NSCC Human Biology

NSCC HUMAN BIOLOGY

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Halifax

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ABOUT THE BOOK

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UNIT 1. THE AMAZING HUMAN MACHINE

CHAPTER 1: INTRODUCTION TO BIOLOGY

Figure 1.1 This NASA image is a composite of several satellite-based views of Earth. To make the whole-Earth image, NASA scientists combine observations of different parts of the planet. (credit: modification of work by NASA)

Viewed from space, Earth offers few clues about the diversity of life forms that reside there. The first forms of life on Earth are thought to have been microorganisms that existed for billions of years before plants and animals appeared. The mammals, birds, and flowers so familiar to us are all relatively recent, originating 130 to 200 million years ago. Humans have inhabited this planet for only the last 2.5 million years, and only in the last 200,000 years have humans started looking like we do today.

Learning Objectives

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

- Identify and describe the properties of life
- Describe the levels of organization among living things

Biology is the science that studies life. What exactly is life? This may sound like a silly question with an obvious answer, but it is not easy to define life. For example, a branch of biology called virology studies viruses, which exhibit some of the characteristics of living entities but lack others. It turns out that although viruses can attack living organisms, cause diseases, and even reproduce, they do not meet the criteria that biologists use to define life.

Properties of Life

All groups of living organisms share several key characteristics or functions: order, sensitivity or response to stimuli, reproduction, adaptation, growth and development, regulation, homeostasis, and energy processing. When viewed together, these eight characteristics serve to define life.

Order

Organisms are highly organized structures that consist of one or more cells. Even very simple, single-celled organisms are remarkably complex. Inside each cell, atoms make up molecules. These in turn make up cell components or organelles. Multicellular organisms, which may consist of millions of individual cells, have an advantage over single-celled organisms in that their cells can be specialized to perform specific functions, and even sacrificed in certain situations for the good of the organism as a whole. How these specialized cells come together to form organs such as the heart, lung, or skin in organisms like the toad shown in Figure 1. 2 will be discussed later.

Figure 1.2 A toad represents a highly organized structure consisting of cells, tissues, organs, and organ systems.

Sensitivity or Response to Stimuli

Organisms respond to diverse stimuli. For example, plants can bend toward a source of light or respond to touch. Even tiny bacteria can move toward or away from chemicals (a process called chemotaxis) or light (phototaxis). Movement toward a stimulus is considered a positive response, while movement away from a stimulus is considered a negative response.

Figure 1.3 The leaves of this sensitive plant (Mimosa pudica) will instantly droop and fold when touched. After a few minutes, the plant returns to its normal state.

Concept in Action

Watch this video to see how the sensitive plant responds to a touch stimulus.

A video element has been excluded from this version of the text. You can watch it online here: https://pressbooks.nscc.ca/humanbiology/?p=22

Print version – Use the QR code to play the video.

Reproduction

Single-celled organisms reproduce by first duplicating their DNA, which is the genetic material, and then dividing it equally as the cell prepares to divide to form two new cells. Many multicellular organisms (those made up of more than one cell) produce specialized reproductive cells that will form new individuals. When reproduction occurs, DNA containing genes is passed along to an organism's offspring. These genes are the reason that the offspring will belong to the same species and will have characteristics similar to the parent, such as fur color and blood type.

Adaptation

All living organisms exhibit a "fit" to their environment. Biologists refer to this fit as adaptation and it is a consequence of **evolution** by natural selection, which operates in every lineage of reproducing organisms. Examples of adaptations are diverse and unique, from heat-resistant Archaea that live in boiling hot springs to the tongue length of a nectar-feeding moth that matches the size of the flower from which it feeds. All adaptations enhance the reproductive potential of the individual exhibiting them, including their ability to survive to reproduce. Adaptations are not constant. As an environment changes, natural selection causes the characteristics of the individuals in a population to track those changes.

Growth and Development

Organisms grow and develop according to specific instructions coded for by their genes. These genes provide instructions that will direct cellular growth and development, ensuring that a species' young will grow up to exhibit many of the same characteristics as its parents.

Figure 1.4 Although no two look alike, these kittens have inherited genes from both parents and share many of the same characteristics.

Regulation

Even the smallest organisms are complex and require multiple regulatory mechanisms to coordinate internal functions, such as the transport of nutrients, response to stimuli, and coping with environmental stresses. For example, organ systems such as the digestive or circulatory systems perform specific functions like carrying oxygen throughout the body, removing wastes, delivering nutrients to every cell, and cooling the body.

Homeostasis

To function properly, cells require appropriate conditions such as proper temperature, pH, and concentrations of diverse chemicals.

These conditions may, however, change from one moment to the next. Organisms are able to maintain internal conditions within a narrow range almost constantly, despite environmental changes, through a process called homeostasis or "steady state"—the ability of an organism to maintain constant internal conditions. For example, many organisms regulate their body temperature in a process known as thermoregulation. Organisms that live in cold climates, such as the polar bear, have body structures that help them withstand low temperatures and conserve body heat. In hot climates, organisms have methods (such as perspiration in humans or panting in dogs) that help them to shed excess body heat.

Figure 1.5 Polar bears and other mammals living in ice-covered regions maintain their body temperature by generating heat and reducing heat loss through thick fur and a dense layer of fat under their skin.

Energy Processing

All organisms (such as the California condor shown in Figure 1.6) use a source of energy for their metabolic activities. Some organisms capture energy from the sun and convert it into chemical energy in food; others use chemical energy from molecules they take in.

Figure 1.6 A lot of energy is required for a California condor to fly. Chemical energy derived from food is used to power flight. California condors are an endangered species; scientists have strived to place a wing tag on each bird to help them identify and locate each individual bird.

Levels of Organization of Living Things

Living things are highly organized and structured, following a hierarchy on a scale from small to large. The **atom** is the smallest and most fundamental unit of matter. It consists of a nucleus surrounded by electrons. Atoms form molecules. A **molecule** is a chemical structure consisting of at least two atoms held together by a chemical bond. Many molecules that are biologically important are **macromolecules**, large molecules that are typically formed by combining smaller units called monomers. An example of a macromolecule is deoxyribonucleic acid (DNA), which contains the instructions for the functioning of the organism that contains it.

Concept in Action

To see an animation of this DNA molecule, click here.

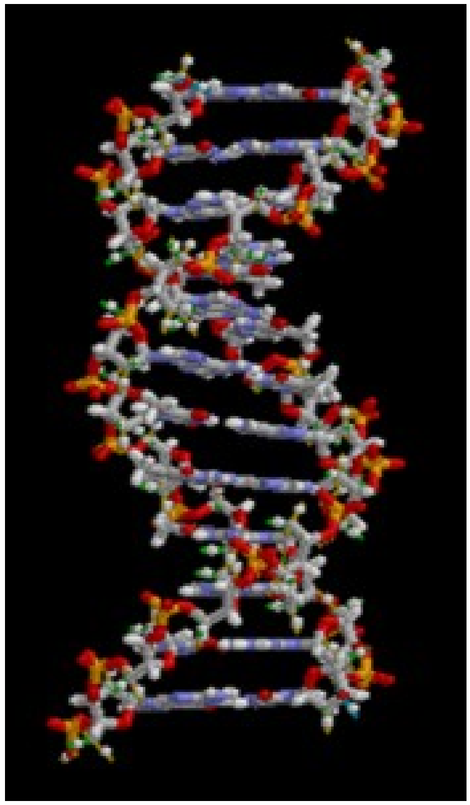

Figure 1.7 A molecule, like this large DNA molecule, is composed of atoms.

Print version – Use the QR code to play the video.

Some cells contain aggregates of macromolecules surrounded by membranes; these are called **organelles**. Organelles are small structures that exist within cells and perform specialized functions. All living things are made of cells; the **cell** itself is the smallest fundamental unit of structure and function in living organisms. (This requirement is why viruses are not considered living: they are not made of cells. To make new viruses, they have to invade and hijack a living cell; only then can they obtain the materials they need to reproduce.) Some organisms consist of a single cell and others are multicellular.

In most multicellular organisms, cells combine to make **tissues**, which are groups of similar cells carrying out the same function. **Organs** are collections of tissues grouped together based on a common function. An organ system is a higher level of organization that consists of functionally related organs. For example vertebrate animals have many organ systems, such as the circulatory system that transports blood throughout the body and to and from the lungs; it includes organs such as the heart and blood vessels. Organisms are individual living entities. For example, each tree in a forest is an organism. There are also single-celled organisms, such as bacteria, typically referred to as microorganisms.

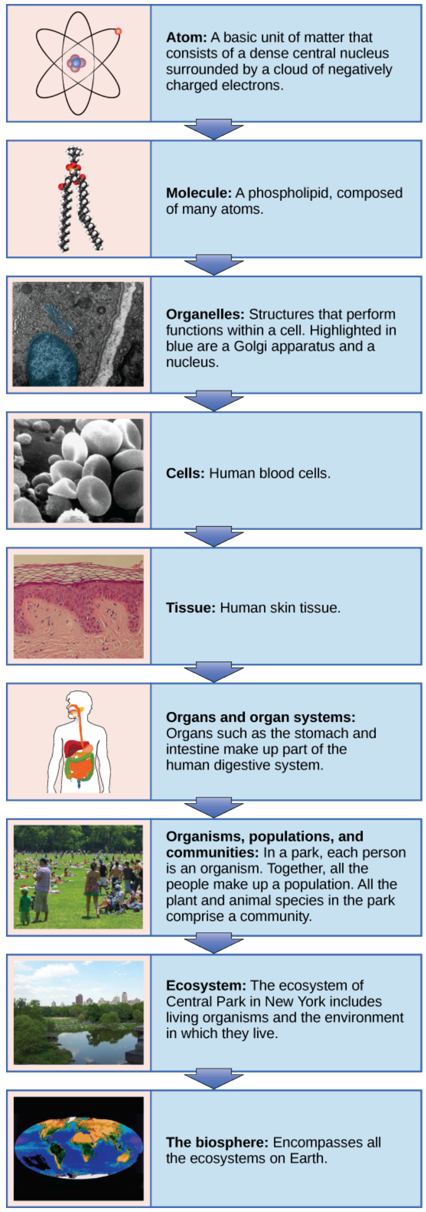

Figure 1.8 From an atom to the entire Earth, biology examines all aspects of life.

All the individuals of a species living within a specific area are collectively called a **population**. For example, a forest may include many white pine trees. All of these pine trees represent the population of white pine trees in this forest. Different populations may live in the same specific area. For example, the forest with the pine trees includes populations of flowering plants and also insects and microbial populations. A **community** is the set of populations inhabiting a particular area. For instance, all of the trees, flowers, insects, and other populations in a forest form the forest's community. The forest itself is an **ecosystem.** An ecosystem consists of all the living things in a particular area together with the abiotic, or non-living, parts of that environment such as nitrogen in the soil or rainwater. At the highest level of organization, the **biosphere** is the collection of all ecosystems, and it represents the zones of life on Earth. It includes land, water, and portions of the atmosphere.

Exercises

1. Which of the following statements is false?
    A. Tissues exist within organs which exist within organ systems.
    B. Communities exist within populations which exist within ecosystems.
    C. Organelles exist within cells which exist within tissues.
    D. Communities exist within ecosystems which exist in the biosphere.
2. The smallest unit of biological structure that meets the functional requirements of "living" is the ________.
    A. organ
    B. organelle
    C. cell
    D. macromolecule
3. Which of the following sequences represents the hierarchy of biological organization from the most complex to the least complex level?
    A. organelle, tissue, biosphere, ecosystem, population
    B. organ, organism, tissue, organelle, molecule
    C. organism, community, biosphere, molecule, tissue, organ
    D. biosphere, ecosystem, community, population, organism
4. Using examples, explain how biology can be studied from a microscopic approach to a global approach.

Answers

1. B
2. C
3. D
4. Researchers can approach biology from the smallest to the largest, and everything in between. For instance, an ecologist may study a population of individuals, the population's community, the community's ecosystem, and the ecosystem's part in the biosphere. When studying an individual organism, a biologist could examine the cell and its organelles, the tissues that the cells make up, the organs and their respective organ systems, and the sum total—the organism itself.

Glossary

atom: a basic unit of matter that cannot be broken down by normal chemical reactions

biology: the study of living organisms and their interactions with one another and their environments

biosphere: a collection of all ecosystems on Earth

cell: the smallest fundamental unit of structure and function in living things

community: a set of populations inhabiting a particular area

ecosystem: all living things in a particular area together with the abiotic, nonliving parts of that environment

evolution: the process of gradual change in a population that can also lead to new species arising from older species

homeostasis: the ability of an organism to maintain constant internal conditions

macromolecule: a large molecule typically formed by the joining of smaller molecules

molecule: a chemical structure consisting of at least two atoms held together by a chemical bond

organ: a structure formed of tissues operating together to perform a common function

organ system: the higher level of organization that consists of functionally related organs

organelle: a membrane-bound compartment or sac within a cell

organism: an individual living entity

population: all individuals within a species living within a specific area

tissue: a group of similar cells carrying out the same function

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CHAPTER 2: CELLS: THEORY AND STRUCTURE

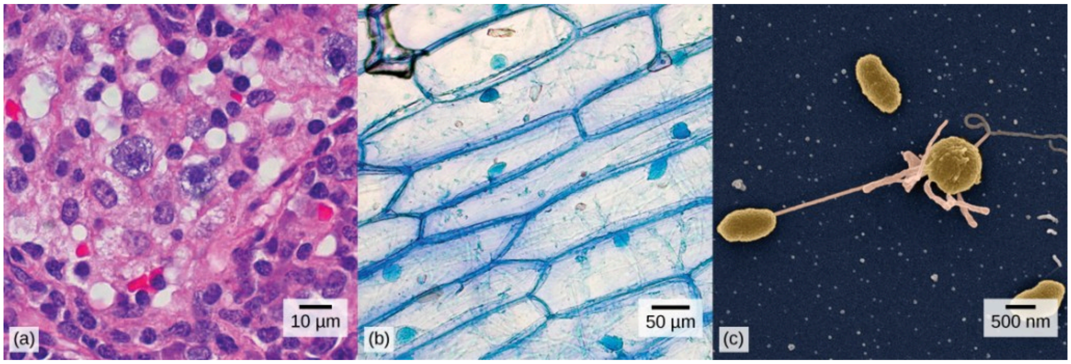


Figure 2.1 (a) Nasal sinus cells (viewed with a light microscope), (b) onion cells (viewed with a light microscope), and (c) Vibrio tasmaniensis bacterial cells (viewed using a scanning electron microscope) are from very different organisms, yet all share certain characteristics of basic cell structure. Close your eyes and picture a brick wall. What is the basic building block of that wall? It is a single brick, of course. Like a brick wall, your body is composed of basic building blocks, and the building blocks of your body are cells. An average human is thought to have 37.2 trillion cells.

Your body has many kinds of cells, each specialized for a specific purpose. Just as a home is made from a variety of building materials, the human body is constructed from many cell types. For example, epithelial cells protect the surface of the body and cover the organs and body cavities within. Bone cells help to support and protect the body. Cells of the immune system fight invading bacteria. Additionally, red blood cells carry oxygen throughout the body. Each of these cell types plays a vital role during the growth, development, and day-to-day maintenance of the body. In spite of their enormous variety, however, all cells share certain fundamental characteristics.

Cell Theory

Learning Objectives

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

- Describe the roles of cells in organisms
- Summarize the cell theory

A cell is the smallest unit of a living thing. A living thing, like you, is called an organism. Thus, cells are the basic building blocks of all organisms.

In multicellular organisms, several cells of one particular kind interconnect with each other and perform shared functions to form tissues (for example, muscle tissue, connective tissue, and nervous tissue), several tissues combine to form an organ (for example, stomach, heart, or brain), and several organs make up an organ system (such as the digestive system, circulatory system, or nervous system). Several systems functioning together form an organism (such as an elephant, for example).

There are many types of cells, and all are grouped into one of two broad categories: prokaryotic and eukaryotic. Animal cells, plant cells, fungal cells, and protist cells are classified as **eukaryotic**, whereas bacteria and archaea cells are classified as **prokaryotic**.

Cells vary in size. With few exceptions, individual cells are too small to be seen with the naked eye, so scientists use microscopes to study them. A **microscope** is an instrument that magnifies an object.

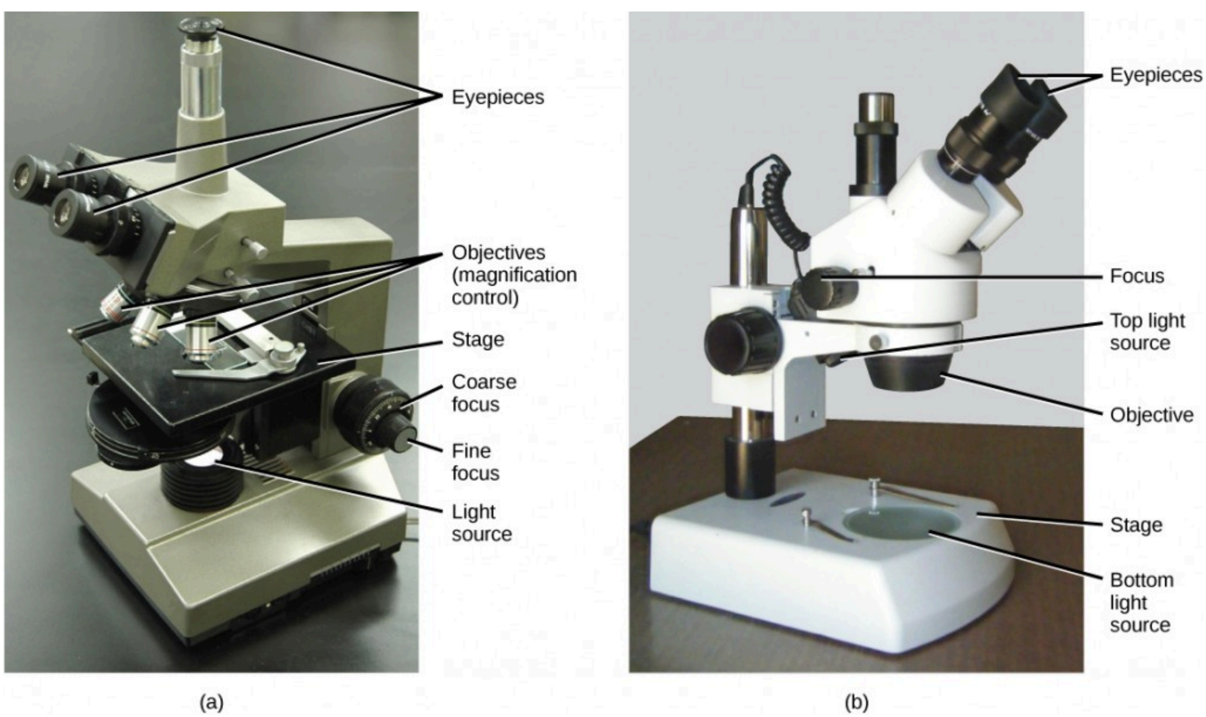


Figure 2.2 (a) Most light microscopes used in a college biology lab can magnify cells up to approximately 400 times. (b) Dissecting microscopes have a lower magnification than light microscopes and are used to examine larger objects, such as tissues.

The microscopes we use today are far more complex than those used in the 1600s by Antony van Leeuwenhoek, a Dutch shopkeeper who had great skill in crafting lenses, and the first scientist to observe cells. Despite the limitations of his now-ancient lenses, van Leeuwenhoek observed the movements of protists (a type of single-celled organism) and sperm, which he collectively termed “animalcules.”

In a 1665 publication called *Micrographia*, experimental scientist Robert Hooke coined the term “cell” (from the Latin *cella*, meaning “small room”) for the box-like structures he observed when viewing cork tissue through a lens. In the 1670s, van Leeuwenhoek discovered bacteria and protozoa. Later advances in lenses and microscope construction enabled other scientists to see different components inside cells.

By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the **unified cell theory**, which states that all living things are composed of one or more cells, that the cell is the basic unit of life, and that all new cells arise from existing cells.

Since then, we’ve learned much about cells. All plants and animals are made of cells. Some organisms are single cell organisms, made up of only one cell, while many are multicellular organisms, made up of many cells. All cells have a purpose. In single-cell organisms, like bacteria, the cell performs all the functions needed to keep itself alive. In multicellular organisms, the cells will specialize. Some cells will transport nerve signals while others make up organs, for example.

Cells do not spontaneously appear but are created from other cells. This process is called mitosis and is one of the tenets of cell theory. Cell theory is one of the overarching themes of biology. It has evolved over the years, growing from three points to six, and now includes the idea of passing down genetic material from parent to offspring, as well.

Modern Cell Theory

1. Cells make up all life.
2. Cells are functional, structural units.
3. Cells are formed by division.
4. Cells contain hereditary information.
5. Cells are chemically the same.
6. Energy flow occurs within cells.

Section Summary

A cell is the smallest unit of life. Most cells are so small that they cannot be viewed with the naked eye. Therefore, scientists must use microscopes to study cells. The unified cell theory states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells.

Exercises

1. The ___________ is the basic unit of life.
   A. organism
   B. cell
   C. tissue
   D. organ
2. What is the difference between prokaryotic and eukaryotic cells?

3. What is the Cell Theory?

Answers

1. B
2. Eukaryotic cells have organelles and a plasma membrane and make up multicellular organisms. Prokaryotic cells do not have organelles, and make up microorganisms.
3. It is the theory that cells are the fundamental unit of all living organisms and that all cells comes from pre-existing cells.

Glossary

unified cell theory: the biological concept that states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells

eukaryotic cells: cells that contain a nucleus and organelles, and are enclosed by a plasma membrane; organisms that have eukaryotic cells include protozoa, fungi, plants and animals

microscope: the instrument that magnifies an object

prokaryotic cells: unicellular organisms that lack organelles or other internal membrane-bound structures

Media Attribution

- Figure 2.1
  - Nasal sinus cell: modification of work by Ed Uthman, MD;
  - Onion cell: modification of work by Umberto Salvagnin;
  - Vibrio tasmaniensis bacterial cells: modification of work by Anthony D'Onofrio; scale-bar data from Matt Russell

2.2 CELL STRUCTURES AND ORGANELLES

Learning Objectives

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

- Describe the structure of human cells
- Summarize the functions of the major cell organelles and parts

At this point, it should be clear that human cells have a complex structure. Organelles allow for various functions to occur in the cell at the same time. Before discussing the functions of organelles within a cell, let us first examine two important components of the cell: the plasma membrane and the cytoplasm.

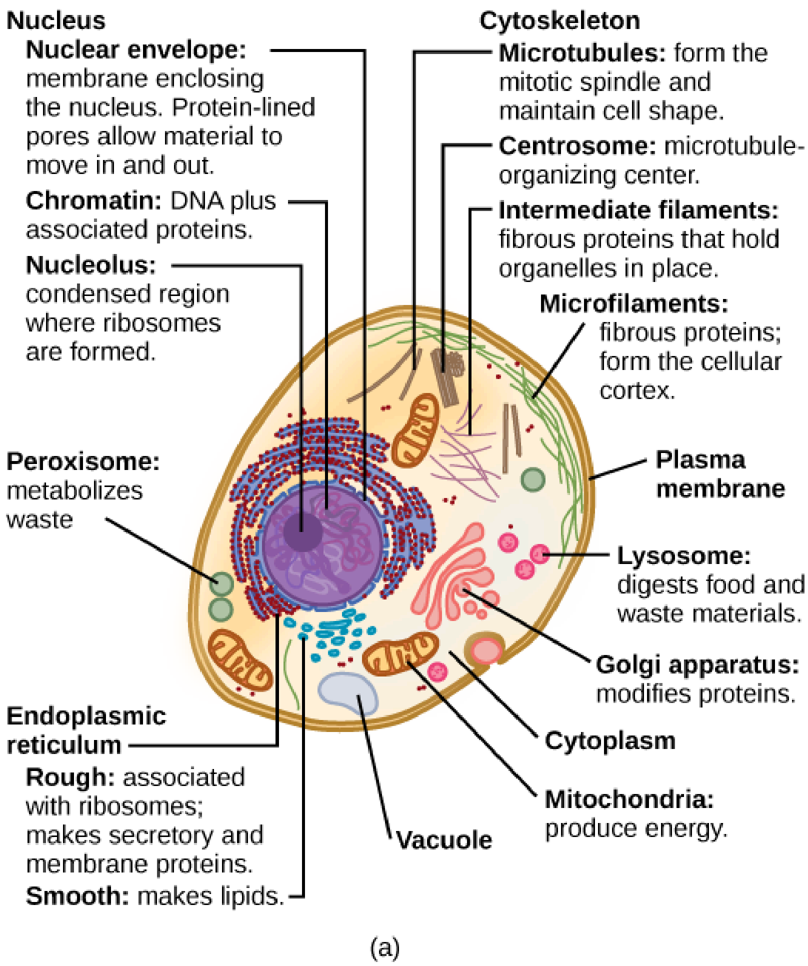


Figure 2.3 This figure shows a typical animal cell

The Plasma Membrane

Cells have a **plasma membrane** (Figure 2.4) made up of a phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. A phospholipid is a lipid molecule composed of two fatty acid chains, a glycerol backbone, and a phosphate group. The plasma membrane regulates the passage of some substances, such as organic molecules, ions, and water, preventing the passage of some to maintain internal conditions, while actively bringing in or removing others. Other compounds move passively across the membrane.

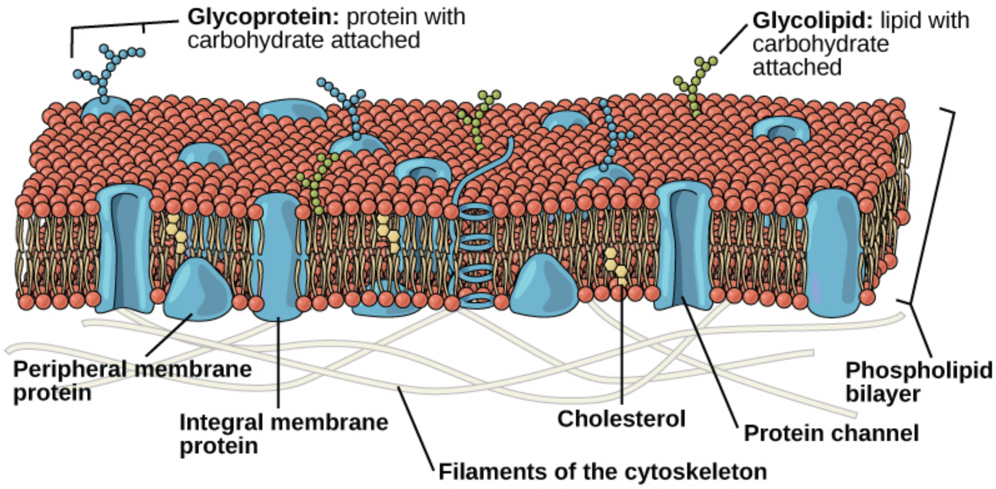


Figure 2.4 The plasma membrane is a phospholipid bilayer with embedded proteins. There are other components, such as cholesterol and carbohydrates, which can be found in the membrane in addition to phospholipids and protein.

The plasma membranes of cells that specialize in absorption are folded into fingerlike projections called microvilli (singular = microvillus). This folding increases the surface area of the plasma membrane. Such cells are typically found lining the small intestine, the organ that absorbs nutrients from digested food. This is an excellent example of form matching the function of a structure.

People with celiac disease have an immune response to gluten, which is a protein found in wheat, barley, and rye. The immune response damages microvilli, and thus, afflicted individuals cannot absorb nutrients. This leads to malnutrition, cramping, and diarrhea. Patients suffering from celiac disease must follow a gluten-free diet.

The Cytoplasm

The **cytoplasm** comprises the contents of a cell between the plasma membrane and the nuclear envelope (a structure to be discussed shortly). It's basically a thick solution of salts and proteins that make up the inside of the cell, and that surround organelles and the nucleus. It is made up of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals. Even though the cytoplasm consists of 70 to 80 percent water, it has a semi-solid consistency, which comes from the proteins within it. However, proteins are not the only organic molecules found in the cytoplasm. Glucose and other simple sugars, polysaccharides, amino acids, nucleic acids, fatty acids, and derivatives of glycerol are found there too. Ions of sodium, potassium, calcium, and many other elements are also dissolved in the cytoplasm. Many metabolic reactions, including protein synthesis, take place in the cytoplasm.

The Cytoskeleton

If you were to remove all the organelles from a cell, would the plasma membrane and the cytoplasm be the only components left? No. Within the cytoplasm, there would still be ions and organic molecules, plus a network of protein fibers that helps to maintain the shape of the cell, secures certain organelles in specific positions, and allows cytoplasm and vesicles to move within the cell. Collectively, this network of protein fibers is known as the **cytoskeleton**. There are three types of fibers within the cytoskeleton: microfilaments, also known as actin filaments, intermediate filaments, and microtubules (Figure 2.5).

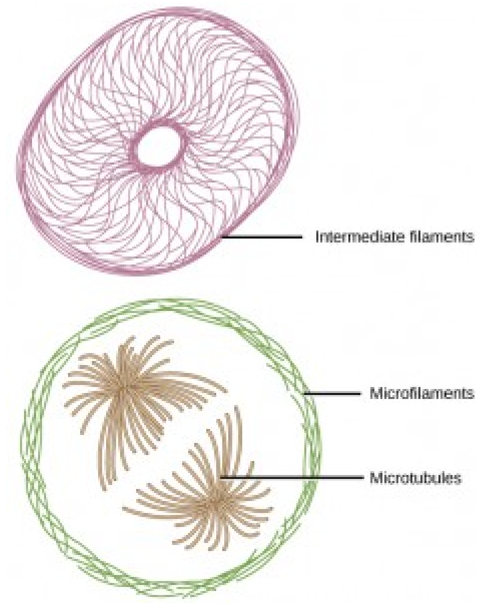


Figure 2.5 Microfilaments, intermediate filaments, and microtubules compose a cell's cytoskeleton.

Microfilaments are the thinnest of the cytoskeletal fibers and function in moving cellular components, for example, during cell division. They also maintain the structure of microvilli, the extensive folding of the plasma membrane found in cells dedicated to absorption. These components are also common in muscle cells and are responsible for muscle cell contraction. Intermediate filaments are of intermediate diameter and have structural functions, such as maintaining the shape of the cell and anchoring organelles. Keratin, the compound that strengthens hair and nails, forms one type of intermediate filament. Microtubules are the thickest of the cytoskeletal fibers. These are hollow tubes that can dissolve and reform quickly. Microtubules guide organelle movement and are the structures that pull chromosomes to their poles during cell division. They are also the structural components of flagella and cilia. In cilia and flagella, the microtubules are organized as a circle of nine double microtubules on the outside and two microtubules in the center.

Flagella and Cilia

Flagella (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and are used to move an entire cell, (for example, sperm, *Euglena*). When present, the cell has just one flagellum or a few flagella. When cilia (singular = cilium) are present, however, they are many in number and extend along the entire surface of the plasma membrane. They are short, hair-like structures that are used to move entire cells (such as paramecium) or move substances along the outer surface of the cell (for example, the cilia of cells lining the fallopian tubes that move the ovum toward the uterus, or cilia lining the cells of the respiratory tract that move particulate matter toward the throat that mucus has trapped).

The Endomembrane System

The **endomembrane system** (*endo* = within) is a group of membranes and organelles in animal cells that work together to modify, package, and transport lipids and proteins. It includes the nuclear envelope, lysosomes, vesicles, endoplasmic reticulum and the

Golgi apparatus, which we will cover shortly. Although not technically *within* the cell, the plasma membrane is included in the endomembrane system because, as you will see, it interacts with the other endomembranous organelles.

The Nucleus

Typically, the nucleus is the most prominent organelle in a cell. The **nucleus** (plural = nuclei) houses the cell's DNA in the form of chromatin and directs the synthesis of ribosomes and proteins. Let us look at it in more detail (Figure 2.6).

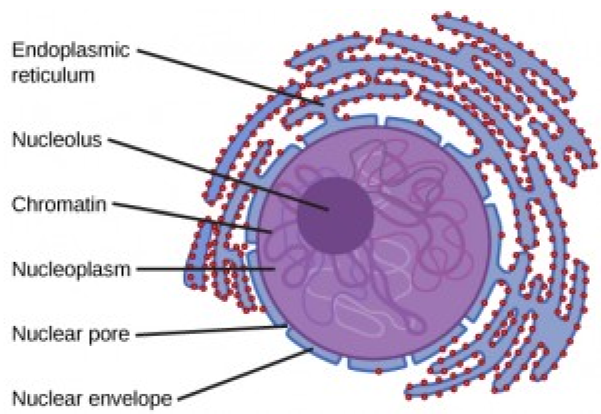


Figure 2.6 The outermost boundary of the nucleus is the nuclear envelope. Notice that the nuclear envelope consists of two phospholipid bilayers (membranes)—an outer membrane and an inner membrane—in contrast to the plasma membrane, which consists of only one phospholipid bilayer.

The **nuclear envelope** is a double-membrane structure that constitutes the outermost portion of the nucleus. Both the inner and outer membranes of the nuclear envelope are phospholipid bilayers. The nuclear envelope is punctuated with pores that control the passage of ions, molecules, and RNA between the nucleoplasm (similar to cytoplasm, but in the nucleus) and the cytoplasm.

To understand chromatin, it is helpful to first consider chromosomes. Chromosomes are structures within the nucleus that are made up of DNA, the hereditary material, and proteins. This combination of DNA and proteins is called chromatin. In eukaryotes, chromosomes are linear structures. Every species has a specific number of chromosomes in the nucleus of its body cells. For example, in humans, the chromosome number is 46, whereas in fruit flies, the chromosome number is eight. Chromosomes are only visible and distinguishable from one another when the cell is getting ready to divide. When the cell is in the growth and maintenance phases of its life cycle, the chromosomes resemble an unwound, jumbled bunch of threads.

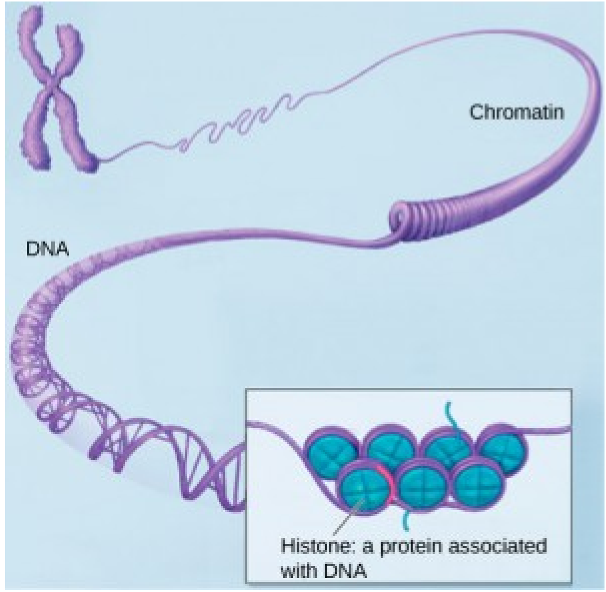


Figure 2.7 This image shows various levels of the organization of chromatin (DNA and protein).

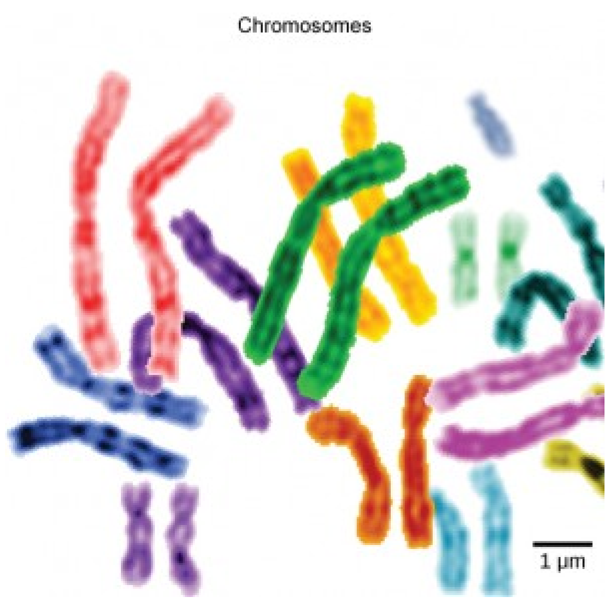


Figure 2.8 This image shows paired chromosomes. (credit: modification of work by NIH; scale-bar data from Matt Russell)

We already know that the nucleus directs the synthesis of ribosomes, but how does it do this? Some chromosomes have sections of DNA that encode ribosomal RNA. A darkly stained area within the nucleus, called the **nucleolus** (plural = nucleoli), aggregates the ribosomal RNA with associated proteins to assemble the ribosomal subunits that are then transported through the nuclear pores into the cytoplasm.

