INTRODUCTION TO ANATOMY AND PHYSIOLOGY

The human body is a complex organism that functions at many different levels. This module provides a broad prospective on what the rest of this text will cover in detail. It is important that you achieve a complete understanding of each module before you move on to the next.

heart of the matter

Each of your cells is its own incredible world, containing basic knowledge of how to survive. Instead of living for itself, however, each cell cooperates with other cells to form and sustain the anatomy and physiology of your body. You are probably not even aware of your cells' individual presences. As you read through this chapter, take a few moments to contemplate how complex your body is and how no part functions entirely on its own.

Anatomy is the study of the structure of the body and its parts, while physiology is the study of how those parts function and work together to make the human body the wonder that it is. There are many different ways that anatomy can be studied.

Developmental anatomy is the study of the changes that begin in the human body at conception and proceed into adulthood. Embryology is the subdivision of developmental anatomy that covers the first eight weeks following conception. This time period is filled with amazing moment-to-moment changes.

Surface anatomy is used for diagnosis. When a physician feels your skin to determine whether your glands are swollen or if there are any suspicious lumps or bumps on your body, the physician is using surface anatomy.

Regional anatomy means analysis of specific parts of the body. Have you ever been to a podiatrist (foot doctor)? Podiatrists treat diseases of the feet, including warts, infected toenails, and aches and pains of the many joints within the feet. Podiatry is a good example of an application of regional anatomy. The podiatrist needs to know the precise location of blood vessels, nerves, muscles, tendons, ligaments, and bones. How else could the podiatrist, for example, safely inject an anti-inflammatory medication into a patient's painful foot?

In this course, the majority of study will focus on gross anatomy. *Gross* in this context means large, so you will be studying systems that you can see. The term macroscopic anatomy is also used to mean gross anatomy. To understand how an organism functions, however, you sometimes have to see it up close. Microscopic anatomy is the study of structures so small that you will be required to use a microscope to see them. As necessary, we will cover microscopic anatomy.

This text concentrates on systemic anatomy, which means anatomy of the organ systems—groups of organs related by shared functions. One example of systemic anatomy is the digestive system. The organs—teeth, tongue, esophagus, stomach, intestines, liver, pancreas, and others—all cooperate as a system to provide a common function, which is digesting food. Systemic anatomy is the best approach when both anatomy and physiology are being studied at the same time.

Comparative anatomy refers to the anatomy of nonhuman species, and it can be used to assist in the study of the human body. Your dissection labs are a comparative anatomy study. For example, the bones of some animals are homologous (huh mol' uh gus), which means that they are similar.

As demonstrated by figure 1.1, comparative anatomy is truly a fascinating study. The human forearm is made of two bones called the radius and the ulna. A porpoise's flipper also has a radius and ulna, and the bones that form a bird's wing include a radius and ulna. Thus, we could say that a porpoise swims with its "arms" and a bird flies with its "arms." A bat's "arm" also contains a radius and an ulna, but they are small. Bones that are similar to human finger bones (phalanges) form the bat's wings. Thus, we can say that the bat flies with its "fingers."

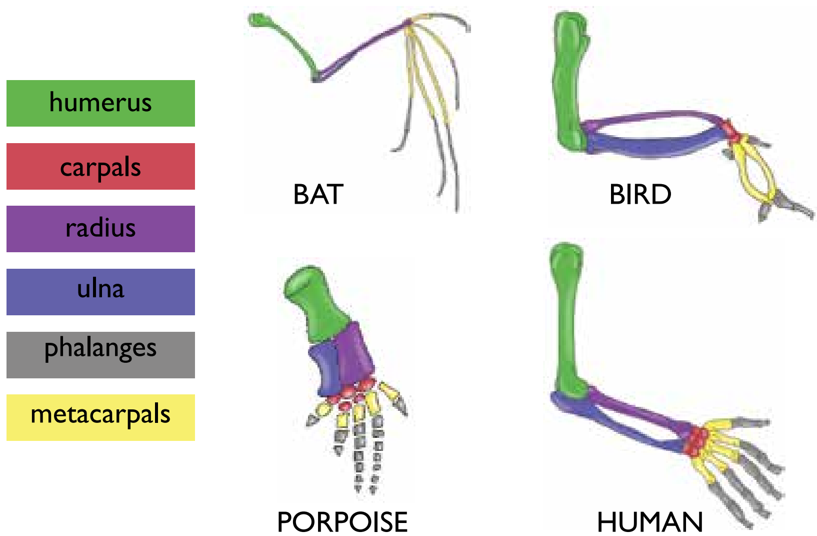


FIGURE 1.1
Comparative Anatomy of Upper (Fore) Limbs
Illustration by Megan Fruchte

Do not worry about memorizing the bones in this figure. For right now, just notice that even though bats, birds, porpoises, and people are quite different from one another, they have similar bones. In other words, these bones are homologous.

ORGANIZATIONAL LEVELS OF THE HUMAN BODY

The first thing you need to be familiar with is that the human body is organized on several different levels. The highest level of organization is the entire person, or whole **organism**. The entire person, of course, is made up of a single human body. When we look at that human body from a scientific point of view, what do we see? First, *we can divide the entire body into eleven different organ systems*.

