: Human Cells and Tissues
reticular layer
3.3: Layers of the Skin
reticulocyte
9.4: Erythrocytes
Rh blood group
9.7: Blood Typing
rib cage
4.3: Divisions of the Skeletal System
ribosome
2.2: Discovery of Cells and Cell Theory
ribosomes
2.6: Cell Organelles
rickets
3.5: Functions of the Integumentary System
rough endoplasmic reticulum
2.6: Cell Organelles

S

sagittal plane
1.7: Anatomical Terminology
saliva
13.4: Upper Gastrointestinal Tract
salivary glands
13.4: Upper Gastrointestinal Tract

sarcomere
5.3: Types of Muscle Tissue
scar
3.6: Diseases, Disorders, and Injuries of the Integumentary System
Schistosoma
11.2: Introduction to the Immune System
scrotum
15.3: Structures of the Male Reproductive System
sebaceous gland
3.4: Accessory Structures of the Skin
sebum
3.4: Accessory Structures of the Skin
secondary active transport
2.8: Active Transport and Homeostasis
secondary sex characteristics
15.2: Introduction to the Reproductive System
secondhand smoke
12.5: Smoking and Health
Section
1.7: Anatomical Terminology
seman
15.3: Structures of the Male Reproductive System
seminiferous tubule
15.3: Structures of the Male Reproductive System
Sensor
1.6: Homeostasis
sensory nerves
6.6: Peripheral Nervous System
sensory neurons
6.3: Neurons
serosa
1.7: Anatomical Terminology
serous membrane
1.7: Anatomical Terminology
Sertoli cell
15.3: Structures of the Male Reproductive System
serum
9.6: Hemostasis
Set Point
1.6: Homeostasis
Sex Hormones
15.2: Introduction to the Reproductive System
sickle cell disease
9.4: Erythrocytes
simple difussion
2.7: Cell Transport
sinoatrial (SA) node
10.4: Cardiac Cycle and Electrical Activity
sinus rhythm
10.3: Heart
10.4: Cardiac Cycle and Electrical Activity
skeletal muscles
2.10: Human Cells and Tissues
5.3: Types of Muscle Tissue
skeletal system
4.1: Case Study- Your Support System
4.2: Introduction to the Skeletal System
4.8: Case Study Conclusion- Heels and Chapter Summary
skin
3.2: Introduction to the Integumentary System
skin cancer
3.1: Case Study- Skin Cancer
skull
4.3: Divisions of the Skeletal System
sleep apnea
12.4: Disorders of the Respiratory System
sliding filament theory
5.6: Muscle Contraction
small intestine
13.5: Lower Gastrointestinal Tract
smooth endoplasmic reticulum
2.6: Cell Organelles
smooth muscle
2.10: Human Cells and Tissues
sodium potassium pump
2.8: Active Transport and Homeostasis
solute
2.7: Cell Transport
solution
2.7: Cell Transport
solvent
2.7: Cell Transport
somatic nervous system
6.6: Peripheral Nervous System
somatostatin
8.8: Pancreas
sperm
15.4: Functions of the Male Reproductive System
sperm donation
15.10: Infertility
spermatogenesis
15.4: Functions of the Male Reproductive System
sphincter
13.4: Upper Gastrointestinal Tract
spinal cavity
1.7: Anatomical Terminology
spinal cord
6.5: Central Nervous System
spleen
11.3: Lymphatic System
spongy bone tissue
4.4: Structure of Bone
spontaneous depolarizationv
10.4: Cardiac Cycle and Electrical Activity
squamous cell carcinoma
3.6: Diseases, Disorders, and Injuries of the Integumentary System
3.7: Case Study Conclusion- Skin Cancer and Chapter Summary
Sterilization
15.11: Contraception
steroid hormone
8.3: Endocrine Hormones
stomach
13.4: Upper Gastrointestinal Tract
stratum basale
3.3: Layers of the Skin
stratum corneum
3.3: Layers of the Skin
stratum granulosum
3.3: Layers of the Skin
stratum lucidum
3.3: Layers of the Skin
stratum spinosum
3.3: Layers of the Skin
stretch mark
3.6: Diseases, Disorders, and Injuries of the Integumentary System
stroke
5.6: Muscle Contraction
6.5: Central Nervous System
10.7: Cardiovascular Disease
sudoriferous gland
3.4: Accessory Structures of the Skin
Superficial
1.7: Anatomical Terminology
superior
1.7: Anatomical Terminology
superior vena cava
10.6: Blood Vessels
Supine
1.7: Anatomical Terminology
surrogate mother
15.10: Infertility
synapse
6.4: Nerve Impulses
synovial joint
4.6: Joints
Systemic Anatomy
1.2: Overview of Anatomy and Physiology
systemic circulation
10.2: Introduction to the Cardiovascular System
systole
10.3: Heart
10.5: Cardiac Cycle