The Endoplasmic Reticulum

The endoplasmic reticulum (ER) is a series of interconnected membranous tubules that collectively modify proteins and synthesize lipids. However, these two functions are performed in separate areas of the endoplasmic reticulum: the rough endoplasmic reticulum and the smooth endoplasmic reticulum, respectively.

The **rough endoplasmic reticulum (RER)** is so named because the ribosomes attached to its surface give it a studded appearance when viewed through an electron microscope.

The ribosomes synthesize proteins while attached to the ER, resulting in the transfer of their newly synthesized proteins into the RER where they undergo modifications such as folding or addition of sugars. The RER also makes phospholipids for cell membranes.

If the phospholipids or modified proteins are not destined to stay in the RER, they will be packaged within vesicles and transported from the RER by budding from the membrane. Since the RER is engaged in modifying proteins that will be secreted from the cell, it is abundant in cells that secrete proteins, such as the liver.

The **smooth endoplasmic reticulum (SER)** is continuous with the RER but has few or no ribosomes on its cytoplasmic surface. The SER's functions include synthesis of carbohydrates, lipids (including phospholipids), and steroid hormones; detoxification of medications and poisons; alcohol metabolism; and storage of calcium ions.

The Golgi Apparatus

We have already mentioned that vesicles can bud from the ER, but where do the vesicles go? Before reaching their final destination, the lipids or proteins within the transport vesicles need to be sorted, packaged, and tagged so that they wind up in the right place. The sorting, tagging, packaging, and distribution of lipids and proteins take place in the **Golgi apparatus** (also called the Golgi body), a series of flattened membranous sacs.

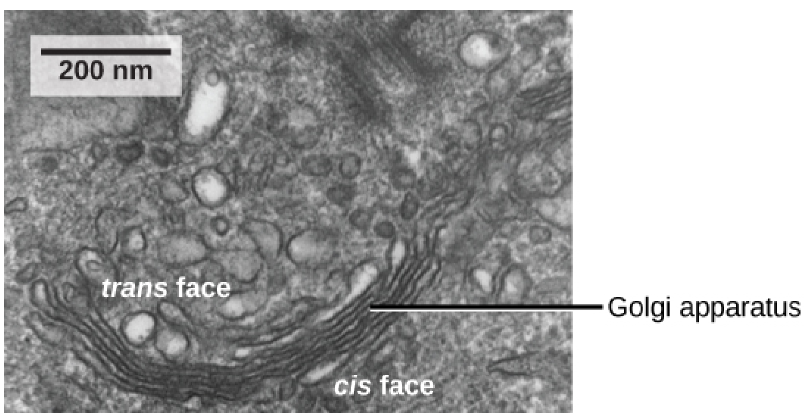


Figure 2.9 The Golgi apparatus in this transmission electron micrograph of a white blood cell is visible as a stack of semicircular flattened rings in the lower portion of this image. Several vesicles can be seen near the Golgi apparatus. (credit: modification of work by Louisa Howard; scale-bar data from Matt Russell)

The Golgi apparatus has a receiving face near the endoplasmic reticulum and a releasing face on the side away from the ER, toward the cell membrane. The transport vesicles that form from the ER travel to the receiving face, fuse with it, and empty their contents into the the Golgi apparatus. As the proteins and lipids travel through the Golgi, they undergo further modifications. The most frequent modification is the addition of short chains of sugar molecules. The newly modified proteins and lipids are then tagged with small molecular groups to enable them to be routed to their proper destinations.

Finally, the modified and tagged proteins are packaged into vesicles that bud from the opposite face of the Golgi. While some of these vesicles, transport vesicles, deposit their contents into other parts of the cell where they will be used, others, secretory vesicles, fuse with the plasma membrane and release their contents outside the cell.

The amount of Golgi in different cell types again illustrates that form follows function within cells. Cells that engage in a great deal of secretory activity (such as cells of the salivary glands that secrete digestive enzymes or cells of the immune system that secrete antibodies) have an abundant number of Golgi.

Lysosomes

In animal cells, the **lysosomes** are the cell's "garbage disposal." Digestive enzymes within the lysosomes aid the breakdown of proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles. These enzymes are active at a much lower pH (more acidic) than those located in the cytoplasm. Many reactions that take place in the cytoplasm could not occur at a low pH, thus the advantage of compartmentalizing the eukaryotic cell into organelles is apparent.

Lysosomes also use their hydrolytic enzymes to destroy disease-causing organisms that might enter the cell. A good example of this occurs in a group of white blood cells called macrophages, which are part of your body's immune system. In a process known as phagocytosis, a section of the plasma membrane of the macrophage folds in and engulfs a pathogen. The section with the pathogen inside then pinches itself off from the plasma membrane and becomes a vesicle. The vesicle fuses with a lysosome. The lysosome's hydrolytic enzymes then destroy the pathogen (Figure 2.10).

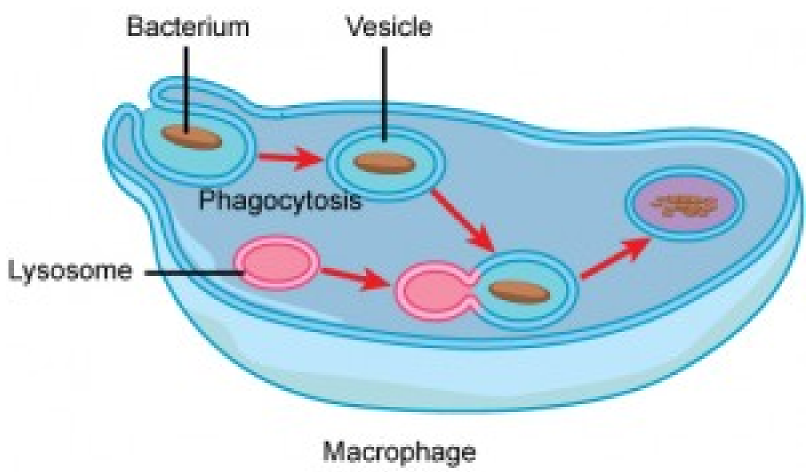


Figure 2.10 A macrophage has phagocytized a potentially pathogenic bacterium into a vesicle, which then fuses with a lysosome within the cell so that the pathogen can be destroyed. Other organelles are present in the cell, but for simplicity, are not shown.

Vesicles and Vacuoles

Vesicles and **vacuoles** are membrane-bound sacs that function in storage and transport. Vacuoles are somewhat larger than vesicles, and the membrane of a vacuole does not fuse with the membranes of other cellular components. Vesicles can fuse with other membranes within the cell system. Additionally, enzymes within plant vacuoles can break down macromolecules.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. When viewed through an electron microscope, free ribosomes appear as either clusters or single tiny dots floating freely in the cytoplasm. Ribosomes may be attached to either the cytoplasmic side of the plasma membrane or the cytoplasmic side of the endoplasmic reticulum.

Because protein synthesis is essential for all cells, ribosomes are found in practically every cell. They are particularly abundant in immature red blood cells for the synthesis of hemoglobin, which functions in the transport of oxygen throughout the body.

Mitochondria

Mitochondria (singular = mitochondrion) are often called the "powerhouses" or "energy factories" of a cell because they are responsible for making adenosine triphosphate (ATP), the cell's main energy-carrying molecule. Mitochondria are oval-shaped, double-membrane organelles (Figure 2.11) that have their own ribosomes and DNA. Each membrane is a phospholipid bilayer embedded with proteins. The inner layer has folds called cristae, which increase the surface area of the inner membrane. Muscle cells have a very high concentration of mitochondria because muscle cells need a lot of energy to contract.

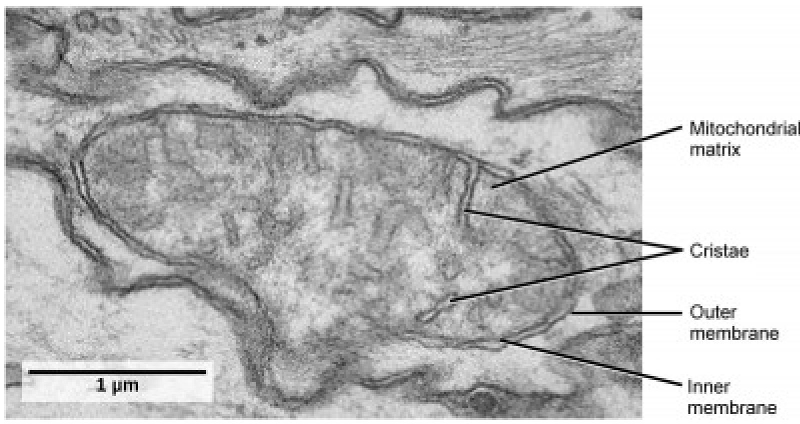


Figure 3.11 This transmission electron micrograph shows a mitochondrion as viewed with an electron microscope. Notice the inner and outer membranes, the cristae, and the mitochondrial matrix.

Peroxisomes

Peroxisomes are small, round organelles enclosed by single membranes. They carry out oxidation reactions that break down fatty acids and amino acids. They also detoxify many poisons that may enter the body. Alcohol is detoxified by peroxisomes in liver cells. A byproduct of these oxidation reactions is hydrogen peroxide, H_2O_2, which is contained within the peroxisomes to prevent the chemical from causing damage to cellular components outside of the organelle. Hydrogen peroxide is safely broken down by peroxisomal enzymes into water and oxygen.

Table 2.1 Components of Animal Cells and Their Functions

Cell Component	Function
Plasma membrane	Separates cell from external environment; controls passage of organic molecules, ions, water, oxygen, and wastes into and out of the cell
Cytoplasm	Provides structure to cell; site of many metabolic reactions; medium in which organelles are found
Nucleus	Cell organelle that houses DNA and directs synthesis of ribosomes and proteins
Ribosomes	Protein synthesis
Mitochondria	ATP production/cellular respiration
Peroxisomes	Oxidizes and breaks down fatty acids and amino acids, and detoxifies poisons
Vesicles and vacuoles	Storage and transport; digestive function in plant cells
Centrosome	Unspecified role in cell division in animal cells; organizing center of microtubules in animal cells
Lysosomes	Digestion of macromolecules; recycling of worn-out organelles
Endoplasmic reticulum	Modifies proteins and synthesizes lipids
Golgi apparatus	Modifies, sorts, tags, packages, and distributes lipids and proteins
Cytoskeleton	Maintains cell's shape, secures organelles in specific positions, allows cytoplasm and vesicles to move within the cell, and enables unicellular organisms to move independently
Flagella	Cellular locomotion
Cilia	Cellular locomotion, movement of particles along extracellular surface of plasma membrane, and filtration

Section Summary

Generally, a human cell has a plasma membrane, cytoplasm, and ribosomes, has a true nucleus (meaning its DNA is surrounded by a membrane), and has other membrane-bound organelles that allow for compartmentalization of functions. The plasma membrane is a phospholipid bilayer embedded with proteins. The nucleolus within the nucleus is the site for ribosome assembly. Ribosomes are found in the cytoplasm or are attached to the cytoplasmic side of the plasma membrane or endoplasmic reticulum. They perform protein synthesis. Mitochondria perform cellular respiration. Peroxisomes break down fatty acids, amino acids, and some toxins. Vesicles and vacuoles are storage and transport compartments. Lysosomes are the digestive organelles of animal cells. The endomembrane system includes the nuclear envelope, the endoplasmic reticulum, Golgi apparatus, lysosomes, vesicles, as well as the plasma membrane. These cellular components work together to modify, package, tag, and transport membrane lipids and proteins.

The cytoskeleton has three different types of protein elements. Microfilaments provide rigidity and shape to the cell, and facilitate cellular movements. Intermediate filaments bear tension and anchor the nucleus and other organelles in place. Microtubules help the cell resist compression, serve as tracks for motor proteins that move vesicles through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. They are also the structural elements of centrioles, flagella, and cilia.

Glossary

cilium: (plural: cilia) a short, hair-like structure that extends from the plasma membrane in large numbers and is used to move an entire cell or move substances along the outer surface of the cell

cytoplasm: the entire region between the plasma membrane and the nuclear envelope, consisting of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals

cytoskeleton: the network of protein fibers that collectively maintains the shape of the cell, secures some organelles in specific positions, allows cytoplasm and vesicles to move within the cell, and enables unicellular organisms to move

cytosol: the gel-like material of the cytoplasm in which cell structures are suspended

endomembrane system: the group of organelles and membranes in eukaryotic cells that work together to modify, package, and transport lipids and proteins

endoplasmic reticulum (ER): a series of interconnected membranous structures within eukaryotic cells that collectively modify proteins and synthesize lipids

flagellum: (plural: flagella) the long, hair-like structure that extends from the plasma membrane and is used to move the cell

Golgi apparatus: a eukaryotic organelle made up of a series of stacked membranes that sorts, tags, and packages lipids and proteins for distribution

lysosome: an 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

mitochondria: (singular: mitochondrion) the cellular organelles responsible for carrying out cellular respiration, resulting in the production of ATP, the cell's main energy-carrying molecule

nuclear envelope: the double-membrane structure that constitutes the outermost portion of the nucleus

nucleolus: the darkly staining body within the nucleus that is responsible for assembling ribosomal subunits

nucleus: the cell organelle that houses the cell's DNA and directs the synthesis of ribosomes and proteins

peroxisome: a small, round organelle that contains hydrogen peroxide, oxidizes fatty acids and amino acids, and detoxifies many poisons

plasma membrane: a membrane made of phospholipids and proteins that separates the internal contents of the cell from its surrounding environment

ribosome: a cellular structure that carries out protein synthesis

rough endoplasmic reticulum (RER): the region of the endoplasmic reticulum that is studded with ribosomes and engages in protein modification

smooth endoplasmic reticulum (SER): the region of the endoplasmic reticulum that has few or no ribosomes on its cytoplasmic surface and synthesizes carbohydrates, lipids, and steroid hormones; detoxifies chemicals like pesticides, preservatives, medications, and environmental pollutants, and stores calcium ions

vacuole: a membrane-bound sac, somewhat larger than a vesicle, that functions in cellular storage and transport

vesicle: a 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

Media Attributions

- Figure 2.6: modification of work by NIGMS, NIH
- Figure 2.8: modification of work by NIH; scale-bar data from Matt Russell
- Figure 2.9: modification of work by Louisa Howard; scale-bar data from Matt Russell
- Figure 2.11: modification of work by Matthew Britton; scale-bar data from Matt Russell

2.3 CANCER

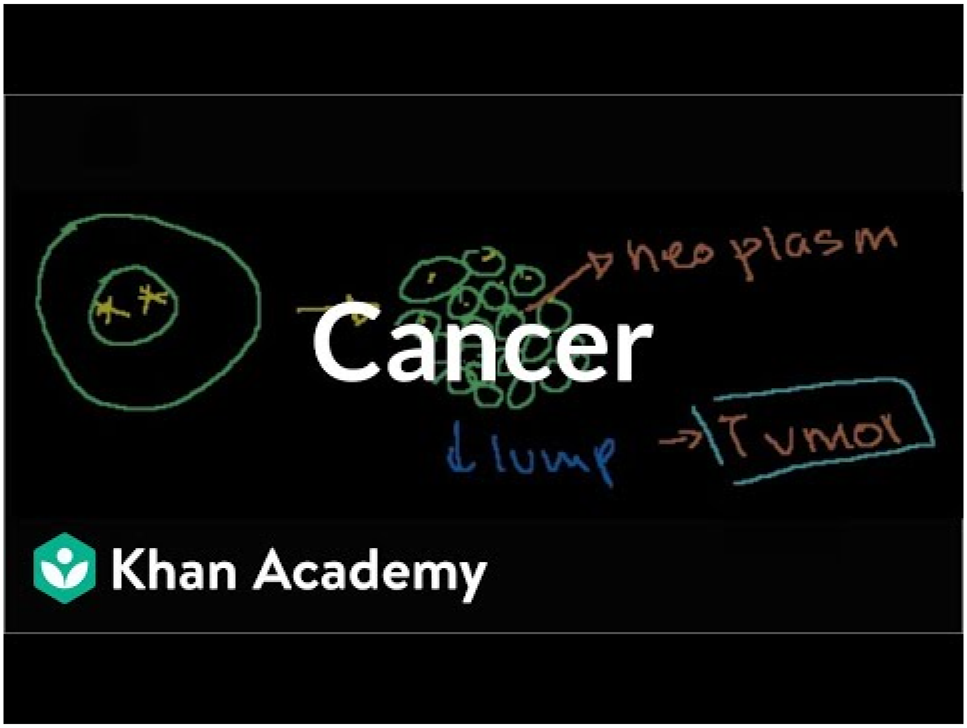
Learning Objectives

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

- Explain how cancer is caused by uncontrolled cell division

Cancer is a collective name for many different diseases caused by a common mechanism: uncontrolled cell division. Despite the redundancy and overlapping levels of cell-cycle control when cells divide, errors occur. One of the critical processes monitored by the cell-cycle checkpoint surveillance mechanism is the proper replication of DNA. Even when all of the cell-cycle controls are fully functional, a small percentage of replication errors (mutations) will be passed on to the daughter cells. If one of these changes to the DNA nucleotide sequence occurs within a gene, a gene mutation results. All cancers begin when a gene mutation gives rise to a faulty protein that participates in the process of cell reproduction. The change in the cell that results from the malformed protein may be minor. Even minor mistakes, however, may allow subsequent mistakes to occur more readily. Over and over, small, uncorrected errors are passed from parent cell to daughter cells and accumulate as each generation of cells produces more non-functional proteins from uncorrected DNA damage. Eventually, the pace of the cell cycle speeds up as the effectiveness of the control and repair mechanisms decreases. Uncontrolled growth of the mutated cells outpaces the growth of normal cells in the area, and a tumor can result.

Watch an animation of how cancer results from errors in the cell cycle.



A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.nscc.ca/humanbiology/?p=1210

Print version – Use the QR code to play the video.

Section Summary

Cancer is the result of unchecked cell division caused by a breakdown of the mechanisms regulating the cell cycle. The loss of control begins with a change in the DNA sequence of a gene that codes for one of the regulatory molecules. Faulty instructions lead to a protein that does not function as it should. Any disruption of the monitoring system can allow other mistakes to be passed on to the daughter cells. Each successive cell division will give rise to daughter cells with even more accumulated damage. Eventually, all checkpoints become nonfunctional, and rapidly reproducing cells crowd out normal cells, resulting in tumorous growth.

Exercises

Outline the steps that lead to a cell becoming cancerous.

Answers

If one of the genes that produce regulator proteins becomes mutated, it produces a malformed, possibly non-functional, cell-cycle regulator. This increases the chance that more mutations will be left unrepaired in the cell. Each subsequent generation of cells sustains more damage. The cell cycle can speed up as a result of loss of functional checkpoint proteins. The cells can lose the ability to self-destruct.

CHAPTER 3: HUMAN TISSUES AND SYSTEMS

Figure 3.1 An arctic fox is a complex animal, well adapted to its environment. (credit: Keith Morehouse, USFWS)

The arctic fox, a complex animal that has adapted to its environment, illustrates the relationships between an animal's form and function. The multicellular bodies of animals consist of tissues that make up more complex organs and organ systems. The organ systems of an animal maintain homeostasis within the multicellular body. These systems are adapted to obtain the necessary nutrients and other resources needed by the cells of the body, to remove the wastes those cells produce, to coordinate the activities of the cells, tissues, and organs throughout the body, and to coordinate the many responses of the individual organism to its environment.

Types of Cells and Tissues

Learning Objectives

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

- Describe epithelial tissues
- Discuss the different types of connective tissues in animals
- Describe three types of muscle tissues
- Describe nervous tissue

Multicellular, complex animals have four primary types of tissue: epithelial, connective, muscle, and nervous. Recall that tissues are groups of similar cells carrying out related functions. These tissues combine to form organs—like the skin or kidney—that have specific, specialized functions within the body. Organs are organized into organ systems to perform functions; examples include the circulatory system, which consists of the heart and blood vessels, and the digestive system, consisting of several organs, including the stomach, intestines, liver, and pancreas. Organ systems come together to create an entire organism.

Epithelial Tissues

Epithelial tissues cover the outside of organs and structures in the body and line the lumens (inside cavity) of organs in a single layer or multiple layers of cells. The types of epithelia are classified by the shapes of cells present and the number of layers of cells. Epithelia composed of a single layer of cells are called *simple* **epithelia**; epithelial tissue composed of multiple layers is called **stratified epithelia**. Table 3.1 summarizes the different types of epithelial tissues.

Table 3.1. Different Types of Epithelial Tissues

Cell shape	Description	Location
squamous	flat, irregular round shape	simple: lung alveoli, capillaries stratified: skin, mouth, vagina
cuboidal	cube shaped, central nucleus	glands, renal tubules
columnar	tall, narrow, nucleus toward base tall, narrow, nucleus along cell	simple: digestive tract pseudostratified: respiratory tract
transitional	round, simple but appear stratified	urinary bladder

Squamous Epithelia

Squamous epithelial cells are generally round, flat, and have a small, centrally located nucleus. The cell outline is slightly irregular, and cells fit together to form a covering or lining. When the cells are arranged in a single layer (simple epithelia), they facilitate diffusion in tissues, such as the areas of gas exchange in the lungs and the exchange of nutrients and waste at blood capillaries.

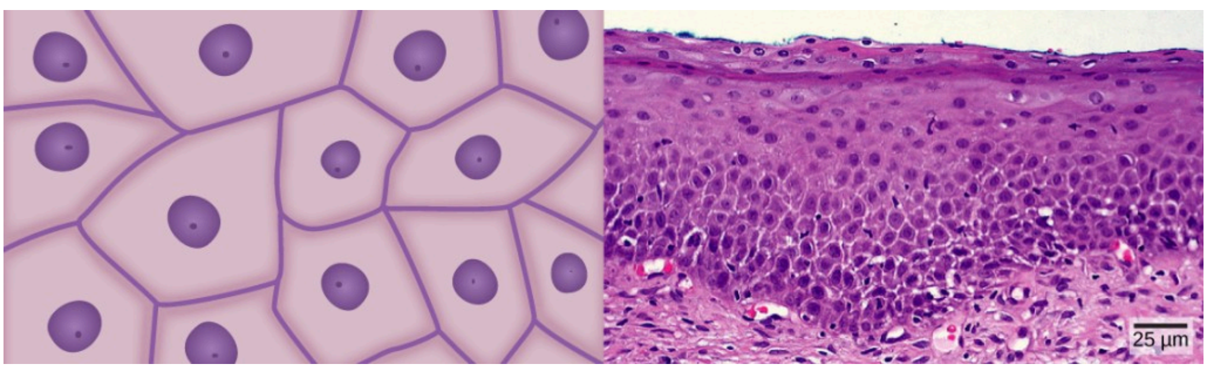


Figure 3.2 Squamous epithelia cells (a) have a slightly irregular shape, and a small, centrally located nucleus. These cells can be stratified into layers, as in (b) this human cervix specimen. (credit b: modification of work by Ed Uthman; scale-bar data from Matt Russell)

Figure 3.2a illustrates a layer of squamous cells with their membranes joined together to form an epithelium. Figure 3.2b illustrates squamous epithelial cells arranged in stratified layers, where protection is needed on the body from outside abrasion and damage. This is called a stratified squamous epithelium and occurs in the skin and in tissues lining the mouth and vagina.

Cuboidal Epithelia

Cuboidal epithelial cells are cube-shaped with a single, central nucleus. They are most commonly found in a single layer representing a simple epithelia in glandular tissues throughout the body where they prepare and secrete glandular material. They are also found in the walls of tubules and in the ducts of the kidney and liver.

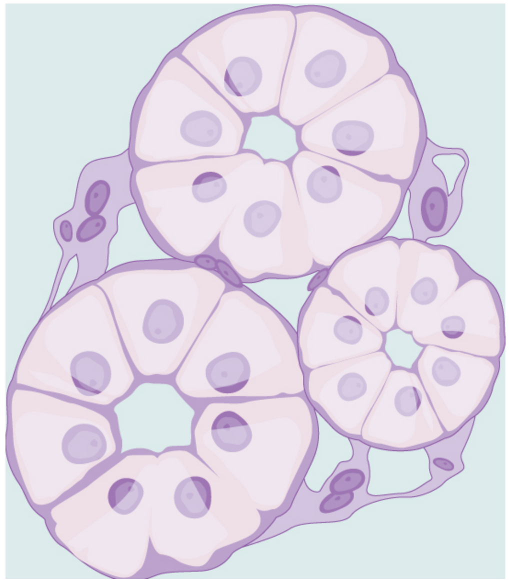


Figure 3.3. Simple cuboidal epithelial cells line tubules in the mammalian kidney, where they are involved in filtering the blood.

Columnar Epithelia

Columnar epithelial cells are taller than they are wide: they resemble a stack of columns in an epithelial layer, and are most commonly found in a single-layer arrangement. The nuclei of columnar epithelial cells in the digestive tract appear to be lined up at the base of the cells, as illustrated in Figure 3.4. These cells absorb material from the lumen of the digestive tract and prepare it for entry into the body through the circulatory and lymphatic systems.

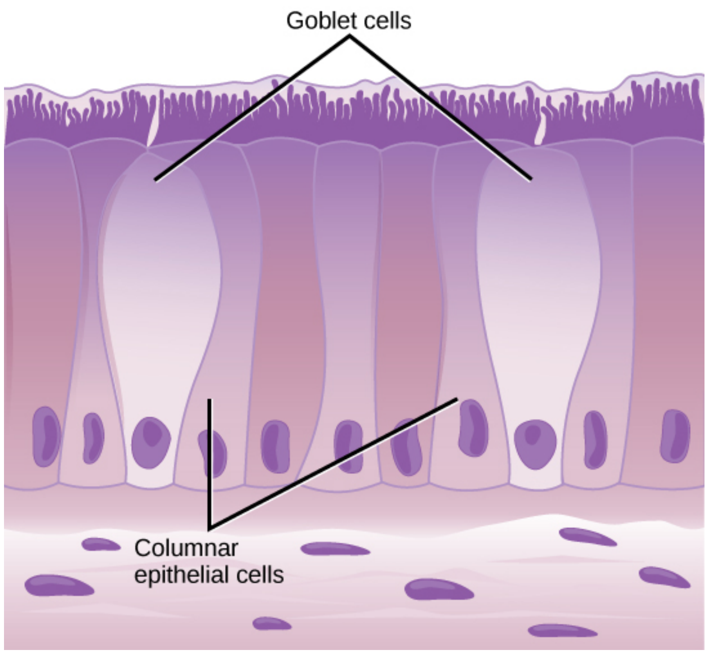


Figure 3.4. Simple columnar epithelial cells absorb material from the digestive tract. Goblet cells secret mucous into the digestive tract lumen.

Columnar epithelial cells lining the respiratory tract appear to be stratified. However, each cell is attached to the base membrane of the tissue and, therefore, they are simple tissues. The nuclei are arranged at different levels in the layer of cells, making it appear as though there is more than one layer, as seen in Figure 3.5. This is called **pseudostratified**, columnar epithelia. This cellular covering has cilia at the apical, or free, surface of the cells. The cilia enhance the movement of mucous and trapped particles out of the respiratory tract, helping to protect the system from invasive microorganisms and harmful material that has been breathed into the body. Goblet cells are interspersed in some tissues (such as the lining of the trachea). The goblet cells contain mucous that traps irritants, which in the case of the trachea keep these irritants from getting into the lungs.

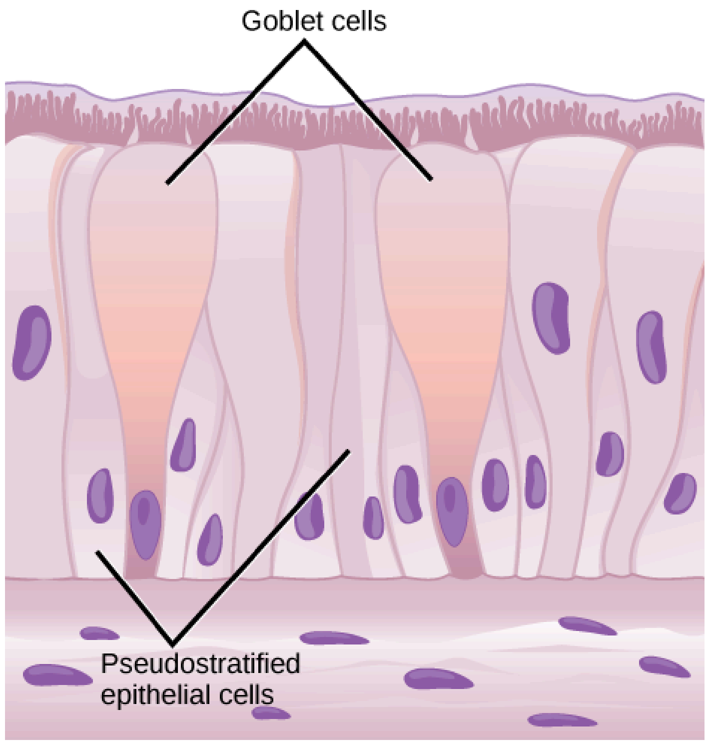


Figure 3.5. Pseudostratified columnar epithelia line the respiratory tract. They exist in one layer, but the arrangement of nuclei at different levels makes it appear that there is more than one layer. Goblet cells interspersed between the columnar epithelial cells secrete mucous into the respiratory tract.

Transitional Epithelia

Transitional or uroepithelial cells appear only in the urinary system, primarily in the bladder and ureter. These cells are arranged in a stratified layer, but they have the capability of appearing to pile up on top of each other in a relaxed, empty bladder, as illustrated in Figure 3.6. As the urinary bladder fills, the epithelial layer unfolds and expands to hold the volume of urine introduced into it. As the bladder fills, it expands and the lining becomes thinner. In other words, the tissue transitions from thick to thin.

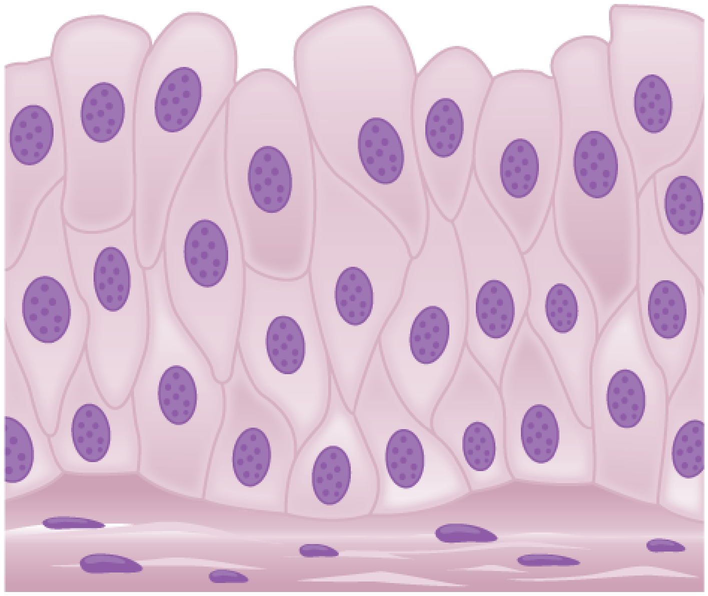


Figure 3.6. Transitional epithelia of the urinary bladder undergo changes in thickness depending on how full the bladder is.

Connective Tissues

Connective tissues are made up of a matrix consisting of living cells and a non-living substance, called the ground substance. The ground substance is made of an organic substance (usually a protein) and an inorganic substance (usually a mineral or water). The principal cell of connective tissues is the fibroblast. This cell makes the fibers found in nearly all of the connective tissues. Fibroblasts are motile, able to carry out mitosis, and can synthesize whichever connective tissue is needed. Macrophages, lymphocytes, and, occasionally, leukocytes can be found in some of the tissues. Some tissues have specialized cells that are not found in the others. The **matrix** in connective tissues gives the tissue its density. When a connective tissue has a high concentration of cells or fibers, it has proportionally a less dense matrix.

The organic portion or protein fibers found in connective tissues are either collagen, elastic, or reticular fibers. Collagen fibers provide strength to the tissue, preventing it from being torn or separated from the surrounding tissues. Elastic fibers are made of the protein elastin; this fiber can stretch to one and one half of its length and return to its original size and shape. Elastic fibers provide flexibility to the tissues. Reticular fibers are the third type of protein fiber found in connective tissues. This fiber consists of thin strands of collagen that form a network of fibers to support the tissue and other organs to which it is connected. The various types of connective tissues, the types of cells and fibers they are made of, and sample locations of the tissues is summarized in Table 3.2.

Table 3.2. Connective Tissues

Tissue	Cells	Fibers	Location
loose/areolar	fibroblasts, macrophages, some lymphocytes, some neutrophils	few: collagen, elastic, reticular	around blood vessels; anchors epithelia
dense, fibrous connective tissue	fibroblasts, macrophages,	mostly collagen	irregular: skin regular: tendons, ligaments
cartilage	chondrocytes, chondroblasts	hyaline: few collagen fibrocartilage: large amount of collagen	shark skeleton, fetal bones, human ears, intervertebral discs
bone	osteoblasts, osteocytes, osteoclasts	some: collagen, elastic	vertebrate skeletons
adipose	adipocytes	few	adipose (fat)
blood	red blood cells, white blood cells	none	blood

Loose/Areolar Connective Tissue

Loose connective tissue, also called areolar connective tissue, has a sampling of all of the components of a connective tissue. As illustrated in Figure 3.7, loose connective tissue has some fibroblasts; macrophages are present as well. Collagen fibers are relatively wide and stain a light pink, while elastic fibers are thin and stain dark blue to black. The space between the formed elements of the tissue is filled with the matrix. The material in the connective tissue gives it a loose consistency similar to a cotton ball that has been pulled apart. Loose connective tissue is found around every blood vessel and helps to keep the vessel in place. The tissue is also found around and between most body organs. In summary, areolar tissue is tough, yet flexible, and comprises membranes.

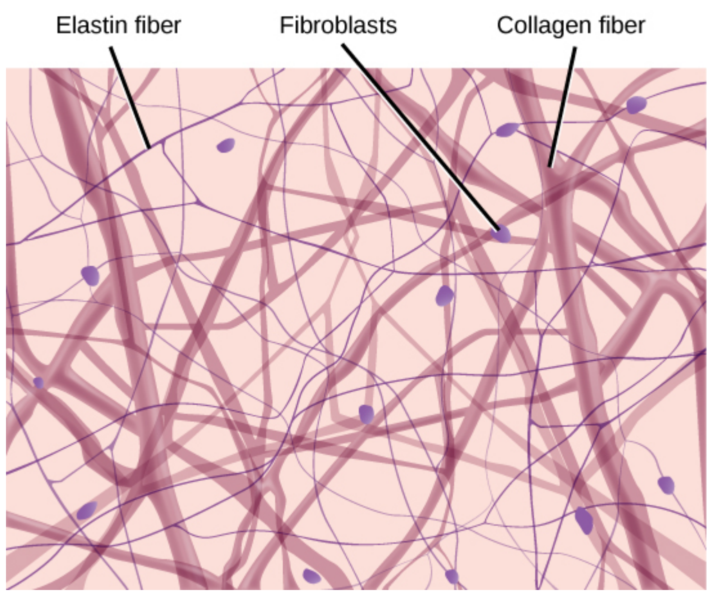


Figure 3.7. Loose connective tissue is composed of loosely woven collagen and elastic fibers. The fibers and other components of the connective tissue matrix are secreted by fibroblasts.

Fibrous Connective Tissue

Fibrous connective tissues contain large amounts of collagen fibers and few cells or matrix material. The fibers can be arranged irregularly or regularly with the strands lined up in parallel. Irregularly arranged fibrous connective tissues are found in areas of the body where stress occurs from all directions, such as the dermis of the skin. Regular fibrous connective tissue, shown in Figure 3.8, is found in tendons (which connect muscles to bones) and ligaments (which connect bones to bones).

