# 20

# Internal Balance


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## Donating Blood


Have you ever seen one of these buses? The people who operate this bus have a very important job. These people go to different places encouraging people to come and donate their blood. Every day, people are in need of a blood transfusion. They may have been involved in a serious accident, have had surgery, or need blood for some other reason. After the donor's blood is collected, it is carefully tested to make sure it doesn't contain any pathogens. Then the blood is stored. Eventually it will be distributed to hospitals or clinics that will use the blood to help people and save lives.

Should healthy, qualified people donate some of their blood? The Bible doesn't tell us to donate blood, but it does say that we should do good to all men (Gal. 6:10). Donating blood for people who are sick or had an accident would be one way of doing good. Statistics show that every two seconds someone in the United States needs blood! Blood is important because it performs so many vital tasks in the body. As you read this chapter, notice all the incredible things that your blood is doing right now.

# 20A A Balancing Act

It's Friday night, and you are totally psyched. It's the night of the championship basketball game! You jump, stretch, run, dribble, and block. Your heart pumps faster; you can feel it throbbing. Beads—no, buckets—of sweat pour from your body. Two hours later, hot, sweaty, and tired, you head for the showers. Your stomach begins to rumble. It's time for the biggest pizza party of the year—because your team came out victorious! Many changes happened in your body during this time, and the conditions inside your body had to be kept within a safe range. How did your body do this? By maintaining homeostasis.

### 20A Section Objectives

- ✓ Compare homeostasis in the human body to walking a tightrope.
- ✓ Explain how the circulatory, immune, and excretory systems help the body maintain homeostasis.

## 20.1 Homeostasis

The conditions inside your body need to be maintained within a safe range. This is true whether you are reading a book or playing basketball. Your heart should beat only so fast or so slow, your temperature should vary by only a few degrees, and you can breathe only so deeply or shallowly. If your body does not maintain these conditions, you will probably feel sick and might even die.

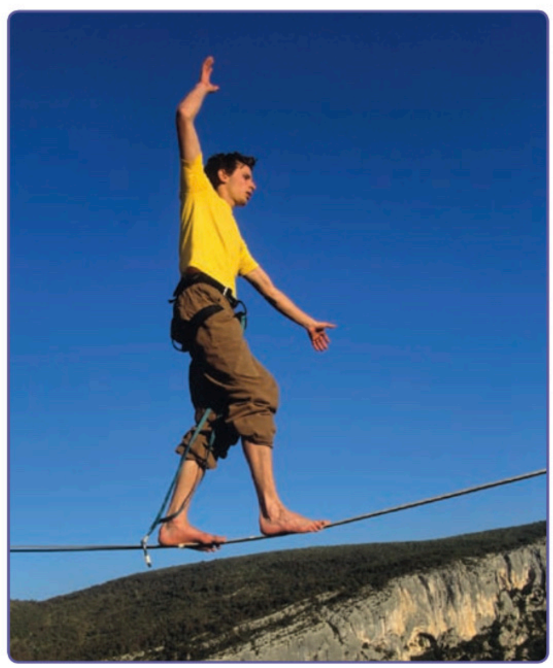
As your activities change, your body must adjust. For example, when you are resting, you normally have enough sugar and oxygen in your blood to supply your cells. But when you exercise vigorously, your cells need more sugar and oxygen. To keep the proper amounts of these substances in supply, your heart beats faster, forcing more blood through your blood vessels. Your cells then receive more oxygen and sugar because of the greater amount of blood that passes by them. When you stop exercising, and the extra sugar and oxygen are no longer needed, your heart adjusts by slowing down.

### Think About It

Why do your body cells need sugar? Why do they need oxygen?

homeostasis: homeo- (Gk. *homos*—same) + -stasis (Gk. *stasis*—standstill)

The internal balance of a living organism is called **homeostasis** (HO mee oh STAY sis). This word literally means "staying the same." Your body maintains homeostasis by keeping internal conditions the same or, more accurately, by keeping them as they should be. Homeostasis is like walking a tightrope. A tightrope walker does not automatically balance on a thin line of rope. He must constantly move and make adjustments with his body to maintain his balance. Similarly, your body must constantly respond to its environment by making adjustments to maintain homeostasis.