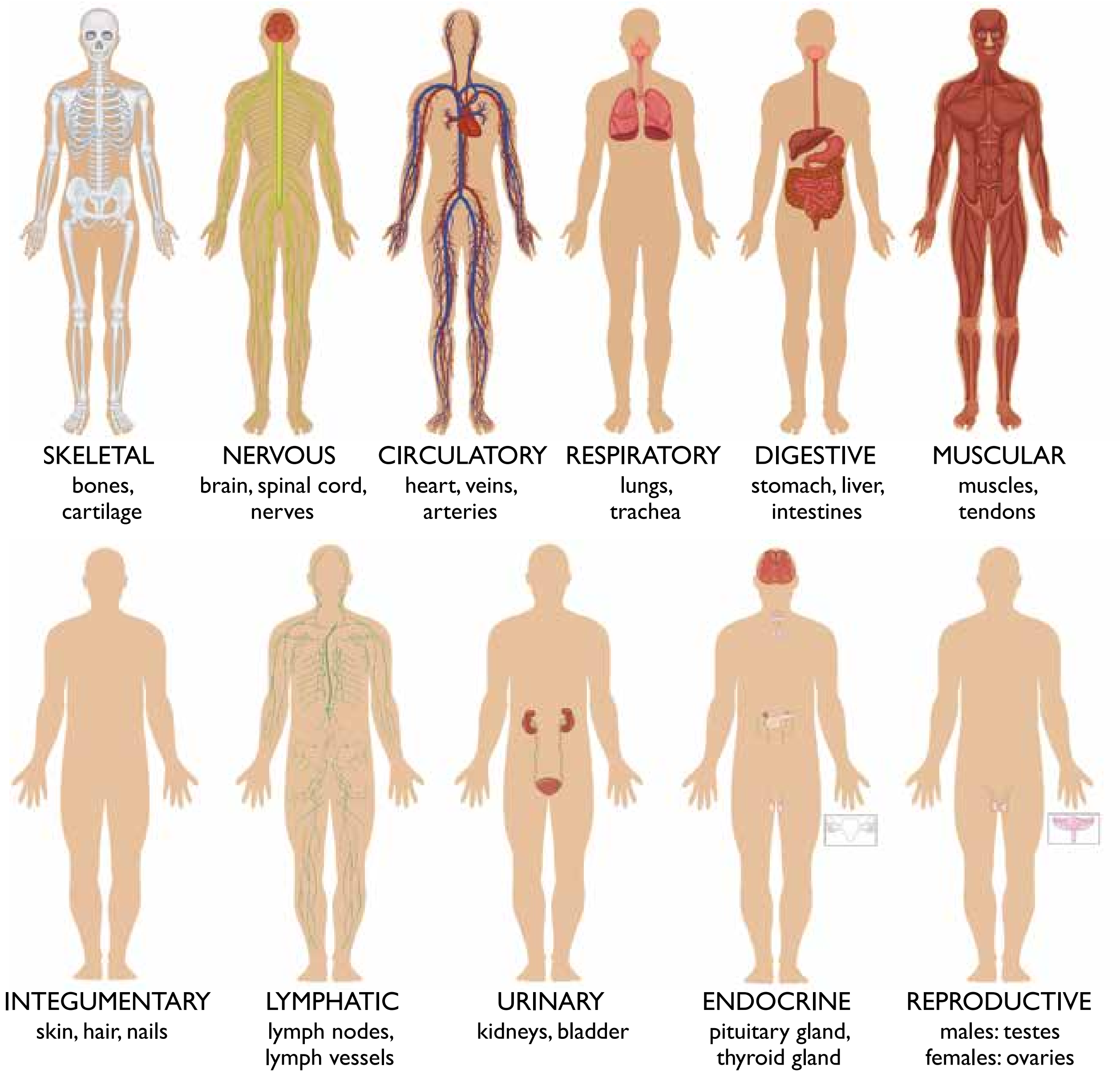


FIGURE 1.2
The Eleven Organ Systems in the Human Body with Examples of Organs
Illustrations: first eight © Matthew Cole, last three by Megan Fruchte

An organ system is a group of organs that work together to perform related functions. As you will learn, some organs belong to more than one organ system.

The skeletal system is made up of the bones in your body and their associated cartilages, ligaments, and joints. It provides support, as in the leg bones, and protection, as in the skull and ribs. It gives shape to the body, and its joints allow the body to move. It also produces blood cells.

The nervous system is composed of the brain, spinal cord, nerves, and all of your body's sensory receptors, including vision, hearing, smell, taste, and touch receptors. It detects sensations and controls movement, and it controls intellectual function. It regulates the other organ systems, and so is "in charge" of many physiological processes, both conscious and unconscious. It is capable of very rapid responses.

The circulatory system is composed of the heart, blood vessels, and blood. It transports gases, nutrients, waste products, hormones, and many other molecules throughout your body. It has an active role in your immune system and also aids in the regulation of your body temperature.

The respiratory system contains your lungs, respiratory passages, and diaphragm. It enables the exchange of oxygen and carbon dioxide between your blood and the air. It also has a role in regulating your blood pH.

The digestive system is perhaps the most familiar of all the organ systems. Your mouth, esophagus, stomach, intestines, liver, gallbladder, pancreas, appendix, and rectum are all part of it. It breaks down the foods you eat so that they can be absorbed out of the intestines into the blood, and it eliminates waste products.

The muscular system consists of the muscles of your body. It powers the movements of your skeleton and maintains your posture when you stand still. It enables internal organs such as the heart, diaphragm, stomach, and intestines to move. It is also used to generate heat, as when you shiver.

The integumentary system consists of skin, hair, sweat glands, oil glands, and nails. Its purpose is to protect your body, regulate your body temperature, prevent water loss, and aid in the production of vitamin D.

The lymphatic system consists of a multitude of organs, including your spleen, thymus gland, lymphatic vessels, and lymph nodes. It is sometimes called the immune system, because it gets rid of foreign substances such as bacteria, viruses, and fungi that may invade your body. But in addition to fighting disease, its thin-walled lymphatic vessels maintain the right amount of fluid around your cells, and these vessels also absorb fat from your digestive tract.

The urinary system consists of your kidneys, urinary bladder, ureters, and urethra. It removes waste products from your blood, and it regulates blood pH, ion balance, and water balance.

The endocrine system is made up of a number of organs that secrete signal molecules called hormones. The hypothalamus, pineal gland, pituitary gland, thyroid gland, parathyroids, thymus, adrenals, pancreas, ovaries (female), and testes (male) are all typical hormone glands.

However, the heart, stomach, small intestine, and kidneys also secrete hormones, even though we usually classify them with other organs systems. Along with the nervous system, the endocrine system regulates other organ systems. This system influences metabolism, growth, reproduction, and many other unconscious internal functions of your body. It generally acts more slowly than does the nervous system.

The reproductive systems are made up of the female ovaries, vagina, uterus, and mammary glands; or the male testes, penis, prostate gland, and other internal organs.

The female reproductive system produces oocytes for fertilization, provides a place for fetal development, and produces milk for the newborn. The male reproductive system produces and transfers sperm for fertilization. Both the female ovaries and male testes produce important reproductive hormones.

This is the big picture of what you will study throughout this course. By the time you are done, you will have greater knowledge of each of these organ systems.

We've mentioned the term *organ* a few times, but we really have not defined it yet.

COLORING BOOK EXERCISE 1.1

In the laboratory supplies for this course, we have included *The Anatomy Coloring Book* by Kaplan. This is an excellent tool for remembering anatomy. We recommend reviewing what you have just learned by coloring in the organ systems found on pages 9-13 in this coloring book.

Organ—A group of tissues specialized for a particular function

Examples of organs include the liver, lungs, kidneys, heart, skin, and many others that you could list. Of course, the definition of an organ does not do much good without a definition of tissues. Tissues are like building materials that can be assembled in multiple ways to build the structures of your body.

Tissues—Groups of cells forming various building materials of the body

Now, here is an amazing thing. There are eleven organ systems in your body, and each of those systems is made up of many different organs. Thus, there are a *lot* of organs in your body, and some organs are members of more than one organ system. You would, therefore, expect there to be a multitude of tissues in the body; however, *there are only four basic kinds of tissue in the entire human body!*