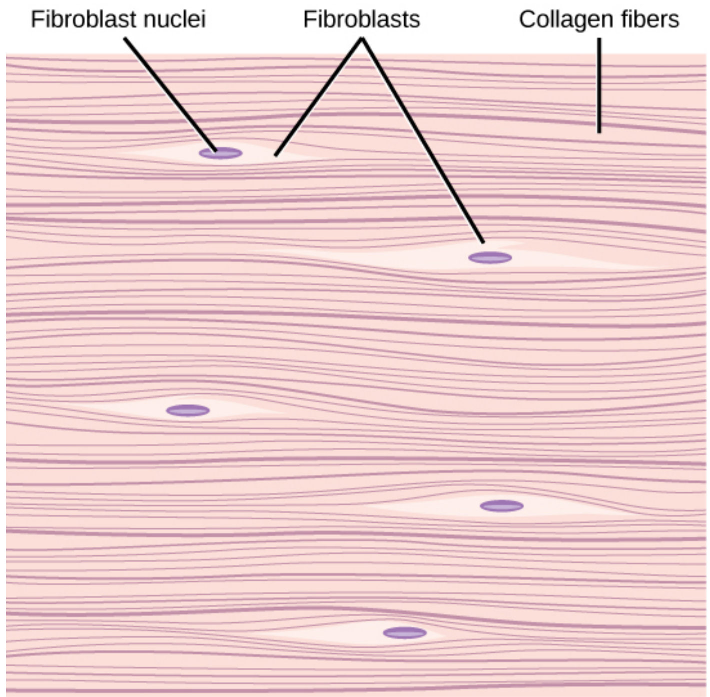


Figure 3.8. Fibrous connective tissue from the tendon has strands of collagen fibers lined up in parallel.

Cartilage

Cartilage is a connective tissue with a large amount of the matrix and variable amounts of fibers. The cells, called **chondrocytes**, make the matrix and fibers of the tissue. Chondrocytes are found in spaces within the tissue called **lacunae**.

A cartilage with few collagen and elastic fibers is hyaline cartilage, illustrated in Figure 3.9. The lacunae are randomly scattered throughout the tissue and the matrix takes on a milky or scrubbed appearance with routine histological stains. Sharks have cartilaginous skeletons, as does nearly the entire human skeleton during a specific pre-birth developmental stage. A remnant of this cartilage persists in the outer portion of the human nose. Hyaline cartilage is also found at the ends of long bones, reducing friction and cushioning the articulations of these bones.

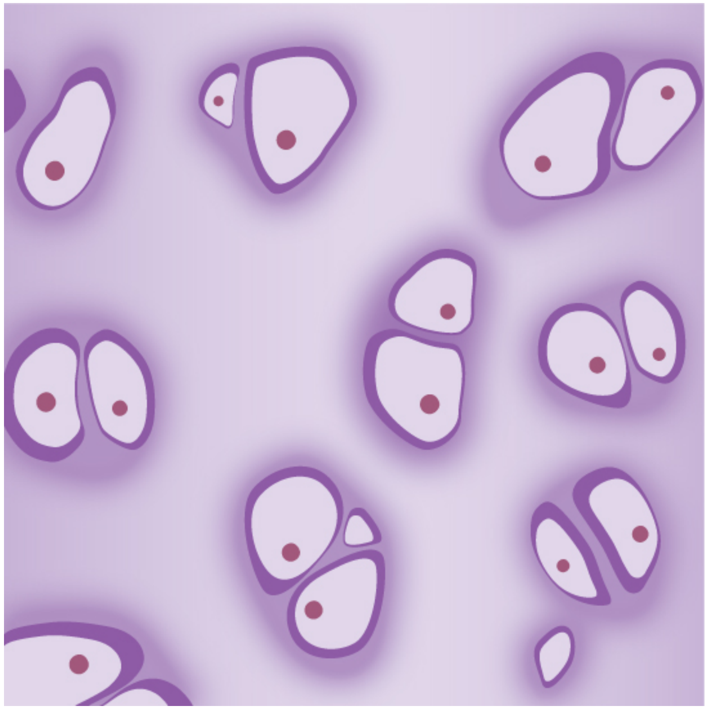


Figure 3.9. Hyaline cartilage consists of a matrix with cells called chondrocytes embedded in it. The chondrocytes exist in cavities in the matrix called lacunae.

Elastic cartilage has a large amount of elastic fibers, giving it tremendous flexibility. The ears of most vertebrate animals contain this cartilage as do portions of the larynx, or voice box. Fibrocartilage contains a large amount of collagen fibers, giving the tissue tremendous strength. Fibrocartilage comprises the intervertebral discs in vertebrate animals. Hyaline cartilage found in movable joints such as the knee and shoulder becomes damaged as a result of age or trauma. Damaged hyaline cartilage is replaced by fibrocartilage and results in the joints becoming "stiff."

Bone

Bone, or osseous tissue, is a connective tissue that has a large amount of two different types of matrix material. The organic matrix is similar to the matrix material found in other connective tissues, including some amount of collagen and elastic fibers. This gives strength and flexibility to the tissue. The inorganic matrix consists of mineral salts—mostly calcium salts—that give the tissue hardness. Without adequate organic material in the matrix, the tissue breaks; without adequate inorganic material in the matrix, the tissue bends.

There are three types of cells in bone: osteoblasts, osteocytes, and osteoclasts. Osteoblasts are active in making bone for growth and remodeling. Osteoblasts deposit bone material into the matrix and, after the matrix surrounds them, they continue to live, but in a reduced metabolic state as osteocytes. Osteocytes are found in lacunae of the bone. Osteoclasts are active in breaking down bone for bone remodeling, and they provide access to calcium stored in tissues. Osteoclasts are usually found on the surface of the tissue.

Bone can be divided into two types: compact and spongy. Compact bone is found in the shaft (or diaphysis) of a long bone and the surface of the flat bones, while spongy bone is found in the end (or epiphysis) of a long bone. Compact bone is organized into subunits called **osteons**, as illustrated in Figure 3.10. A blood vessel and a nerve are found in the center of the structure within the Haversian canal, with radiating circles of lacunae around it known as lamellae. The wavy lines seen between the lacunae are microchannels called canaliculi; they connect the lacunae to aid diffusion between the cells. Spongy bone is made of tiny plates called **trabeculae** these plates serve as struts to give the spongy bone strength. Over time, these plates can break causing the bone to become less resilient. Bone tissue forms the internal skeleton of vertebrate animals, providing structure to the animal and points of attachment for tendons.

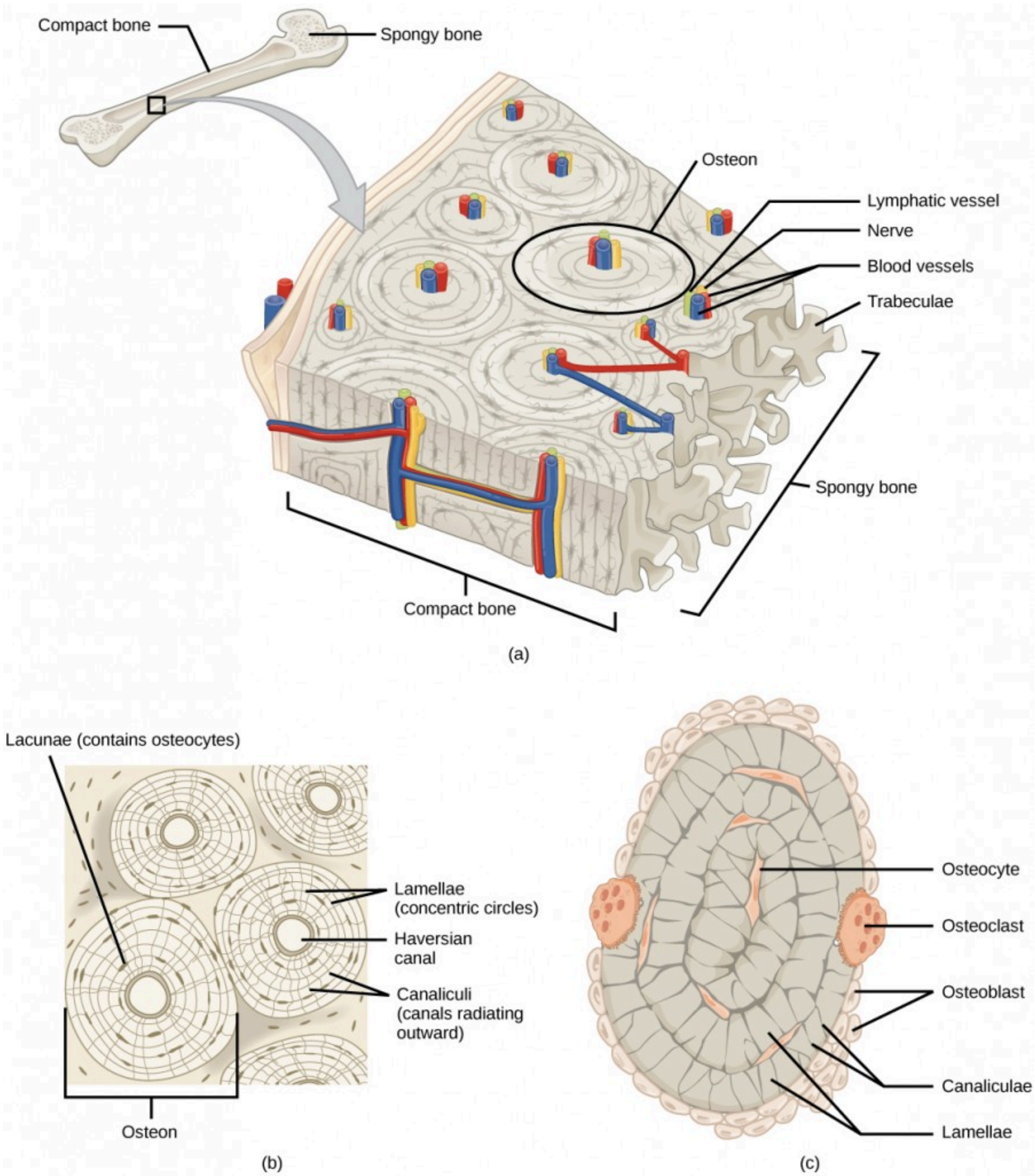


Figure 3.10. (a) Compact bone is a dense matrix on the outer surface of bone. Spongy bone, inside the compact bone, is porous with web-like trabeculae. (b) Compact bone is organized into rings called osteons. Blood vessels, nerves, and lymphatic vessels are found in the central Haversian canal. Rings of lamellae surround the Haversian canal. Between the lamellae are cavities called lacunae. Canaliculi are microchannels connecting the lacunae together. (c) Osteoblasts surround the exterior of the bone. Osteoclasts bore tunnels into the bone and osteocytes are found in the lacunae.

Adipose Tissue

Adipose tissue, or fat tissue, is considered a connective tissue even though it does not have fibroblasts or a real matrix and only has a few fibers. Adipose tissue is made up of cells called adipocytes that collect and store fat in the form of triglycerides, for energy metabolism. Adipose tissues additionally serve as insulation to help maintain body temperatures, allowing animals to be endothermic, and they function as cushioning against damage to body organs. Under a microscope, adipose tissue cells appear empty due to the extraction of fat during the processing of the material for viewing, as seen in Figure 3.11. The thin lines in the image are the cell membranes, and the nuclei are the small, black dots at the edges of the cells.

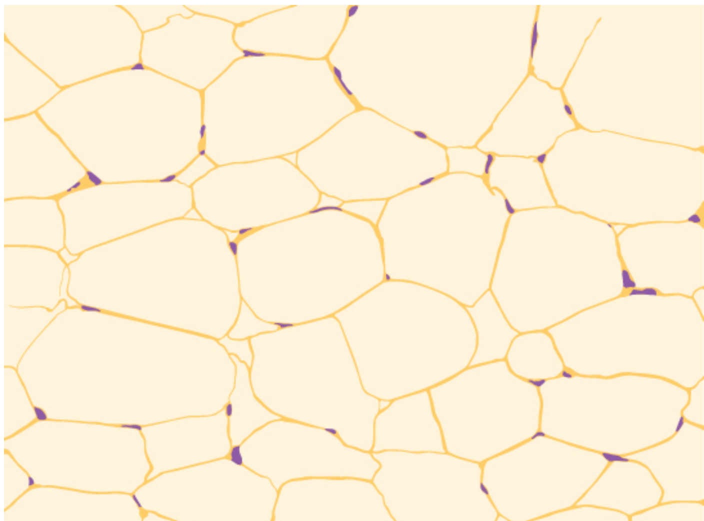


Figure 3.11. Adipose is a connective tissue made up of cells called adipocytes. Adipocytes have small nuclei localized at the cell edge.

Blood

Blood is considered a connective tissue because it has a matrix, as shown in Figure 3.12. The living cell types are red blood cells (RBC), also called **erythrocytes**, and white blood cells (WBC), also called **leukocytes**. The fluid portion of whole blood, its matrix, is commonly called plasma.

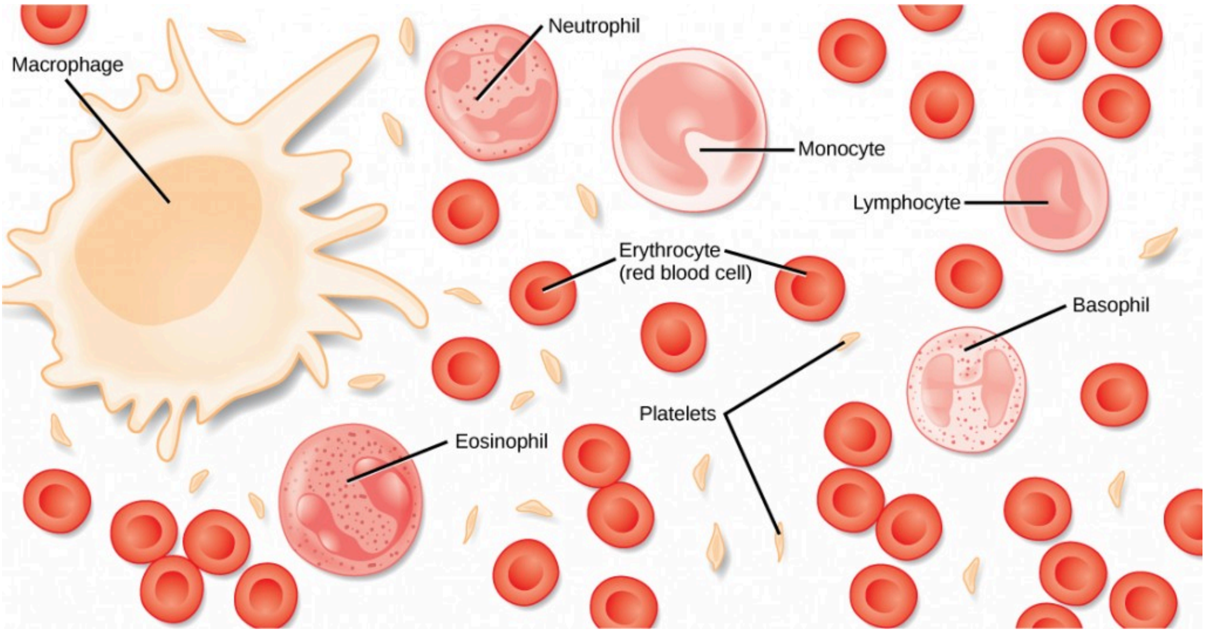


Figure 3.12. Blood is a connective tissue that has a fluid matrix, called plasma, and no fibers. Erythrocytes (red blood cells), the predominant cell type, are involved in the transport of oxygen and carbon dioxide. Also present are various leukocytes (white blood cells) involved in immune response.

The cell found in greatest abundance in blood is the erythrocyte. Erythrocytes are counted in millions in a blood sample: the average number of red blood cells in primates is 4.7 to 5.5 million cells per microliter. The principal job of an erythrocyte is to carry and deliver oxygen to the tissues.

Leukocytes are the predominant white blood cells found in the peripheral blood. Leukocytes are counted in the thousands in the blood. They function primarily in the immune response to foreign antigens or material. Different types of leukocytes make antibodies tailored to the foreign antigens and control the production of those antibodies.

The slightly granular material among the cells is a cytoplasmic fragment of a cell in the bone marrow. This is called a platelet or thrombocyte. Platelets participate in the stages leading up to coagulation of the blood to stop bleeding through damaged blood vessels. Blood has a number of functions, but primarily it transports material through the body to bring nutrients to cells and remove waste material from them.

Muscle Tissues

There are three types of muscle in animal bodies: smooth, skeletal, and cardiac. They differ by the presence or absence of striations or bands, the number and location of nuclei, whether they are voluntarily or involuntarily controlled, and their location within the body. Table 3.3 summarizes these differences.

Table 3.3. Types of Muscles

Type of Muscle	Striations	Nuclei	Control	Location
smooth	no	single, in center	involuntary	visceral organs
skeletal	yes	many, at periphery	voluntary	skeletal muscles
cardiac	yes	single, in center	involuntary	heart

Smooth Muscle

Smooth muscle does not have striations in its cells. It has a single, centrally located nucleus, as shown in Figure 3.13. Constriction of smooth muscle occurs under involuntary, autonomic nervous control and in response to local conditions in the tissues. Smooth muscle tissue is also called non-striated as it lacks the banded appearance of skeletal and cardiac muscle. The walls of blood vessels, the tubes of the digestive system, and the tubes of the reproductive systems are composed of mostly smooth muscle.

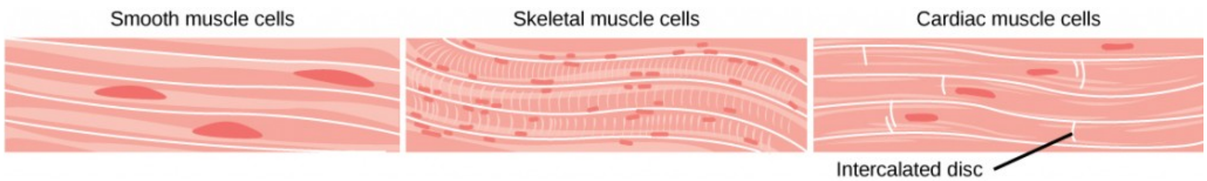


Figure 3.13. Smooth muscle cells do not have striations, while skeletal muscle cells do. Cardiac muscle cells have striations, but, unlike the multinucleate skeletal cells, they have only one nucleus. Cardiac muscle tissue also has intercalated discs, specialized regions running along the plasma membrane that join adjacent cardiac muscle cells and assist in passing an electrical impulse from cell to cell.

Skeletal Muscle

Skeletal muscle has striations across its cells caused by the arrangement of contractile proteins. These muscle cells are relatively long and have multiple nuclei along the edge of the cell. Skeletal muscle is under voluntary, somatic nervous system control and is found in the muscles that move bones. Figure 3.13 illustrates the histology of skeletal muscle.

Cardiac Muscle

Cardiac muscle, shown in Figure 3.13, is found only in the heart. Like skeletal muscle, it has cross striations in its cells, but cardiac muscle has a single, centrally located nucleus. Cardiac muscle is not under voluntary control but can be influenced by the autonomic nervous system to speed up or slow down. An added feature to cardiac muscle cells is a line than extends along the end of the cell as it abuts the next cardiac cell in the row. This line is called an intercalated disc: it assists in passing electrical impulse efficiently from one cell to the next and maintains the strong connection between neighboring cardiac cells.

Nervous Tissues

Nervous tissues are made of cells specialized to receive and transmit electrical impulses from specific areas of the body and to send them to specific locations in the body. The main cell of the nervous system is the neuron, illustrated in Figure 3.14. The large structure with a central nucleus is the cell body of the neuron. Projections from the cell body are either dendrites specialized in receiving input or a single axon specialized in transmitting impulses. Some glial cells are also shown. Astrocytes regulate the chemical environment of the nerve cell, and oligodendrocytes insulate the axon so the electrical nerve impulse is transferred more efficiently. Other glial cells that are not shown support the nutritional and waste requirements of the neuron. Some of the glial cells are phagocytic and remove debris or damaged cells from the tissue. A nerve consists of neurons and glial cells.

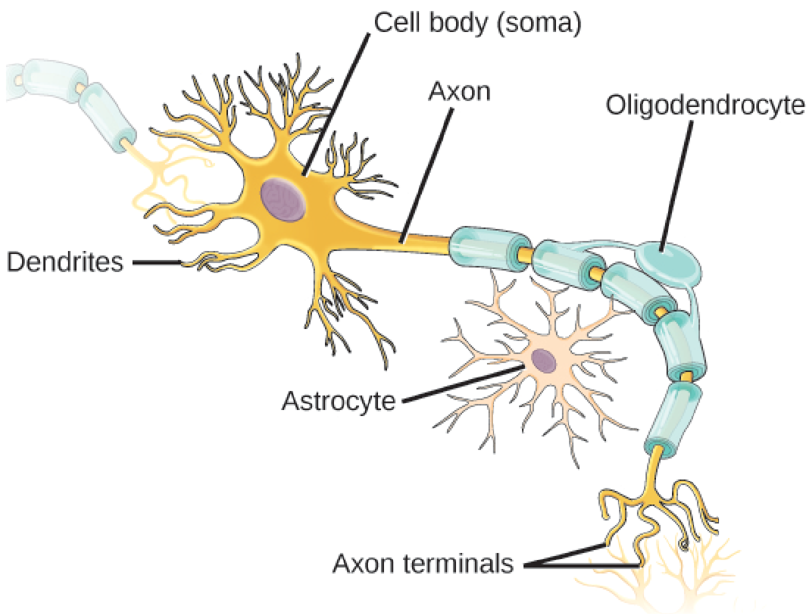


Figure 3.14. The neuron has projections called dendrites that receive signals and projections called axons that send signals. Also shown are two types of glial cells: astrocytes regulate the chemical environment of the nerve cell, and oligodendrocytes insulate the axon so the electrical nerve impulse is transferred more efficiently.

Pathologist

A pathologist is a medical doctor or veterinarian who has specialized in the laboratory detection of disease in animals, including humans. These professionals complete medical school education and follow it with an extensive post-graduate residency at a medical center. A pathologist may oversee clinical laboratories for the evaluation of body tissue and blood samples for the detection of disease or infection. They examine tissue specimens through a microscope to identify cancers and other diseases. Some pathologists perform autopsies to determine the cause of death and the progression of disease.

Exercises

1. Which of the following statements about types of epithelial cells is false?
    1. Simple columnar epithelial cells line the tissue of the lung.
    2. Simple cuboidal epithelial cells are involved in the filtering of blood in the kidney.
    3. Pseudostratisfied columnar epithilia occur in a single layer, but the arrangement of nuclei makes it appear that more than one layer is present.
    4. Transitional epithelia change in thickness depending on how full the bladder is.
2. Which type of epithelial cell is best adapted to aid diffusion?
    1. squamous
    2. cuboidal
    3. columnar
    4. transitional
3. Which type of epithelial cell is found in glands?
    1. squamous
    2. cuboidal
    3. columnar
    4. transitional
4. Which type of epithelial cell is found in the urinary bladder?
    1. squamous
    2. cuboidal
    3. columnar
    4. transitional
5. Which type of connective tissue has the most fibers?
    1. loose connective tissue
    2. fibrous connective tissue
    3. cartilage
    4. bone
6. Which type of connective tissue has a mineralized different matrix?
    1. loose connective tissue
    2. fibrous connective tissue
    3. cartilage
    4. bone
7. The cell found in bone that breaks it down is called an ________.

1. osteoblast
2. osteocyte
3. osteoclast
4. osteon

8. The cell found in bone that makes the bone is called an ________.

    1. osteoblast
    2. osteocyte
    3. osteoclast
    4. osteon

9. Plasma is the ________.

    1. fibers in blood
    2. matrix of blood
    3. cell that phagocytizes bacteria
    4. cell fragment found in the tissue

10. The type of muscle cell under voluntary control is the ________.

    1. smooth muscle
    2. skeletal muscle
    3. cardiac muscle
    4. visceral muscle

11. The part of a neuron that contains the nucleus is the

    1. cell body
    2. dendrite
    3. axon
    4. glial

12. How can squamous epithelia both facilitate diffusion and prevent damage from abrasion?
13. What are the similarities between cartilage and bone?

Answers

1. A
2. C
3. B
4. D
5. B
6. D
7. C
8. A
9. B
10. B

11. B
12. Squamous epithelia can be either simple or stratified. As a single layer of cells, it presents a very thin epithelia that minimally inhibits diffusion. As a stratified epithelia, the surface cells can be sloughed off and the cells in deeper layers protect the underlying tissues from damage.
13. Both contain cells other than the traditional fibroblast. Both have cells that lodge in spaces within the tissue called lacunae. Both collagen and elastic fibers are found in bone and cartilage. Both tissues participate in vertebrate skeletal development and formation.

Glossary

cartilage: type of connective tissue with a large amount of ground substance matrix, cells called chondrocytes, and some amount of fibers

chondrocyte: cell found in cartilage

columnar epithelia: epithelia made of cells taller than they are wide, specialized in absorption

connective tissue: type of tissue made of cells, ground substance matrix, and fibers

cuboidal epithelia: epithelia made of cube-shaped cells, specialized in glandular functions

epithelial tissue: tissue that either lines or covers organs or other tissues

erythrocytes: red blood cells

fibrous connective tissue: type of connective tissue with a high concentration of fibers

lacuna: space in cartilage and bone that contains living cells

leukocytes: white blood cells

matrix: component of connective tissue made of both living and non-living (ground substances) cells

osteon: subunit of compact bone

pseudostratified: layer of epithelia that appears multilayered, but is a simple covering

simple epithelia: single layer of epithelial cells

squamous epithelia: type of epithelia made of flat cells, specialized in aiding diffusion or preventing abrasion

stratified epithelia: multiple layers of epithelial cells

trabecula: tiny plate that makes up spongy bone and gives it strength

3.2 HUMAN BODY SYSTEMS

Learning Objectives

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

- Identify the 11 systems of the human body and their functions
- Identify key organs and tissues of various body systems

In multicellular organisms, cells specialize to perform certain tasks. A group of cells together form tissues, which in turn make up organs, and then systems. For example, cardiac tissue is made up of cardiac muscle cells, and the tissue comes together to make an organ, the heart! The heart is, in turn, part of the cardiovascular system.

Table 3.4 lists the eleven systems of the human body, with their function and a list of the main organs and tissues that make each one. Although each system has specific functions or tasks, they all work together to maintain a stable environment in the body – homeostasis. As an example of how closely linked the systems are, let's consider the blood. It is part of the cardiovascular system, however it also carries nutrients (digestive) and oxygen (respiratory) to the cells, carries hormones throughout the body (endocrine), and removes waste produced by the kidneys (urinary).

Table 3.4 Systems of the Human Body, their Main Organs and Tissues, and Function

System	Organs/Tissues	Function
Circulatory (Cardiovascular)	heart, arteries, veins, capillaries, blood	carries oxygen, carbon dioxide and nutrients
Digestive	mouth, esophagus, liver, stomach, small intestine, large intestine, anus	Ingests and digests food, to get nutrients, and eliminates waste
Endocrine	thymus, adrenal gland, pancreas, hypothalamus, pituitary gland, thyroid gland	maintains homeostasis
Integumentary	hair, skin, nails	protects body from injury, infections and other external factors
Lymphatic	lymph nodes, thymus, spleen, appendix, bone marrow	returns fluid to the body, and contributes to immunity
Muscular	skeletal muscles	movement and posture
Nervous	brain, spinal cord, nerves	detect stimuli and directs responses
Reproductive (male and female)	females – ovaries, uterus, vagina males – prostate gland, seminal vesicles, vas deferens, penis, testis	produces sex hormones and gametes for reproduction
Respiratory	lungs, trachea, larynx, pharynx, nasal cavity	supplies blood with oxygen and eliminates carbon dioxide
Skeletal	bones, cartilage	movement, protecting organs, giving shape and size to the body
Urinary	kidney, bladder, ureter, urethra	removes waste from blood and excretes urine, regulates pH and chemicals of blood

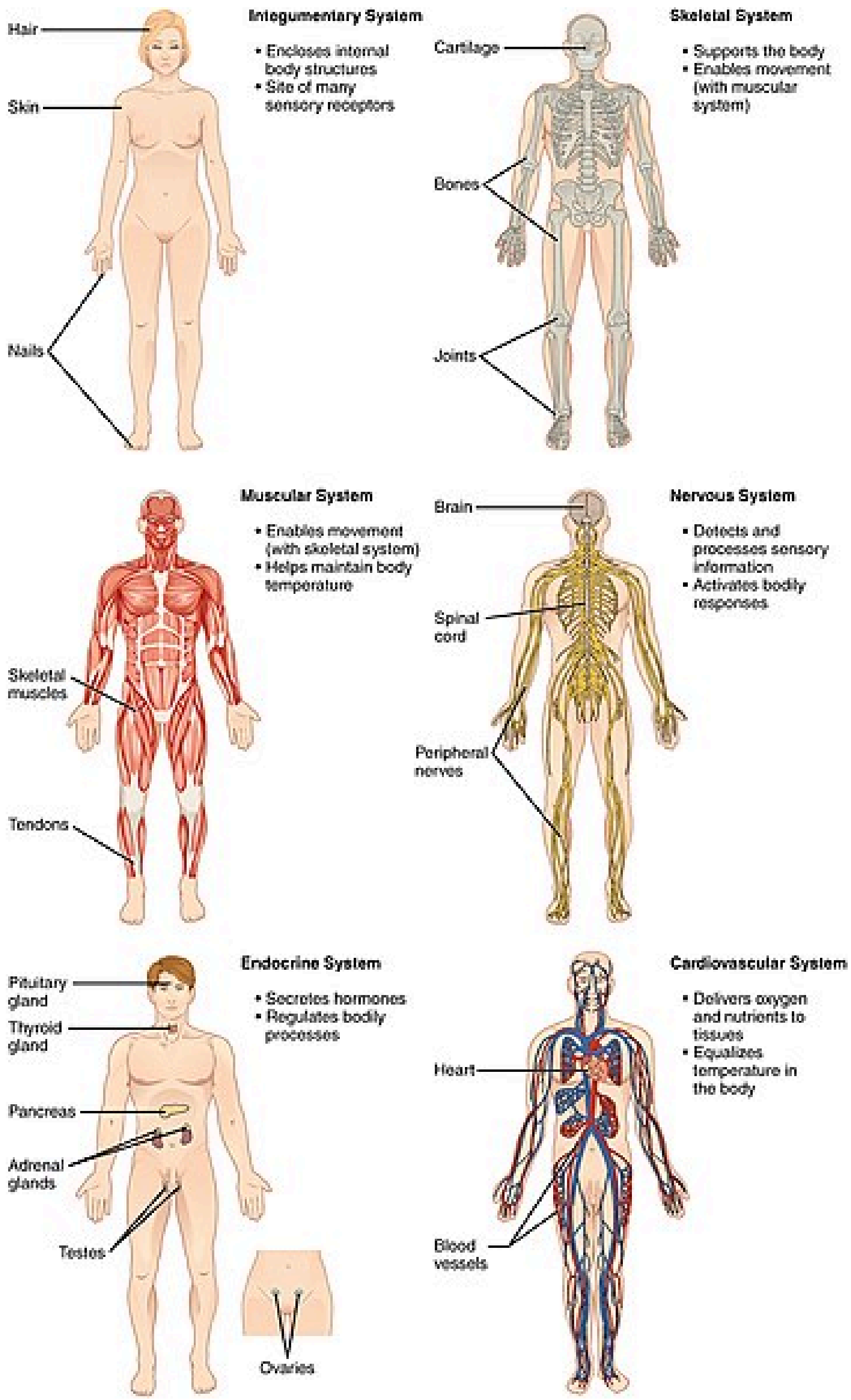


Figure 3.15 Systems of the Human Body.

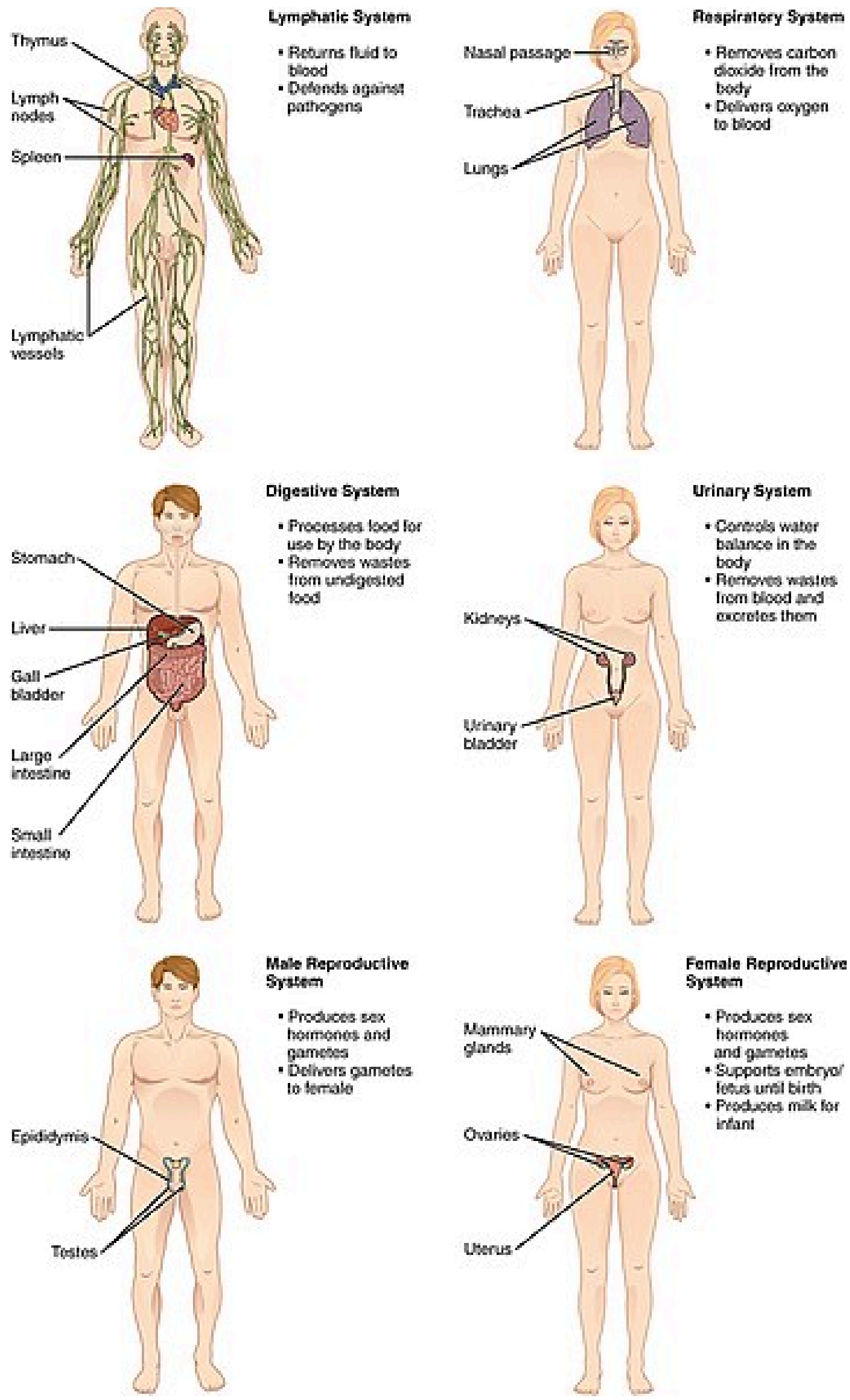


Figure 3.16 Systems of the Human Body.

Summary

The human body is comprised of a number of different systems, each responsible for specific tasks, but working together to maintain homeostasis.

Media Attribution

- Figure 3.15 & 3:16 Betts, G. J., Young, K. A., Wise, J. A., Johnson, E., Poe, B., Kruse, D. H., Korol, O., Johnson, J. E., Womble, M. & DeSaix, P. (2015). Anatomy and Physiology (section 1.2) . OpenStax. CC BY

CHAPTER 4: IMMUNITY

Learning Objectives

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

- Describe physical and chemical immune barriers
- Explain innate immune responses
- Explain adaptive immunity
- Compare and contrast adaptive and innate immunity
- Explain how vaccines work

Organisms have a wide array of adaptations for preventing attacks of parasites and diseases. The human defense system is complex, multilayered, and has unique defenses. These unique defenses interact with other defense systems inherited from ancestral lineages, and include complex and specific pathogen recognition and memory mechanisms. Research continues to unravel the complexities and vulnerabilities of the immune system.

Immunity

The environment consists of numerous **pathogens**, which are agents, usually microorganisms, that cause diseases in their hosts. A **host** is the organism that is invaded and often harmed by a pathogen. Pathogens include bacteria, fungi and other infectious organisms. We are constantly exposed to pathogens in food and water, on surfaces, and in the air. The immune systems for mammals evolved for protection from such pathogens; they are composed of an extremely diverse array of specialized cells and soluble molecules that coordinate a rapid and flexible defense system capable of providing protection from a majority of these disease agents.