20-1 Maintaining homeostasis is similar to walking a tightrope. The goal is to stay on the rope, and adjustments must be made to do this.

You are healthiest when your body maintains the proper homeostatic levels. You may become ill when something upsets your body's ability to maintain these levels. Things that may affect homeostasis include parasites, viruses, bacteria, poor nutrition, and the breakdown of a body part that helps maintain homeostasis.

The *circulatory system* (Sections 20B and 20C) is one of the main systems for maintaining homeostasis. Your circulatory system consists of your heart, blood vessels, and blood. The chief functions of the circulatory system are to transport substances such as food, oxygen, hormones, and enzymes to the cells of your body and to remove carbon dioxide ($CO_2$) and other waste products.

There are many disease-causing organisms that can harm your body and interfere with homeostasis. The body's *defense systems* (Section 20D) help protect you from these pathogens. Some of these defenses are nonspecific. For example, the skin helps prevent all sorts of pathogens and harmful substances from entering your body. But when organisms and substances break through the skin's protective barriers, your body's specific defenses spring into action. The *immune system* produces special chemicals and blood cells to fight against specific pathogens.

Another system important in the maintenance of your body's homeostasis is the *excretory system* (Section 20E). The kidneys filter waste substances out of the blood and help restore the proper amounts of other substances to the blood.

### 20A Section Review

1. What is homeostasis?
2. (True or False) Pathogens and poor nutrition can both affect the body's homeostasis.
3. List some substances in the body that must be kept in proper balance.
4. How do the kidneys help maintain homeostasis?

## 20B The Blood

### *20B Section Objectives*

- ✓ Compare the anatomy and physiology of erythrocytes, leukocytes, and platelets.
- ✓ Summarize the process of blood clotting.
- ✓ Discuss several problems encountered with blood transfusions.
- ✓ Describe the anatomy and physiology of blood plasma.

Your body's *circulatory system* contains about 4–5 L (4–5 qt) of blood. If you place a sample of blood in a test tube and spin it in a machine called a centrifuge, the blood will separate into three layers. The straw-colored top layer is blood plasma. Plasma makes up a little over half the volume of blood. The next layer is a thin white layer that contains white blood cells and platelets. The lowest layer, red blood cells, makes up a little less than half the volume of blood.



**20-2** (a) Blood can be rapidly separated by spinning it in a centrifuge. (b) The erythrocytes (red blood cells) are at the bottom of the test tube.

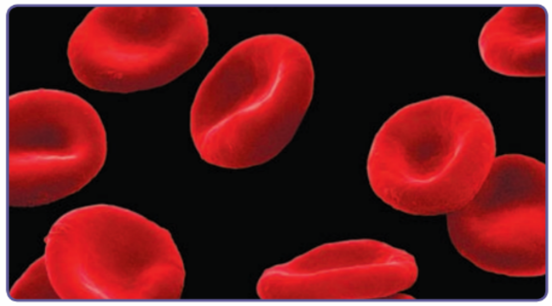
## 20.2 Erythrocytes—Red Blood Cells

The proper name for red blood cells is **erythrocytes** (ih RITH ruh SITES). Actually, erythrocytes are not complete cells. They are formed by special cells in the red bone marrow. These cells first divide and then begin to produce a pigment called hemoglobin. **Hemoglobin** is an iron-containing pigment that makes erythrocytes appear red. When the cells are filled with hemoglobin, the nuclei are forced out of the cells, and the erythrocytes take on their usual shape: a disc, dented on both sides. Erythrocytes cannot move themselves. They are carried along by the flow of blood.