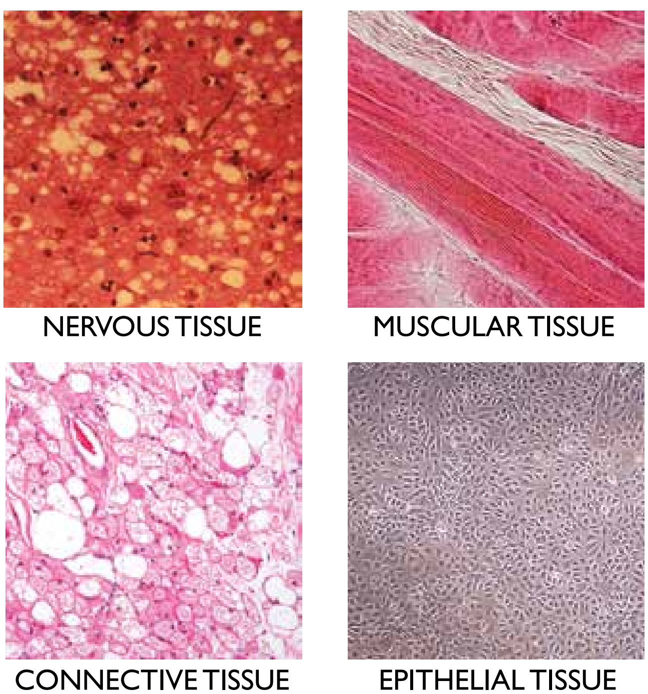


FIGURE 1.3
Four Types of Tissue
Photos (clockwise from top left): Public Health Image Library, APHIS, PD; Department of Histology, Jagiellonian University Medical College, cc-by-sa 3; Nephron cc-by-sa 3; Subclavian, PD

The first basic kind of tissue is nervous tissue. It makes up the brain, spinal cord, and nerves. Nervous tissue has the ability to conduct electrical signals.

Muscular tissue comprises the muscles that enable your skeleton to move, your heart to beat, and your other internal organs to push food or fluid along.

The third type of tissue is connective tissue, which makes up bone, cartilage, the deeper layer of the skin, and the bindings or connectors around and between organs. The bridge of your nose and the flexible part of your ears are cartilage. Even your body fat and your blood are connective tissues.

The last of the four basic kinds of tissue is epithelial (ep uh theel' ee uhl) tissue. The surface of your skin is epithelial tissue, as is the inner lining of your respiratory passages, digestive tract, urinary tract, and reproductive tract. Glands, including your thyroid gland, liver, and many others, are also made of epithelial tissue.

Are you beginning to see a pattern here? The human body is organized into organ systems. Each organ system is composed of specific organs, which do one or more jobs to achieve common goals. Each organ is composed of tissues. Notice, then, that we have already discussed four levels of organization in the human body: whole body, organ system, organ, and tissue. The first three levels are part of the study of gross anatomy.

Tissues are best studied at the level of microscopic anatomy because each tissue is composed of specific cells. The cell is the basic unit of life. The trillions of living cells that make up your body are themselves composed of membrane-bound organelles, which means little organs. Thus, even your cells are composed of smaller units! Beyond this level is biochemistry. Organelles are formed from incredibly complex molecules, such as proteins, fatty acids, and carbohydrates. Finally, these molecules are a combination of atoms; see figure 1.4.

COLORING BOOK EXERCISE 1.2

The levels of organization are illustrated and discussed on page 5 of your coloring book. Use this as a review for what you have just learned. Note that the coloring book refers to these levels as the hierarchy of the body.

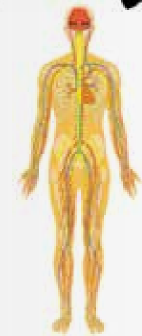
ON YOUR OWN

1.1 Certain muscles are attached to your skeleton by tendons. Of the four tissue types, which kind makes up tendons?

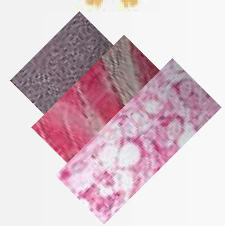
1.2 Which three levels of organization in the human body are studied in gross anatomy?

1. The Whole Organism is made up of eleven organ systems.

2. Organ Systems consist of groups of organs that work together to perform related functions.



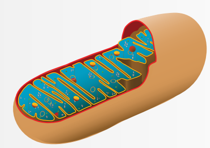
3. Organs consist of different types of tissues.



4. Tissues consist of similar types of cells and the materials around them.

5. Cells are made up of organelles.

6. Organelles are the "little organs" of the cell. They are made of molecules.



7. Molecules that cells make include DNA, RNA, proteins, fatty acids, and carbohydrates. Molecules consist of complex arrangements of atoms.

FIGURE 1.4
Seven Levels of Organization
Photos (top to bottom): Dreamstime; composite of illustrations by Matthew Cole; Department of Histology, Jagiellonian University Medical College, cc-by-sa 3; Nephron cc-by-sa 3; Subclavian, PD; Mariana Ruiz Villarreal LadyofHats; Inc ru, cc-by-sa 3.0

think about this

When you were growing up, you found stability and security in having boundaries. Your parents set the boundaries for you because they knew what was required to help you grow and learn about God's purpose for your life. Your physical body also requires boundaries. Homeostasis keeps your body functioning within the boundaries necessary for maintaining your life.

HOMEOSTASIS

We have briefly introduced to you the anatomy (structure) of the body, which underlies the physiology (function) of the human body. What is the goal of physiology? *The goal is to maintain life and health in spite of the many changes, inside and out, that are always occurring.*

Energy must be expended constantly to maintain life, so energy must be acquired from outside the body in the form of food. That food must be processed, delivered to each cell, and then used by those cells as building materials or as an energy source. For example, the molecules that make up your organelles deteriorate and must be replaced, a process that requires both materials and energy. In thousands of ways, moment by moment, the organ systems maintain the body so that it can continue to live and be healthy. We could say that the goal is to keep the body working "normally" or "with stability" despite constant external and internal changes. The scientific term for this ongoing stability despite ongoing change is homeostasis (ho' me oh stay' sis).

Homeostasis—A state of dynamic equilibrium in the body with respect to its internal environment and functions

Let's analyze that definition for a minute. Equilibrium means balance or stability, and dynamic refers to energy. The "internal environment" in this usage means the surroundings of the cells that make up the body. "Functions" might be defined as the tasks the cells perform. So, homeostasis means the ability of your body to maintain itself in a stable balance despite the fact that energy must be used to do so. That healthy stability is maintained internally around the cells. That environment is far different from the external environment, outside the body.

Homeostasis is *the* big idea of physiology, and we will help you to gradually develop your understanding of it. Yes, we need to have a stable environment within our bodies, and there are many different variables within, such as temperature, acid-base balance, nutrient levels, blood pressure levels, oxygen levels, and waste levels, that must be controlled. What keeps us alive is the ability to maintain these variables and many more around some normal level, which we call a set point. These variables can change somewhat, but only within certain limits. If they would change too much, serious problems, illness, or death would result. Each of the organ systems illustrated in Figure 1.2 is responsible for maintaining some aspect of homeostasis for the entire person.

Set point—Ideal normal value of a variable around which homeostasis is maintained through a normal range of values that are acceptable to the body

Blood pressure is a variable that offers a good example of how homeostasis is maintained. Your blood pressure can go up under certain conditions (such as when you exercise), and it can go down under other conditions (such as when you are asleep), but it is controlled within a normal range. Thus, your body is constantly working to ensure that your blood pressure stays in equilibrium around the set point. That is a practical application of the concept of homeostasis.