Components of the immune system constantly search the body for signs of pathogens. When pathogens are found, immune factors are mobilized to the site of an infection. The immune factors identify the nature of the pathogen, strengthen the corresponding cells and molecules to combat it efficiently, and then halt the immune response after the infection is cleared to avoid unnecessary cell damage in the host. The immune system can remember pathogens to which it has been exposed to create a more efficient response upon re-exposure. This memory can last several decades. Features of the immune system, such as pathogen identification, specific response, amplification, retreat, and remembrance are essential for survival against pathogens. The immune response can be classified as either innate or adaptive. The innate immune response is always present and attempts to defend against all pathogens rather than focusing on specific ones. Conversely, the adaptive immune response stores information about past infections and mounts pathogen-specific defenses. There is also a third type of immunity called passive immunity. This occurs when immunity is b'borrowed' from another source, and often only lasts a short time.

Innate Immunity

Innate immunity occurs naturally because of genetic factors or physiology; it is not induced by infection or vaccination but works to reduce the workload for the adaptive immune response. It is a general response to pathogens. The innate immune system developed early in animal evolution, roughly a billion years ago, as an essential response to infection. Innate immunity has a limited number of specific targets: any pathogenic threat triggers a consistent sequence of events that can identify the type of pathogen and either clear the infection independently or mobilize a highly specialized adaptive immune response. For example, tears and mucus secretions contain microbicidal factors (agents that kills microscopic organisms). Other examples of innate immunity include the skin, which acts as a physical barrier, the cough reflex, and stomach acids.

Adaptive Immunity

The adaptive, or acquired, immune response takes days or even weeks to become established—much longer than the innate response; however, adaptive immunity is more specific to pathogens and has memory. **Adaptive immunity** is an immunity that occurs after exposure to an antigen either from a pathogen or a vaccination. This part of the immune system is activated when the innate immune response is insufficient to control an infection. In fact, without information from the innate immune system, the adaptive response could not be mobilized. The response is specific to the pathogen, and produces antibodies specific to that pathogen. Adaptive immunity also involves a memory to provide the host with long-term protection from reinfection with the same type of pathogen; on re-exposure, this memory will facilitate an efficient and quick response.

Passive Immunity

The **passive immune** response last only a short time. This immunity is 'borrowed' from another source. For example, a newborn baby benefits from the mother's antibodies found in her breast milk. These antibodies can protect the infant from diseases the mother has encountered and for which she has produced antibodies.

Vaccines

(a) (b)

Figure 4.1 (a) This smallpox (variola) vaccine is derived from calves exposed to cowpox virus. Vaccines provoke a reaction in the immune system that prepares it for a subsequent infection by smallpox. (b) Viewed under a transmission electron microscope, you can see the variola's dumbbell-shaped structure that contains the viral DNA. (credit a: modification of work by James Gathany, CDC; credit b: modification of work by Dr. Fred Murphy; Sylvia Whitfield, CDC; scale-bar data from Matt Russell)

Despite a poor understanding of the workings of the body in the early 18th century in Europe, the practice of inoculation as a method to prevent the often-deadly effects of smallpox was introduced from the courts of the Ottoman Empire. The method involved causing limited infection with the smallpox virus by introducing the pus of an affected individual to a scratch in an uninfected person. The resulting infection was milder than if it had been caught naturally and mortality rates were shown to be about two percent rather than 30 percent from natural infections. Moreover, the inoculation gave the individual immunity to the disease. It was from these early experiences with inoculation that the methods of **vaccination** were developed, in which a weakened or relatively harmless (killed) derivative of a pathogen is introduced into the individual. The vaccination induces immunity to the disease with few of the risks of being infected. A modern understanding of the causes of the infectious disease and the mechanisms of the immune system began in the late 19th century and continues to grow today.

Vaccinologist

Vaccination (or immunization) involves the delivery, usually by injection as shown in Figure 4.2, of noninfectious antigen(s) derived from known pathogens. Other components are delivered at the same time to help stimulate the immune response. Immunological memory is the reason vaccines work. Ideally, the effect of vaccination is to elicit immunological memory, and thus resistance to specific pathogens without the individual having to experience an infection. By introducing a weakened or harmless form of the pathogen, the immune response is to produce antibodies against that antigen. These antibodies stay in the body and serve as memory to fight off this specific pathogen in the future.

Figure 4.2. Vaccines are often delivered by injection into the arm. (credit: U.S. Navy Photographer's Mate Airman Apprentice Christopher D. Blachly)

Vaccinologists are involved in the process of vaccine development from the initial idea to the availability of the completed vaccine. This process can take decades, can cost millions of dollars, and can involve many obstacles along the way. For instance, injected vaccines stimulate the systemic immune system, eliciting humoral and cell-mediated immunity, but have little effect on the mucosal response, which presents a challenge because many pathogens are deposited and replicate in mucosal compartments, and the injection does not provide the most efficient immune memory for these disease agents. For this reason, vaccinologists are actively involved in developing new vaccines that are applied via intranasal, aerosol, oral, or transcutaneous (absorbed through the skin) delivery methods. Importantly, mucosal-administered vaccines elicit both mucosal and systemic immunity and produce the same level of disease resistance as injected vaccines.

Figure 4.3. The polio vaccine can be administered orally. (credit: modification of work by UNICEF Sverige)

Currently, a version of intranasal influenza vaccine is available, and the polio and typhoid vaccines can be administered orally, as shown in Figure 4.3. Similarly, the measles and rubella vaccines are being adapted to aerosol delivery using inhalation devices. Eventually, transgenic plants may be engineered to produce vaccine antigens that can be eaten to confer disease resistance. Other vaccines may be adapted to rectal or vaginal application to elicit immune responses in rectal, genitourinary, or reproductive mucosa. Finally, vaccine antigens may be adapted to transdermal application in which the skin is lightly scraped and microneedles are used to pierce the outermost layer. In addition to mobilizing the mucosal immune response, this new generation of vaccines may end the anxiety associated with injections and, in turn, improve patient participation.

Summary

The innate immune system serves as a first responder to pathogenic threats that bypass natural physical and chemical barriers of the body. Using a combination of cellular and molecular attacks, the innate immune system identifies the nature of a pathogen and responds. When innate mechanisms are insufficient to clear an infection, the adaptive immune response is informed and mobilized. The adaptive immune response is a slower-acting, longer-lasting, and more specific response than the innate response. However, the adaptive response requires information from the innate immune system to function. Vaccines use the adaptive immune response to create antibodies against specific pathogens to protect the organism from future attacks.

Glossary

adaptive immunity: immunity that has memory and occurs after exposure to an antigen either from a pathogen or a vaccination **antigen**: foreign or "non-self" protein that triggers the immune response

antibody: a protective protein produced by the immune system in response to the presence of a foreign substance

host: an organism that is invaded by a pathogen or parasite

innate immunity: immunity that occurs naturally because of genetic factors or physiology, and is not induced by infection or vaccination

passive immunity: immunity borrowed from another source

pathogen: an agent, usually a microorganism, that causes disease in the organisms that they invade

vaccination: the process by which a weakened or harmless derivative of a pathogen is introduced in order to produce an immune response and so the organism may produce antibodies as protection

UNIT 2: SENSING THE WORLD AROUND YOU

CHAPTER 5: THE NERVOUS SYSTEM

Learning Objectives

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

- Describe the basic parts and functions of the central nervous system
- Describe the basic parts and functions of the peripheral nervous system

As you read this, your nervous system is performing several functions simultaneously. The visual system is processing what is seen on the page; the motor system controls your eye movements and the turn of the pages (or click of the mouse); the prefrontal cortex maintains attention. Even fundamental functions, like breathing and regulation of body temperature, are controlled by the nervous system. The nervous system is one of two systems that exert control over all the organ systems of the body; the other is the endocrine system (hormonal). There are some major differences between the two. The nervous system's control is much more specific and rapid than the hormonal system. It communicates signals through cells and the tiny gaps between them rather than through the circulatory system as in the endocrine system. It uses a combination of chemical and electrochemical signals, rather than purely chemical signals used by the endocrine system to cover long distances quickly. The nervous system acquires information from sensory organs, processes it and then may initiate a response either through motor function, leading to movement, or in a change in the organism's physiological state.

Neurons and Glial Cells

Neurons are specialized cells of the nervous system. They receive and sent electrical and chemical signals. The nervous system of the common laboratory fly, *Drosophila melanogaster*, contains around 100,000 neurons, the same number as a lobster. This number compares to 75 million in the mouse and 300 million in the octopus. A human brain contains around 86 billion neurons. Despite these very different numbers, the nervous systems of these animals control many of the same behaviors—from basic reflexes to more complicated behaviors like finding food and courting mates. The ability of neurons to communicate with each other as well as with other types of cells underlies all of these behaviors.

Most neurons share the same cellular components. But neurons are also highly specialized—different types of neurons have different sizes and shapes that relate to their functional roles.

Like other cells, each neuron has a cell body (or soma) that contains a nucleus, smooth and rough endoplasmic reticulum, Golgi apparatus, mitochondria, and other cellular components. Neurons also contain unique structures for receiving and sending the electrical signals that make communication between neurons possible (Figure 5.1). **Dendrites** are tree-like structures that extend away from the cell body to receive messages from other neurons at specialized junctions called **synapses**. Although some neurons do not have any dendrites, most have one or many dendrites.

An **axon** is a tube-like structure that propagates the signal from the cell body to specialized endings called axon terminals. These terminals in turn then synapse with other neurons, muscle, or target organs. When the signal reaches the axon terminal, this causes the release of neurotransmitter onto the dendrite of another neuron. Neurotransmitters released at axon terminals allow signals to be communicated to these other cells, and the process begins again. Neurons usually have one or two axons, but some neurons do not contain any axons.

Some axons are covered with a special structure called a **myelin sheath**, which acts as an insulator to keep the electrical signal from dissipating as it travels down the axon. This insulation is important, as the axon from a human motor neuron can be as long as a meter (3.2 ft)—from the base of the spine to the toes. The myelin sheath is produced by **glial cells**. Along the axon there are periodic gaps in the myelin sheath. These gaps are called nodes of Ranvier and are sites where the signal is "recharged" as it travels along the axon.

It is important to note that a single neuron does not act alone—neuronal communication depends on the connections that neurons make with one another (as well as with other cells, like muscle cells). Dendrites from a single neuron may receive synaptic contact from many other neurons. For example, dendrites from a Purkinje cell in the cerebellum are thought to receive contact from as many as 200,000 other neurons.

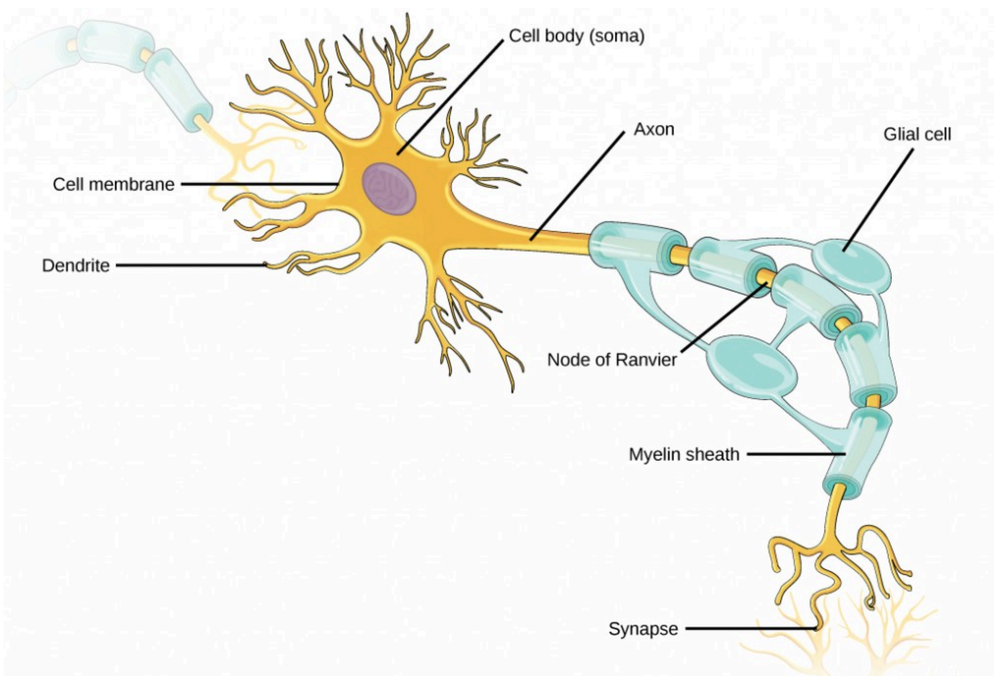


Figure 5.1 Neurons contain organelles common to other cells, such as a nucleus and mitochondria. They also have more specialized structures, including dendrites and axons.

Neurogenesis

At one time, scientists believed that people were born with all the neurons they would ever have. Research performed during the last few decades indicates that **neurogenesis**, the birth of new neurons, continues into adulthood. Neurogenesis was first discovered in songbirds that produce new neurons while learning songs. For mammals, new neurons also play an important role in learning: about 1,000 new neurons develop in the hippocampus (a brain structure involved in learning and memory) each day. While most of the new neurons will die, researchers found that an increase in the number of surviving new neurons in the hippocampus correlated with how well rats learned a new task. Interestingly, both exercise and some antidepressant medications also promote neurogenesis in the hippocampus. Stress has the opposite effect. While neurogenesis is quite limited compared to regeneration in other tissues, research in this area may lead to new treatments for disorders such as Alzheimer's, stroke, and epilepsy.

How do scientists identify new neurons? A researcher can inject a compound called bromodeoxyuridine (BrdU) into the brain of an animal. While all cells will be exposed to BrdU, BrdU will only be incorporated into the DNA of newly generated cells that are in S phase. A technique called immunohistochemistry can be used to attach a fluorescent label to the incorporated BrdU, and a researcher can use fluorescent microscopy to visualize the presence of BrdU, and thus new neurons, in brain tissue (Figure 5.2).

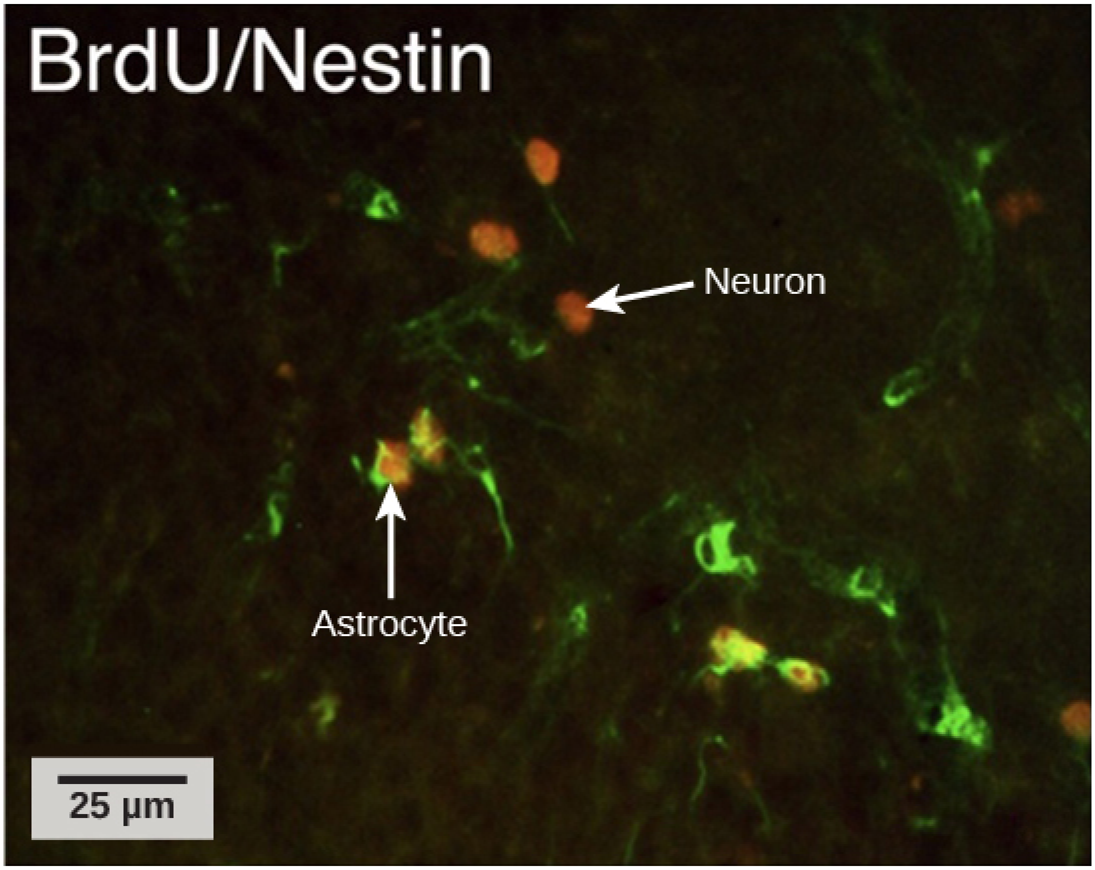


Figure 5.2 This image shows new neurons in a rat hippocampus. New neurons tagged with BrdU glow red in this micrograph. (credit: modification of work by Dr. Maryam Faiz, University of Barcelona)

Concept in Action

Visit this link interactive lab to see more information about neurogenesis, including an interactive laboratory simulation and a video that explains how BrdU labels new cells.

Print edition – Use the QR code to access the lab.

openstax COLLEGE

While glial cells are often thought of as the supporting cast of the nervous system, the number of glial cells in the brain actually outnumbers the number of neurons by a factor of 10. Neurons would be unable to function without the vital roles that are fulfilled by these glial cells. Glia guide developing neurons to their destinations, buffer ions and chemicals that would otherwise harm neurons, and provide myelin sheaths around axons. When glia do not function properly, the result can be disastrous—most brain tumors are caused by mutations in glia.

How Neurons Communicate

All functions performed by the nervous system—from a simple motor reflex to more advanced functions like making a memory or a decision—require neurons to communicate with one another. Neurons communicate between the axon of one neuron and the dendrites, and sometimes the cell body, of another neuron across the gap between them, known as the **synaptic cleft**. When an **action potential** (a change in the electrical potential in the cell) reaches the end of an axon it stimulates the release of neurotransmitter molecules into the synaptic cleft between the synaptic knob of the axon and the post-synaptic membrane of the dendrite or soma of the next cell. The neurotransmitter diffuses (moves) across the synaptic cleft and binds to receptors in the post-synaptic membrane. If sufficient neurotransmitter has been released an action potential may be initiated in the next cell and the signal continues to move along, but this is not guaranteed. If insufficient neurotransmitter is released the nerve signal will die at this point.

The Central Nervous System

The **central nervous system** (CNS) is made up of the brain and spinal cord and is covered with three layers of protective coverings called **meninges** ("meninges" is derived from the Greek and means "membranes") (Figure 5.3). The outermost layer is the dura mater, the middle layer is the web-like arachnoid mater, and the inner layer is the pia mater, which directly contacts and covers the brain and spinal cord. The space between the arachnoid and pia maters is filled with **cerebrospinal fluid** (CSF). The brain floats in CSF, which acts as a cushion and shock absorber.

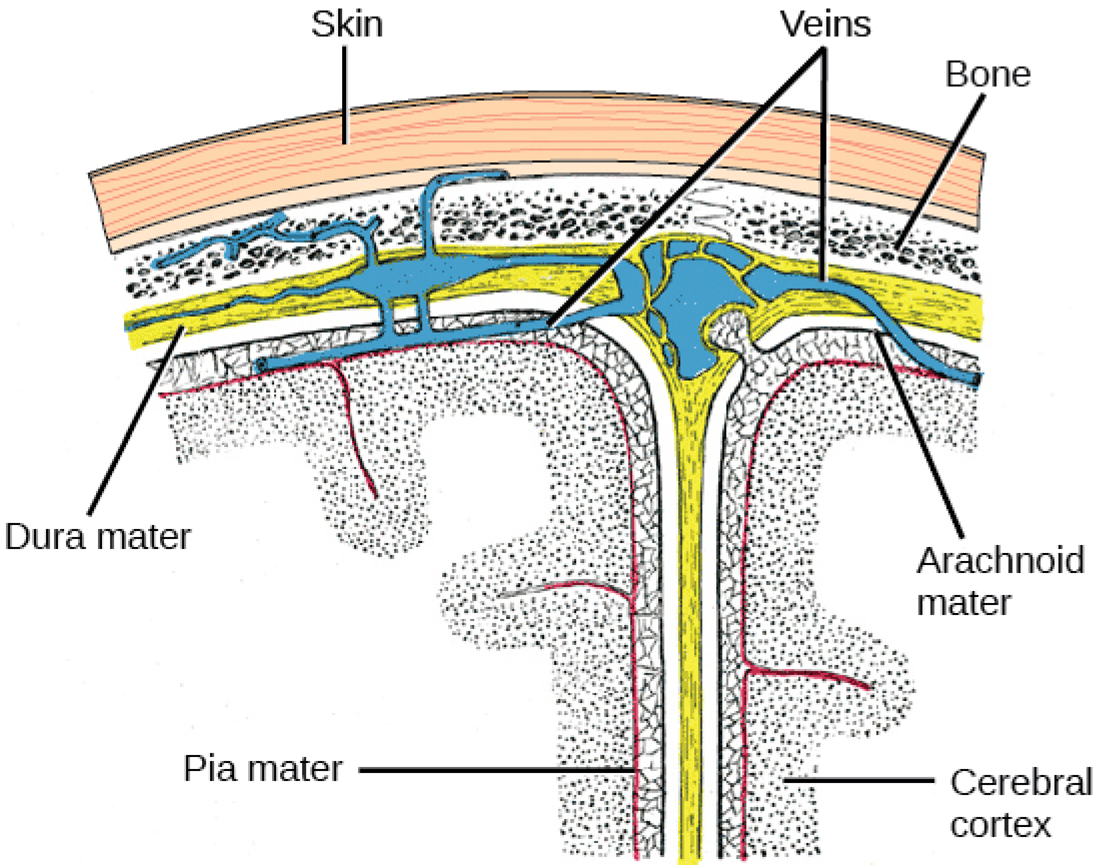


Figure 5.3 The cerebral cortex is covered by three layers of meninges: the dura, arachnoid, and pia maters. (credit: modification of work by Gray's Anatomy)

The Brain

The brain is the part of the central nervous system that is contained in the cranial cavity of the skull. It includes the cerebral cortex, limbic system, basal ganglia, thalamus, hypothalamus, cerebellum, brainstem, and retinas. The outermost part of the brain is a thick piece of nervous system tissue called the **cerebral cortex**. The cerebral cortex, limbic system, and basal ganglia make up the two cerebral hemispheres. A thick fiber bundle called the **corpus callosum** (corpus = "body"; callosum = "tough") connects the two hemispheres. Although there are some brain functions that are localized more to one hemisphere than the other, the functions of the two hemispheres are largely redundant. In fact, sometimes (very rarely) an entire hemisphere is removed to treat severe epilepsy. While patients do suffer some deficits following the surgery, they can have surprisingly few problems, especially when the surgery is performed on children who have very immature nervous systems.

Each hemisphere contains regions called lobes that are involved in different functions. Each hemisphere of the mammalian cerebral cortex can be broken down into four functionally and spatially defined lobes: frontal, parietal, temporal, and occipital (Figure 5.4).

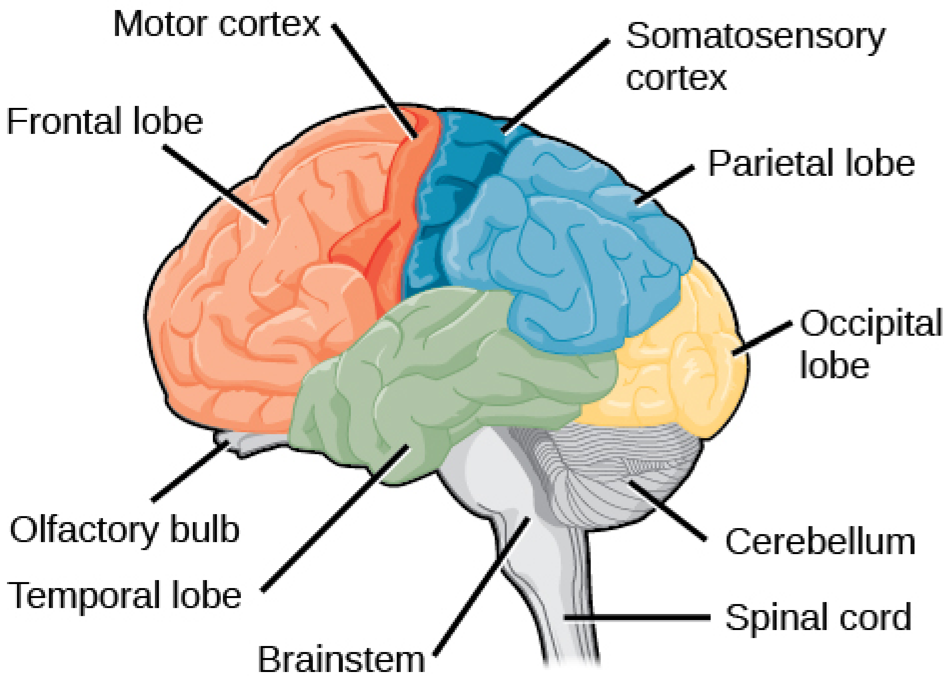


Figure 5.4 The human cerebral cortex includes the frontal, parietal, temporal, and occipital lobes.

The **frontal lobe** is located at the front of the brain, over the eyes. This lobe contains the olfactory bulb, which processes smells. The frontal lobe also contains the motor cortex, which is important for planning and implementing movement. Areas within the motor cortex map to different muscle groups. Neurons in the frontal lobe also control cognitive functions like maintaining attention, speech, and decision-making. Studies of humans who have damaged their frontal lobes show that parts of this area are involved in personality, socialization, and assessing risk. The **parietal lobe** is located at the top of the brain. Neurons in the parietal lobe are involved in speech and also reading. Two of the parietal lobe's main functions are processing somatosensation—touch sensations like pressure, pain, heat, cold—and processing proprioception—the sense of how parts of the body are oriented in space. The parietal lobe contains a somatosensory map of the body similar to the motor cortex. The **occipital lobe** is located at the back of the brain. It is primarily involved in vision—seeing, recognizing, and identifying the visual world. The **temporal lobe** is located at the base of the brain and is primarily involved in processing and interpreting sounds. It also contains the **hippocampus** (named from the Greek for "seahorse," which it resembles in shape) a structure that processes memory formation. The role of the hippocampus in memory was partially determined by studying one famous epileptic patient, HM, who had both sides of his hippocampus removed in an attempt to cure his epilepsy. His seizures went away, but he could no longer form new memories (although he could remember some facts from before his surgery and could learn new motor tasks). Interconnected brain areas called the **basal ganglia** play important roles in movement control and posture. The basal ganglia also regulate motivation.

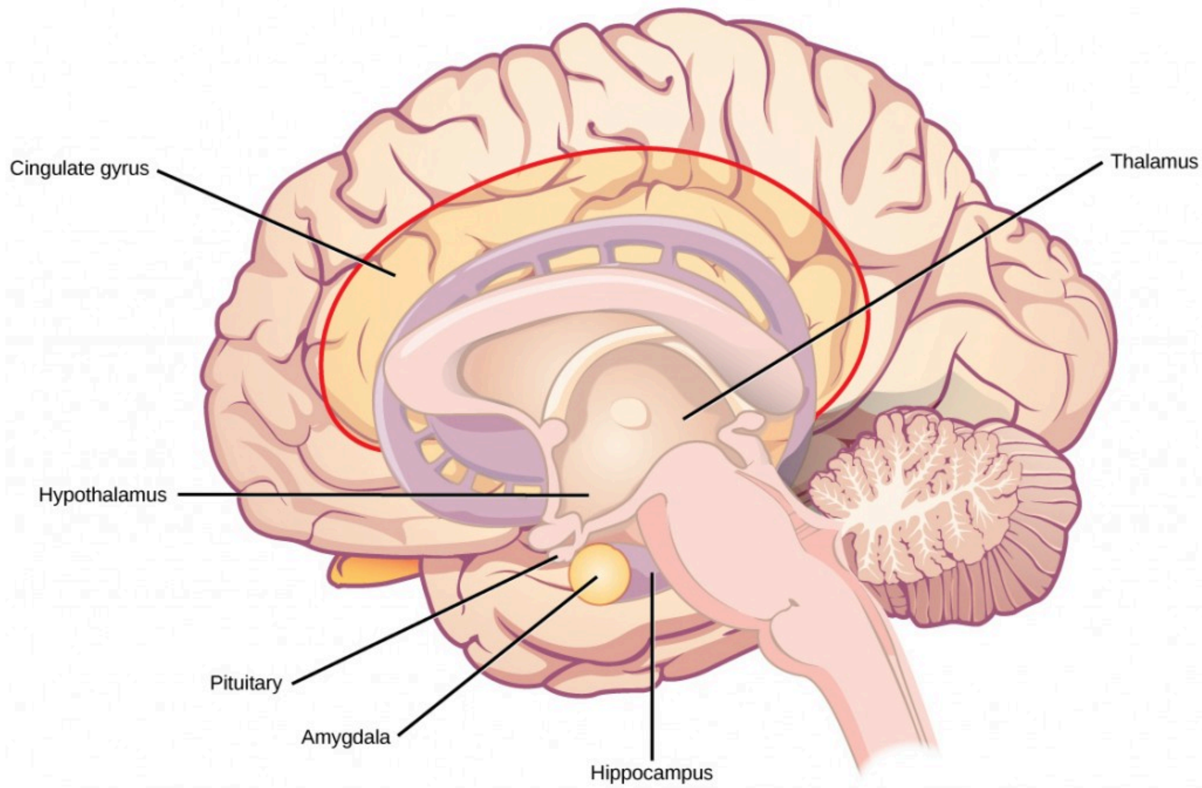


Figure 5.6. The limbic system regulates emotion and other behaviors. It includes parts of the cerebral cortex located near the center of the brain, including the cingulate gyrus and the hippocampus as well as the thalamus, hypothalamus and amygdala.

The **thalamus** acts as a gateway to and from the cortex. It receives sensory and motor inputs from the body and also receives feedback from the cortex. This feedback mechanism can modulate conscious awareness of sensory and motor inputs depending on the attention and arousal state of the animal. The thalamus helps regulate consciousness, arousal, and sleep states. Below the thalamus is the hypothalamus. The **hypothalamus** controls the endocrine system by sending signals to the pituitary gland. Among other functions, the hypothalamus is the body's thermostat—it makes sure the body temperature is kept at appropriate levels. Neurons within the hypothalamus also regulate circadian rhythms, sometimes called sleep cycles.

The **limbic system** is a connected set of structures that regulates emotion, as well as behaviors related to fear and motivation. It plays a role in memory formation and includes parts of the thalamus and hypothalamus as well as the hippocampus. One important structure within the limbic system is a temporal lobe structure called the **amygdala**. The two amygdala (one on each side) are important both for the sensation of fear and for recognizing fearful faces.

The **cerebellum** (cerebellum = "little brain") sits at the base of the brain on top of the brainstem. The cerebellum controls balance and aids in coordinating movement and learning new motor tasks. The cerebellum of birds is large compared to other vertebrates because of the coordination required by flight. The **brainstem** connects the rest of the brain with the spinal cord and regulates some of the most important and basic functions of the nervous system including breathing, swallowing, digestion, sleeping, walking, and sensory and motor information integration.

Spinal cord

Connecting to the brainstem and extending down the body through the spinal column is the spinal cord. The **spinal cord** is a thick bundle of nerve tissue that carries information about the body to the brain and from the brain to the body. The spinal cord is contained within the meninges and the bones of the vertebral column but is able to communicate signals to and from the body through its connections with spinal nerves (part of the peripheral nervous system). A cross-section of the spinal cord looks like a white oval containing a gray butterfly-shape (Figure 5.7). Axons make up the "white matter" and neuron and glia cell bodies (and interneurons) make up the "gray matter." Axons and cell bodies in the dorsal spinal cord convey mostly sensory information from the body to the brain. Axons and cell bodies in the ventral spinal cord primarily transmit signals controlling movement from the brain to the body.

The spinal cord also controls motor reflexes. These reflexes are quick, unconscious movements—like automatically removing a hand from a hot object. Reflexes are so fast because they involve local synaptic connections. This way, the signal does not travel to the brain and back before the reflex happens. For example, the knee reflex that a doctor tests during a routine physical is controlled by a single synapse between a sensory neuron and a motor neuron. While a reflex may only require the involvement of one or two synapses, synapses with interneurons in the spinal column transmit information to the brain to convey what has happened (the knee jerked, or the hand was hot).

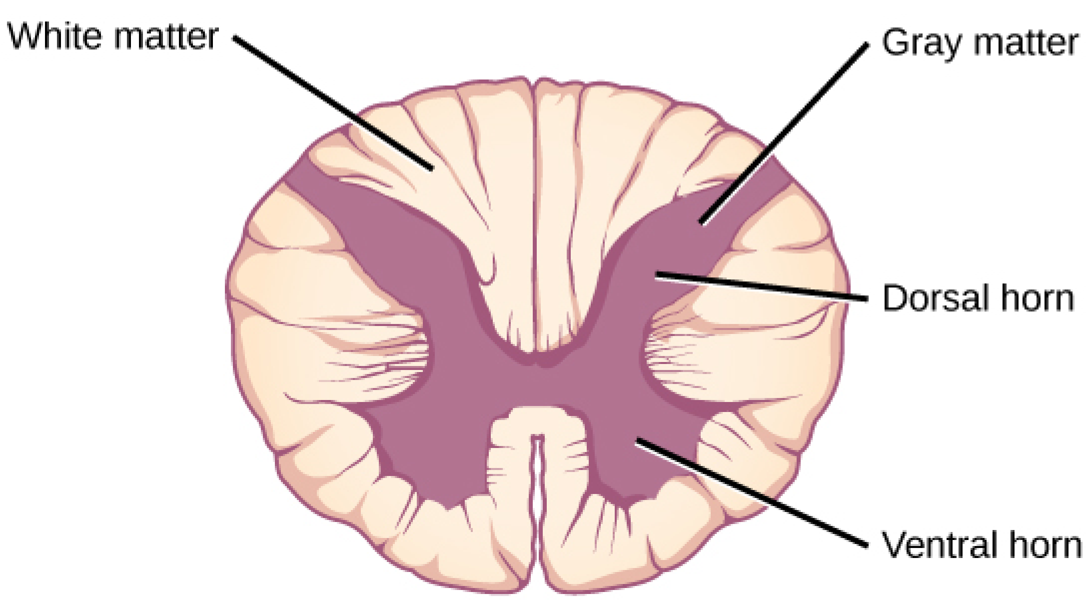


Figure 5.7 A cross-section of the spinal cord shows gray matter (containing cell bodies and interneurons) and white matter (containing myelinated axons).

The Peripheral Nervous System

The **peripheral nervous system** (PNS) is the connection between the central nervous system and the rest of the body. The PNS can be broken down into the autonomic nervous system, which controls bodily functions without conscious control, and the sensory-somatic nervous system, which transmits sensory information from the skin, muscles, and sensory organs to the CNS and sends motor commands from the CNS to the muscles.

The **autonomic nervous system** serves as the relay between the CNS and the internal organs. It controls the lungs, the heart, smooth muscle, and exocrine and endocrine glands. The autonomic nervous system controls these organs largely without conscious control; it can continuously monitor the conditions of these different systems and implement changes as needed. There are two divisions of the autonomic nervous system that often have opposing effects: the sympathetic nervous system and the parasympathetic nervous system. The **sympathetic nervous system** is responsible for the immediate responses an animal makes when it encounters a dangerous situation. One way to remember this is to think of the "fight-or-flight" response a person feels when encountering a snake ("snake" and "sympathetic" both begin with "s"). Examples of functions controlled by the sympathetic nervous system include an accelerated heart rate and inhibited digestion. These functions help prepare an organism's body for the physical strain required to escape a potentially dangerous situation or to fend off a predator.While the sympathetic nervous system is activated in stressful situations, the **parasympathetic nervous system** allows an animal to "rest and digest." One way to remember this is to think that during a restful situation like a picnic, the parasympathetic nervous system is in control ("picnic" and "parasympathetic" both start with "p"). The parasympathetic nervous system resets organ function after the sympathetic nervous system is activated including slowing of heart rate, lowered blood pressure, and stimulation of digestion (Figure 5.8).