T

T cell
11.5: Adaptive Immune System
T lymphocytes
9.5: Leukocytes and Platelets
T wave
10.4: Cardiac Cycle and Electrical Activity
target cell
8.3: Endocrine Hormones
telogen
3.4: Accessory Structures of the Skin
temporal lobe
6.5: Central Nervous System
tendon
5.3: Types of Muscle Tissue
testes
15.3: Structures of the Male Reproductive System
testicular cancer
15.5: Disorders of the Male Reproductive System
testosterone
15.2: Introduction to the Reproductive System
thalamus
6.5: Central Nervous System
thalassemia
9.4: Erythrocytes
thoracic cavity
1.7: Anatomical Terminology
thrombin
9.6: Hemostasis
thrombocytes
9.5: Leukocytes and Platelets
thrombocytopenia
9.5: Leukocytes and Platelets

thrombocytosis
9.5: Leukocytes and Platelets
thrombopoietin
9.3: Production of the Formed Elements
thrombosis
9.6: Hemostasis
thrombus
9.6: Hemostasis
thymus
11.3: Lymphatic System
thyroid gland
8.5: Thyroid Gland
thyroxine
8.5: Thyroid Gland
tissue
1.3: Structural Organization of the Human Body
tissue factor
9.6: Hemostasis
Tonsillitis
11.3: Lymphatic System
tonsils
11.3: Lymphatic System
totipotent stem cell
9.3: Production of the Formed Elements
trachea
12.2: Structure and Function of the Respiratory System
Transverse Plane
1.7: Anatomical Terminology
tri
5.4: Naming Skeletal Muscle
triad
5.6: Muscle Contraction
triiodothyronine
8.5: Thyroid Gland
Triple X syndrome
2.9: Cell Reproduction- Mitosis and Meiosis
trisomy 21
2.9: Cell Reproduction- Mitosis and Meiosis
tubal ligation
15.11: Contraception
tubulin
2.6: Cell Organelles
tunica albuginea
15.3: Structures of the Male Reproductive System
tunica vaginalis
15.3: Structures of the Male Reproductive System
tunica vasculosa
15.3: Structures of the Male Reproductive System
Turner Syndrome
2.9: Cell Reproduction- Mitosis and Meiosis
type 2 diabetes
8.8: Pancreas
type I diabetes mellitus
8.8: Pancreas

U

Ulcerative colitis
13.7: Disorders of the Gastrointestinal Tract
universal donor
9.7: Blood Typing
universal recipient
9.7: Blood Typing
Upper Gastrointestinal Tract
13.4: Upper Gastrointestinal Tract
ureters
14.4: Ureters, Urinary Bladder, and Urethra
urethra
14.4: Ureters, Urinary Bladder, and Urethra
urinary bladder
14.4: Ureters, Urinary Bladder, and Urethra
urinary system
14.2: Introduction to the Urinary System
urination
14.2: Introduction to the Urinary System
urine
14.2: Introduction to the Urinary System