FIGURE 1.5
Homeostasis
Your body constantly monitors its temperature and adjusts to maintain homeostasis. This child is sweating (integumentary system) because he is too hot. If this child were to get too cold, he would start to shiver (muscular system). The motion of the muscles would produce heat, warming the body.
Photo © iStockphoto/TerryJ

Your body temperature is another variable that must be controlled. Whether your external environment is really cold or really hot, the temperature of your internal environment does not vary much. Even when you have a fever, your body temperature is still not out of control. Your body has merely increased the set point for body temperature to deal with an infection. There are many variables within the body that must be controlled in order for the body to work properly. When those variables are within the normal range of acceptable values, the body is in a state of homeostasis. It is healthy!

Your body requires mechanisms to maintain homeostasis because the outside world (the external environment) and the needs of the body itself subject your body to stress. Now when you hear the term stress, you probably have a specific idea in mind. For example, studying for a hard test might cause you stress. In this course, however, we use the term in a much broader sense. Stress is an imbalance in the internal or external environment that causes one or more variables to move away from its set point. This causes your body to react to return the variable to an acceptable value. If the variables are not corrected, your health will be affected. In other words, stress is an imbalance that must be corrected to maintain homeostasis.

Stress—A factor that causes one or more physiological variables to move away from its homeostatic set point

The common cold is an example of a stress. Colds are caused by viruses that have invaded your body. You might not think that a cold is very bad but that's because you have an organ system (the lymphatic system) which creates uncomfortable symptoms as it combats the virus and rids it from your body, restoring homeostasis. Without your lymphatic system, the common cold probably would be called *the fatal cold*.

The organ systems in the body, each in their own ways, contribute to homeostasis. The urinary system maintains acid-base balance; the respiratory system maintains oxygen and carbon dioxide balance, and so on, as you will learn throughout this course. Each organ system counteracts particular stresses so as to maintain the body's normal balance. Some physiologists propose that there is one exception among the eleven organ systems, however. Can you guess which one? It is the reproductive system, which is designed to propagate the human race. We will discuss this in a later chapter.

CONTROL OF HOMEOSTASIS: FEEDBACK SYSTEMS

Let's look for a moment at the control mechanisms of homeostasis. You will see that the issue of control will come up again and again throughout this course. It is one of the most fundamental aspects of physiology. Two organ systems, the nervous system and the endocrine system, are responsible for "deciding" if a variable is moving away from a state of homeostasis. They then initiate a message to correct the imbalance. The brain and spinal cord, together called the central nervous system, act as the nervous system's control center. Endocrine glands also serve as control centers. They secrete chemical messengers called **hormones** that signal the proper organs to respond in such a way as to maintain homeostasis.

think about this

Did you know that the simple act of standing up after lying down is actually a major change for your body? When you stand up after you have been lying down, your blood pressure drops as gravity pulls your blood away from your head. Your body quickly compensates for this change through a negative feedback mechanism. Otherwise, if you stood up suddenly, you would faint, because your blood pressure would be too low. Have you ever gotten light-headed after standing up too quickly? That happened because your negative feedback system took a little too long to raise your blood pressure.

Control center—The part of the body, either central nervous system or endocrine gland, that receives information about a variable, determines the set point, and signals a response to correct imbalances

Here's an example of how homeostasis works. Earlier, we told you that blood pressure must not get too high or too low. A "happy medium" keeps you healthy. Your body's blood pressure is detected by sensory receptors located in arteries near the heart and in the neck. When these receptors sense high blood pressure, nerves associated with them send a message to your brain, the control center, indicating that your blood pressure is too high.

Receptor—A structure in the body that monitors the values of your body's variables

Your brain, however, can't directly lower blood pressure. In order to get the job done, it sends a message via nerves to an effector. The effector makes the change. In this example, the effector is the heart, which slows down in order to lower your blood pressure.

Effector—A structure in the body that can change the value of a variable in response to a signal from the control center

As the definition indicates, the effector can change the blood pressure. In this example, the brain sends a message via nerves to the effector, and the effector then lowers the blood pressure. The effect, called the "response," is that your blood pressure drops. This, then, is an example of how your body detects and counteracts stress. What we have here is a really useful process called a negative-feedback system, which is illustrated in figure 1.6.

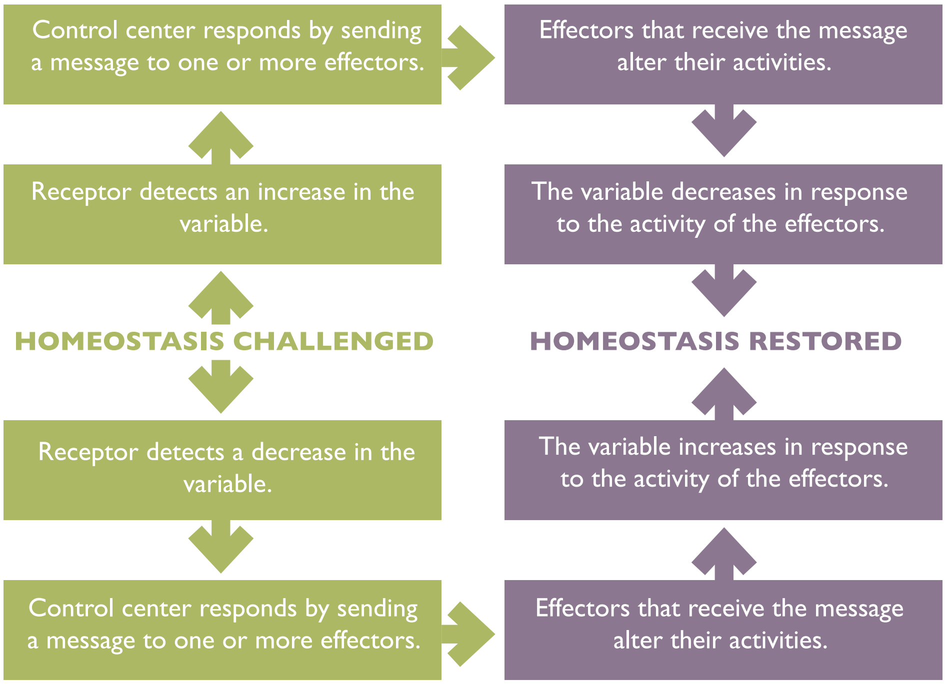


FIGURE 1.6
The Body's Negative-Feedback System

Negative-Feedback System—A control mechanism consisting of receptors, control center, and effectors through which homeostasis in the body is maintained by regulation of the body's organ systems. It is called negative feedback because the control system *opposes* or *reverses* the original stress.

Now think of the blood pressure example we just gave you in terms of the upper part of figure 1.6. An increase in blood pressure is detected by the receptors in your arteries. Those receptors send signals about the blood pressure that your brain (the control center) monitors. If the brain senses that your blood pressure is getting too high, it sends a message via nerves to one or more effectors. In our example, we used only one effector, the heart. Your heart changes its activity (it slows down), and the result is that your blood pressure decreases. Thus, an *increase* in blood pressure detected by the control center produced a reaction that caused a *decrease* in the blood pressure.