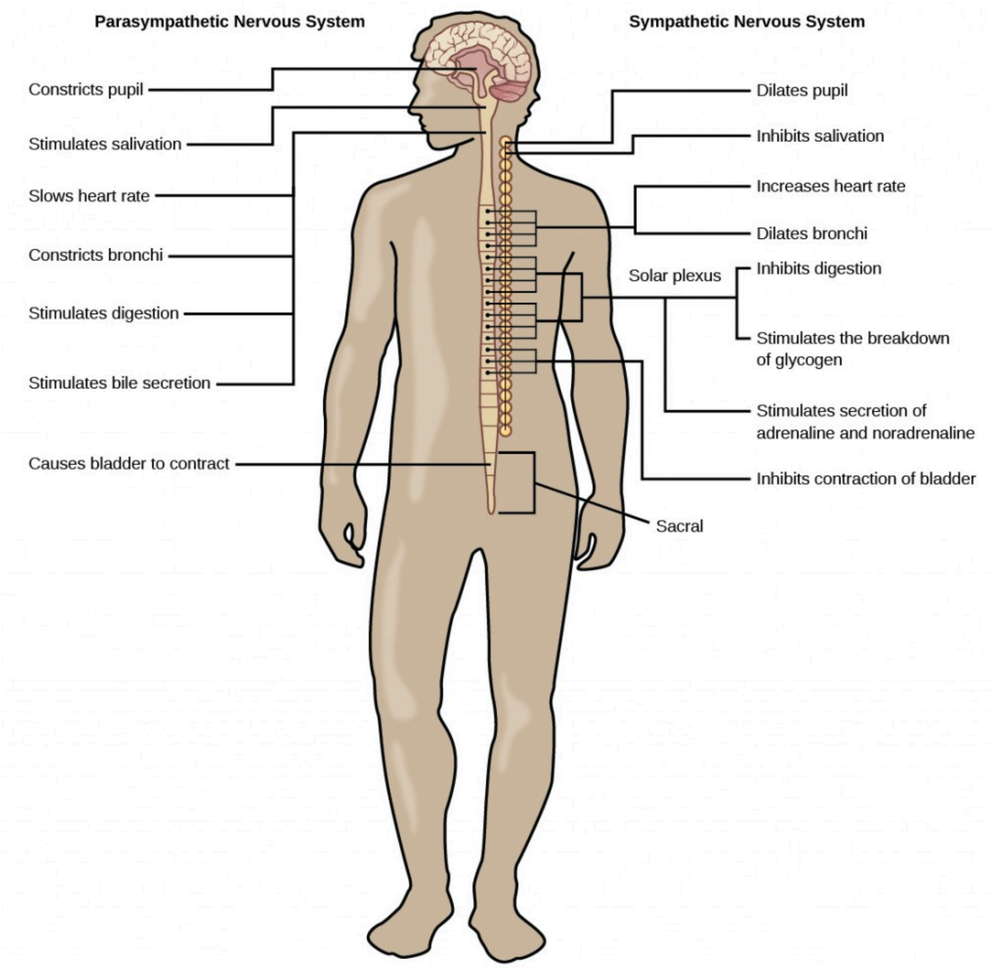


Figure 5.8 The sympathetic and parasympathetic nervous systems often have opposing effects on target organs.

The **sensory-somatic nervous system** is made up of cranial and spinal nerves and contains both sensory and motor neurons. Sensory neurons transmit sensory information from the skin, skeletal muscle, and sensory organs to the CNS. Motor neurons transmit messages about desired movement from the CNS to the muscles to make them contract. Without its sensory-somatic nervous system, an animal would be unable to process any information about its environment (what it sees, feels, hears, and so on) and could not control motor movements.

Section Summary

The nervous system is made up of neurons and glia. Neurons are specialized cells that are capable of sending electrical as well as chemical signals. Most neurons contain dendrites, which receive these signals, and axons that send signals to other neurons or tissues. Glia are non-neuronal cells in the nervous system that support neuronal development and signaling. Neurons have a resting potential across their membranes and when they are stimulated by a strong enough signal from another neuron an action potential may carry an electrochemical signal along the neuron to a synapse with another neuron. Neurotransmitters carry signals across synapses to initiate a response in another neuron.

The vertebrate central nervous system contains the brain and the spinal cord, which are covered and protected by three meninges. The brain contains structurally and functionally defined regions. In humans, these include the cortex (which can be broken down into four primary functional lobes: frontal, temporal, occipital, and parietal), basal ganglia, thalamus, hypothalamus, limbic system, cerebellum, and brainstem—although structures in some of these designations overlap. While functions may be primarily localized to one structure in the brain, most complex functions, like language and sleep, involve neurons in multiple brain regions. The spinal cord is the information superhighway that connects the brain with the rest of the body through its connections with peripheral nerves. It transmits sensory and motor input and also controls motor reflexes.

The peripheral nervous system contains both the autonomic and sensory-somatic nervous systems. The autonomic nervous system provides unconscious control over visceral functions and has two divisions: the sympathetic and parasympathetic nervous systems. The sympathetic nervous system is activated in stressful situations to prepare the animal for a "fight-or-flight" response. The parasympathetic nervous system is active during restful periods. The sensory-somatic nervous system is made of cranial and spinal nerves that transmit sensory information from skin and muscle to the CNS and motor commands from the CNS to the muscles.

Exercises

1. Neurons contain _________, which can receive signals from other neurons.
    1. axons
    2. mitochondria
    3. dendrites
    4. Golgi bodies
2. The part of the brain that is responsible for coordination during movement is the ______.
    1. limbic system
    2. thalamus
    3. cerebellum
    4. parietal lobe
3. Which part of the nervous system directly controls the digestive system?
    1. parasympathetic nervous system
    2. central nervous system
    3. spinal cord
    4. sensory-somatic nervous system
4. How are neurons similar to other cells? How are they unique?
5. What are the main functions of the spinal cord?
6. What are the main differences between the sympathetic and parasympathetic branches of the autonomic nervous

system?
7. What are the main functions of the sensory-somatic nervous system?

Answers

1. C
2. C
3. A
4. Neurons contain organelles common to all cells, such as a nucleus and mitochondria. They are unique because they contain dendrites, which can receive signals from other neurons, and axons that can send these signals to other cells.
5. The spinal cord transmits sensory information from the body to the brain and motor commands from the brain to the body through its connections with peripheral nerves. It also controls motor reflexes.
6. The sympathetic nervous system prepares the body for "fight or flight," whereas the parasympathetic nervous system allows the body to "rest and digest." Activation of the sympathetic nervous system increases heart rate and blood pressure and decreases digestion and blood flow to the skin. Activation of the parasympathetic nervous system decreases heart rate and blood pressure and increases digestion and blood flow to the skin.
7. The sensory-somatic nervous system transmits sensory information from the skin, muscles, and sensory organs to the CNS. It also sends motor commands from the CNS to the muscles, causing them to contract.

Glossary

action potential: a momentary change in the electrical potential of a neuron (or muscle) membrane

amygdala: a structure within the limbic system that processes fear

autonomic nervous system: the part of the peripheral nervous system that controls bodily functions

axon: a tube-like structure that propagates a signal from a neuron's cell body to axon terminals

basal ganglia: an interconnected collections of cells in the brain that are involved in movement and motivation

brainstem: a portion of brain that connects with the spinal cord; controls basic nervous system functions like breathing and swallowing

central nervous system (CNS): the nervous system made up of the brain and spinal cord; covered with three layers of protective meninges

cerebellum: the brain structure involved in posture, motor coordination, and learning new motor actions

cerebral cortex: the outermost sheet of brain tissue; involved in many higher-order functions

cerebrospinal fluid (CSF): a clear liquid that surrounds the brain and fills its ventricles and acts as a shock absorber

corpus callosum: a thick nerve bundle that connects the cerebral hemispheres

dendrite: a structure that extends away from the cell body to receive messages from other neurons

frontal lobe: the part of the cerebral cortex that contains the motor cortex and areas involved in planning, attention, and language

glial cells: the cells that provide support functions for neurons

hippocampus: the brain structure in the temporal lobe involved in processing memories

hypothalamus: the brain structure that controls hormone release and body homeostasis

limbic system: a connected brain area that processes emotion and motivation

meninges: (singular: meninx) the membranes that cover and protect the central nervous system

myelin sheath: a cellular extension containing a fatty substance produced by glia that surrounds and insulates axons

neurogenesis: the birth of new neurons

neuron: a specialized cell that can receive and transmit electrical and chemical signals

occipital lobe: the part of the cerebral cortex that contains visual cortex and processes visual stimuli

parasympathetic nervous system: the division of autonomic nervous system that regulates visceral functions during relaxation

parietal lobe: the part of the cerebral cortex involved in processing touch and the sense of the body in space

peripheral nervous system (PNS): the nervous system that serves as the connection between the central nervous system and the rest of the body; consists of the autonomic nervous system and the sensory-somatic nervous system

sensory-somatic nervous system: the system of sensory and motor nerves

spinal cord: a thick fiber bundle that connects the brain with peripheral nerves; transmits sensory and motor information; contains neurons that control motor reflexes

sympathetic nervous system: the division of autonomic nervous system activated during stressful “fight-or-flight” situations

synapse: a junction between two neurons where neuronal signals are communicated

synaptic cleft: a space between the presynaptic and postsynaptic membranes

temporal lobe: the part of the cerebral cortex that processes auditory input; parts of the temporal lobe are involved in speech, memory, and emotion processing

thalamus: the brain area that relays sensory information to the cortex

UNIT 3: FUELING YOUR MACHINE

CHAPTER 6: THE DIGESTIVE SYSTEM

Learning Objectives

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

- Explain the processes of digestion and absorption
- Explain the specialized functions of the organs involved in processing food in the body
- Describe the ways in which organs work together to digest food and absorb nutrients
- Describe the essential nutrients required for cellular function that cannot be synthesized by the animal body
- Describe how excess carbohydrates and energy are stored in the body

All living organisms need nutrients to survive. While plants can obtain nutrients from their roots and the energy molecules required for cellular function through the process of photosynthesis, animals obtain their nutrients by the consumption of other organisms. At the cellular level, the biological molecules necessary for animal function are amino acids, lipid molecules, nucleotides, and simple sugars. However, the food consumed consists of protein, fat, and complex carbohydrates. Animals must convert these macromolecules into the simple molecules required for maintaining cellular function. The conversion of the food consumed to the nutrients required is a multistep process involving digestion and absorption. During digestion, food particles are broken down to smaller components, which are later absorbed by the body. This happens by both physical means, such as chewing, and by chemical means.

One of the challenges in human nutrition is maintaining a balance between food intake, storage, and energy expenditure. Taking in more food energy than is used in activity leads to storage of the excess in the form of fat deposits. The rise in obesity and the resulting diseases like type 2 diabetes makes understanding the role of diet and nutrition in maintaining good health all the more important.

The Human Digestive System

The process of digestion begins in the mouth with the intake of food. The teeth play an important role in masticating (chewing) or physically breaking food into smaller particles. The enzymes present in saliva also begin to chemically break down food. The food is then swallowed and enters the esophagus—a long tube that connects the mouth to the stomach. Using peristalsis, or wave-like smooth-muscle contractions, the muscles of the esophagus push the food toward the stomach. The stomach contents are extremely acidic, with a pH between 1.5 and 2.5. This acidity kills microorganisms, breaks down food tissues, and activates digestive enzymes. Further breakdown of food takes place in the small intestine where bile produced by the liver, and enzymes produced by the small intestine and the pancreas, continue the process of digestion. The smaller molecules are absorbed into the blood stream through the epithelial cells lining the walls of the small intestine. The waste material travels on to the large intestine where water is absorbed and the drier waste material is compacted into feces. It is stored until it is excreted through the anus.

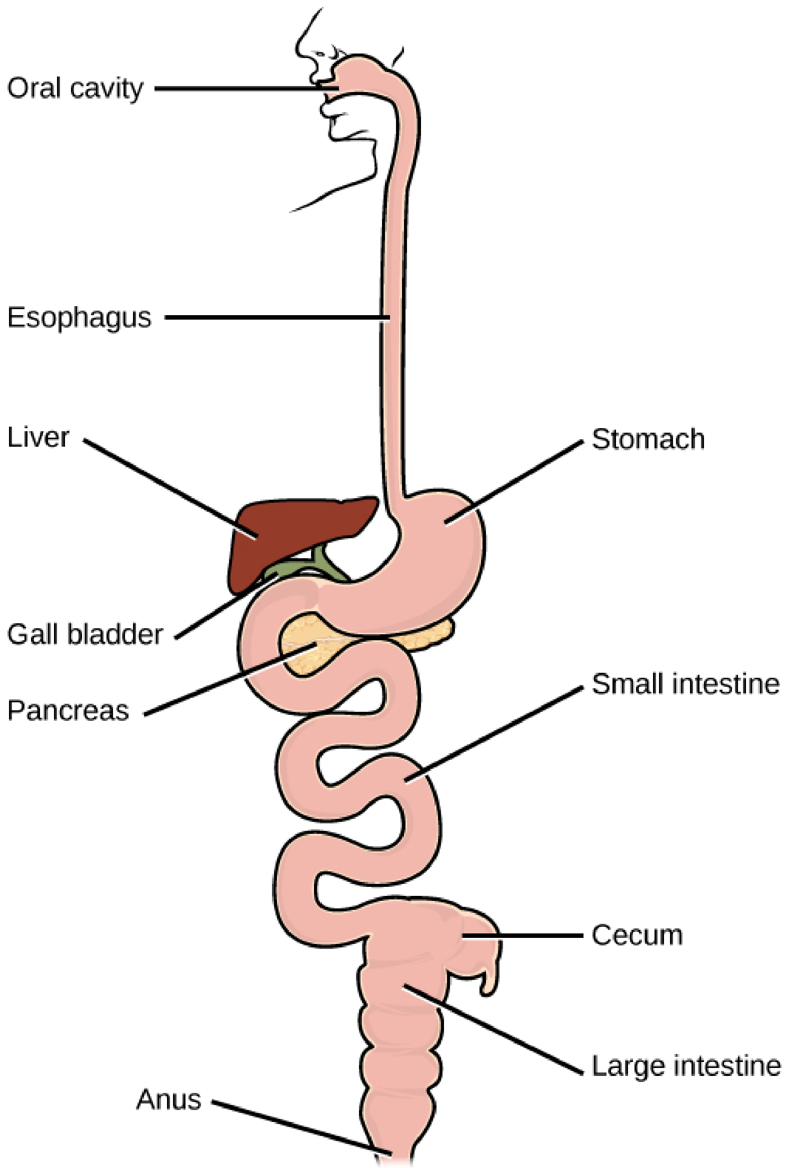


Figure 6.1 The components of the human digestive system are shown.

Oral Cavity

Both physical and chemical digestion begin in the mouth or **oral cavity**, which is the point of entry of food into the digestive system. The food is broken into smaller particles by mastication, the chewing action of the teeth. All mammals have teeth and can chew their food to begin the process of physically breaking it down into smaller particles.

The chemical process of digestion begins during chewing as food mixes with saliva, produced by the **salivary glands** (Figure 6.2). Saliva contains mucus that moistens food and buffers the pH of the food. Saliva also contains lysozyme, which has antibacterial action. It also contains an enzyme called salivary **amylase** that begins the process of converting starches in the food into a disaccharide called maltose. Another enzyme called lipase is produced by cells in the tongue to break down fats. The chewing and wetting action provided by the teeth and saliva prepare the food into a mass called the **bolus** for swallowing. The tongue helps in swallowing—moving the bolus from the mouth into the pharynx. The pharynx opens to two passageways: the esophagus and the trachea. The esophagus leads to the stomach and the trachea leads to the lungs. The epiglottis is a flap of tissue that covers the tracheal opening during swallowing to prevent food from entering the lungs.

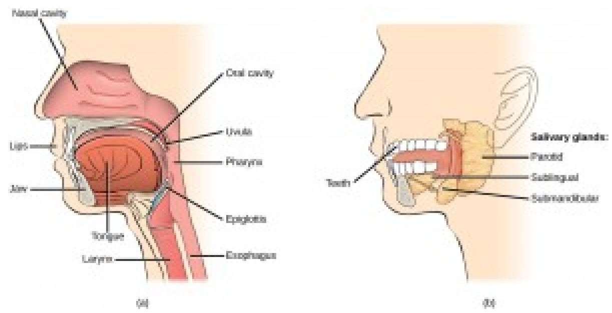


Figure 6.2 (a) Digestion of food begins in the mouth. (b) Food is masticated by teeth and moistened by saliva secreted from the salivary glands. Enzymes in the saliva begin to digest starches and fats. With the help of the tongue, the resulting bolus is moved into the esophagus by swallowing. (credit: modification of work by Mariana Ruiz Villareal)

Esophagus

The **esophagus** is a tubular organ that connects the mouth to the stomach. The chewed and softened food passes through the esophagus after being swallowed. The smooth muscles of the esophagus undergo **peristalsis** that pushes the food toward the stomach. The peristaltic wave is unidirectional—it moves food from the mouth to the stomach, and reverse movement is not possible, except in the case of the vomit reflex. The peristaltic movement of the esophagus is an involuntary reflex; it takes place in response to the act of swallowing.

Ring-like muscles called sphincters form valves in the digestive system. The gastro-esophageal sphincter (or cardiac sphincter) is located at the stomach end of the esophagus. In response to swallowing and the pressure exerted by the bolus of food, this sphincter opens, and the bolus enters the stomach. When there is no swallowing action, this sphincter is shut and prevents the contents of the stomach from traveling up the esophagus. Acid reflux or "heartburn" occurs when the acidic digestive juices escape into the esophagus.

Stomach

A large part of protein digestion occurs in the **stomach** (Figure 6.3). The stomach is a saclike organ that secretes gastric digestive juices.

Protein digestion is carried out by an enzyme called **pepsin** in the stomach chamber. The highly acidic environment kills many microorganisms in the food and, combined with the action of the enzyme pepsin, results in the breakdown of protein in the food. Chemical digestion is facilitated by the churning action of the stomach caused by contraction and relaxation of smooth muscles. The partially digested food and gastric juice mixture is called **chyme**. Gastric emptying occurs within two to six hours after a meal. Only a small amount of chyme is released into the small intestine at a time. The movement of chyme from the stomach into the small intestine is regulated by hormones, stomach distension and muscular reflexes that influence the pyloric sphincter.

The stomach lining is unaffected by pepsin and the acidity because pepsin is released in an inactive form and the stomach has a thick mucus lining that protects the underlying tissue.

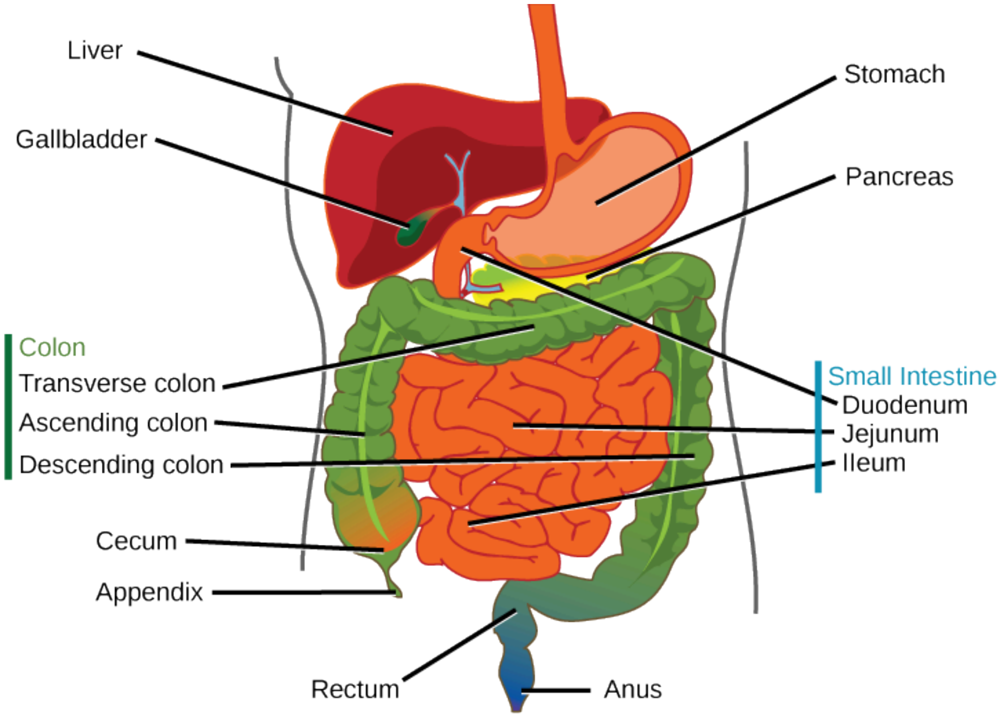


Figure 6.3 The stomach has an extremely acidic environment where most of the protein gets digested. (credit: modification of work by Mariana Ruiz Villareal)

Small Intestine

Chyme moves from the stomach to the **small intestine**. The small intestine is the organ where the digestion of protein, fats, and carbohydrates is completed. The small intestine is a long tube-like organ with a highly folded surface containing finger-like projections called the villi. The top surface of each villus has many microscopic projections called microvilli. The epithelial cells of these structures absorb nutrients from the digested food and release them to the bloodstream on the other side. The villi and microvilli, with their many folds, increase the surface area of the small intestine and increase absorption efficiency of the nutrients.

The human small intestine is over 6 m (19.6 ft) long and is divided into three parts: the duodenum, the jejunum and the ileum. The duodenum is separated from the stomach by the pyloric sphincter. The chyme is mixed with pancreatic juices, an alkaline solution rich in bicarbonate that neutralizes the acidity of chyme from the stomach. Pancreatic juices contain several digestive enzymes that break down starches, disaccharides, proteins, and fats. **Bile** is produced in the liver and stored and concentrated in the gallbladder; it enters the duodenum through the bile duct. Bile contains bile salts, which make lipids accessible to the water-soluble enzymes. The monosaccharides, amino acids, bile salts, vitamins, and other nutrients are absorbed by the cells of the intestinal lining.

The undigested food is sent to the colon from the ileum via peristaltic movements. The ileum ends and the large intestine begins at the ileocecal valve. The vermiform, "worm-like," appendix is located at the ileocecal valve. The appendix of humans has a minor role in immunity.

Large Intestine

The **large intestine** reabsorbs the water from indigestible food material and processes the waste material (Figure 6.4). The human large intestine is much smaller in length compared to the small intestine but larger in diameter. It has three parts: the cecum, the colon, and the rectum. The cecum joins the ileum to the colon and is the receiving pouch for the waste matter. The colon is home to many bacteria or "intestinal flora" that aid in the digestive processes. The **colon** has four regions, the ascending colon, the transverse colon, the descending colon and the sigmoid colon. The main functions of the colon are to extract the water and mineral salts from undigested food, and to store waste material.

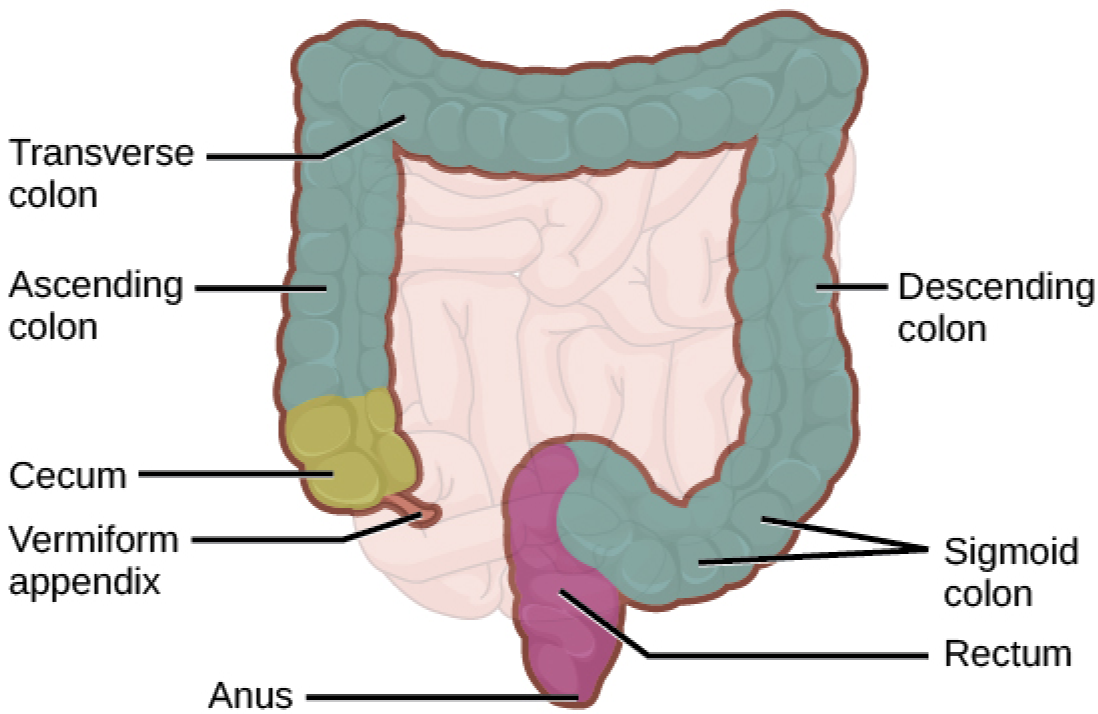


Figure 6.4 The large intestine reabsorbs water from undigested food and stores waste until it is eliminated. (credit: modification of work by Mariana Ruiz Villareal)

The **rectum** (Figure 6.4) stores feces until defecation. The feces are propelled using peristaltic movements during elimination. The **anus** is an opening at the far-end of the digestive tract and is the exit point for the waste material. Two sphincters regulate the exit of feces, the inner sphincter is involuntary and the outer sphincter is voluntary.

Accessory Organs

The organs discussed above are the organs of the digestive tract through which food passes. Accessory organs add secretions and enzymes that break down food into nutrients. Accessory organs include the salivary glands, the liver, the pancreas, and the gall bladder (Figure 6.3). The secretions of the liver, pancreas, and gallbladder are regulated by hormones in response to food consumption.

The **liver** is the largest internal organ in humans and it plays an important role in digestion of fats and detoxifying blood. The liver produces **bile**, a digestive juice that is required for the breakdown of fats in the duodenum. The liver also processes the absorbed vitamins and fatty acids and synthesizes many plasma proteins. The **gallbladder** is a small organ that aids the liver by storing bile and concentrating bile salts. The **pancreas** secretes bicarbonate that neutralizes the acidic chyme and a variety of enzymes for the digestion of protein and carbohydrates.

Nutrition

The human diet should be well balanced to provide nutrients required for bodily function and the minerals and vitamins required for maintaining structure and regulation necessary for good health and reproductive capability.

The organic molecules required for building cellular material and tissues must come from food. During digestion, digestible carbohydrates are ultimately broken down into glucose and used to provide energy within the cells of the body. Complex carbohydrates, including polysaccharides, can be broken down into glucose through biochemical modification; however, humans do not produce the enzyme necessary to digest cellulose (fiber). The intestinal flora in the human gut are able to extract some nutrition from these plant fibers. These plant fibers are known as dietary fiber and are an important component of the diet. The excess sugars in the body are converted into glycogen and stored for later use in the liver and muscle tissue. Glycogen stores are used to fuel prolonged exertions, such as long-distance running, and to provide energy during food shortage.

Proteins in food are broken down during digestion and the resulting amino acids are absorbed. All of the proteins in the body must be formed from these amino-acid constituents; no proteins are obtained directly from food.

Fats add flavor to food and promote a sense of satiety or fullness. Fatty foods are also significant sources of energy, and fatty acids are required for the construction of lipid membranes. Fats are also required in the diet to aid the absorption of fat-soluble vitamins and the production of fat-soluble hormones. Fats are stored under the skin of mammals for insulation and energy reserves.

While the animal body can synthesize many of the molecules required for function from precursors, there are some nutrients that must be obtained from food. These nutrients are termed **essential nutrients**, meaning they must be eaten, because the body cannot produce them. The fatty acids omega-3 alpha-linolenic acid and omega-6 linoleic acid are essential fatty acids needed to make some membrane phospholipids. **Vitamins** are another class of essential organic molecules that are required in small quantities. Many of these assist enzymes in their function and, for this reason, are called coenzymes. Absence or low levels of vitamins can have a dramatic effect on health. **Minerals** are another set of inorganic essential nutrients that must be obtained from food. Minerals perform many functions, from muscle and nerve function, to acting as enzyme cofactors. Certain amino acids also must be procured from food and cannot be synthesized by the body. These amino acids are the "essential" amino acids. The human body can synthesize only 11 of the 20 required amino acids; the rest must be obtained from food.

Obesity

With obesity at high rates in North America, there is a public health focus on reducing obesity and associated health risks, which include diabetes, colon and breast cancer, and cardiovascular disease. How does the food consumed contribute to obesity?

Fatty foods are calorie-dense, meaning that they have more calories per unit mass than carbohydrates or proteins. One gram of carbohydrates has four calories, one gram of protein has four calories, and one gram of fat has nine calories. Animals tend to seek lipid-rich (fatty) food for their higher energy content. Greater amounts of food energy taken in than the body's requirements will result in storage of the excess in fat deposits.

Excess carbohydrate is used by the liver to synthesize glycogen. When glycogen stores are full, additional glucose is converted into fatty acids. These fatty acids are stored in adipose tissue cells—the fat cells in the mammalian body whose primary role is to store fat for later use.

The rate of obesity among children is rapidly rising in the United States. To combat childhood obesity and ensure that children get a healthy start in life, in 2010 First Lady Michelle Obama launched the Let's Move! campaign. The goal of this campaign is to educate parents and caregivers on providing healthy nutrition and encouraging active lifestyles in future generations. This program aims to involve the entire community, including parents, teachers, and healthcare providers to ensure that children have access to healthy foods—more fruits, vegetables, and whole grains—and consume fewer calories from processed foods. Another goal is to ensure that children get physical activity. With the increase in television viewing and stationary pursuits such as video games, sedentary lifestyles have become the norm. Visit www.letsmove.gov to learn more.

Section Summary

There are many organs that work together to digest food and absorb nutrients. The mouth is the point of ingestion and the location where both mechanical and chemical breakdown of food begins. Saliva contains an enzyme called amylase that breaks down carbohydrates. The food bolus travels through the esophagus by peristaltic movements to the stomach. The stomach has an extremely acidic environment. The enzyme pepsin digests protein in the stomach. Further digestion and absorption take place in the small intestine. The large intestine reabsorbs water from the undigested food and stores waste until elimination.

Carbohydrates, proteins, and fats are the primary components of food. Some essential nutrients are required for cellular function but cannot be produced by the animal body. These include vitamins, minerals, some fatty acids, and some amino acids. Food intake in more than necessary amounts is stored as glycogen in the liver and muscle cells, and in adipose tissue. Excess adipose storage can lead to obesity and serious health problems.

Exercises

1. Which of the following statements about the digestive system is false?
    1. Chyme is a mixture of food and digestive juices that is produced in the stomach.
    2. Food enters the large intestine before the small intestine.
    3. In the small intestine, chyme mixes with bile, which emulsifies fats.
    4. The stomach is separated from the small intestine by the pyloric sphincter.
2. Where does the majority of fat digestion take place?
    1. mouth
    2. stomach
    3. small intestine
    4. large intestine
3. The bile from the liver is delivered to the ________.
    1. stomach
    2. liver
    3. small intestine
    4. colon
4. Which of the following statements is not true?
    1. Essential nutrients can be synthesized by the body.
    2. Vitamins are required in small quantities for bodily function.
    3. Some amino acids can be synthesized by the body, while others need to be obtained from diet.
    4. Vitamins come in two categories: fat-soluble and water-soluble.

5. What is the role of the accessory organs in digestion?
6. What is the role of minerals in maintaining good health?
7. Discuss why obesity is a growing epidemic.

Answers

1. B
2. C
3. C
4. A
5. Accessory organs play an important role in producing and delivering digestive juices to the intestine during digestion and absorption. Specifically, the salivary glands, liver, pancreas, and gallbladder play important roles. Malfunction of any of these organs can lead to disease states.
6. Minerals—such as potassium, sodium, and calcium—are required for the functioning of many cellular processes. While minerals are required in trace amounts, not having minerals in the diet can be potentially harmful.
7. In North America, obesity, particularly childhood obesity, is a growing concern. Some of the contributors to this situation include sedentary lifestyles and consuming more processed foods and less fruits and vegetables. As a result, even young children who are obese can face health concerns.

Glossary

amylase: an enzyme found in saliva and secreted by the pancreas that converts carbohydrates to maltose

anus: the exit point of the digestive system for waste material

bile: a digestive juice produced by the liver; important for digestion of lipids

bolus: a mass of food resulting from chewing action and wetting by saliva

colon: the largest portion of the large intestine consisting of the ascending colon, transverse colon, and descending colon

chyme: a mixture of partially digested food and stomach juices

esophagus: a tubular organ that connects the mouth to the stomach

essential nutrient: a nutrient that cannot be synthesized by the body; it must be obtained from food

gallbladder: the organ that stores and concentrates bile

large intestine: a digestive system organ that reabsorbs water from undigested material and processes waste matter

liver: an organ that produces bile for digestion and processes vitamins and lipids

mineral: an inorganic, elemental molecule that carries out important roles in the body

oral cavity: the point of entry of food into the digestive system

pancreas: a gland that secretes digestive juices

pepsin: an enzyme found in the stomach whose main role is protein digestion

peristalsis: wave-like movements of muscle tissue

rectum: the area of the body where feces is stored until elimination

salivary gland: one of three pairs of exocrine glands in the mammalian mouth that secretes saliva, a mix of watery mucus and enzymes

small intestine: the organ where digestion of protein, fats, and carbohydrates is completed

stomach: a saclike organ containing acidic digestive juices

vitamin: an organic substance necessary in small amounts to sustain life

UNIT 4: YOUR INTERNAL TRANSPORTATION SYSTEM

CHAPTER 7: THE RESPIRATORY SYSTEM

Learning Objectives

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

- Describe the passage of air from the outside environment to the lungs
- Describe the function of the respiratory system

Take a breath in and hold it. Wait several seconds and then let it out. Humans, when they are not exerting themselves, breathe approximately 15 times per minute on average. This equates to about 900 breaths an hour or 21,600 breaths per day. With every inhalation, air fills the lungs, and with every exhalation, it rushes back out. That air is doing more than just inflating and deflating the lungs in the chest cavity. The air contains oxygen that crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. There, oxygen is exchanged for carbon dioxide, which is a cellular waste material. Carbon dioxide exits the cells, enters the bloodstream, travels back to the lungs, and is expired out of the body during exhalation.

The Human Respiratory System

Breathing is both a voluntary and an involuntary event. How often a breath is taken and how much air is inhaled or exhaled is regulated by the respiratory center in the brain in response to signals it receives about the carbon dioxide content of the blood. However, it is possible to override this automatic regulation for activities such as speaking, singing and swimming under water.