V

vacuole
2.6: Cell Organelles
vagina
15.6: Structures of the Female Reproductive System
Vaginitis
15.9: Disorders of the Female Reproductive System
varicose veins
10.6: Blood Vessels
vas deferens
15.3: Structures of the Male Reproductive System
vascular spasm
9.6: Hemostasis
vasectomy
15.11: Contraception
vasodilation
10.6: Blood Vessels
vasopressin
8.4: Pituitary Gland and Hypothalamus
ventilation
12.3: Breathing
Ventral
1.7: Anatomical Terminology
ventral cavity
1.7: Anatomical Terminology
ventricle
10.3: Heart
ventricular ejection phase
10.5: Cardiac Cycle
vertebrae
4.3: Divisions of the Skeletal System
Vesicle
2.6: Cell Organelles
vesicular transport
2.8: Active Transport and Homeostasis
villi
13.2: Introduction to the Digestive System
vimentin
2.5: Cytoplasm and Cytoskeleton
vitamin D
3.5: Functions of the Integumentary System
vitiligo
3.3: Layers of the Skin
vulva
15.6: Structures of the Female Reproductive System

W

white matter
2.10: Human Cells and Tissues

Glossary

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    - 3.2: Introduction to the Integumentary System - *CC BY-NC-SA 3.0*
    - 3.3: Layers of the Skin - *CC BY-NC-SA 4.0*
    - 3.4: Accessory Structures of the Skin - *CC BY-NC-SA 4.0*
    - 3.5: Functions of the Integumentary System - *CC BY-NC-SA 4.0*
    - 3.6: Diseases, Disorders, and Injuries of the Integumentary System - *CC BY-NC-SA 4.0*
    - 3.7: Case Study Conclusion- Skin Cancer and Chapter Summary - *CC BY-NC-SA 3.0*
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    - 4.1: Case Study- Your Support System - *CC BY-NC-SA 3.0*
    - 4.2: Introduction to the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.3: Divisions of the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.4: Structure of Bone - *CC BY-NC-SA 3.0*
    - 4.5: Bone Growth, Remodeling, and Repair - *CC BY-NC-SA 3.0*
    - 4.6: Joints - *CC BY-NC-SA 3.0*
    - 4.7: Disorders of the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.8: Case Study Conclusion- Heels and Chapter Summary - *CC BY-NC-SA 3.0*
  - 5: Muscular System - *CC BY-NC-SA 3.0*
    - 5.1: Case Study- Muscles and Movement - *CC BY-NC-SA 3.0*

- 5.2: Introduction to the Muscular System - *CC BY-NC-SA 3.0*
- 5.3: Types of Muscle Tissue - *CC BY-NC-SA 3.0*
- 5.4: Naming Skeletal Muscle - *CC BY-NC-SA 4.0*
- 5.5: Skeletal Muscle Functions and Structures - *CC BY-NC-SA 4.0*
- 5.6: Muscle Contraction - *CC BY-NC-SA 3.0*
- 5.7: Physical Exercise - *CC BY-NC-SA 3.0*
- 5.8: Disorders of the Muscular System - *CC BY-NC-SA 3.0*
- 5.9: Case Study Conclusion- Needing to Relax and Chapter Summary - *CC BY-NC-SA 3.0*

6: Nervous System - *CC BY-NC-SA 3.0*

- 6.1: Case Study- The Control Center of Your Body - *CC BY-NC-SA 3.0*
- 6.2: Introduction to the Nervous System - *CC BY-NC-SA 3.0*
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- 6.4: Nerve Impulses - *CC BY-NC-SA 3.0*
- 6.5: Central Nervous System - *CC BY-NC-SA 3.0*
- 6.6: Peripheral Nervous System - *CC BY-NC-SA 3.0*
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- 7.3: Hearing and Balance - *CC BY-NC-SA 4.0*
- 7.4: Taste and Smell - *CC BY-NC-SA 4.0*
- 7.5: Touch - *CC BY-NC-SA 4.0*