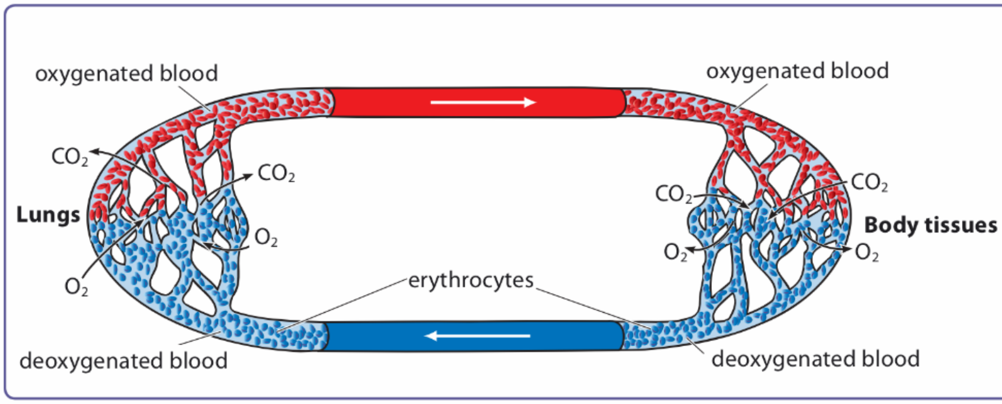
Since erythrocytes lack a nucleus, they cannot reproduce or make new cellular parts. Remember, the nucleus contains the genetic code, or DNA, for making cell parts. About 120 days after the erythrocytes are formed, they begin to fall apart. These worn-out cells are constantly filtered out by the liver and spleen. Most of the materials from these old red blood cells are used to make new erythrocytes. To keep enough healthy red blood cells in circulation, your bone marrow must produce over a billion new erythrocytes every day.

Whether the blood is *oxygenated* or *deoxygenated* depends on how much oxygen is attached to the hemoglobin in the erythrocytes. Blood becomes oxygenated when it passes through the lungs. It becomes deoxygenated when it delivers the oxygen to the body's tissues.

erythrocyte: erythro- (Gk. *eruthros*—red) + -cyte (hollow vessel or cell)



20-3 Erythrocytes are red blood cells.




20-4 The exchange of gases in the body. Red indicates oxygenated blood, and blue indicates deoxygenated blood.

### Think About It

Figure 20-4 shows the blood removing carbon dioxide from body tissues and taking it to the lungs to be removed from the body. What process produces carbon dioxide as a waste product?

## 20.3 Leukocytes—White Blood Cells

White blood cells are properly called **leukocytes** (LOO kuh SITES). Since leukocytes do not contain hemoglobin, they are not red. Leukocytes are considerably larger than red blood cells. Unlike erythrocytes, leukocytes have nuclei and can move by themselves. To move, leukocytes change their shape like amoebas. There are several different types of leukocytes, and they all have two main functions that are a major part of the body's defense against disease.

***Destroying bacteria and other foreign matter.*** Some leukocytes destroy bacteria and other foreign matter in the body by engulfing and digesting them. Chemicals released by injured cells or cells attacked by foreign organisms attract these leukocytes. The leukocytes travel to injured areas by leaving the capillaries (tiny blood vessels) and entering the body tissues. (Red blood cells leave the capillaries only when you are bleeding.)

leukocyte: leuko- (Gk. *leukos*—clear or white) + -cyte (hollow vessel or cell)

### Functions of the Circulatory System

- Transportation of substances throughout the body (nutrients, oxygen, hormones, waste products, and so forth)
- Adjustment of the amount and presence of materials to the varying needs of the body

## Disorders Involving Hemoglobin

Hemoglobin is very important to the body because it carries oxygen. Oxygen is needed for cellular respiration. Cellular respiration produces usable energy, and energy is needed for all the processes your cells must perform. If hemoglobin is damaged, it can have a detrimental effect on the body.

***Anemia.*** A person has *anemia* (uh NEE mee uh) if his blood cannot carry enough oxygen to his body cells. Usually anemia is caused by a lack of hemoglobin or by hemoglobin that does not work properly.

Iron is one component of hemoglobin. If a person does not have enough iron in his body, he cannot make enough hemoglobin. This condition is called *iron-deficiency anemia*. As a result, his blood cannot carry enough oxygen. Eating foods that contain iron (such as meat, eggs, peas, and nuts) or taking mineral tablets usually corrects this kind of anemia.

***Carbon monoxide poisoning.*** A person can suffer anemia-like effects by breathing carbon monoxide (CO). Carbon monoxide is a colorless, odorless, tasteless gas that is produced when something burns (such as gasoline in a car, fires in fireplaces, and fuel in kerosene space heaters). This gas easily combines with hemoglobin at the same place that oxygen does. But carbon monoxide attaches to hemoglobin much more tightly than oxygen. Therefore, once carbon monoxide attaches to a hemoglobin molecule, that hemoglobin can no longer carry oxygen.