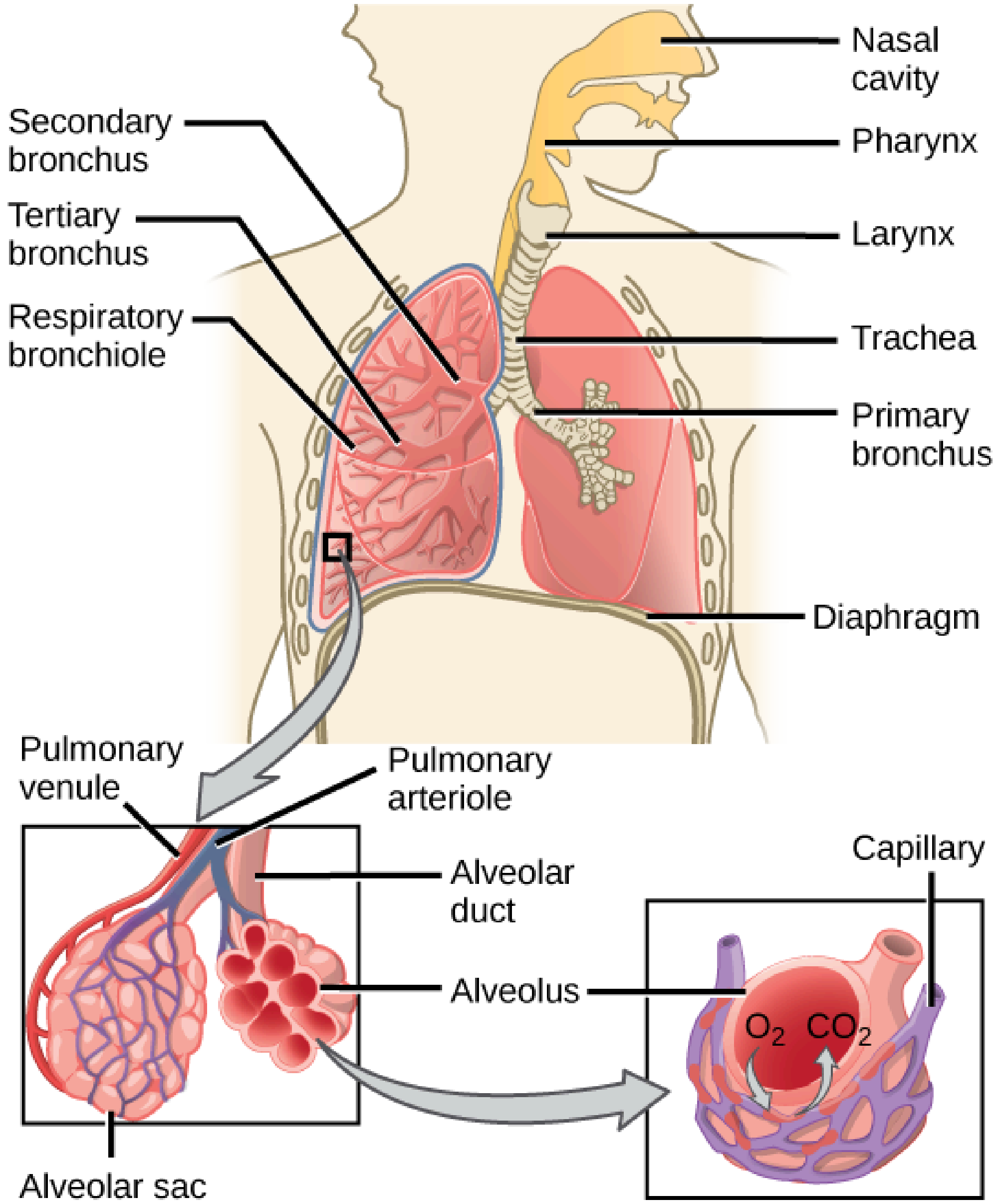


Figure 7.1 Air enters the respiratory system through the nasal cavity, and then passes through the pharynx and the trachea into the lungs. (credit: modification of work by NCI)

In humans, pulmonary ventilation occurs via inhalation (breathing). During inhalation, air enters the body through the **nasal cavity** located just inside the nose (Figure 7.1). As air passes through the nasal cavity, the air is warmed to body temperature and humidified. The respiratory tract is coated with mucus to seal the tissues from direct contact with air. Mucus is high in water. As air crosses these surfaces of the mucous membranes, it picks up water. These processes help equilibrate the air to the body conditions, reducing any damage that cold, dry air can cause. Particulate matter that is floating in the air is removed in the nasal passages via mucus and cilia. The processes of warming, humidifying, and removing particles are important protective mechanisms that prevent damage to the trachea and lungs. Air is also chemically sampled by the sense of smell. Thus, inhalation serves several purposes in addition to bringing oxygen into the respiratory system.

From the nasal cavity, air passes through the **pharynx** (throat) and the **larynx** (voice box), as it makes its way to the **trachea** (Figure 7.2). The main function of the trachea is to funnel the inhaled air to the lungs and the exhaled air back out of the body. The human trachea is a cylinder about 10 to 12 cm long and 2 cm in diameter that sits in front of the esophagus and extends from the larynx into the chest cavity where it divides into the two primary bronchi. It is made of incomplete rings of cartilage and smooth muscle. The cartilage provides strength and support to the trachea to keep the passage open. The trachea is lined with cells that have cilia and secrete mucus. The mucus catches particles that have been inhaled, and the cilia move the particles toward the pharynx. The cartilage provides strength and support to the trachea to keep the passage open. The smooth muscle can contract, decreasing the trachea's diameter, which causes expired air to rush upwards from the lungs at a great force. The forced exhalation helps expel mucus when we cough. Smooth muscle can contract or relax, depending on stimuli from the external environment or the body's nervous system.

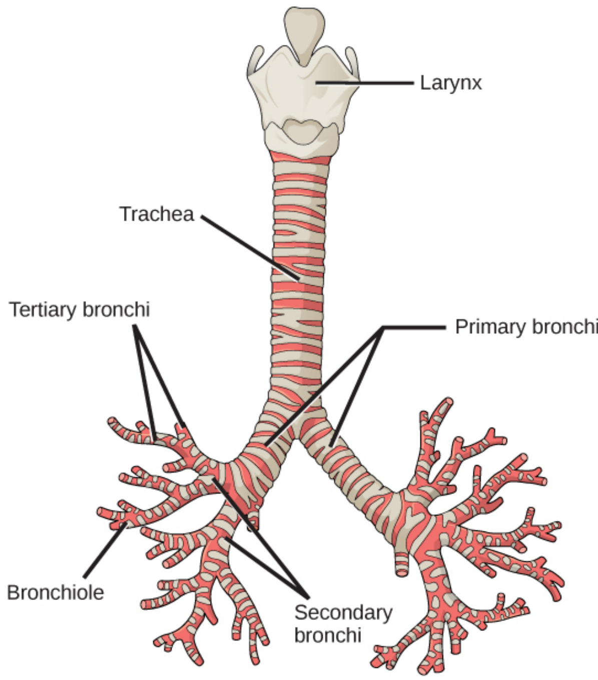


Figure 7.2. The trachea and bronchi are made of incomplete rings of cartilage. (credit: modification of work by Gray's Anatomy)

Lungs: Bronchi and Alveoli

The end of the trachea bifurcates (divides) to the right and left lungs. The lungs are not identical. The right lung is larger and contains three lobes, whereas the smaller left lung contains two lobes (Figure 7.3). The muscular **diaphragm,** which facilitates breathing, is below the lungs and marks the end of the thoracic cavity.

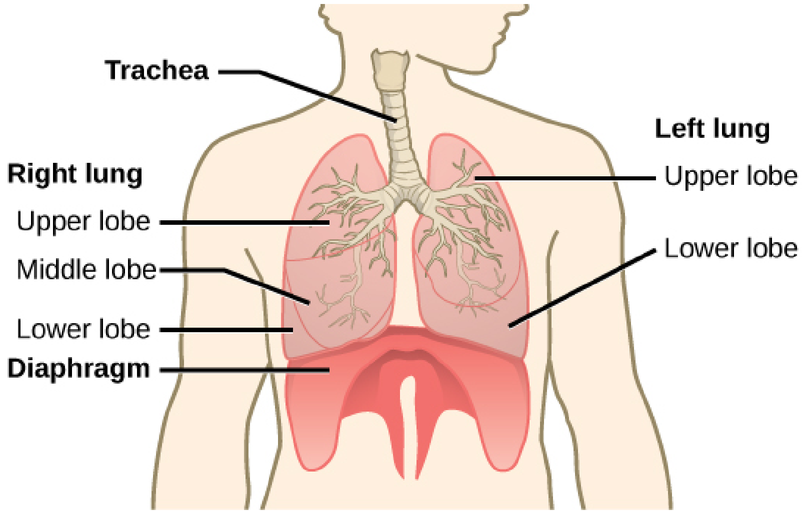


Figure 7.3. The trachea bifurcates into the right and left bronchi in the lungs. The right lung is made of three lobes and is larger. To accommodate the heart, the left lung is smaller and has only two lobes.

In the lungs, air is diverted into smaller and smaller passages, or **bronchi**. Air enters the lungs through the two **primary (main) bronchi** (singular: bronchus). Each bronchus divides into secondary bronchi, then into tertiary bronchi, which in turn divide, creating smaller and smaller diameter **bronchioles** as they split and spread through the lung. Like the trachea, the bronchi are made of cartilage and smooth muscle. At the bronchioles, the cartilage is replaced with elastic fibers. Bronchi are innervated by nerves of both the parasympathetic and sympathetic nervous systems that control muscle contraction (parasympathetic) or relaxation (sympathetic) in the bronchi and bronchioles, depending on the nervous system's cues. In humans, bronchioles with a diameter smaller than 0.5 mm are the respiratory bronchioles. They lack cartilage and therefore rely on inhaled air to support their shape. As the passageways decrease in diameter, the relative amount of smooth muscle increases.

The terminal bronchioles subdivide into microscopic branches called respiratory bronchioles. The respiratory bronchioles subdivide into several alveolar ducts. Numerous alveoli and alveolar sacs surround the alveolar ducts. The alveolar sacs resemble bunches of grapes tethered to the end of the bronchioles (Figure 7.4). Gas exchange occurs only in **alveoli**. The alveoli are thin-walled and look like tiny bubbles within the sacs. The alveoli are in direct contact with capillaries (very small blood vessels) of the circulatory system. Such intimate contact ensures that oxygen will diffuse (move) from the alveoli into the blood. In addition, carbon dioxide will diffuse from the blood into the alveoli to be exhaled. The anatomical arrangement of capillaries and alveoli emphasizes the structural and functional relationship of the respiratory and circulatory systems.

Because there are so many alveoli (~300 million per lung) within each alveolar sac and so many sacs at the end of each alveolar duct, the lungs have a sponge-like consistency. Estimates for the surface area of alveoli in the lungs vary around 100 m^2. This large area is about the area of half a tennis court. This large surface area, combined with the thin-walled nature of the alveolar cells, allows gases to easily diffuse across the cells. The primary function of the respiratory system is to deliver oxygen to the cells of the body's tissues and remove carbon dioxide, a cell waste product. The main structures of the human respiratory system are the nasal cavity, the trachea, and lungs.

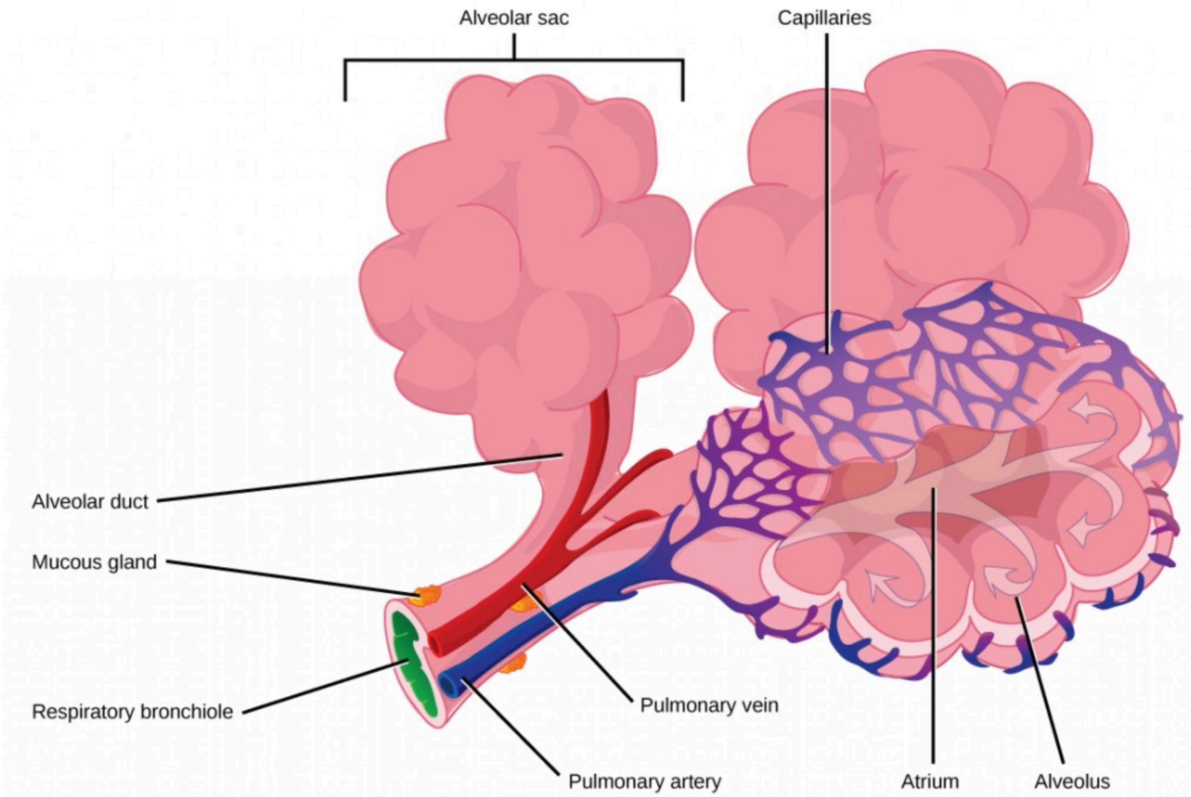


Figure 7.4. Terminal bronchioles are connected by respiratory bronchioles to alveolar ducts and alveolar sacs. Each alveolar sac contains 20 to 30 spherical alveoli and has the appearance of a bunch of grapes. Air flows into the atrium of the alveolar sac, then circulates into alveoli where gas exchange occurs with the capillaries. Mucous glands secrete mucous into the airways, keeping them moist and flexible. (credit: modification of work by Mariana Ruiz Villareal)

Protective Mechanisms

The air that organisms breathe contains particulate matter such as dust, dirt, viral particles, and bacteria that can damage the lungs or trigger allergic immune responses. The respiratory system contains several protective mechanisms to avoid problems or tissue damage. In the nasal cavity, hairs and mucus trap small particles, viruses, bacteria, dust, and dirt to prevent their entry.

If particulates do make it beyond the nose, or enter through the mouth, the bronchi and bronchioles of the lungs also contain several protective devices. The lungs produce mucus—a sticky substance made of mucin, a complex glycoprotein, as well as salts and water—that traps particulates. The bronchi and bronchioles contain cilia, small hair-like projections that line the walls of the bronchi and bronchioles (Figure 7.5). These cilia beat in unison and move mucus and particles out of the bronchi and bronchioles back up to the throat where it is swallowed and eliminated via the esophagus.

Tar and other substances in cigarette smoke destroy or paralyze the cilia, making the removal of particles more difficult. In addition, smoking causes the lungs to produce more mucus, which the damaged cilia are not able to move. This causes a persistent cough, as the lungs try to rid themselves of particulate matter, and makes smokers more susceptible to respiratory ailments.

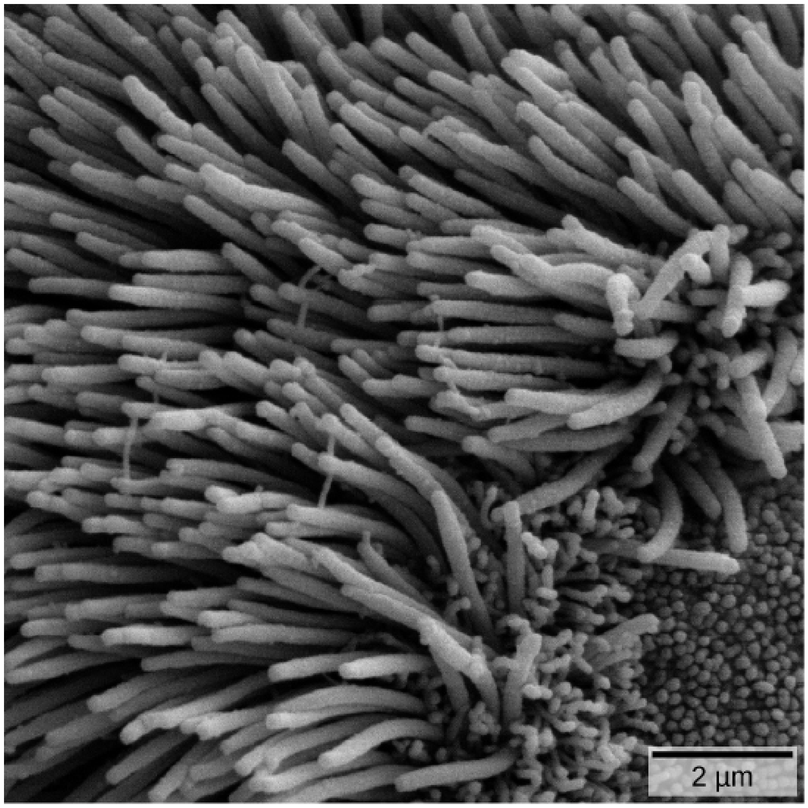


Figure 7.5. The bronchi and bronchioles contain cilia that help move mucus and other particles out of the lungs. (credit: Louisa Howard, modification of work by Dartmouth Electron Microscope Facility)

Summary

The human respiratory system is designed to facilitate gas exchange. Air is warmed and humidified in the nasal cavity, then travels down the pharynx, through the trachea, and into the lungs. In the lungs, air passes through the branching bronchi, reaching the respiratory bronchioles, which house the first site of gas exchange. The respiratory bronchioles open into the alveolar ducts, alveolar sacs, and alveoli. Because there are so many alveoli and alveolar sacs in the lung, the surface area for gas exchange is very large. Several protective mechanisms are in place to prevent damage or infection. These include the hair and mucus in the nasal cavity that trap dust, dirt, and other particulate matter before they can enter the system. In the lungs, particles are trapped in a mucus layer and transported via cilia up to the esophageal opening at the top of the trachea to be swallowed.

Exercises

1. Which of the following statements about the human respiratory system is false?
    1. When we breathe in, air travels from the pharynx to the trachea.
    2. The bronchioles branch into bronchi.

3. Alveolar ducts connect to alveolar sacs.
4. Gas exchange between the lungs and blood takes place in the alveolus.

2. The respiratory system ________.

    1. provides body tissues with oxygen
    2. provides body tissues with oxygen and carbon dioxide
    3. establishes how many breaths are taken per minute
    4. provides the body with carbon dioxide

3. Which is the order of airflow during inhalation?

    1. nasal cavity, trachea, larynx, bronchi, bronchioles, alveoli
    2. nasal cavity, larynx, trachea, bronchi, bronchioles, alveoli
    3. nasal cavity, larynx, trachea, bronchioles, bronchi, alveoli
    4. nasal cavity, trachea, larynx, bronchi, bronchioles, alveoli

4. Describe the function of these terms and describe where they are located: main bronchus, trachea, alveoli.
5. How does the structure of alveoli maximize gas exchange?

Answers

1. B
2. A
3. B
4. The main bronchus is the conduit in the lung that funnels air to the airways where gas exchange occurs. The main bronchus attaches the lungs to the very end of the trachea where it bifurcates. The trachea is the cartilaginous structure that extends from the pharynx to the lungs. It serves to funnel air to the lungs. The alveoli are the site of gas exchange; they are located at the terminal regions of the lung and are attached to the alveolar sacs, which come from the alveolar ducts and respiratory bronchioles terminal bronchi.
5. The sac-like structure of the alveoli increases their surface area. In addition, the alveoli are made of thin-walled cells. These features allows gases to easily diffuse across the cells.

Glossary

alveolus: (plural: alveoli) (also, air sacs) the terminal structure of the lung passage where gas exchange occurs

bronchi: (singular: bronchus) smaller branches of cartilaginous tissue that stem off of the trachea; air is funneled through the bronchi to the region where gas exchange occurs in the alveoli

bronchiole: an airway that extends from the main bronchus to the alveolar sac

diaphragm: a skeletal muscle located under lungs that encloses the lungs in the thorax

larynx: the voice box, located within the throat

nasal cavity: an opening of the respiratory system to the outside environment

pharynx: the throat

primary bronchus: (also, main bronchus) a region of the airway within the lung that attaches to the trachea and bifurcates to form the bronchioles

trachea: the cartilaginous tube that transports air from the throat to the lungs

CHAPTER 8: THE CIRCULATORY SYSTEM

Learning Objectives

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

- Describe the function of the circulatory system
- Describe the cardiac cycle
- Explain how blood flows through the body
- List the basic components of the blood

Animals are complex multicellular organisms that require a mechanism for transporting nutrients throughout their bodies and removing wastes. The human circulatory system has a complex network of blood vessels that reach all parts of the body. This extensive network supplies the cells, tissues, and organs with oxygen and nutrients, and removes carbon dioxide and waste compounds.

The medium for transport of gases and other molecules is the blood, which continually circulates through the system. Pressure differences within the system cause the movement of the blood and are created by the pumping of the heart.

Gas exchange between tissues and the blood is an essential function of the circulatory system. In humans and other mammals, blood absorbs oxygen and releases carbon dioxide in the lungs. Thus the circulatory and respiratory system, whose function is to obtain oxygen and discharge carbon dioxide, work in tandem.

The Circulatory System

The circulatory system is a network of vessels—the arteries, veins, and capillaries—and a pump, the heart. In all vertebrate organisms this is a closed-loop system, in which the blood is largely separated from the body's other extracellular fluid compartment, the interstitial fluid, which is the fluid bathing the cells. Blood circulates inside blood vessels and circulates in one direction from the heart around one of two circulatory routes, then returns to the heart again.

The Heart

The heart is a complex muscle that consists of two pumps: one that pumps blood through **pulmonary circulation** to the lungs, and the other that pumps blood through **systemic circulation** to the rest of the body's tissues (and the heart itself) (Figure 8.1).

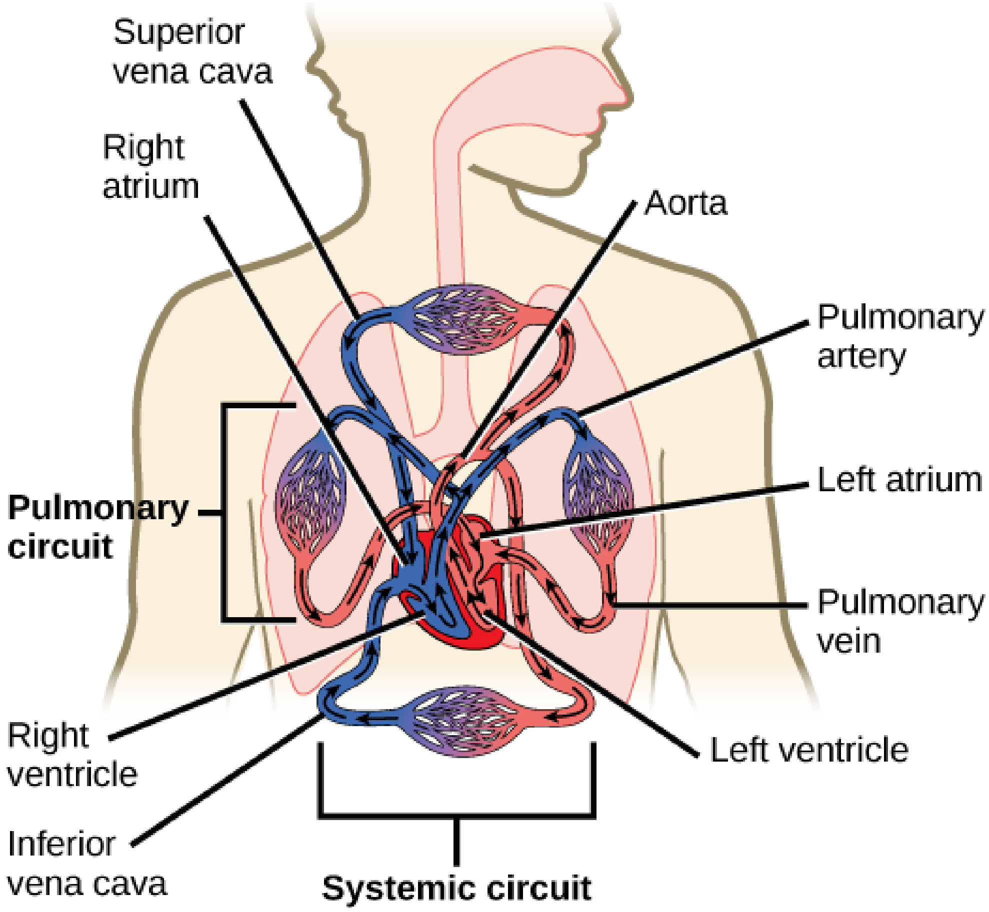


Figure 8.1. The right side of the heart receives deoxygenated blood from the body (systemic circuit) and pumps it to the lungs (pulmonary circuit). The left side of the heart pumps blood to the rest of the body.

The heart is asymmetrical, with the left side being larger than the right side, correlating with the different sizes of the pulmonary and systemic circuits (Figure 8.1). In humans, the heart is about the size of a clenched fist; it is divided into four chambers: two **atria** and two **ventricles**. There is one atrium and one ventricle on the right side and one atrium and one ventricle on the left side. The right atrium receives deoxygenated (oxygen-poor) blood from the systemic circulation through the major veins: the **superior vena cava**, which drains blood from the head and from the veins that come from the arms, as well as the **inferior vena cava**, which drains blood from the veins that come from the lower organs and the legs. This deoxygenated blood then passes to the right ventricle through the **tricuspid valve**, which prevents the backflow of blood. After it is filled, the right ventricle contracts, pumping the blood to the lungs for reoxygenation. The left atrium receives the oxygen-rich blood from the lungs. This blood passes through the **bicuspid valve** to the left ventricle where the blood is pumped into the aorta. The **aorta** is the major artery of the body, taking oxygenated blood to the organs and muscles of the body. This pattern of pumping is referred to as double circulation and is found in all mammals. (Figure 8.2).

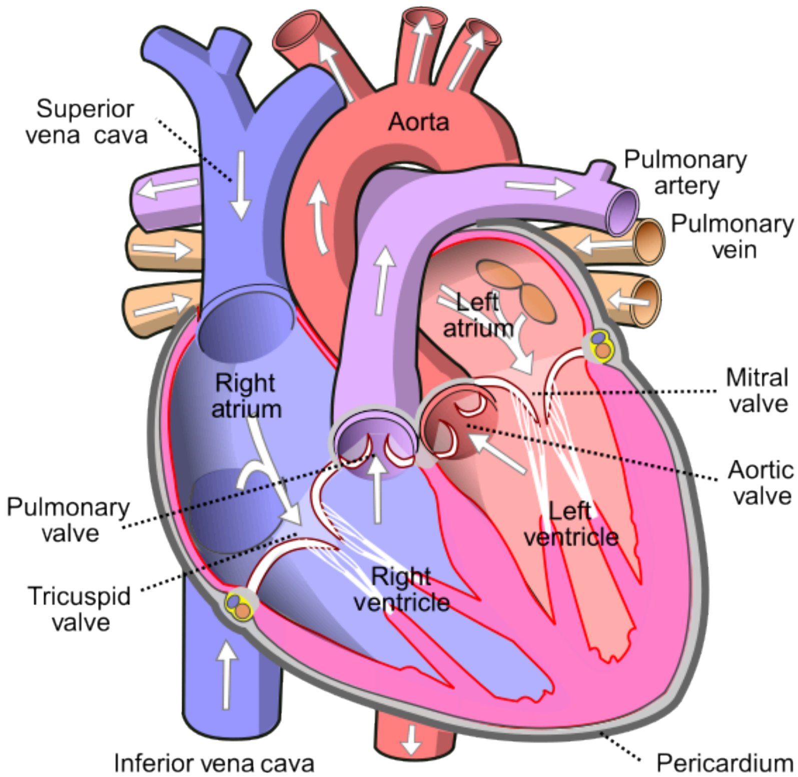


Figure 8.2. The heart is divided into four chambers, two atria, and two ventricles. Each chamber is separated by one-way valves.

The Cardiac Cycle

The main purpose of the heart is to pump blood through the body. It does so in a repeating sequence called the **cardiac cycle**. The cardiac cycle is the flow of blood through the heart coordinated by electrochemical signals that cause the heart muscle to contract and relax. In each cardiac cycle, a sequence of contractions pushes out the blood, pumping it through the body; this is followed by a relaxation phase, where the heart fills with blood. These two phases are called the **systole** (contraction) and **diastole** (relaxation), respectively (Figure 8.3). The signal for contraction begins at a location on the outside of the right atrium. The electrochemical signal moves from there across the atria causing them to contract. The contraction of the atria forces blood through the valves into the ventricles. Closing of these valves caused by the contraction of the ventricles produces a “lub” sound. The signal has, by this time, passed down the walls of the heart, through a point between the right atrium and right ventricle. The signal then causes the ventricles to contract. The ventricles contract together forcing blood into the aorta and the pulmonary arteries. Closing of the valves to these arteries caused by blood being drawn back toward the heart during ventricular relaxation produces a monosyllabic “dub” sound.

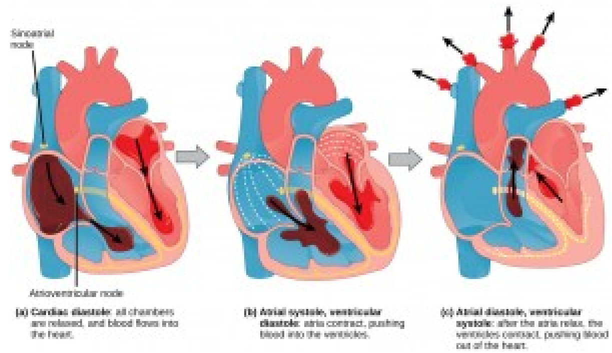


Figure 8.3. In each cardiac cycle, a series of contractions (systoles) and relaxations (diastoles) pumps blood through the heart and through the body. (a) During cardiac diastole, blood flows into the heart while all chambers are relaxed. (b) Then the ventricles remain relaxed while atrial systole pushes blood into the ventricles. (c) Once the atria relax again, ventricle systole pushes blood out of the heart.

The pumping of the heart is a function of the cardiac muscle cells, or cardiomyocytes, that make up the heart muscle. Cardiomyocytes are distinctive muscle cells that are striated like skeletal muscle but pump rhythmically and involuntarily like smooth muscle; adjacent cells are connected by intercalated disks found only in cardiac muscle. These connections allow the electrical signal to travel directly to neighboring muscle cells.

The electrical impulses in the heart produce electrical currents that flow through the body and can be measured on the skin using electrodes. This information can be observed as an **electrocardiogram** (ECG) a recording of the electrical impulses of the cardiac muscle.

Blood Vessels

The blood from the heart is carried through the body by a complex network of blood vessels (Figure 8.4). **Arteries** take blood away from the heart. The main artery of the systemic circulation is the aorta; it branches into major arteries that take blood to different limbs and organs. The aorta and arteries near the heart have heavy but elastic walls that respond to and smooth out the pressure differences caused by the beating heart. Arteries farther away from the heart have more muscle tissue in their walls that can constrict to affect flow rates of blood. The major arteries diverge into minor arteries, and then smaller vessels called arterioles, to reach more deeply into the muscles and organs of the body.

Arterioles diverge into capillary beds. Capillary beds contain a large number, 10's to 100's of capillaries that branch among the cells of the body. **Capillaries** are narrow-diameter tubes that can fit single red blood cells and are the sites for the exchange of nutrients, waste, and oxygen with tissues at the cellular level. Fluid also leaks from the blood into the interstitial space from the capillaries. The capillaries converge again into venules that connect to minor veins that finally connect to major veins. **Veins** are blood vessels that bring blood high in carbon dioxide back to the heart. Veins are not as thick-walled as arteries, since pressure is lower, and they have valves along their length that prevent backflow of blood away from the heart. The major veins drain blood from the same organs and limbs that the major arteries supply.

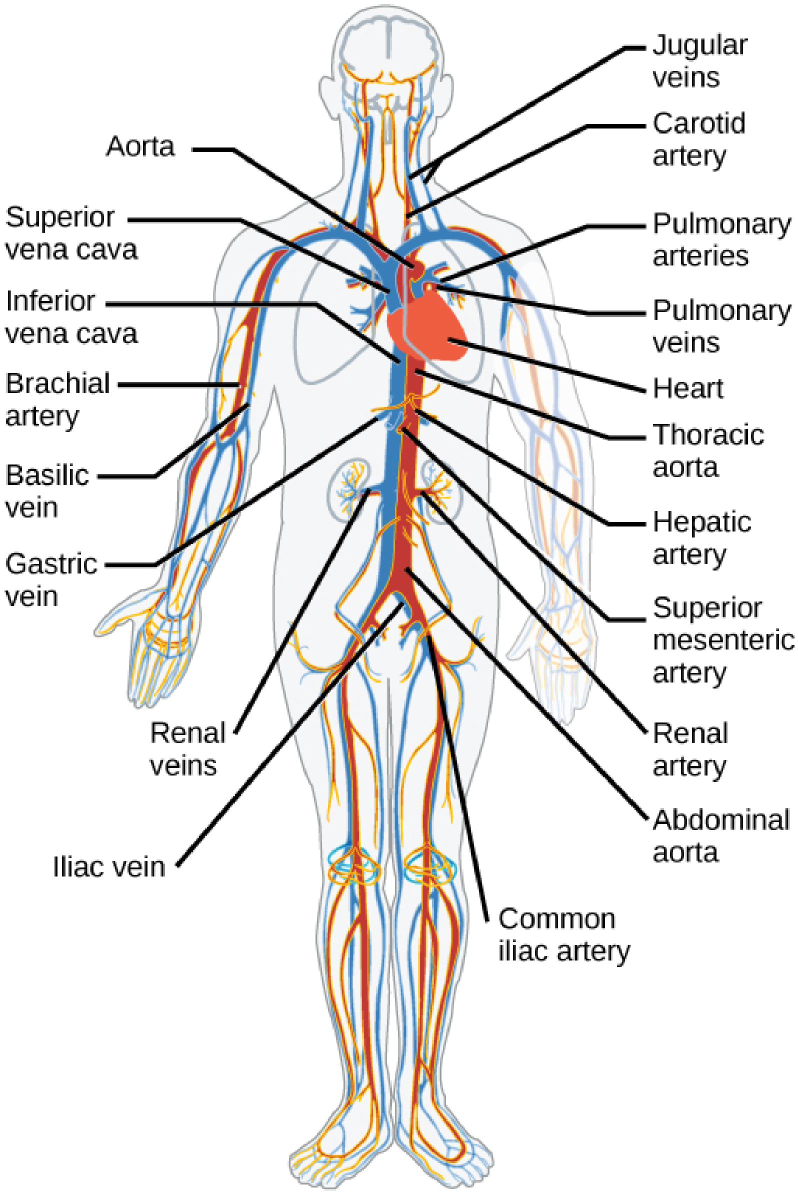


Figure 8.4. The arteries of the body, indicated in red, start at the aortic arch and branch to supply the organs and muscles of the body with oxygenated blood. The veins of the body, indicated in blue, return blood to the heart. The pulmonary arteries are blue to reflect the fact that they are deoxygenated, and the pulmonary veins are red to reflect that they are oxygenated. (credit: modification of work by Mariana Ruiz Villareal)

Blood

Hemoglobin is responsible for distributing oxygen, and to a lesser extent, carbon dioxide, throughout the circulatory system. The blood is more than the proteins, though. Blood is actually a term used to describe the liquid that moves through the vessels and includes plasma (the liquid portion, which contains water, proteins, salts, lipids, and glucose) and the cells (red and white cells) and cell fragments called platelets. Blood plasma is actually the dominant component of blood and contains the water, proteins, electrolytes, lipids, and glucose. The cells are responsible for carrying the gases (red cells) and immune response (white). The platelets are responsible for blood clotting. In humans, cellular components make up approximately 45 percent of the blood and the liquid plasma 55 percent. Blood is 20 percent of a person's extracellular fluid and eight percent of weight.

The Role of Blood in the Body

Blood is important for regulation of the body's systems and homeostasis (Figure 8.5). Blood helps maintain homeostasis by stabilizing pH, temperature, osmotic pressure, and by eliminating excess heat. Blood supports growth by distributing nutrients and hormones, and by removing waste. Blood plays a protective role by transporting clotting factors and platelets to prevent blood loss and transporting the disease-fighting agents or white blood cells to sites of infection.

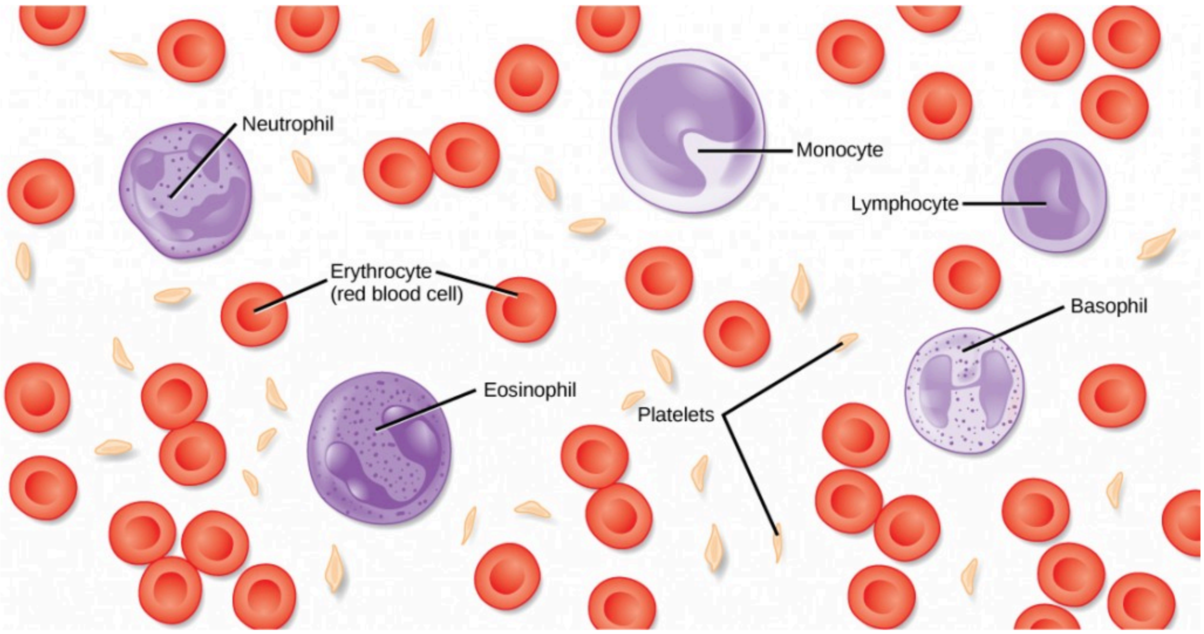


Figure 8.5. The cells and cellular components of human blood are shown. Red blood cells deliver oxygen to the cells and remove carbon dioxide. White blood cells—including neutrophils, monocytes, lymphocytes, eosinophils, and basophils—are involved in the immune response. Platelets form clots that prevent blood loss after injury.