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- 8.2: Introduction to the Endocrine System - *CC BY-NC-SA 3.0*
- 8.3: Endocrine Hormones - *CC BY-NC-SA 3.0*
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- 8.6: Parathyroid Glands - *CC BY-NC-SA 4.0*
- 8.7: Adrenal Glands - *CC BY-NC-SA 3.0*
- 8.8: Pancreas - *CC BY-NC-SA 3.0*
- 8.9: Case Study Conclusion- Hormonal and Chapter Summary - *CC BY-NC-SA 3.0*

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- 9.2: An Overview of Blood - *CC BY-NC-SA 4.0*
- 9.3: Production of the Formed Elements - *CC BY-NC-SA 4.0*
- 9.4: Erythrocytes - *CC BY-NC-SA 4.0*
- 9.5: Leukocytes and Platelets - *CC BY-NC-SA 4.0*
- 9.6: Hemostasis - *CC BY-NC-SA 4.0*
- 9.7: Blood Typing - *CC BY-NC-SA 4.0*
- 9.9: Blood- Chapter Review - *CC BY-NC-SA 4.0*

10: Cardiovascular System- Heart and Blood Vessels - *CC BY-NC-SA 3.0*

- 10.1: Case Study- Your Body's Transportation System - *CC BY-NC-SA 3.0*
- 10.2: Introduction to the Cardiovascular System - *CC BY-NC-SA 3.0*
- 10.3: Heart - *CC BY-NC-SA 3.0*
- 10.4: Cardiac Cycle and Electrical Activity - *CC BY-NC-SA 4.0*
- 10.5: Cardiac Cycle - *CC BY-NC-SA 4.0*
- 10.6: Blood Vessels - *CC BY-NC-SA 3.0*
- 10.7: Cardiovascular Disease - *CC BY-NC-SA 3.0*
- 10.8: Case Study Conclusion- Flight and Chapter Summary - *CC BY-NC-SA 3.0*

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- 11.1: Case Study- Your Defense System - *CC BY-NC-SA 3.0*
- 11.2: Introduction to the Immune System - *CC BY-NC-SA 3.0*
- 11.3: Lymphatic System - *CC BY-NC-SA 3.0*
- 11.4: Innate Immune System - *CC BY-NC-SA 3.0*
- 11.5: Adaptive Immune System - *CC BY-NC-SA 3.0*
- 11.6: Disorders of the Immune System - *CC BY-NC-SA 3.0*
- 11.7: Human Microbiome - *CC BY-NC-SA 3.0*
- 11.8: Case Study Conclusion- Lymphoma and Chapter Summary - *CC BY-NC-SA 3.0*

12: Respiratory System - *CC BY-NC-SA 3.0*

- 12.1: Case Study- Respiratory System and Gas Exchange - *CC BY-NC-SA 3.0*
- 12.2: Structure and Function of the Respiratory System - *CC BY-NC-SA 3.0*
- 12.3: Breathing - *CC BY-NC-SA 3.0*
- 12.4: Disorders of the Respiratory System - *CC BY-NC-SA 3.0*
- 12.5: Smoking and Health - *CC BY-NC-SA 3.0*
- 12.6: Case Study Conclusion- Bronchitis and Chapter Summary - *CC BY-NC-SA 3.0*

13: Digestive System - *CC BY-NC-SA 3.0*

- 13.1: Case Study- Food Processing - *CC BY-NC-SA 3.0*

- 13.2: Introduction to the Digestive System - *CC BY-NC-SA 3.0*
- 13.3: Digestion and Absorption - *CC BY-NC-SA 3.0*
- 13.4: Upper Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.5: Lower Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.6: Accessory Organs of Digestion - *CC BY-NC-SA 3.0*
- 13.7: Disorders of the Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.8: Case Study Conclusion- Celiac and Chapter Summary - *CC BY-NC-SA 3.0*