If only a small amount of hemoglobin is affected, deeper breaths usually supply the body with enough oxygen. In time, the contaminated erythrocytes will be replaced with new ones, and the person will no longer suffer from any symptoms. If a large amount of hemoglobin is affected, the body's tissues will not receive enough oxygen. Decreased oxygen to vital organs, such as the brain, can result in permanent damage. If too much carbon monoxide combines with hemoglobin, the person may need to receive a blood transfusion to replace the damaged cells, or he could die. This is why people are warned not to leave their cars running or burn fires in an enclosed space.

## Blood and Water from Jesus' Side

Jesus was crucified on the day of preparation for Passover (Mark 15:42; John 19:31). Jewish law and custom prohibited execution on Passover day. To avoid breaking Jewish law, a Roman soldier was sent to break the legs of Jesus and the two criminals executed with Him to hasten their deaths. However, the soldiers did not break Jesus' legs. John 19:33 tells us, "But when they came to Jesus, and saw that he was dead already, they brake not his legs," in perfect fulfillment of the Old Testament law and the prophecies in Exodus 12:46 and Psalm 34:20. John continues by saying, "But one of the soldiers with a spear pierced his side, and forthwith came there out blood and water" (v. 34), fulfilling Zechariah 12:10.

*The Crucifixion*, Pieter Vlerick (attr. to), from the Bob Jones University Collection

The blood inside the blood vessels of a dead body does not normally separate into clotted blood and watery plasma. However, a long, violent struggle that ends in death can involve severe internal bleeding and the pooling of blood in the chest and abdomen. This blood could separate and thus account for blood and water flowing from a wound.

Christ may have had such internal bleeding, but this is somewhat unlikely because it takes blood a long time to collect around internal organs. Also, Jesus did not put up a violent struggle. He humbly endured the torture before His death. He was "brought as a lamb to the slaughter, and as a sheep before her shearers is dumb, so he openeth not his mouth" (Isa. 53:7).

Many people believe that Christ's heart ruptured (broke). There are records of strong emotions causing people to die of a ruptured heart. If one of the heart chambers or large blood vessels near the heart had ruptured, blood probably would have flooded into the pericardium (the sac surrounding the heart). Here the blood could have rapidly separated into clotted blood cells and watery plasma. The Roman soldier, surprised to find Christ already dead, may have aimed his spear toward the heart. If he pierced the pericardium, clotted blood and watery plasma could have drained from the wound in Christ's side.

Jesus' physical death on the cross was real. He did not swoon or faint and then revive in the tomb. Blood and water could have flowed from His body only if He had been physically dead. But the important aspect of the death of Christ is not the specific injuries to His physical body. What is important is that the sinless Son of God died for the sins of all mankind. Christ gave Himself on the cross that we might be saved (John 19:30).

No one and nothing on earth could kill Jesus because He is God. Earlier in His life Christ declared, "I lay down my life, that I might take it again. No man taketh it from me, but I lay it down of myself" (John 10:17–18). Jesus died because He chose to give His life "a ransom for all" (1 Tim. 2:6).

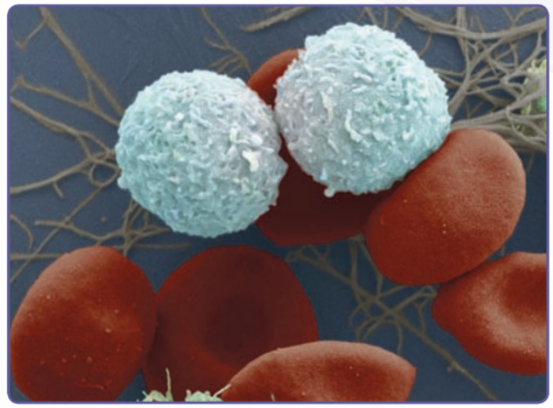
Death, however, was not the end for Christ; He rose three days after He died, conquering death. He now lives in a glorified, eternal body (Phil. 3:21). Those who trust in Him for salvation will also die (or be raptured) and receive a glorified, eternal body like His (1 Cor. 6:14; 2 Cor. 4:14; 1 John 3:2).