Red Blood Cells

Red blood cells, or erythrocytes (erythro- = "red"; -cyte = "cell"), are specialized cells that circulate through the body delivering oxygen to cells. They are formed from stem cells in the bone marrow. In humans, red blood cells are small biconcave cells that at maturity do not contain a nucleus or mitochondria and are only 7–8 µm in size.

The red coloring of blood comes from the iron-containing protein **hemoglobin**. The principal job of this protein is to carry oxygen, but it also transports carbon dioxide as well. Hemoglobin is packed into red blood cells at a rate of about 250 million molecules of hemoglobin per cell. Each hemoglobin molecule binds four oxygen molecules so that each red blood cell carries one billion molecules of oxygen. There are approximately 25 trillion red blood cells in the five liters of blood in the human body, which could carry up to 25 sextillion (25×10^{21}) molecules of oxygen in the body at any time.

White Blood Cells

White blood cells, also called leukocytes (leuko = white), make up approximately one percent by volume of the cells in blood. The role of white blood cells is very different than that of red blood cells: they are primarily involved in the immune response to identify and target pathogens, such as invading bacteria, viruses, and other foreign organisms. White blood cells are formed continually; some only live for hours or days, but some live for years.

Platelets and Coagulation Factors

Blood must clot to heal wounds and prevent excess blood loss. Small cell fragments called **platelets** (thrombocytes) are attracted to the wound site where they adhere by extending many projections and releasing their contents. These contents activate other platelets and also interact with other coagulation factors, which convert fibrinogen, a water-soluble protein present in blood serum into fibrin (a non-water soluble protein), causing the blood to clot. Many of the clotting factors require vitamin K to work, and vitamin K deficiency can lead to problems with blood clotting. Many platelets converge and stick together at the wound site forming a platelet plug (also called a fibrin clot) (Figure 8.6b). The plug or clot lasts for a number of days and stops the loss of blood. Platelets are formed from the disintegration of larger cells called megakaryocytes (Figure 8.6a).

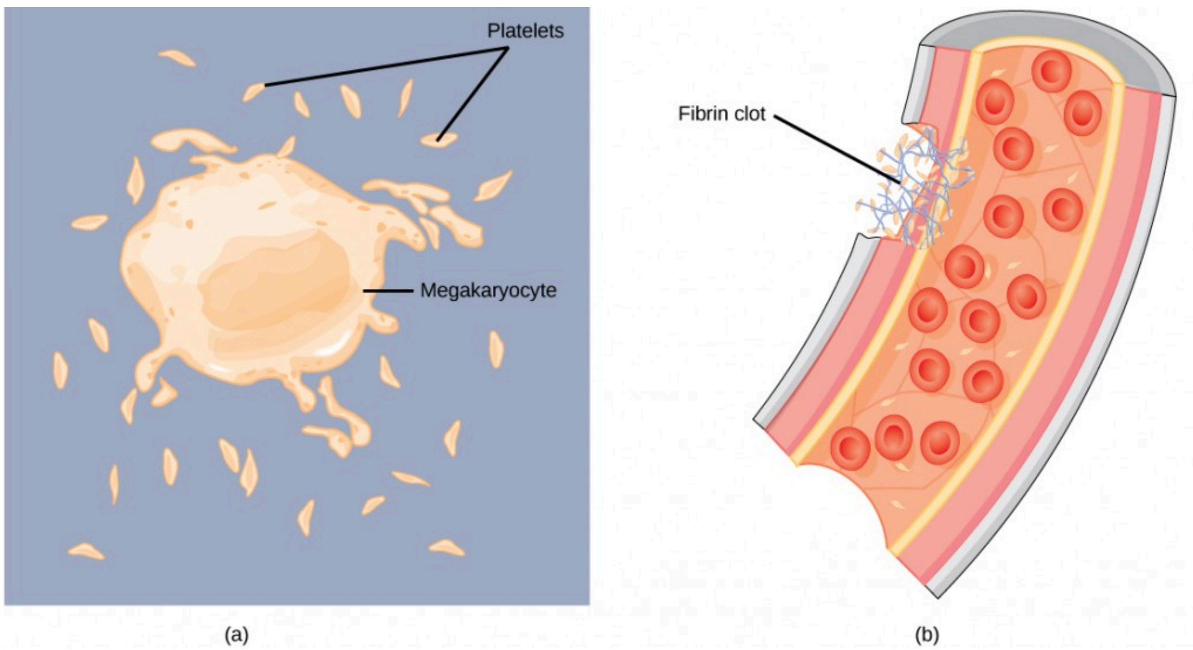


Figure 8.6. (a) Platelets are formed from large cells called megakaryocytes. The megakaryocyte breaks up into thousands of fragments that become platelets. (b) Platelets are required for clotting of the blood. The platelets collect at a wound site in conjunction with other clotting factors, such as fibrinogen, to form a fibrin clot that prevents blood loss and allows the wound to heal.

Plasma

The liquid component of blood is called **plasma**, and it is separated by spinning or centrifuging the blood at high rotations (3000 rpm or higher). The blood cells and platelets are separated by centrifugal forces to the bottom of a specimen tube. The upper liquid layer, the plasma, consists of 90 percent water along with various substances required for maintaining the body's pH, osmotic load, and for protecting the body. The plasma also contains the coagulation factors and antibodies. The plasma component of blood without the coagulation factors is called the **serum.**

Blood Types Related to Proteins on the Surface of the Red Blood Cells

Red blood cells are coated in antigens whose composition is determined by genetics, which have evolved over time. In humans, the different surface antigens are grouped into 24 different blood groups with more than 100 different antigens on each red blood cell. The two most well known blood groups are the ABO (Figure 8.7) and Rh systems.

The surface antigens in the ABO blood group are glycolipids, called antigen A and antigen B. People with blood type A have antigen A, those with blood type B have antigen B, those with blood type AB have both antigens, and people with blood type O have neither antigen. Antibodies called agglutinogens are found in the blood plasma and react with the A or B antigens, if the two are mixed. When type A and type B blood are combined, agglutination (clumping) of the blood occurs because of antibodies in the plasma that bind with the opposing antigen This causes clots that coagulate in the kidney causing kidney failure. Type O blood has neither A or B antigens, and therefore, type O blood can be given to all blood types. Type O negative blood is the universal donor. Type AB positive blood is the universal acceptor because it has both A and B antigen. The ABO blood groups were discovered in 1900 and 1901 by Karl Landsteiner at the University of Vienna.

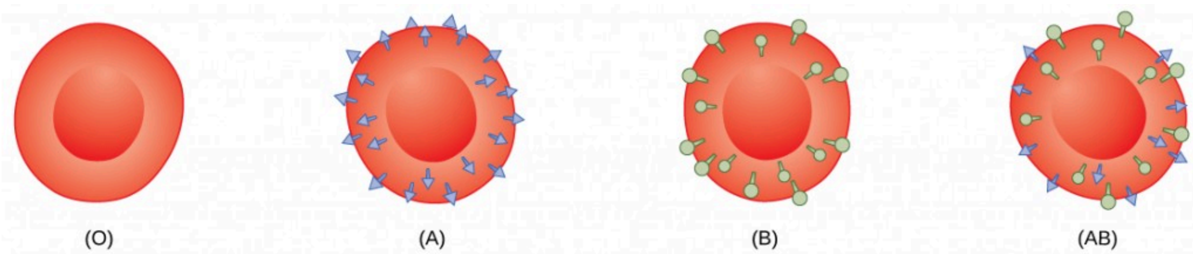


Figure 8.7. Human red blood cells may have either type A or B glycoproteins on their surface, both glycoproteins combined (AB), or neither (O). The glycoproteins serve as antigens and can elicit an immune response in a person who receives a transfusion containing unfamiliar antigens. Type O blood, which has no A or B antigens, does not elicit an immune response when injected into a person of any blood type. Thus, O is considered the universal donor. Persons with type AB blood can accept blood from any blood type, and type AB is considered the universal acceptor.

The Rh blood group was first discovered in Rhesus monkeys. Most people have the Rh antigen (Rh+) and do not have anti-Rh antibodies in their blood. The few people who do not have the Rh antigen and are Rh– can develop anti-Rh antibodies if exposed to Rh+ blood. This can happen after a blood transfusion or after an Rh– woman has an Rh+ baby. The first exposure does not usually cause a reaction; however, at the second exposure, enough antibodies have built up in the blood to produce a reaction that causes agglutination and breakdown of red blood cells. An injection can prevent this reaction.

Summary

The human circulatory system consists of a network of vessels containing blood that circulates because of pressure differences generated by the heart. The heart contains two pumps that move blood through the pulmonary and systemic circulations. There is one atrium and one ventricle on the right side and one atrium and one ventricle on the left side. The pumping of the heart is a function of muscle cells that are striated like skeletal muscle but pump rhythmically and involuntarily like smooth muscle. The electrochemical signal causes the two atria to contract in unison, then the signal causes the ventricles to contract. The blood from the heart is carried through the body by a complex network of blood vessels. Arteries take blood away from the heart, and veins bring blood back to the heart.

Specific components of the blood include red blood cells, white blood cells, platelets, and the plasma, which contains coagulation factors and serum. Blood is important for regulation of the body's pH, temperature, osmotic pressure, the circulation of nutrients and removal of waste, the distribution of hormones from endocrine glands, and the elimination of excess heat. It also contains components for blood clotting. Red blood cells are specialized cells that contain hemoglobin and circulate through the body delivering oxygen to cells. White blood cells are involved in the immune response to identify and target invading bacteria, viruses, and other foreign organisms. They also recycle waste components, such as old red blood cells. Platelets and blood clotting factors cause the change of the soluble protein fibrinogen to the insoluble protein fibrin at a wound site forming a plug. Plasma consists of 90 percent water along with various substances, such as coagulation factors and antibodies.

Exercises

1. Which of the following statements about the circulatory system is false?
   1. Blood in the pulmonary vein is deoxygenated.
   2. Blood in the inferior vena cava is deoxygenated.
   3. Blood in the pulmonary artery is deoxygenated.
   4. Blood in the aorta is oxygenated.
2. Where does the right ventricle send blood?
   1. the head
   2. the upper body
   3. the lungs
   4. the lower body
3. During the systolic phase of the cardiac cycle, the heart is ________.
   1. contracting
   2. relaxing
   3. contracting and relaxing
   4. filling with blood
4. How do arteries differ from veins?
   1. Arteries have thicker wall layers to accommodate the changes in pressure from the heart.
   2. Arteries carry blood.
   3. Arteries have thinner wall layers and valves and move blood by the action of skeletal muscle.
   4. Arteries are thin walled and are used for gas exchange.
5. Describe the cardiac cycle.
6. White blood cells
   1. can be classified as granulocytes or agranulocytes
   2. defend the body against bacteria and viruses
   3. are also called leucocytes
   4. All of the above
7. Platelet plug formation occurs at which point?
   1. when large megakaryocytes break up into thousands of smaller fragments
   2. when platelets are dispersed through the blood stream
   3. when platelets are attracted to a site of blood vessel damage

    4. none of the above

8. In humans, the plasma comprises what percentage of the blood?
    1. 45 percent
    2. 55 percent
    3. 25 percent
    4. 90 percent
9. The red blood cells of birds differ from mammalian red blood cells because:
    1. they are white and have nuclei
    2. they do not have nuclei
    3. they have nuclei
    4. they fight disease
10. Describe the cause of different blood type groups.
11. List some of the functions of blood in the body.
12. How does the lymphatic system work with blood flow?

Answers

1. A
2. C
3. A
4. A
5. The heart receives an electrical signal triggering the cardiac muscle cells in the atria to contract. The signal pauses before passing onto the ventricles so the blood is pumped through the body. This is the systolic phase. The heart then relaxes in diastole and fills again with blood.
6. D
7. C
8. B
9. C
10. Red blood cells are coated with proteins called antigens made of glycolipids and glycoproteins. When type A and type B blood are mixed, the blood agglutinates because of antibodies in the plasma that bind with the opposing antigen. Type O blood has no antigens. The Rh blood group has either the Rh antigen (Rh+) or no Rh antigen (Rh–).
11. Blood is important for regulation of the body's pH, temperature, and osmotic pressure, the circulation of nutrients and removal of wastes, the distribution of hormones from endocrine glands, the elimination of excess heat; it also contains components for the clotting of blood to prevent blood loss. Blood also transports clotting factors and disease-fighting agents.
12. Lymph capillaries take fluid from the blood to the lymph nodes. The lymph nodes filter the lymph by percolation through connective tissue filled with white blood cells. The white blood cells remove infectious agents, such as bacteria and viruses, to clean the lymph before it returns to the bloodstream.

Key Takeaways

aorta: the major artery that takes blood away from the heart to the systemic circulatory system

artery: a blood vessel that takes blood away from the heart

atrium: (plural: atria) a chamber of the heart that receives blood from the veins

bicuspid valve: a one-way opening between the atrium and the ventricle in the left side of the heart

capillary: the smallest blood vessel that allows the passage of individual blood cells and the site of diffusion of oxygen and nutrient exchange

cardiac cycle: the filling and emptying the heart of blood caused by electrical signals that cause the heart muscles to contract and relax

diastole: the relaxation phase of the cardiac cycle when the heart is relaxed and the ventricles are filling with blood

electrocardiogram (ECG): a recording of the electrical impulses of the cardiac muscle

hemoglobin: a protein found in red blood cells responsible for transporting oxygen and carbon dioxide

inferior vena cava: the major vein of the body returning blood from the lower parts of the body to the right atrium

plasma: liquid component of blood that is left after the cells are removed

platelet: small cellular fragment that collects at wounds, cross-reacts with clotting factors, and forms a plug to prevent blood loss

pulmonary circulation: the flow of blood away from the heart through the lungs where oxygenation occurs and then back to the heart

red blood cell: small biconcave cell without mitochondria that is packed with hemoglobin, giving the cell its red color; transports oxygen through the body

serum: plasma without the coagulation factors

superior vena cava: the major vein of the body returning blood from the upper part of the body to the right atrium

systemic circulation: the flow of blood away from the heart to the brain, liver, kidneys, stomach, and other organs, the limbs, and the muscles of the body, and then back to the heart

systole: the contraction phase of cardiac cycle when the ventricles are pumping blood into the arteries

tricuspid valve: a one-way opening between the atrium and the ventricle in the right side of the heart

vein: a blood vessel that brings blood back to the heart

ventricle: (of the heart) a large chamber of the heart that pumps blood into arteries

white blood cell: large cell with nuclei of which there are many types with different roles including the protection of the body from viruses and bacteria, and cleaning up dead cells and other waste

Media Attributions

Figure 8. 2 Wapcalet. (2020). Diagram of the human heart. Wikipedia. CC BY

UNIT 5: REPRODUCTION, GENETICS AND INHERITANCE

CHAPTER 9: HUMAN REPRODUCTION

Learning Objectives

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

- Describe human male and female reproductive anatomies
- Describe the roles of male and female reproductive hormones
- Describe the processes of gestation and labour

As in all animals, the adaptations for reproduction in humans are complex. They involve specialized and different anatomies in the two sexes, a hormone regulation system, and specialized behaviors regulated by the brain and endocrine system.

The Human Reproductive System

The reproductive tissues of male and female humans develop similarly *in utero* until about the seventh week of gestation when a low level of the hormone testosterone is released from the gonads of the developing male. Testosterone causes the primitive gonads to differentiate into male sexual organs. When testosterone is absent, the primitive gonads develop into ovaries. Tissues that produce a penis in males produce a clitoris in females. The tissue that will become the scrotum in a male becomes the labia in a female. Thus the male and female anatomies arise from a divergence in the development of what were once common embryonic structures.

Male Reproductive Anatomy

Sperm are immobile at body temperature; therefore, the testes are external to the body so that a correct temperature is maintained for motility. In humans, the pair of testes must be suspended outside the body so the environment of the sperm is about 2 °C lower than body temperature to produce viable sperm. If the testes do not descend through the abdominal cavity during fetal development, the individual has reduced fertility.

The **scrotum** houses the testicles or testes (singular: testis), and provides passage for blood vessels, nerves, and muscles related to testicular function. The **testes** are a pair of male gonads that produce sperm and reproductive hormones. Each testis is approximately 2.5 by 3.8 cm (1.5 by 1 inch) in size and divided into wedge-shaped lobes by septa. Coiled in each wedge are **seminiferous tubules** that produce sperm.

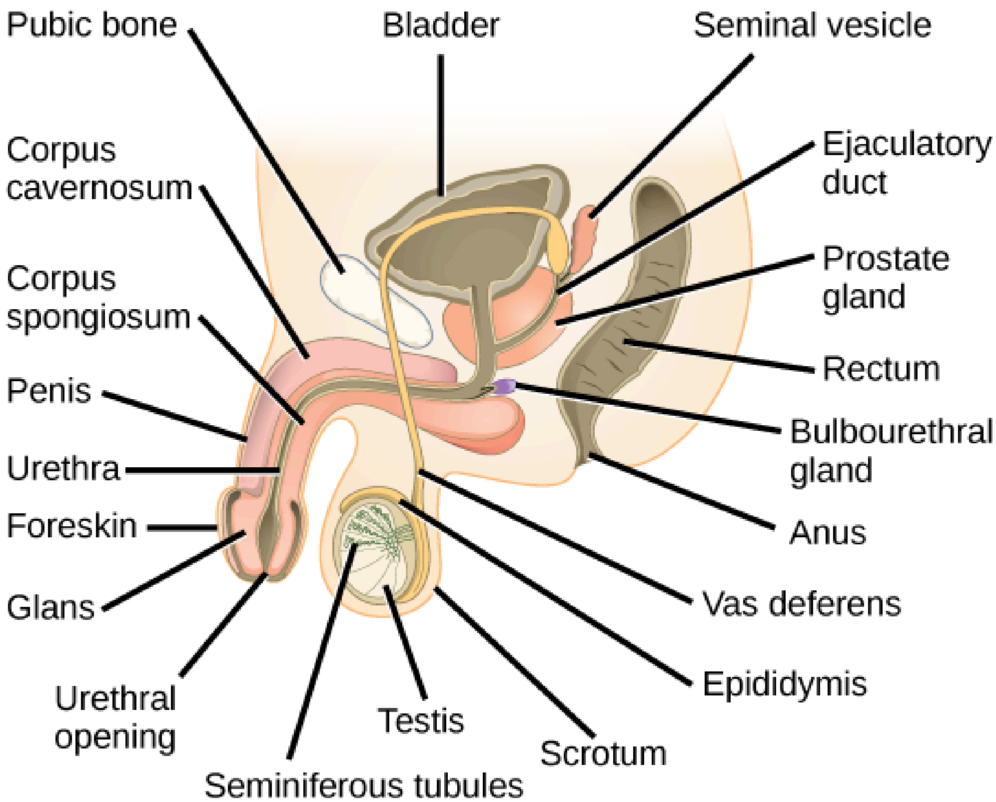


Figure 9.1 The reproductive structures of the human male are shown.

The **penis** drains urine from the urinary bladder and is a copulatory organ during intercourse (Figure 9.1, Table 9.1). The penis contains three tubes of erectile tissue that become engorged with blood, making the penis erect, in preparation for intercourse. The organ is inserted into the vagina culminating with an ejaculation. During orgasm, the accessory organs and glands connected to the testes contract and empty the semen (containing sperm) into the urethra and the fluid is expelled from the body by muscular contractions causing ejaculation. After intercourse, the blood drains from the erectile tissue and the penis becomes flaccid.

Semen is a mixture of sperm (about five percent of the total) and fluids from accessory glands that contribute most of the semen's volume. Sperm are the male reproductive cells, consisting of a flagellum for motility, a neck that contains the cell's energy-producing mitochondria, and a head that contains the genetic material (Figure 9.2). At the top of the head of the sperm is the acrosome, a structure containing enzymes that can digest the protective coverings that surround the egg and allow the sperm to fuse with the egg. An ejaculate will contain from two to five milliliters of fluid and from 50–120 million sperm per milliliter.

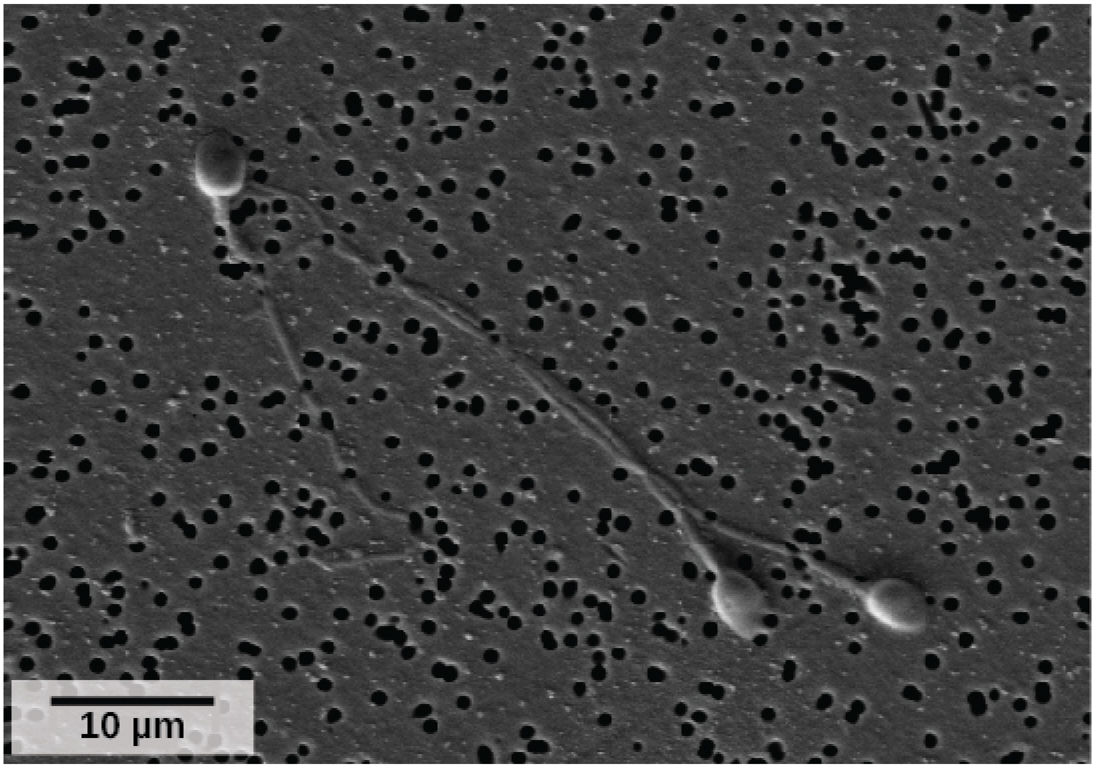


Figure 9.2 As seen in this scanning electron micrograph, human sperm has a flagellum, neck, and head. (credit: scale-bar data from Matt Russell)

Sperm form in the walls of seminiferous tubules that are coiled inside the testes (Figure 9.1, Table 9.1). When the sperm have developed flagella they leave the seminiferous tubules and enter the epididymis (Figure 9.1, Table 9.1). This structure lies along the top and posterior of the testes and is the site of sperm maturation. The sperm leave the epididymis and enter the vas deferens, which carries the sperm behind the bladder, and forms the ejaculatory duct with the duct from the seminal vesicles. During a vasectomy, a section of the vas deferens is removed, preventing sperm (but not the secretions of the accessory glands) from being passed out of the body during ejaculation and preventing fertilization.

The bulk of the semen comes from the accessory glands associated with the male reproductive system. These are the **seminal vesicles**, the **prostate gland**, and the **bulbourethral gland** (Figure 9.1, Table 9.1). The secretions from the accessory glands provide important compounds for the sperm including nutrients, electrolytes, and pH buffering. There are also coagulation factors that affect sperm delivery and motility.

Table 9.1 Male Reproductive Anatomy

Organ	Location	Function
Scrotum	External	Supports testes and regulates their temperature
Penis	External	Delivers urine, copulating organ
Testes	Internal	Produce sperm and male hormones
Seminal Vesicles	Internal	Contribute to semen production
Prostate Gland	Internal	Contributes to semen production
Bulbourethtral Glands	Internal	Neutralize urine in urethra

Female Reproductive Anatomy

Internal female reproductive structures include ovaries, oviducts, the uterus, and the vagina (Figure 9.3, Table 9.2). The pair of ovaries is held in place in the abdominal cavity by a system of ligaments. The outermost layer of the ovary is made up of follicles, each consisting of one or more follicular cells that surround, nourish, and protect a single egg. During the menstrual period, a batch of follicular cells develops and prepares their eggs for release. At **ovulation**, one follicle ruptures and one egg is released. Following ovulation, the follicular tissue that surrounded the ovulated egg stays within the ovary and grows to form a solid mass called the **corpus luteum**. The corpus luteum secretes additional estrogen and the hormone progesterone that helps maintain the uterine lining during pregnancy. The ovaries also produce hormones, such as estrogen.

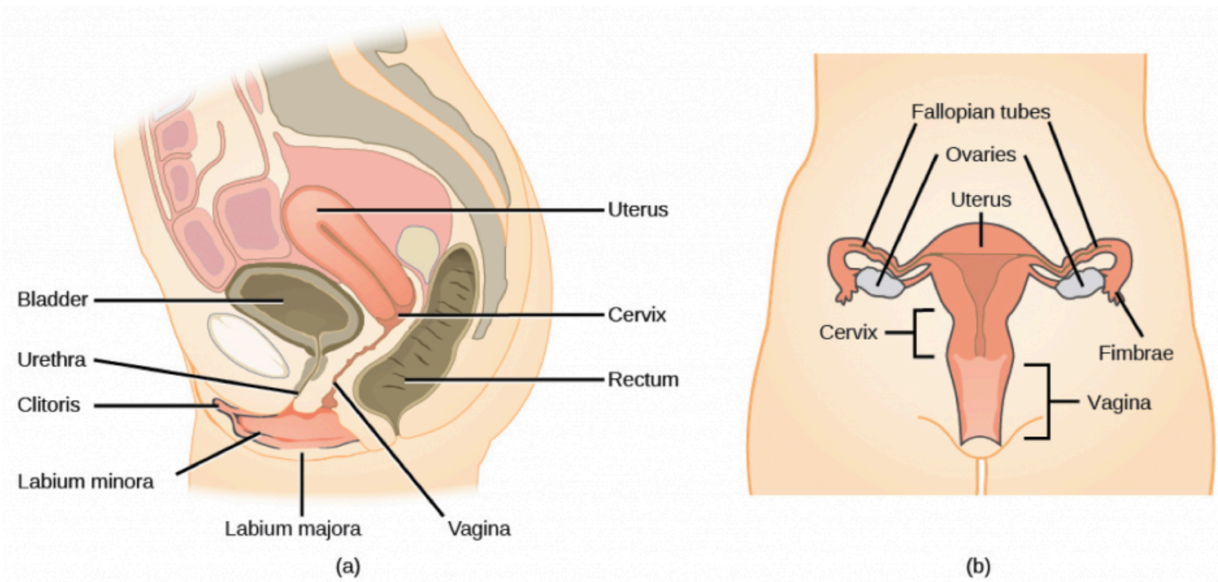


Figure 9.3 A number of female reproductive structures are exterior to the body. These include the breasts and the vulva, which consists of the mons pubis, clitoris, labia majora, labia minora, and the vestibular glands (Table 9.2).

The **oviducts**, or fallopian tubes, extend from the uterus in the lower abdominal cavity to the ovaries, but they are not in contact with the ovaries. The lateral ends of the oviducts flare out into a trumpet-like structure and have a fringe of finger-like projections called fimbrae (Figure 9.3b). When an egg is released at ovulation, the fimbrae help the nonmotile egg enter into the tube. The walls of the oviducts have a ciliated epithelium over smooth muscle. The cilia beat, and the smooth muscle contracts, moving the egg toward the uterus. Fertilization usually takes place within the oviduct and the developing embryo is moved toward the uterus. It usually takes the egg or embryo a week to travel through the oviduct.

Sterilization in women is called a tubal ligation; it is analogous to a vasectomy in males in that the oviducts are severed and sealed, preventing sperm from reaching the egg.

The **uterus** is a structure about the size of a woman's fist. The uterus has a thick muscular wall and is lined with an endometrium rich in blood vessels and mucus glands that develop and thicken during the female cycle. Thickening of the endometrium prepares the uterus to receive the fertilized egg or zygote, which will then implant itself in the endometrium. The uterus supports the developing embryo and fetus during gestation. Contractions of the smooth muscle in the uterus aid in forcing the baby through the vagina during labor. If fertilization does not occur, a portion of the lining of the uterus sloughs off during each menstrual period. The endometrium builds up again in preparation for implantation. Part of the uterus, called the cervix, protrudes into the top of the vagina.

The **vagina** is a muscular tube that serves several purposes. It allows menstrual flow to leave the body. It is the receptacle for the penis during intercourse and the pathway for the delivery of offspring.

The breasts consist of mammary glands and fat. Each gland consists of 15 to 25 lobes that have ducts that empty at the nipple and that supply the nursing child with nutrient- and antibody-rich milk to aid development and protect the child.

Table 9.2 Female Reproductive Anatomy

Organ	Location	Function
Clitoris	External	Sensory organ
Mons pubis	External	Fatty area overlying pubic bone
Labia majora	External	Covers labia minora; contains sweat and sebaceous glands
Labia minora	External	Covers vestibule
Greater vestibular glands	External	Secrete mucus; lubricate vagina
Breast	External	Produces and delivers milk
Ovaries	Internal	Produce and develop eggs
Oviducts	Internal	Transport egg to uterus; site of fertilization
Uterus	Internal	Supports developing embryo
Vagina	Internal	Common tube for intercourse, birth canal, passing menstrual flow

Hormonal Control of Reproduction

The human male and female reproductive cycles are controlled by the interaction of hormones from the hypothalamus and anterior pituitary with hormones from reproductive tissues and organs. In both sexes, the hypothalamus monitors and causes the release of hormones from the anterior pituitary gland. When the reproductive hormone is required, the hypothalamus sends a **gonadotropin-releasing hormone** (GnRH) to the anterior pituitary. This causes the release of **follicle stimulating hormone** (FSH) and **luteinizing hormone** (LH) from the anterior pituitary into the blood. Although these hormones are named after their functions in female reproduction, they are produced in both sexes and play important roles in controlling reproduction. Other hormones have specific functions in the male and female reproductive systems.

Male Hormones

At the onset of puberty, the hypothalamus causes the release of FSH and LH into the male system for the first time. FSH enters the testes and stimulates the Sertoli cells located in the walls of the seminiferous tubules to begin promoting spermatogenesis. LH also enters the testes and stimulates the interstitial cells of Leydig, located in between the walls of the seminiferous tubules, to make and release testosterone into the testes and the blood.

Testosterone stimulates spermatogenesis. This hormone is also responsible for the secondary sexual characteristics that develop in the male during adolescence. The secondary sex characteristics in males include a deepening of the voice, the growth of facial, axillary, and pubic hair, an increase in muscle bulk, and the beginnings of the sex drive.

Female Hormones

The control of reproduction in females is more complex. The female reproductive cycle is divided into the ovarian cycle and the menstrual cycle. The **ovarian cycle** governs the preparation of endocrine tissues and release of eggs, while the **menstrual cycle** governs the preparation and maintenance of the uterine lining. These cycles are coordinated over a 22–32 day cycle, with an average length of 28 days.

As with the male, the GnRH from the hypothalamus causes the release of the hormones FSH and LH from the anterior pituitary. In addition, estrogen and progesterone are released from the developing follicles. As with testosterone in males, estrogen is responsible for the secondary sexual characteristics of females. These include breast development, flaring of the hips, and a shorter period for bone growth.

The ovarian and menstrual cycles are regulated by hormones of the hypothalamus, pituitary, and ovaries. The ebb and flow of the hormones causes the ovarian and menstrual cycles to advance. The ovarian and menstrual cycles occur concurrently. The first half of the ovarian cycle is the follicular phase. Slowly rising levels of FSH cause the growth of follicles on the surface of the ovary. This process prepares the egg for ovulation. As the follicles grow, they begin releasing estrogen. The first few days of this cycle coincide with menstruation or the sloughing off of the functional layer of the endometrium in the uterus. After about five days, estrogen levels rise and the menstrual cycle enters the proliferative phase. The endometrium begins to regrow, replacing the blood vessels and glands that deteriorated during the end of the last cycle.

Just prior to the middle of the cycle (approximately day 14), the high level of estrogen causes FSH and especially LH to rise rapidly then fall. The spike in LH causes the most mature follicle to rupture and release its egg. This is **ovulation**. The follicles that did not rupture degenerate and their eggs are lost. The level of estrogen decreases when the extra follicles degenerate.

Following ovulation, the ovarian cycle enters its luteal phase, and the menstrual cycle enters its secretory phase, both of which run from about day 15 to 28. The luteal and secretory phases refer to changes in the ruptured follicle. The cells in the follicle undergo physical changes and produce a structure called a corpus luteum. The corpus luteum produces estrogen and progesterone. The progesterone facilitates the regrowth of the uterine lining and inhibits the release of further FSH and LH. The uterus is being prepared to accept a fertilized egg, should it occur during this cycle. The inhibition of FSH and LH prevents any further eggs and follicles from developing, while the progesterone is elevated. The level of estrogen produced by the corpus luteum increases to a steady level for the next few days.

If no fertilized egg is implanted into the uterus, the corpus luteum degenerates and the levels of estrogen and progesterone decrease. The endometrium begins to degenerate as the progesterone levels drop, initiating the next menstrual cycle. The decrease in progesterone also allows the hypothalamus to send GnRH to the anterior pituitary, releasing FSH and LH and starting the cycles again. Figure 9.4 visually compares the ovarian and uterine cycles as well as the commensurate hormone levels.