14: Urinary System - *CC BY-NC-SA 3.0*

- 14.1: Case Study- Waste Management - *CC BY-NC-SA 3.0*
- 14.2: Introduction to the Urinary System - *CC BY-NC-SA 3.0*
- 14.3: Kidneys - *CC BY-NC-SA 3.0*
- 14.4: Ureters, Urinary Bladder, and Urethra - *CC BY-NC-SA 3.0*
- 14.5: Disorders of the Urinary System - *CC BY-NC-SA 3.0*
- 14.6: Case Study Conclusion- Alcohol and Chapter Summary - *CC BY-NC-SA 3.0*

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- 15.1: Case Study- Making Babies - *CC BY-NC-SA 3.0*
- 15.2: Introduction to the Reproductive System - *CC BY-NC-SA 3.0*
- 15.3: Structures of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.4: Functions of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.5: Disorders of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.6: Structures of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.7: Menstrual Cycle - *CC BY-NC-SA 3.0*
- 15.8: Functions of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.9: Disorders of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.10: Infertility - *CC BY-NC-SA 3.0*
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- 15.12: Case Study Conclusion- Trying to Conceive and Chapter Summary - *CC BY-NC-SA 3.0*

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    - Licensing - *CC BY-NC-SA 4.0*
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    - 1.1: The Human Body - Introduction - *CC BY-NC-SA 4.0*
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    - 1.3: Structural Organization of the Human Body - *CC BY-NC-SA 4.0*
    - 1.4: Functions of Human Life - *CC BY-NC-SA 4.0*
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    - 1.7: Anatomical Terminology - *CC BY-NC-SA 4.0*
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    - 2.1: Cells Introduction- Case Study- The Importance of Cells - *CC BY-NC-SA 3.0*
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    - 2.10: Human Cells and Tissues - *CC BY-NC-SA 3.0*
    - 2.11: Case Study Conclusion- Tired and Chapter Summary - *CC BY-NC-SA 3.0*
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    - 3.1: Case Study- Skin Cancer - *CC BY-NC-SA 3.0*
    - 3.2: Introduction to the Integumentary System - *CC BY-NC-SA 3.0*
    - 3.3: Layers of the Skin - *CC BY-NC-SA 4.0*
    - 3.4: Accessory Structures of the Skin - *CC BY-NC-SA 4.0*
    - 3.5: Functions of the Integumentary System - *CC BY-NC-SA 4.0*
    - 3.6: Diseases, Disorders, and Injuries of the Integumentary System - *CC BY-NC-SA 4.0*
    - 3.7: Case Study Conclusion- Skin Cancer and Chapter Summary - *CC BY-NC-SA 3.0*
  - 4: Skeletal System - *CC BY-NC-SA 3.0*
    - 4.1: Case Study- Your Support System - *CC BY-NC-SA 3.0*
    - 4.2: Introduction to the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.3: Divisions of the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.4: Structure of Bone - *CC BY-NC-SA 3.0*
    - 4.5: Bone Growth, Remodeling, and Repair - *CC BY-NC-SA 3.0*
    - 4.6: Joints - *CC BY-NC-SA 3.0*
    - 4.7: Disorders of the Skeletal System - *CC BY-NC-SA 3.0*
    - 4.8: Case Study Conclusion- Heels and Chapter Summary - *CC BY-NC-SA 3.0*
  - 5: Muscular System - *CC BY-NC-SA 3.0*
    - 5.1: Case Study- Muscles and Movement - *CC BY-NC-SA 3.0*

- 5.2: Introduction to the Muscular System - *CC BY-NC-SA 3.0*
- 5.3: Types of Muscle Tissue - *CC BY-NC-SA 3.0*
- 5.4: Naming Skeletal Muscle - *CC BY-NC-SA 4.0*
- 5.5: Skeletal Muscle Functions and Structures - *CC BY-NC-SA 4.0*
- 5.6: Muscle Contraction - *CC BY-NC-SA 3.0*
- 5.7: Physical Exercise - *CC BY-NC-SA 3.0*
- 5.8: Disorders of the Muscular System - *CC BY-NC-SA 3.0*
- 5.9: Case Study Conclusion- Needing to Relax and Chapter Summary - *CC BY-NC-SA 3.0*