The opposite can happen as well. Look at the lower portion of figure 1.6. Remember, blood pressure that is too low is also a stressor. If the receptors in your arteries detect a decrease in blood pressure, they will relay that information to the brain. As the control center, the brain will recognize that your blood pressure is getting too low, and it will send a message to your heart (the effector). The message will be for your heart to speed up, and the result will be that your blood pressure increases. So, in this case, a *decrease* in blood pressure produces a reaction that will *increase* blood pressure. That's what negative feedback means—the feedback system detects a change and initiates the *opposite* effect. *Negative* in this usage means "opposite."

Let's go through one more example. As you know, the level of glucose in your blood is closely regulated, whether you have just eaten a big meal or whether you have not eaten for many hours. Blood glucose is sensed by receptors in your pancreas. If your pancreas (the control center in this case) receives information from its receptors that blood glucose levels are too high, it releases the hormone insulin (in' suh lin) into your blood. Insulin affects most of the cells in your body. They respond to the insulin by taking in glucose. This removes glucose from your blood, which results in a decrease in the blood glucose level. This is negative-feedback because the response *reverses* the stress.

What body system is the control center in this negative feedback mechanism? The *endocrine* system. Hormones are secreted by the endocrine system. Thus, *if a hormone is involved, the endocrine system must be involved.*

In summary, homeostasis is controlled by negative-feedback mechanisms. Both the nervous system and the endocrine system are used as control centers to maintain homeostasis within the body. This is no small feat given that these systems coordinate homeostasis for trillions of cells!

Before we end this discussion, we should mention positive-feedback systems. That sounds great, does not it? *Positive* means "good," right? Well, not when it comes to feedback mechanisms! Positive-feedback systems are naturally unstable and *escalate* the imbalance, moving the body farther and farther away from homeostasis. They can lead to disease or death unless they are interrupted.

Nevertheless, there are certain times when positive-feedback systems are important in human physiology. When we study the reproductive process toward the end of this course, you will see an example of a positive-feedback system that is necessary for childbirth. However, that positive-feedback system is *eventually* interrupted by the birth of the baby, and a negative-feedback system takes its place. Thus, even the positive-feedback systems that are necessary in the body (there are not many of them) must eventually be interrupted.

ON YOUR OWN

We already have discussed shivering as a response to the body being cold. Here's how it works. Receptors in the skin send temperature information to the hypothalamus (hi poh thal' uh mus), a structure in the brain. If the hypothalamus "decides" that the temperature is too low, it can send signals via the nerves to the muscles. These signals cause the muscles to start moving rapidly, which we observe as shivering. This increased movement produces heat, which warms the body.

1.3 Is this a negative- or positive-feedback system? Why?
1.4 What is the control center for the system?
1.5 What is the effector?
1.6 Based on this description, is the endocrine system involved in this process?

A REVIEW OF CELL STRUCTURE AND ORGANELLE FUNCTION

So far, in terms of organization in the human body, we have talked about the organism, the organ systems, and the organs. In the next module, we will discuss tissues, so we will not talk about that level of organization here. Instead, we will jump down to the next levels of organization: the cell and its organelles. We will not spend too much time on this subject. The majority of your anatomy and physiology study will occur at the tissue level and above.

Figure 1.7 is a drawing of an idealized animal cell. All members of kingdom Animalia, including human beings, have this basic kind of cell. You have to realize, however, that there is probably no cell in the human body that looks exactly like the illustration in the figure. Indeed, some cells (such as neurons) look quite different from what you see here. Nevertheless, the features that you find in various cells throughout the body are woven together into this idealized representation of a typical animal cell.

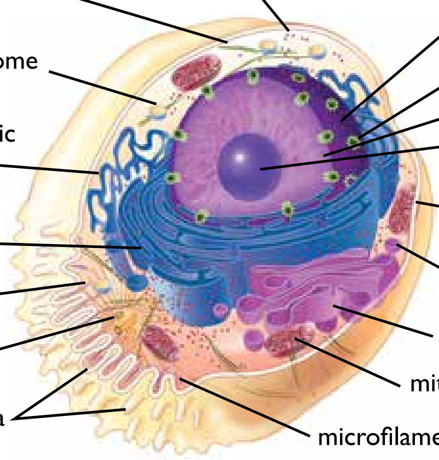


FIGURE 1.7
An Idealized Animal Cell
Illustration: Jennifer Fairman

Of course, not every cell will have all of the features pointed out here. The key is that all of the features pointed out exist in at least some cells. For example, mature red blood cells do not have a nucleus. Nevertheless, most of your other cells do. Cells that line your trachea (the airway to your lungs) are an example of cells with cilia, but most of your cells do not have cilia.

Remember, tissues are composed of cells, and cells are composed of organelles. In order to understand cells, you need to know the major organelles and their functions. Let's start with the plasma membrane. The plasma membrane is the boundary of the cell. It holds the cell together and controls entry and exit of substances. It has many receptors on it, allowing it to determine what substances are transported into the cell and what substances are allowed out of the cell.

The next organelle to consider is the nucleus. It's wrapped in a nuclear membrane called the nuclear envelope. It is actually a double membrane, which is quite porous. The nucleus contains the genetic material, which is DNA (deoxyribonucleic acid). Except during cellular reproduction, the DNA is "spread out" in the nucleus. We usually use the term chromatin (kro' muh tin) to identify it. During cellular reproduction, the DNA forms chromosomes (krom' uh sohms). We will go over that in a later section of this module. The nucleus can be thought of as the control center of the cell because the DNA is there. The DNA codes for all the proteins that the cell produces.

Between the nucleus and the cell membrane, cytoplasm (sigh' toh plaz uhm) is found. The fluid part of the cytoplasm, called cytosol, contains many dissolved chemicals,

think about this

Although the cells in your body are all chemically similar, they are as diverse as flowers in a florist shop. Some journey through your body to bring oxygen to other cells; others enable your body to move. Bone cells provide rigid structure for your body, and soft skin cells contribute to your physical appearance. No matter how small and odd your cells may seem, they all work together to create the wonder of your life.

including ions, proteins, and other molecules. These chemicals are used for various processes, including the breakdown of sugars and fats, as well as for the production of other chemicals that the cell needs.

If we think of the nucleus as the control center of the cell, the ribosomes (rye' buh sohms) can be thought of as tiny kitchens within the cell. Proteins are synthesized in the cell's ribosomes. The proteins that a cell produces are a major part of determining what the cell does for the body. So, the ribosomes are an essential part of the cell. Because they are so tiny, they are represented by dots in the figure. Sometimes, the ribosomes stand alone. If so, they are called free ribosomes. You may also find ribosomes attached to the next organelle that we will to discuss, the endoplasmic (en' doh plaz' mik) reticulum (re tik' you luhm).

The prefix *endo* means "within," and *plasmic* refers to the cell's cytoplasm. The word *reticulum*, from the Latin, means "network." Thus, the endoplasmic reticulum is the network within the cell's cytoplasm. There are two types of endoplasmic reticulum: smooth endoplasmic reticulum and rough endoplasmic reticulum. The smooth endoplasmic reticulum is a series of tubes that are used in intracellular transport (transport within the cell) as well as in the production of lipids and carbohydrates. Rough endoplasmic reticulum is also used for intracellular transport, but it is rough in appearance because it has ribosomes on it. Because of these ribosomes, rough endoplasmic reticulum is used in protein synthesis as well as intracellular transport of proteins. The amount of smooth and rough endoplasmic reticulum can give you a clue as to the function of the cell. Cells with large amounts of smooth endoplasmic reticulum usually specialize in the production of lipids and carbohydrates. Cells with large amounts of rough endoplasmic reticulum specialize in protein synthesis.