Once in the area of infection or injury, white blood cells destroy any invading organisms and clean up the cell fragments in the wounded tissues.

***Producing antibodies.*** **Antibodies** are chemicals produced by leukocytes that attack invading organisms or poisons. These two functions of leukocytes will be discussed further in Section 20D.

White blood cells form in the bone marrow. Some also develop in the spleen, tonsils, and thymus gland. Most of them have a rather short lifespan—usually from 1 to 12 days. Some white blood cells, however, may live for about 10 months.

Although there are normally few leukocytes in the body (red blood cells outnumber them 600 to 1), more are produced when a person has an *infection*. This happens when pathogens, such as harmful bacteria or viruses, enter the body. Physicians often check the number of leukocytes in a sample of a person's blood. If the number is too large, the physician suspects that the person has an infection. This is helpful in diagnosing infections that are difficult to find, such as those in the liver, kidneys, and other internal organs.



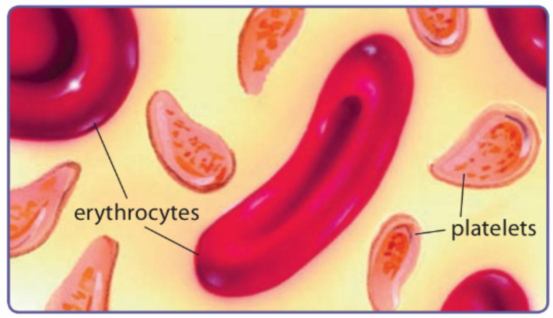
**20-5** Leukocytes (white) and erythrocytes (red)

## 20.4 *Platelets and Blood Clotting*

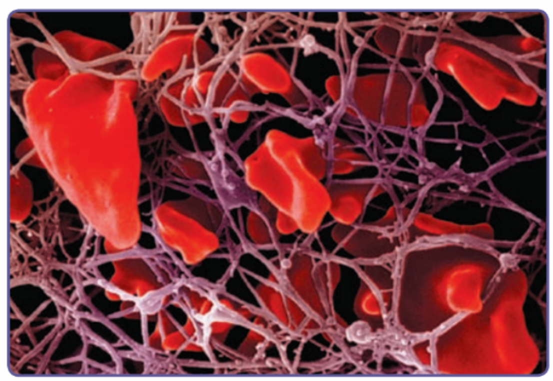
**Platelets** are very small cell fragments that help in blood clotting. They come from large cells in the bone marrow. Platelets are irregular in shape and about one-third the size of red blood cells. They do not have a nucleus and live only about one week.

When blood vessels are broken, platelets first stick together, forming a temporary plug to stop blood loss. Some of the platelets then burst and release a substance that triggers a series of reactions that produce long fibers in the blood. A *blood clot* consists of a microscopic net of these fibers and some trapped blood cells. The clot then serves as a plug, stopping blood loss until the blood vessel can heal.

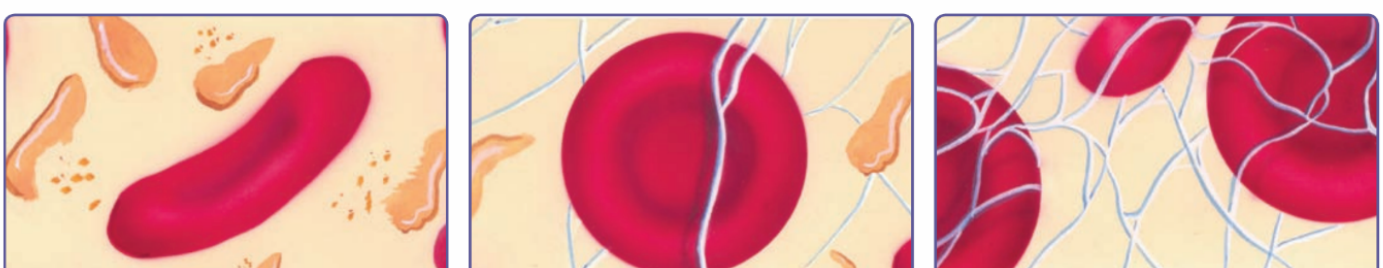
If a blood clot forms inside a blood vessel, it may block the blood supply to some area of the body. If the clot stops the flow of blood to a vital organ, the condition can be deadly. A clot that blocks the flow of blood in the brain could cause a stroke, and a clot that blocks the flow of blood in the heart could cause a heart attack. Your blood contains chemicals that slowly break