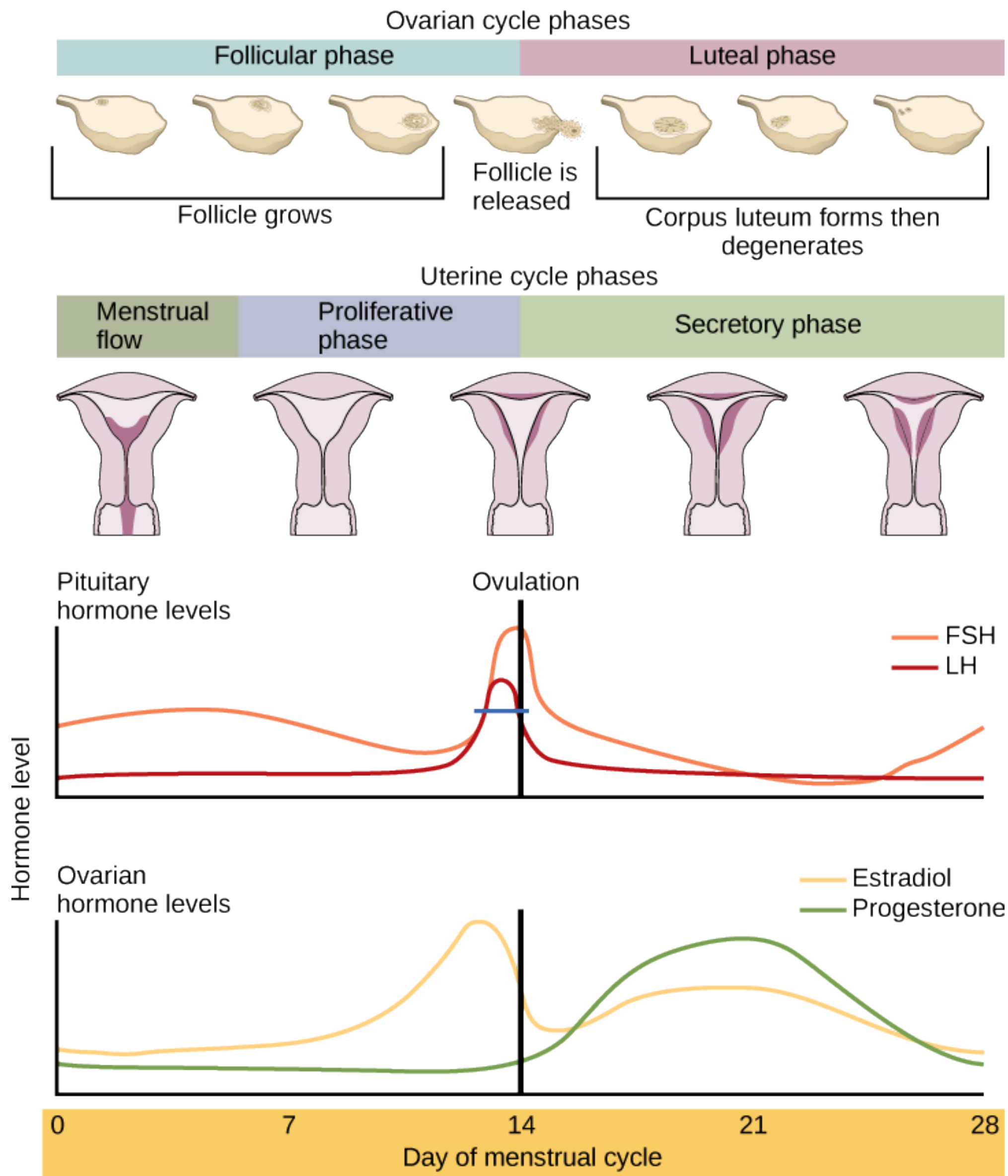


Figure 9.4. Rising and falling hormone levels result in progression of the ovarian and menstrual cycles. (credit: modification of work by Mikael Häggström)

Gestation

Pregnancy begins with the fertilization of an egg and continues through to the birth of the individual. The length of time of gestation, or the **gestation period**, in humans is 266 days and is similar in other great apes.

Within 24 hours of fertilization, the egg and sperm nuclei fuse and the cell is known as a zygote. The zygote initiates cleavage, developing into a greater number of cells, and the developing embryo travels through the oviduct to the uterus (Figure 9.5). The developing embryo must implant into the wall of the uterus within seven days, or it will deteriorate and die. The outer layers of the developing embryo or blastocyst grow into the endometrium by digesting the endometrial cells, and healing of the endometrium closes up the blastocyst into the tissue. Another layer of the blastocyst, the chorion, begins releasing a hormone called human beta chorionic gonadotropin (β-HCG), which makes its way to the corpus luteum and keeps that structure active. This ensures adequate levels of progesterone that will maintain the endometrium of the uterus for the support of the developing embryo. Pregnancy tests determine the level of β-HCG in urine or serum. If the hormone is present, the test is positive.

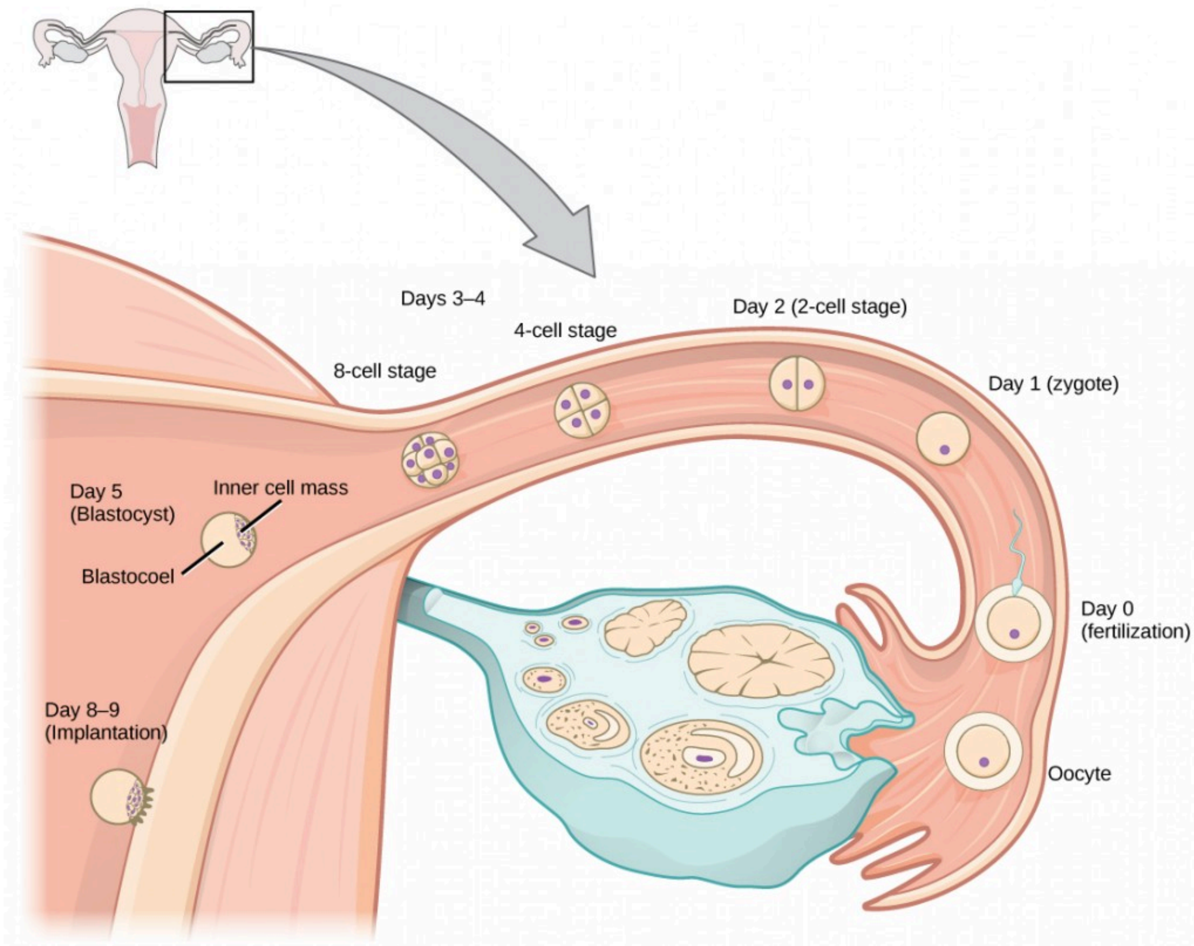


Figure 9.5. In humans, fertilization occurs soon after the oocyte leaves the ovary. Implantation occurs eight or nine days later.(credit: Ed Uthman)

The gestation period is divided into three equal periods or trimesters. During the first two-to-four weeks of the first trimester, nutrition and waste are handled by the endometrial lining through diffusion. As the trimester progresses, the outer layer of the embryo begins to merge with the endometrium, and the placenta forms. The **placenta** takes over the nutrient and waste requirements of the embryo and fetus, with the mother's blood passing nutrients to the placenta and removing waste from it. Chemicals from the fetus, such as bilirubin, are processed by the mother's liver for elimination. Some of the mother's immunoglobulins will pass through the placenta, providing passive immunity against some potential infections.

Internal organs and body structures begin to develop during the first trimester. By five weeks, limb buds, eyes, the heart, and liver have been basically formed. By eight weeks, the term fetus applies, and the body is essentially formed (Figure 9.6a). The individual is about five centimeters (two inches) in length and many of the organs, such as the lungs and liver, are not yet functioning. Exposure to any toxins is especially dangerous during the first trimester, as all of the body's organs and structures are going through initial development. Anything that interferes with chemical signaling during that development can have a severe effect on the fetus' survival.

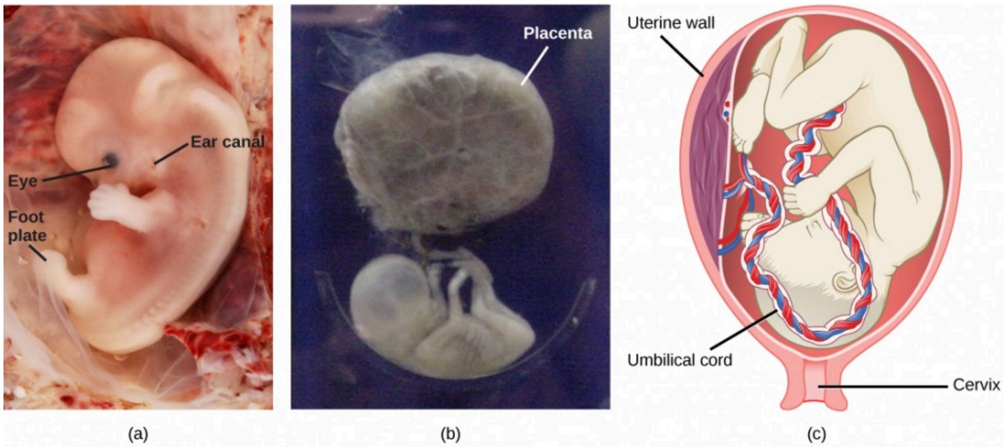


Figure 9.6 (a) Fetal development is shown at nine weeks gestation. (b) This fetus is just entering the second trimester, when the placenta takes over more of the functions performed as the baby develops. (c) There is rapid fetal growth during the third trimester. (credit a: modification of work by Ed Uthman; credit b: modification of work by National Museum of Health and Medicine; credit c: modification of work by Gray's Anatomy)

During the second trimester, the fetus grows to about 30 cm (about 12 inches) (Figure 9.6b). It becomes active and the mother usually feels the first movements. All organs and structures continue to develop. The placenta has taken over the functions of nutrition and waste elimination and the production of estrogen and progesterone from the corpus luteum, which has degenerated. The placenta will continue functioning up through the delivery of the baby. During the third trimester, the fetus grows to 3 to 4 kg (6.5–8.5 lbs.) and about 50 cm (19–20 inches) long (Figure 9.6c). This is the period of the most rapid growth during the pregnancy as all organ systems continue to grow and develop.

Labor is the muscular contractions to expel the fetus and placenta from the uterus. Toward the end of the third trimester, estrogen causes receptors on the uterine wall to develop and bind the hormone oxytocin. At this time, the baby reorients, facing forward and down with the back or crown of the head engaging the cervix (uterine opening). This causes the cervix to stretch and nerve impulses are sent to the hypothalamus, which signals the release of oxytocin from the posterior pituitary. Oxytocin causes smooth muscle in the uterine wall to contract. At the same time, the placenta releases prostaglandins into the uterus, increasing the contractions. As more smooth muscle cells are recruited, the contractions increase in intensity and force.

There are three stages to labor. During stage one, the cervix thins and dilates. This is necessary for the baby and placenta to be expelled during birth. The cervix will eventually dilate to about 10 cm. During stage two, the baby is expelled from the uterus. The uterus contracts and the mother pushes as she compresses her abdominal muscles to aid the delivery. The last stage is the passage of the placenta after the baby has been born and the organ has completely disengaged from the uterine wall. If labor should stop before stage two is reached, synthetic oxytocin, known as Pitocin, can be administered to restart and maintain labor.

Infertility

Infertility is the inability to conceive a child or carry a child to birth. About 75 percent of causes of infertility can be identified. These include diseases, such as sexually transmitted diseases that can cause scarring of the reproductive tubes in either men or women, or developmental problems frequently related to abnormal hormone levels in one of the individuals. Inadequate nutrition, especially starvation, can delay menstruation. Stress can also lead to infertility. Short-term stress can affect hormone levels, while long-term stress can delay puberty and cause less frequent menstrual cycles. Other factors that affect fertility include toxins (such as cadmium), tobacco smoking, marijuana use, gonadal injuries, and aging.

If infertility is identified, several assisted reproductive technologies (ART) are available to aid conception. A common type of

ART is *in vitro* fertilization (IVF) where an egg and sperm are combined outside the body and then placed in the uterus. Eggs are obtained from the woman after extensive hormonal treatments that prepare mature eggs for fertilization and prepare the uterus for implantation of the fertilized egg. Sperm are obtained from the man and they are combined with the eggs and supported through several cell divisions to ensure viability of the zygotes. When the embryos have reached the eight-cell stage, one or more is implanted into the woman's uterus. If fertilization is not accomplished by simple IVF, a procedure that injects the sperm into an egg can be used. This is called intracytoplasmic sperm injection (ICSI) (Figure 9.7). IVF procedures produce a surplus of fertilized eggs and embryos that can be frozen and stored for future use. The procedures can also result in multiple births.

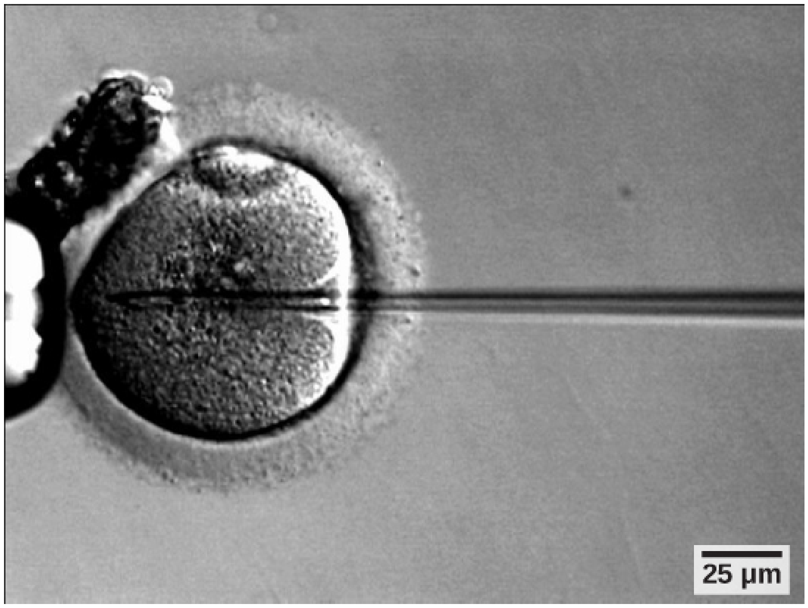


Figure 9.7 A sperm is inserted into an egg for fertilization during intracytoplasmic sperm injection (ICSI). (credit: scale-bar data from Matt Russell)

Reproductive Endocrinologist

A reproductive endocrinologist is a physician who treats a variety of hormonal disorders related to reproduction and infertility in both men and women. The disorders include menstrual problems, infertility, pregnancy loss, sexual dysfunction, and menopause. Doctors may use fertility drugs, surgery, or assisted reproductive techniques (ART) in their therapy. Reproductive endocrinologists undergo extensive medical training, first in a four-year residency in obstetrics and gynecology, then in a three-year fellowship in reproductive endocrinology. To be board certified in this area, the physician must pass written and oral exams in both areas.

Summary

The reproductive structures that evolved in humans allow males and females to mate, fertilize internally, and support the growth and development of offspring.

The male and female reproductive cycles are controlled by hormones released from the hypothalamus and anterior pituitary and hormones from reproductive tissues and organs. The hypothalamus monitors the need for FSH and LH production and release from the anterior pituitary. FSH and LH affect reproductive structures to cause the formation of sperm in males and the preparation of eggs for release in females and possible fertilization.

Human pregnancy begins with fertilization of an egg and proceeds through the three trimesters of gestation. The first trimester lays down the basic structures of the body, including the limb buds, heart, eyes, and the liver. The second trimester continues the development of all of the organs and systems. The third trimester exhibits the greatest growth of the fetus and culminates in labor and delivery. The labor process has three stages (contractions, delivery of the fetus, and expulsion of the placenta), each propelled by hormones.

Exercises

1. Which of the following statements about the male reproductive system is false?
    1. The vas deferens carries sperm from the testes to the seminal vesicles.
    2. The ejaculatory duct joins the urethra.
    3. Both the prostate and the bulbourethral glands produce components of the semen.
    4. The prostate gland is located in the testes.
2. Which of the following statements about hormone regulation of the female reproductive cycle is false?
    1. LH and FSH are produced in the pituitary, and estrogen and progesterone are produced in the ovaries.
    2. Estradiol and progesterone secreted from the corpus luteum cause the endometrium to thicken.
    3. Both progesterone and estrogen are produced by the follicles.
    4. Secretion of GnRH by the hypothalamus is inhibited by low levels of estrogen but stimulated by high levels of estrogen.
3. Sperm are produced in the ________.
    1. scrotum
    2. seminal vesicles
    3. seminiferous tubules
    4. prostate gland
4. Which female organ has an endometrial lining that will support a developing baby?
    1. labia minora
    2. breast
    3. ovaries
    4. uterus
5. Which hormone causes FSH and LH to be released?
    1. testosterone
    2. estrogen
    3. GnRH
    4. progesterone
6. Nutrient and waste requirements for the developing fetus are handled during the first few weeks by ________.
    1. the placenta
    2. diffusion through the endometrium

   3. the chorion
   4. the blastocyst

7. Which hormone is primarily responsible for the contractions during labor?

   1. oxytocin
   2. estrogen
   3. β-HCG
   4. progesterone

8. Describe the events in the ovarian cycle leading up to ovulation.
9. Describe the stages of labor.

Answers

1. D
2. C
3. C
4. D
5. C
6. B
7. A
8. Low levels of progesterone allow the hypothalamus to send GnRH to the anterior pituitary and cause the release of FSH and LH. FSH stimulates follicles on the ovary to grow and prepare the eggs for ovulation. As the follicles increase in size, they begin to release estrogen and a low level of progesterone into the blood. The level of estrogen rises to a peak, causing a spike in the concentration of LH. This causes the most mature follicle to rupture and ovulation occurs.
9. Stage one of labor results in uterine contractions, which thin the cervix and dilate the cervical opening. Stage two delivers the baby, and stage three delivers the placenta.

Glossary

bulbourethral gland: the paired glands in the human male that produce a secretion that cleanses the urethra prior to ejaculation

corpus luteum: the endocrine tissue that develops from an ovarian follicle after ovulation; secretes progesterone and estrogen during pregnancy

estrogen: a reproductive hormone in females that assists in endometrial regrowth, ovulation, and calcium absorption

follicle stimulating hormone (FSH): a reproductive hormone that causes sperm production in men and follicle development in women

gestation: the development before birth of a viviparous animal

gestation period: the length of time of development, from conception to birth, of the young of a viviparous animal

gonadotropin-releasing hormone (GnRH): a hormone from the hypothalamus that causes the release of FSH and LH from the anterior pituitary

human beta chorionic gonadotropin (β-HCG): a hormone produced by the chorion of the zygote that helps to maintain the corpus luteum and elevated levels of progesterone

infertility: the inability to conceive, carry or deliver children

luteinizing hormone (LH): a reproductive hormone in both men and women, causes testosterone production in men and ovulation and lactation in women

menstrual cycle: the cycle of the degradation and re-growth of the endometrium

ovarian cycle: the cycle of preparation of egg for ovulation and the conversion of the follicle to the corpus luteum

oviduct: (also, fallopian tube) the muscular tube connecting uterus with ovary area

ovulation: the release of an oocyte from a mature follicle in the ovary of a vertebrate

penis: the male reproductive structure for urine elimination and copulation

placenta: the organ that supports the transport of nutrients and waste between the mothers and fetus' blood in eutherian mammals

progesterone: a reproductive hormone in women; assists in endometrial regrowth and inhibition of FSH and LH release

prostate gland: a structure that is a mixture of smooth muscle and glandular material and that contributes to semen

scrotum: a sac containing testes, exterior to body

semen: a fluid mixture of sperm and supporting materials

seminal vesicle: a secretory accessory gland in male; contributes to semen

seminiferous tubule: the structures within which sperm production occurs in the testes

testes: a pair of male reproductive organs

testosterone: a reproductive hormone in men that assists in sperm production and promoting secondary sexual characteristics

uterus: a female reproductive structure in which an embryo develops

vagina: a muscular tube for the passage of menstrual flow, copulation, and birth of offspring

9.2 AN OVERVIEW OF DNA AND THE HUMAN GENOME

Learning Objectives

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

- Describe the human genome
- Distinguish between chromosomes, genes, and traits

The continuity of life from one cell to another has its foundation in the reproduction of cells by way of the cell cycle. The cell cycle is an orderly sequence of events in the life of a cell from the division of a single parent cell to produce two new daughter cells, to the subsequent division of those daughter cells. Genetic information is found in the nucleus of cells. This information is stored in the chromosomes in the form of DNA. Chromosomes are difficult to see except for when they coil up tightly during cell division.

Genomic DNA

A cell's complete complement of DNA is called its **genome**. In animals, the genome comprises several double-stranded, linear DNA molecules (Figure 9.8) bound with proteins to form complexes called **chromosomes**. Each species has a characteristic number of chromosomes in the nuclei of its cells. Human body cells have 46 chromosomes. A cell contains two matched sets of chromosomes, a configuration known as **diploid**. The letter *n* is used to represent a single set of chromosomes; therefore a diploid organism is designated 2*n*. Human cells that contain only one set of 23 chromosomes are called **gametes**, or sex cells. These eggs and sperm are designated *n*, or **haploid**.

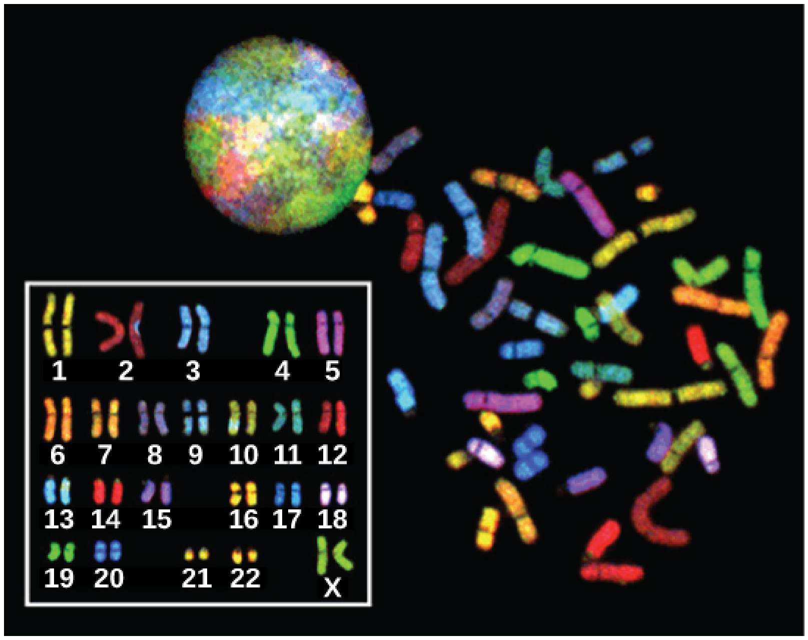


Figure 9.8 There are 23 pairs of homologous chromosomes in a female human somatic cell. These chromosomes are viewed within the nucleus (top), removed from a cell in mitosis (right), and arranged according to length (left) in an arrangement called a karyotype. In this image, the chromosomes were exposed to fluorescent stains to distinguish them. (credit: "718 Bot"/Wikimedia Commons, National Human Genome Research)

The matched pairs of chromosomes in a diploid organism are called homologous chromosomes. **Homologous chromosomes** are the same length and have specific nucleotide segments called genes in exactly the same location, or locus. Humans have more than 20 000 genes, each with its own specific location on the chromosomal pairs. **Genes**, the functional units of chromosomes, determine specific characteristics by coding for specific proteins. Traits are the different forms of a characteristic. For example, the shape of earlobes is a characteristic with traits of free or attached.

So how do parents pass on these traits and genes to their offspring? During formation of gametes (sperm and egg cells), the cells divide and chromosomal pairs pull apart, half of each pair going into the nucleus of the sex cells. When sperm fertilizes the egg cell, the new cell gets half its genes from each parent. Each copy of the homologous pair of chromosomes originates from a different parent; therefore, the copies of each of the genes themselves may not be identical. The variation of individuals within a species is caused by the specific combination of the genes inherited from both parents. For example, there are three possible gene sequences on the human chromosome that codes for blood type: sequence A, sequence B, and sequence O. Because all diploid human cells have two copies of the chromosome that determines blood type, the blood type (the trait) is determined by which two versions of the marker gene are inherited. It is possible to have two copies of the same gene sequence, one on each homologous chromosome (for example, AA, BB, or OO), or two different sequences, such as AB.

Minor variations in traits such as those for blood type, eye color, and height contribute to the natural variation found within a species. The sex chromosomes, X and Y, are the single exception to the rule of homologous chromosomes; other than a small amount of homology that is necessary to reliably produce gametes, the genes found on the X and Y chromosomes are not the same.

Summary

Animals have multiple, linear chromosomes surrounded by a nuclear membrane. Human cells have 46 chromosomes consisting of two sets of 22 homologous chromosomes and a pair of nonhomologous sex chromosomes. This is the 2*n,* or diploid, state. Human

gametes have 23 chromosomes or one complete set of chromosomes. This is the *n,* or haploid, state. Genes are segments of DNA that code for a specific protein or RNA molecule. An organism's traits are determined in large part by the genes inherited from each parent, but also by the environment that they experience. Genes are expressed as characteristics of the organism and each characteristic may have different variants called traits that are caused by differences in the DNA sequence for a gene.

Exercises

1. A diploid cell has ________ the number of chromosomes as a haploid cell.
    1. one-fourth
    2. one-half
    3. twice
    4. four times
2. An organism's traits are determined by the specific combination of inherited ________.
    1. cells
    2. genes
    3. proteins
    4. chromatids
3. Compare and contrast a human somatic cell to a human gamete.

Answers

1. C
2. B
3. Human somatic cells have 46 chromosomes, including 22 homologous pairs and one pair of nonhomologous sex chromosomes. This is the 2*n,* or diploid, condition. Human gametes have 23 chromosomes, one each of 23 unique chromosomes. This is the *n,* or haploid, condition

Glossary

diploid: describes a cell, nucleus, or organism containing two sets of chromosomes (2*n*)

gamete: a haploid reproductive cell or sex cell (sperm or egg)

gene: the physical and functional unit of heredity; a sequence of DNA that codes for a specific peptide or RNA molecule

genome: the entire genetic complement (DNA) of an organism

haploid: describes a cell, nucleus, or organism containing one set of chromosomes (*n*)

homologous chromosomes: chromosomes of the same length with genes in the same location; diploid organisms have pairs of homologous chromosomes, and the members of each pair come from different parents

BACK MATTER

OPEN TEXTBOOK VERSIONING HISTORY

NSCC

Changes made to create:

NSCC Edition, by Rhea Langille, adapter of *Concepts of Biology 1st Canadian Edition*

Unit 1 | The Amazing Human Machine

Chapter 1: Created using section 1.1 Properties of Life and Levels of Organization of Living Things. Removed The Diversity of Life and everything that follows.

Chapter 2: Added a section on Cell Theory.

Section 2.2 from old 3.3 Eukaryotic Cells. Wording revised and terms simplified. Removed plant cell picture, and content after Animal Cells vs Plant Cells.

Section 2.3 from 6.3 Cancer and the Cell Cycle.

Chapter 3: Added a new section using 14.2 Animal Primary Tissues from the previous edition. Edits made to simplify text.

Section 3.2 created on Systems of the Human Body, with two new images inserted.

Chapter 4: Created from content from Chapters 12 (vaccines) and 23 (The Immune System).

Unit 2 | Sensing the World Around You

Chapter 5: Created from Chapter 11.6 Nervous System. Removed some parts of the introduction and parts in the Neuron and Glial Cells section. Added Figure 16.24 into the Brain section.

Unit 3 | Fueling Your Machine

Chapter 6: Created from Chapter 11.2 Digestive System, with some edits and rewording.

Unit 4 | Your Internal Transportation System

Chapter 7: Created from Chapter 11.3 Circulatory and Respiratory System (sections on mammalian respiration and System of Gas Exchanges).

Chapter 8: Created from Chapter 11.3 Circulatory and Respiratory System (section on circulatory system and heart). New image added- Figure 8.2 The Human Heart. Added some parts of 21.2 Components of the Blood

Unit 5 | Reproduction, Genetics and Inheritance

Chapter 9: Created from section 13.3 Human Reproduction. Remove section on Gametogenesis. Added figure 24.17 in the section on female hormones. Added figure 24.18 in the section on fertilization. Added the section on Infertility from section 24.5

Section 9.2: Include section 6.1 The Genome. Some editing and additions needed.

For all Chapters

End of chapter exercises revised and glossaries modified to reflect concepts covered.

BC Campus

Changes made to create:

1st Canadian Edition, by Charles Molnar and Jane Gair, adapters of *Concepts of Biology*

In this survey text, directed at those not majoring in biology, we dispel the assumption that a little learning is a dangerous thing. We hope that by skimming the surface of a very deep subject, biology, we may inspire you to drink more deeply and make more informed choices relating to your health, the environment, politics, and the greatest subject that all of us are entwined in, life itself.

In the adapted textbook, *Concepts of Biology — 1st Canadian Edition*, you will find the following units:

- Unit 1: The Cellular Foundation of Life
- Unit 2: Cell Division and Genetics
- Unit 3: Molecular Biology and Biotechnology
- Unit 4: Animal Structure and Function

Adaptations to the original textbook *Concepts of Biology* by OpenStax College include:

- Remixed *Concepts of Biology* from 6 units into 4 units.
- Removed the original Unit 4: Evolution and the Diversity of Life from *Concepts of Biology.*
- Remixed the original Unit 5: Animal Structure and Function from *Concepts of Biology* by embedding Chapters 33-43 from *Biology* by OpenStax College.
- Adapted PowerPoints for each chapter- includes additional notes, images, and embedded videos.
- Added resources from "Let's Talk Science" to the end of each PowerPoint.

Thanks to BCcampus and Camosun College for funding and support. We are most grateful to the Let's Talk Science organization from their trove of science links.
oncepts of Biology is intended for the introductory biology course for non-science majors taught at most two- and four-year colleges. The scope, sequence, and level of the program are designed to match typical course syllabi. This text includes interesting features that make connections between scientific concepts and the everyday world of students. *Concepts of Biology* conveys the major themes of biology, such as a foundation in evolution, and features a rich and engaging art program.

Welcome to *Concepts of Biology*, an OpenStax College resource. This textbook has been created with several goals in mind: accessibility, customization, and student engagement—all while encouraging students toward high levels of academic scholarship. Instructors and students alike will find that this textbook offers a strong introduction to biology in an accessible format.

Additional Changes

This section provides a record of edits and changes made to this book since its initial publication in the B.C. Open Textbook Collection. Whenever edits or updates are made, we make the required changes in the text and provide a record and description of those changes here. If the change is minor, the version number increases by 0.1. However, if the edits involve substantial updates, the version number goes up to the next full number. The files on our website always reflect the most recent version, including the print-on-demand copy.

If you find an error in this book, please fill out the Report an Open Textbook Error form. We will contact the author, make the necessary changes, and replace all file types as soon as possible. After, this Versioning History page will be updated to reflect the edits made.

Version	Date	Change	Details
1.1	May 1, 2015	Book added to the B.C. Open Textbook collection.	
1.2	November 21, 2017	• Fixed blue text • Reformatted exercise questions	Some <a id=""> tags in the book were causing large sections of text to turn blue. These tags were removed. In addition, all of the exercise questions were edited to ensure a consistent format. This involved putting the content into ordered lists and grouping questions and answers together. Note: We are aware that there is some text missing in Chapter 20.4, that Chapter 14.1 is missing exercise questions, and that Chapter 14.2 and 14.3 have the same exercise questions. The author has been informed of these issues and we will update the book once we receive the corrections.
1.3	September 17, 2018	Image 2.15 replaced.	Original Figure 2.15 image was a duplicate of Figure 2.17. Replaced Figure 2.15 with the correct image.
1.4	June 13, 2019	Updated the book's theme.	The styles of this book have been updated, which may affect the page numbers of the PDF and print copy.

OpenStax
Concepts of Biology

OpenStax College is a non-profit organization committed to improving student access to quality learning materials. Our free textbooks are developed and peer-reviewed by educators to ensure they are readable, accurate, and meet the scope and sequence requirements of today's college courses. Unlike traditional textbooks, OpenStax College resources live online and are owned by the community of educators using them. Through our partnerships with companies and foundations committed to reducing costs for students, OpenStax College is working to improve access to higher education for all. OpenStax College is an initiative of Rice University and is made possible through the generous support of several philanthropic foundation

About *Concepts of Biology*

Concepts of Biology is designed for the single-semester introduction to biology course for non-science majors, which for many students is their only college-level science course. As such, this course represents an important opportunity for students to develop the necessary knowledge, tools, and skills to make informed decisions as they continue with their lives. Rather than being mired down with facts and vocabulary, the typical non-science major student needs information presented in a way that is easy to read and understand. Even more importantly, the content should be meaningful. Students do much better when they understand why biology is relevant to their everyday lives. For these reasons, *Concepts of Biology* is grounded on an evolutionary basis and includes exciting features that highlight careers in the biological sciences and everyday applications of the concepts at hand. We also strive to show the interconnectedness of topics within this extremely broad discipline. In order to meet the needs of today's instructors and students, we maintain the overall organization and coverage found in most syllabi for this course. A strength of *Concepts of Biology* is that instructors can customize the book, adapting it to the approach that works best in their classroom. *Concepts of Biology* also includes an innovative art program that incorporates critical thinking and clicker questions to help students understand—and apply—key concepts.

Coverage and Scope

Our *Concepts of Biology* textbook adheres to the scope and sequence of most one-semester non-majors courses nationwide. We also strive to make biology, as a discipline, interesting and accessible to students. In addition to a comprehensive coverage of core concepts and foundational research, we have incorporated features that draw learners into the discipline in meaningful ways. Our scope of content was developed after surveying over a hundred biology professors and listening to their coverage needs. We provide a thorough treatment of biology's fundamental concepts with a scope that is manageable for instructors and students alike.

- Unit 1: **The Cellular Foundation of Life**. Our opening unit introduces students to the sciences, including the process of science and the underlying concepts from the physical sciences that provide a framework within which learners comprehend biological processes. Additionally, students will gain solid understanding of the structures, functions, and processes of the most basic unit of life: the cell.
- Unit 2: **Cell Division and Genetics**. Our genetics unit takes learners from the foundations of cellular reproduction to the experiments that revealed the basis of genetics and laws of inheritance.
- Unit 3: **Molecular Biology and Biotechnology**. Students will learn the intricacies of DNA, protein synthesis, and gene regulation and current applications of biotechnology and genomics.
- Unit 4: **Evolution and the Diversity of Life**. The core concepts of evolution are discussed in this unit with examples illustrating evolutionary processes. Additionally, the evolutionary basis of biology reappears throughout the textbook in general discussion and is reinforced through special call-out features highlighting specific evolution-based topics. The diversity of life is explored with detailed study of various organisms and discussion of emerging phylogenetic relationships between and among bacteria, protist kingdoms, fungi, plants, and animals.
- Unit 5: **Animal Structure and Function**. An introduction to the form and function of the animal body is followed by chapters on the immune system and animal development. This unit touches on the biology of all organisms while maintaining an engaging focus on human anatomy and physiology that helps students connect to the topics.
- Unit 6: **Ecology**. Ecological concepts are broadly covered in this unit, with features highlighting localized, real-world issues of conservation and biodiversity.

Pedagogical Foundation and Features

Because of the impact science has on students and society, an important goal of science education is to achieve a scientifically literate population that consistently makes informed decisions. Scientific literacy transcends a basic understanding of scientific principles and processes to include the ability to make sense of the myriad instances where people encounter science in day-to-day life. Thus, a scientifically literate person is one who uses science content knowledge to make informed decisions, either personally or socially, about topics or issues that have a connection with science. *Concepts of Biology* is grounded on a solid scientific base and designed to promote scientific literacy. Throughout the text, you will find features that engage the students in scientific inquiry by taking selected topics a step further.

- **Evolution in Action** features uphold the importance of evolution to all biological study through discussions like "Global Decline of Coral Reefs" and "The Red Queen Hypothesis."
- **Career in Action** features present information on a variety of careers in the biological sciences, introducing students to the educational requirements and day-to-day work life of a variety of professions, such as forensic scientists, registered dietitians, and biogeographers.
- **Biology in Action** features tie biological concepts to emerging issues and discuss science in terms of everyday life. Topics include "Invasive Species" and "Photosynthesis at the Grocery Store."

Art and Animations that Engage

Our art program takes a straightforward approach designed to help students learn the concepts of biology through simple, effective illustrations, photos, and micrographs. *Concepts of Biology* also incorporates links to relevant animations and interactive exercises that help bring biology to life for students.

- **Concepts in Action** features direct students to online interactive exercises and animations to add a fuller context and examples to core content.