The Golgi (gol' jee) apparatuses can be thought of as the cell's packaging plants. They take various chemicals and package them for many purposes, especially secretion. This packing may involve chemical modification. Nervous system cells, called neurons, have many Golgi apparatuses. That should tell you something about what they do. They secrete chemicals. When you eat, your salivary glands secrete saliva. This is done by the Golgi apparatuses within the salivary glands' cells.

The secretory (sec' ruh tor ee) vesicle in figure 1.7 came from the Golgi apparatus. When the Golgi apparatus has packaged a chemical for secretion, it puts the chemical into a secretory vesicle, which is a tiny membrane-bound sac. The vesicle then pinches off the Golgi apparatus and travels through the cytoplasm to the plasma membrane, where its contents can be released outside the cell. Often, a cell will build up secretory vesicles, but those vesicles will not release their chemicals until the cell gets a signal. For example, in our earlier discussion of blood glucose level, we mentioned that the pancreas releases insulin when the blood glucose level increases. That is done by cells in the pancreas whose Golgi apparatuses produce secretory vesicles full of insulin. However, those cells do not release their insulin

science and creation

Mitochondrial DNA is ideal for determining your maternal heritage because all of your mitochondrial DNA comes from your mother, as you will understand better when you study reproduction. However, since there is much less mitochondrial DNA compared to nuclear DNA, scientists must be careful about drawing too many conclusions when studying it. In 2008, for example, a study was done comparing mitochondrial DNA found in the skeletons of Neanderthals to that of the mitochondrial DNA from people living today. It was concluded that Neanderthals were a completely different species from humans! However, in 2010, a study was done comparing the nuclear DNA of Neanderthals and people living today, and that study concluded that Neanderthals and humans are both members of the same species. The conclusions of the latter study confirm what creationists have been saying about Neanderthals since they were first discovered. It is the more reliable of the two studies, since nuclear DNA is a more complete data set from which to draw such conclusions.

until they get a signal to do so. So, the vesicles tend to build up until the cells get the signal to release the insulin.

The lysosome (lie' so sohm) is a kind of vesicle, and its main function is to break down lipids, proteins, polysaccharides, carbohydrates, and nucleic acids. What makes the lysosome interesting is that, in order to do its job, it must contain certain enzymes. These enzymes are very damaging to other parts of the cell and can easily kill the entire cell if released from the lysosome.

Have you ever heard that you can only live four to eight minutes without oxygen? Do you know why? After four to eight minutes without oxygen, the lysosomes of the neurons can't hold themselves together. They then burst, dumping their lethal contents into the cell. This kills the neurons.

The rupturing of lysosomes is sometimes actually a *good* thing. When we need to get rid of diseased or damaged tissues, the lysosomes provide a way for these cells to, in effect, self-digest. White blood cells, for example, are full of lysosomes. Have you ever had a cut that got infected? Typically, an infected cut produces white pus. That white pus is from white blood cells (we will talk about these cells in more depth in a later module) that burst their lysosomes. This kills the white blood cell, but it also kills the foreign invader. Isn't that amazing?

Centrioles (sen' tree olz) are found in the centrosome (sen' truh sohm), which is the center of microtubule formation for the cell. Microtubules are spiral strands of proteins that form a rope-like structure. They influence the movement and shape of the cell. Centrioles are important in cellular reproduction.

Cilia are like tiny hairs formed from an intricate arrangement of microtubules. In your first-year biology course, you studied paramecia and perhaps other ciliates. They are examples of microscopic organisms with cilia. What you might not realize, however, is that there are cells in your body with cilia. For example, ciliated cells are in the back of your nose, down your trachea, and all the way down your larger airways. Their cilia beat upward, pushing mucus toward your throat. The mucus typically has dust and other foreign particles that it traps. Once the cilia-containing cells push the mucus far enough upward, it can be swallowed or blown out your nose.

Microfilaments also contribute to movement. They enable certain cells to contract. Muscle cells, for example, do their job by contracting and relaxing. The microfilaments in the muscle cells take care of this function. Your cells also have intermediate filaments, which are responsible for strengthening and supporting the cells. This allows them to maintain their normal shape.

Mitochondria (my tuh kahn' dree uh) are the major site of ATP synthesis in the cell. ATP (adenosine triphosphate) is the "currency" in which cellular energy is stored. As a result, we call the mitochondria the powerhouses of the cell. It is important to remember that not all ATP (and therefore not all cellular energy) is produced in the mitochondria. The first stage of cellular respiration (called glycolysis) actually occurs in the cytoplasm, so some ATP is made there. However, the vast majority of cellular energy is produced in the mitochondria.

Although most of the DNA in a cell is stored in its nucleus, there is actually some DNA in the mitochondria. This DNA, called mitochondrial DNA, codes for the production of certain proteins necessary for the mitochondrion (singular of mitochondria) to do its job. Not only is DNA present in the mitochondria, but ribosomes are as well. With both DNA and ribosomes, a mitochondrion can produce its own proteins. Interestingly enough, however, a mitochondrion cannot produce all of the proteins it needs. Some proteins vital for the mitochondria are still produced by DNA in the nucleus, and the ribosomes in the cytoplasm. Those proteins are then transported to the mitochondria.

COLORING BOOK EXERCISE 1.3

An overview of the cell and its organelles can be found on page 21 of your coloring book. Color and label sections a-p.

ON YOUR OWN

1.7 A microbiologist is looking at a cell under a microscope. It has a large number of Golgi apparatuses in it. What, most likely, is the cell's major function?

1.8 Substances regularly are transported into and out of cells. If a substance is transported into a cell, what is the first structure it must pass through?

A REVIEW OF PROTEIN SYNTHESIS

Proteins are large molecules formed by the joining of amino acids. The type and number of amino acids joined together, along with the order in which they join, determine the properties of the protein. For example, some proteins, called enzymes, act as catalysts. Catalysts are molecules that speed up chemical reactions without being either reactants or products. Other proteins act as hormones. Some act as antibodies, which fight infections. There are thousands and thousands of proteins involved in the processes of life.

Protein synthesis in the cell takes place in two steps, transcription and translation. A transcription is a written representation of something. Historically, scribes were the persons who copied documents—keep that in mind. Translation is the process of rendering the meaning of one thing (transcription) into something else (protein).

For all of its complexity, understanding DNA is rather simple. DNA is similar to the alphabet, except that it has only four letters, not twenty-six. These letters, called bases, are adenine (A), thymine (T), cytosine (C), and guanine (G). Just as the twenty-six letters of the alphabet are combined to form words of communication, these four bases, in groups of three, form "words" that make up genes. Genes are like sentences in that they state complete thoughts. Simply put, a cell can transcribe a gene and then translate that copy into a complete protein.