**20-6** Platelets are small fragments of cells.



**20-7** An electron micrograph of a blood clot



Platelets rupture, releasing a chemical into the blood.

The chemical triggers the formation of protein fibers.

The protein fibers trap blood cells, forming a clot.

**20-8** The process of blood clotting

## Facets of Life Science: Transfusion Solutions

Injuries, illnesses, surgery, and other problems cause many people to lose blood. In the past, people often died from loss of blood rather than from the original injury or illness. The idea of transfusing blood has been around for a long time. In the mid-1600s, a French physician transfused blood from a sheep to a boy and from a calf to a man. The boy recovered, but the man died, and the physician was charged with murder. Although the charge was dropped, laws were established banning blood transfusions.

About 150 years later, a London physician named James Blundell performed the first recorded human-to-human blood transfusion. The patient was a woman who had lost a large amount of blood when her baby was born. He did transfusions on nine other women with similar problems, but six of them died. Since Blundell knew nothing about blood types and did not practice sterile techniques, it is surprising that any of the women survived.

James Blundell

Early blood transfusions were done directly between the *donor* (person giving blood) and the *recipient* (person receiving blood). Usually a short tube was used to carry the blood from one person to another. Occasionally the donor's and recipient's blood vessels were sewn together.

The problem with using this direct blood-transfusion method was that doctors did not know how much blood was being given to the recipient. So physicians developed syringes to measure and transfuse blood. Doctors also used flasks to collect and measure blood. The flasks were set on a shelf above the recipient. Then gravity moved the blood through a tube connected to the flask and into the recipient's arm.

Despite the progress in blood-transfusion methods, major problems still existed. For example, as blood is taken out of the body, it clots quickly. For this reason physicians often found their syringes and tubes clogged by clots. Then in 1868 a physician found that chemicals could be added to prevent blood from clotting. Later it was discovered that containers with smooth surfaces slowed clotting. Soon wax-lined containers were used during blood transfusions.

Since the erythrocytes in stored blood break down quickly, physicians also needed to find a way to store blood. They discovered that by adding certain chemicals, they could prevent red blood cells from breaking down so quickly. Better chemicals were developed, and by 1957 blood could be stored for about 28 days and still be usable in transfusions. Today blood is refrigerated between 1 °C and 8 °C (between 34 °F and 46 °F). At these temperatures it can be kept for up to 42 days.

Modern method of blood storage

Even with these techniques there were still problems to overcome before transfusions became safe. Around 1900 Dr. Karl Landsteiner collected samples of blood from various people working in his lab. He mixed the blood in all the possible combinations and noticed that some blood samples mixed well but other combinations *agglutinated* (uh GLOOT n AY tid), or formed clumps. These clumps were large enough to plug small blood vessels.

Karl Landsteiner

From this, researchers understood why some blood transfusions were successful and others were not. Later, blood samples were grouped in A, B, AB, and O groups, based on whether or not their red-blood-cell membranes contained chemicals called *antigens* (AN tih junz). Type A blood has the A antigen, and type B blood has the B antigen. Type AB blood has both the A antigen and the B antigen. Type O blood has neither antigen.

If a person receives blood that has antigens his body does not normally have, his body recognizes the blood as foreign and causes it to agglutinate. For example, if a person with type A blood received a transfusion of type B or type AB blood, his body would recognize the B antigens in the donor blood as foreign and would cause that blood to clump. Today blood is carefully matched so that people with type A blood usually receive type A blood in transfusions, people with type B blood usually receive type B blood, and so on.