6: Nervous System - *CC BY-NC-SA 3.0*

- 6.1: Case Study- The Control Center of Your Body - *CC BY-NC-SA 3.0*
- 6.2: Introduction to the Nervous System - *CC BY-NC-SA 3.0*
- 6.3: Neurons - *CC BY-NC-SA 3.0*
- 6.4: Nerve Impulses - *CC BY-NC-SA 3.0*
- 6.5: Central Nervous System - *CC BY-NC-SA 3.0*
- 6.6: Peripheral Nervous System - *CC BY-NC-SA 3.0*
- 6.7: Psychoactive Drugs - *CC BY-NC-SA 3.0*
- 6.8: Case Study Conclusion- Memory and Chapter Summary - *CC BY-NC-SA 3.0*

7: Senses - *CC BY-NC-SA 4.0*

- 7.1: Introduction to the Senses - *CC BY-NC-SA 4.0*
- 7.2: Vision - *CC BY-NC-SA 4.0*
- 7.3: Hearing and Balance - *CC BY-NC-SA 4.0*
- 7.4: Taste and Smell - *CC BY-NC-SA 4.0*
- 7.5: Touch - *CC BY-NC-SA 4.0*

8: Endocrine System - *CC BY-NC-SA 3.0*

- 8.1: Case Study- Hormones and Health - *CC BY-NC-SA 3.0*
- 8.2: Introduction to the Endocrine System - *CC BY-NC-SA 3.0*
- 8.3: Endocrine Hormones - *CC BY-NC-SA 3.0*
- 8.4: Pituitary Gland and Hypothalamus - *CC BY-NC-SA 3.0*
- 8.5: Thyroid Gland - *CC BY-NC-SA 3.0*
- 8.6: Parathyroid Glands - *CC BY-NC-SA 4.0*
- 8.7: Adrenal Glands - *CC BY-NC-SA 3.0*
- 8.8: Pancreas - *CC BY-NC-SA 3.0*
- 8.9: Case Study Conclusion- Hormonal and Chapter Summary - *CC BY-NC-SA 3.0*

9: Cardiovascular System - Blood - *CC BY-NC-SA 4.0*

- 9.1: Blood- Introduction - *CC BY-NC-SA 4.0*
- 9.2: An Overview of Blood - *CC BY-NC-SA 4.0*
- 9.3: Production of the Formed Elements - *CC BY-NC-SA 4.0*
- 9.4: Erythrocytes - *CC BY-NC-SA 4.0*
- 9.5: Leukocytes and Platelets - *CC BY-NC-SA 4.0*
- 9.6: Hemostasis - *CC BY-NC-SA 4.0*
- 9.7: Blood Typing - *CC BY-NC-SA 4.0*
- 9.9: Blood- Chapter Review - *CC BY-NC-SA 4.0*

10: Cardiovascular System- Heart and Blood Vessels - *CC BY-NC-SA 3.0*

- 10.1: Case Study- Your Body's Transportation System - *CC BY-NC-SA 3.0*
- 10.2: Introduction to the Cardiovascular System - *CC BY-NC-SA 3.0*
- 10.3: Heart - *CC BY-NC-SA 3.0*
- 10.4: Cardiac Cycle and Electrical Activity - *CC BY-NC-SA 4.0*
- 10.5: Cardiac Cycle - *CC BY-NC-SA 4.0*
- 10.6: Blood Vessels - *CC BY-NC-SA 3.0*
- 10.7: Cardiovascular Disease - *CC BY-NC-SA 3.0*
- 10.8: Case Study Conclusion- Flight and Chapter Summary - *CC BY-NC-SA 3.0*