Here is an analogy to explain transcription and translation: Imagine that you would like a recipe for an old-fashioned johnny cake. You go to the library to a set of encyclopedias and look up "johnny cake." There you find a recipe, but of course, you cannot take the encyclopedia set out of the library. On the other hand, you do not need the whole set, and you do not even need the whole book. You just need the recipe. What do you do? You jot the recipe down on a piece of paper and take the information home. Once you get to your kitchen, you use the recipe to get the right amounts of the correct ingredients together, and then you use them to make the johnny cake.

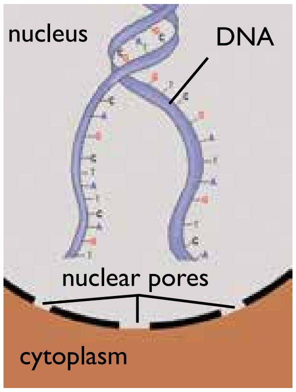
The library with its encyclopedias is like the nucleus of a cell. You can think of the library as having two sets of encyclopedias, each with twenty-three volumes. They are from different publishers, but they cover the same material, though perhaps with a different perspective. Those two sets represent the twenty-three pairs of chromosomes in your cells, one set of each pair inherited from each parent. They contain *all* the information for *everything* every cell in the body can do.

Of course, no one cell needs anywhere near all that information, and it is enclosed in the cell nucleus anyway. When you opened up one volume to the correct page and made a copy on paper, that was transcription. Some of the DNA from one DNA molecule "unwound," so that a copy could be made of just that part. Your paper with the correct information copied from the book is messenger RNA (mRNA).

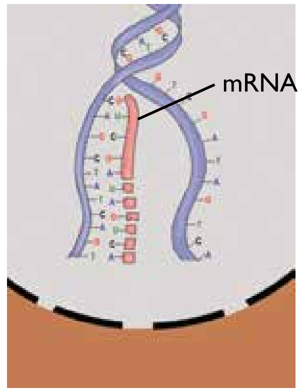
The mRNA, like a recipe, has the information you need, and it is small enough to leave the nucleus. The ribosomes where proteins are made are like the kitchen. When the mRNA is used to call up the right amino acids in the right order to make a protein, that process is called translation. Transfer RNA (tRNA) brings the correct amino acids to the ribosome to make the protein. Figure 1.8 illustrates this process.

think about this

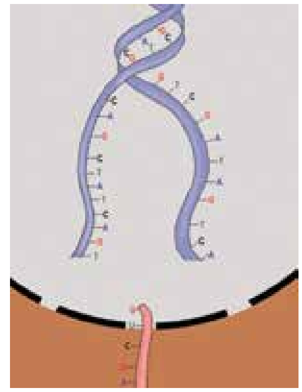
You are now a fully developed, mature person, but you started life as a single cell. At each cell division, your DNA copied itself so that each of your cells contains your entire DNA "encyclopedia." Throughout this process, your cells specialized according to their functions. Using the encyclopedia analogy, we could say, for example, that your muscle cells may operate from "volume four," and your nerve cells use "volume six," but they all have a complete set of DNA instructions. Now you might wonder how your DNA protects its information from mutations, which are abrupt changes in the DNA sequence. A very common kind of mutation is produced when the chemical machinery that copies DNA makes a mistake and uses the wrong nucleotide base. This, of course, will change the codon that is formed in transcription, which could result in a change in the protein, and that might be a real problem for the cell. However, since many codons refer to the same amino acid, many mutations don't result in a change in the protein because the new codon produced by the mutation still refers to the same amino acid to which the old codon referred. This is called redundancy, and it is very important in any kind of coding system. The more redundant the code, the less prone it is to random error. Interestingly enough, when two researchers (Freeland and Hurst) analyzed the genetic code of DNA in terms of how well it uses its redundancy to reduce random error, they found that it is significantly better than codes that scientists could devise. Indeed, the title of the paper by Freeland and Hurst in which they published their results is "The Genetic Code Is One in a Million."
—Freeland and Hurst, 1998



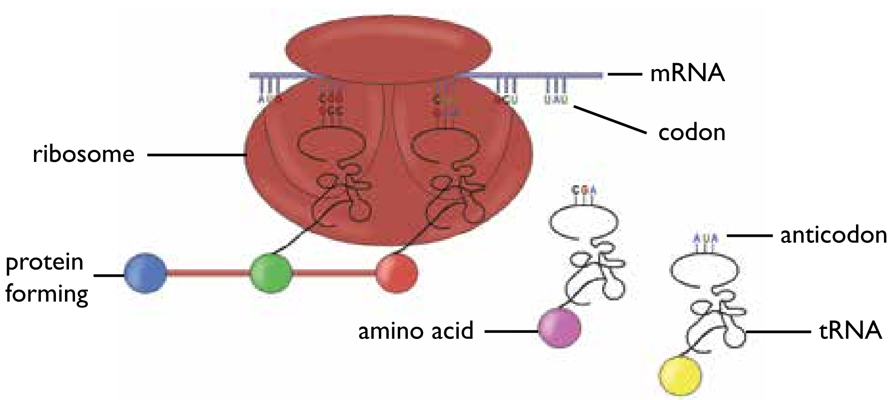
In the nucleus of the cell, DNA unwinds.



RNA nucleotides in the nucleus bind to the exposed DNA nucleotides, forming a strand of mRNA. The mRNA copies only a a small part of the DNA's information.



The smaller mRNA then leaves the nucleus through a nuclear pore and goes to a ribosome, where there are plenty of tRNA molecules and the associated amino acids.



In the ribosome, tRNA strands are attracted to mRNA sections that have a codon with which their anticodon can bind. They bind to that section of the mRNA, dragging their amino acids along with them. This results in amino acids sitting next to each other. The amino acids chemically bond, and after this happens many, many times, a protein is formed.

FIGURE 1.8
A Schematic Describing Protein Synthesis in Cells
Illustration by Megan Fruchte

A REVIEW OF CELLULAR MITOSIS

Before we move on to information that will be new, a review of one more thing about cells is in order. One of the most fundamental processes that a cell must undergo is reproduction. Indeed, you started your life as a single cell. In order to develop into the person you are today, that single cell and all of its *daughter cells*, as they are called, had to reproduce over and over again. In addition, most of the cells in your body must reproduce so that you can grow and repair injuries.