11: Lymphatic and Immune Systems - *CC BY-NC-SA 3.0*

- 11.1: Case Study- Your Defense System - *CC BY-NC-SA 3.0*
- 11.2: Introduction to the Immune System - *CC BY-NC-SA 3.0*
- 11.3: Lymphatic System - *CC BY-NC-SA 3.0*
- 11.4: Innate Immune System - *CC BY-NC-SA 3.0*
- 11.5: Adaptive Immune System - *CC BY-NC-SA 3.0*
- 11.6: Disorders of the Immune System - *CC BY-NC-SA 3.0*
- 11.7: Human Microbiome - *CC BY-NC-SA 3.0*
- 11.8: Case Study Conclusion- Lymphoma and Chapter Summary - *CC BY-NC-SA 3.0*

12: Respiratory System - *CC BY-NC-SA 3.0*

- 12.1: Case Study- Respiratory System and Gas Exchange - *CC BY-NC-SA 3.0*
- 12.2: Structure and Function of the Respiratory System - *CC BY-NC-SA 3.0*
- 12.3: Breathing - *CC BY-NC-SA 3.0*
- 12.4: Disorders of the Respiratory System - *CC BY-NC-SA 3.0*
- 12.5: Smoking and Health - *CC BY-NC-SA 3.0*
- 12.6: Case Study Conclusion- Bronchitis and Chapter Summary - *CC BY-NC-SA 3.0*

13: Digestive System - *CC BY-NC-SA 3.0*

- 13.1: Case Study- Food Processing - *CC BY-NC-SA 3.0*

- 13.2: Introduction to the Digestive System - *CC BY-NC-SA 3.0*
- 13.3: Digestion and Absorption - *CC BY-NC-SA 3.0*
- 13.4: Upper Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.5: Lower Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.6: Accessory Organs of Digestion - *CC BY-NC-SA 3.0*
- 13.7: Disorders of the Gastrointestinal Tract - *CC BY-NC-SA 3.0*
- 13.8: Case Study Conclusion- Celiac and Chapter Summary - *CC BY-NC-SA 3.0*

14: Urinary System - *CC BY-NC-SA 3.0*

- 14.1: Case Study- Waste Management - *CC BY-NC-SA 3.0*
- 14.2: Introduction to the Urinary System - *CC BY-NC-SA 3.0*
- 14.3: Kidneys - *CC BY-NC-SA 3.0*
- 14.4: Ureters, Urinary Bladder, and Urethra - *CC BY-NC-SA 3.0*
- 14.5: Disorders of the Urinary System - *CC BY-NC-SA 3.0*
- 14.6: Case Study Conclusion- Alcohol and Chapter Summary - *CC BY-NC-SA 3.0*

15: Reproductive System - *CC BY-NC-SA 3.0*

- 15.1: Case Study- Making Babies - *CC BY-NC-SA 3.0*
- 15.2: Introduction to the Reproductive System - *CC BY-NC-SA 3.0*
- 15.3: Structures of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.4: Functions of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.5: Disorders of the Male Reproductive System - *CC BY-NC-SA 3.0*
- 15.6: Structures of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.7: Menstrual Cycle - *CC BY-NC-SA 3.0*
- 15.8: Functions of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.9: Disorders of the Female Reproductive System - *CC BY-NC-SA 3.0*
- 15.10: Infertility - *CC BY-NC-SA 3.0*
- 15.11: Contraception - *CC BY-NC-SA 3.0*
- 15.12: Case Study Conclusion- Trying to Conceive and Chapter Summary - *CC BY-NC-SA 3.0*

Back Matter - *CC BY-NC-SA 4.0*

- Index - *CC BY-NC-SA 4.0*
- Glossary - *CC BY-NC-SA 4.0*
- Detailed Licensing - *CC BY-NC-SA 4.0*
- Detailed Licensing - *CC BY-NC-SA 4.0*