Cells reproduce according to a process known as mitosis (mye toh' sis). This process takes place in four broad steps: prophase, metaphase, anaphase, and telophase. When a cell is not undergoing mitosis, it is said to be in interphase, which is the normal state for a living cell. All of these phases of a cell's life are summarized in figure 1.9. In the figure, the only organelles shown are the nucleus and the centrioles. Those are the most important

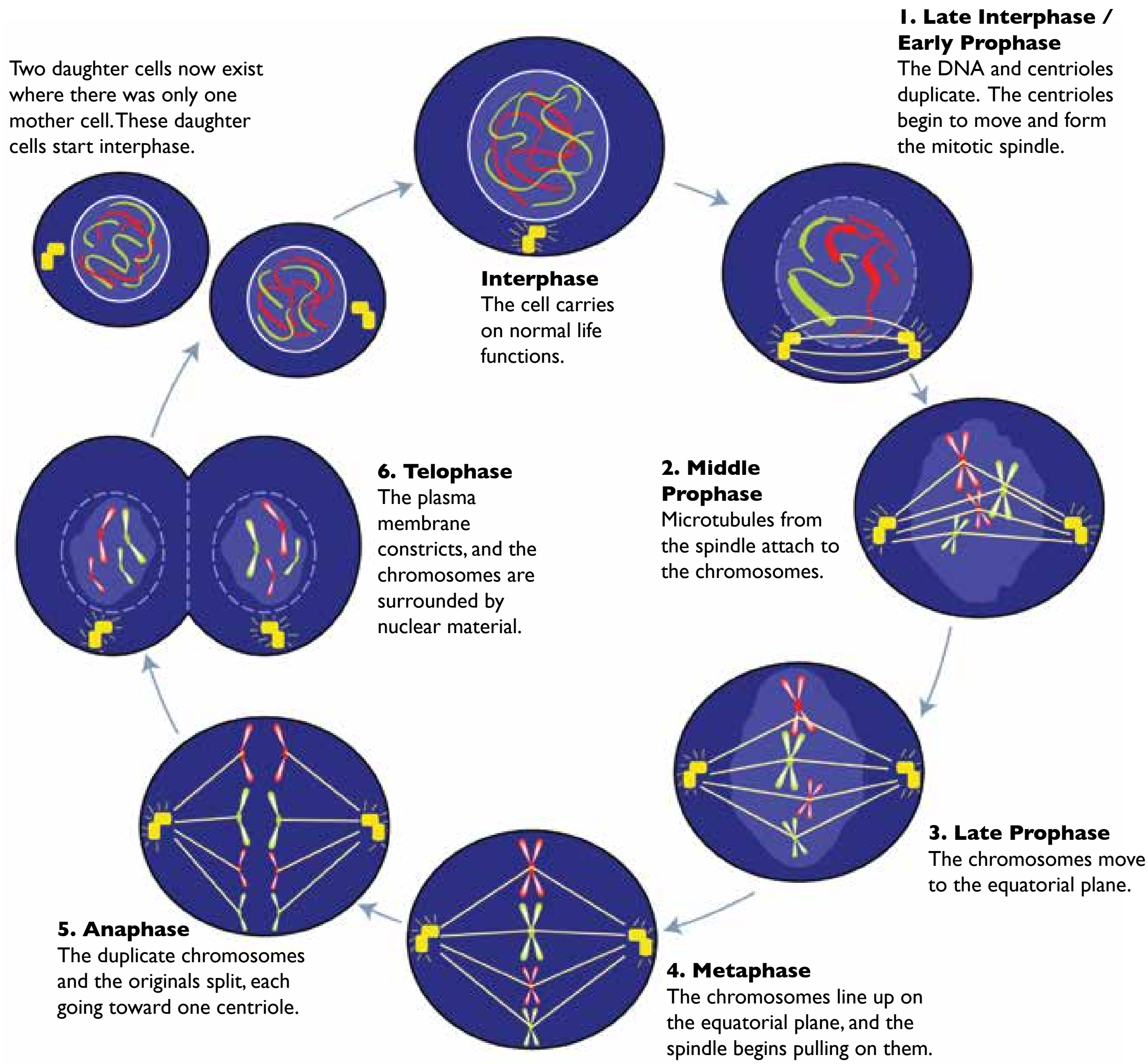


FIGURE 1.9
Mitosis
Illustration: Speartoons

organelles in mitosis. The other organelles of the cell have been removed to make the illustration easy to understand.

Notice that in interphase, there are no distinguishable chromosomes. That's because the DNA is spread throughout the nucleus, and it is called chromatin. During prophase, four things happen. The centrioles duplicate and begin to form a spindle of microtubules between them. They also move toward opposite ends of the cell so that the spindle spreads across the cell. Also, replicated DNA forms chromosomes, which are thick and condensed and can be seen easily under a microscope. Those chromosomes move toward the center of the cell. That place in the center is the equatorial plane.

Once the chromosomes reach the equatorial plane, the cell is in metaphase. The spindle attaches to the chromosomes right at the point where each replicated chromosome is attached to its partner. At that point, the spindle begins to pull so that the duplicates and originals are pulled apart, which is the beginning of anaphase. During anaphase, the duplicates and originals separate and are pulled to opposite ends of the cell.

In the last phase, telophase, one set of chromatin is on one side of the cell, and another set is on the other side. The plasma membrane constricts to pinch the cell in two. The result, then, is two daughter cells that go back to interphase.

Before moving on, note that the X shapes that you see for the chromosomes during prophase and anaphase exist because the chromosome has been replicated (duplicated). A chromosome that has not been replicated does not have the X shape that most people think of when they think of chromosomes. Instead, a normal chromosome before replication looks more like what is shown in the illustration of telophase, and it is called chromatin.

Although most of the cells in your body are able to reproduce via mitosis, there are three types of cells that cannot: *mature neurons, mature skeletal muscle cells, and mature cardiac muscle cells*. These cells lack centrioles and cannot form the spindle for mitosis. This means that if skeletal muscle or cardiac muscle cells die, you lose them forever and cannot get new ones! On the other hand, if a part of your liver gets injured, your remaining liver cells can undergo mitosis and repair that injury.

Since neurons cannot undergo mitosis, scientists thought until recently that once you were past infancy, you could never produce any more neurons. So, if some of your neurons died, you simply lost them forever. We now know that is not true in at least some regions of the brain. These special regions do produce new neurons each year; however, they are not produced via mitosis. They are produced via processes we will discuss when we cover the brain in detail.

ON YOUR OWN

1.9 A human cell has 46 chromosomes. If the illustration in figure 1.9 were of a human cell, how many X shapes would there be in the prophase and metaphase illustrations?

THE PLASMA MEMBRANE

We've been reviewing a lot about the organization of the cell. Before we end this module, however, we do want to go one level deeper in organization. The best way to do this is to examine one aspect of the cell in detail. Since it has so much to do with the physiology of the human body, we have chosen to discuss the details of the plasma membrane. This will probably be new to you. When you look at the plasma membrane of the cell, you are going to find a beautiful relationship between structure and function. That is, you can look at how it is put together and what it is made of, and then you can see how it works. It is truly amazing what the cell membrane does and how well it works!

The cell membrane, of course, holds the cell together. That is not all it does, however. The plasma membrane is incredibly important to the life of the cell because it restricts what goes in and out of the cell, and it lets the cell communicate with its environment. First, let's look at its structure, as illustrated in figure 1.10.

The first thing that you should notice about the figure is that the cell membrane is largely made of a phospholipid bilayer. What's that? A phospholipid is composed of two fatty acids and a phosphate group. The result is a molecule that is polar (water-soluble) on one side and nonpolar (lipid-soluble) on the other. In the figure, the yellow balls represent the polar region of each phospholipid. The two stems coming out of each ball represent two fatty acids, which make up the nonpolar region of the phospholipid. So, that defines the phospholipid part. Bilayer means, as you can see, two layers: a set of phospholipids on top and a set on the bottom.