There are other blood antigens that are important in transfusions. The Rh factor is an antigen located on red blood cells, similar to the A and B antigens. Since the Rh factor also can cause agglutination, it must be checked before blood is transfused. Physicians use a plus sign to indicate the presence of the Rh factor in the blood and a minus sign to indicate its absence. So a person could be blood type A+, B–, O+, and so forth. There are many other blood antigens, but they usually do not cause complications during blood transfusions.

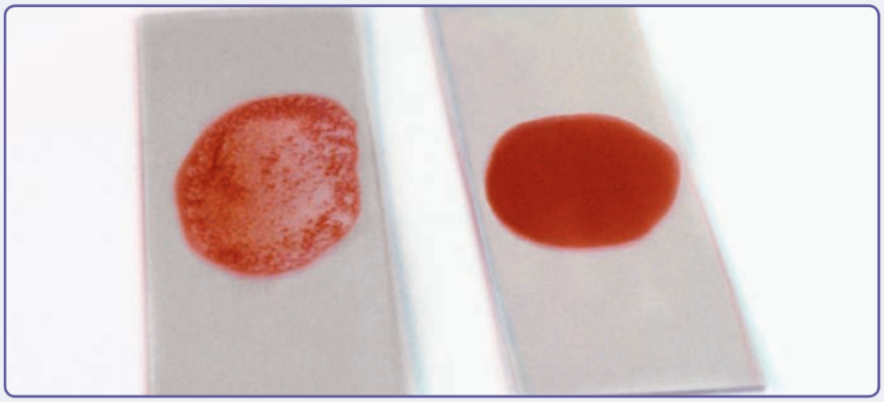
Because the right blood type is not always available, sometimes a technique called *autotransfusion* is used. The blood a person loses during surgery is collected, filtered, and cleaned. Then it is replaced into the patient's own bloodstream. The advantage of autotransfusion is that it eliminates the problems of matching blood types. This is especially important if the person has a rare type of blood. If a patient knows far enough in advance that he is going to have surgery, he can even have his own blood taken and saved for use during the surgery. If a patient needs more blood, a salt solution similar to plasma can be added to the blood before it is returned to the patient.

In spite of all these developments, about 2% of all transfusions have some undesirable effects on the recipient. To remedy this problem, scientists have tried to develop artificial blood. Many substances have been tested, and several show promising results. However, at the time of this printing, none have been approved for use in the United States.

### Think About It

(a) Human blood types are an example of which type of genetic inheritance pattern? (Hint: Think back to Chapter 6.)

(b) Which blood type could be used with any other blood type during a transfusion? Why?



(left) Mixing incompatible blood types causes agglutination. (right) If a transfusion recipient receives a compatible blood type, agglutination will not occur.

## Career Feature: Serving God as a Phlebotomist

### Job Description

A phlebotomist (flih BOT uh mist) is a person who draws blood for tests, research, transfusions, and donations. He or she also performs diagnostic tests on blood in a lab setting, often in cooperation with other lab technicians. Phlebotomists may be involved in analyzing the results of blood tests. In addition to having social skills, phlebotomists must also work accurately and safely to reduce the risk of infection from blood-borne diseases.

### Possible Workplaces

Phlebotomists may work in hospitals, commercial labs, doctors' offices, public health departments, or blood banks.

### Education

In addition to a high-school diploma, most phlebotomists are trained and certified after completing a one- or two-semester program involving classroom and on-the-job training. Several national organizations offer certification, which is required by some states.

### Service Opportunities

By collecting blood to be used in diagnosing diseases and disorders, a phlebotomist can help preserve and improve the quality of life for people. Those who work in blood banks, where blood is stored and then used to help others, also demonstrate a high level of care for others.

down clots that are floating in the blood. These same chemicals also break down blood clots as wounds heal. If a physician suspects a problem with clots in the blood, he can inject such chemicals into a patient's bloodstream. Donated blood must be mixed with certain chemicals to keep it from clotting before it can be given to a patient.

### Think About It

Centrifuges cause materials to separate by density, with the materials having the greatest density ending up on the bottom. What does this tell you about the relative masses of the substances that make up your blood?

## 20.5 Blood Plasma

The fluid portion of the blood is called **blood plasma**. It is about 90% water. The remaining 10% of the materials in blood plasma fall into two groups.

***Substances that are transported by the blood.*** This group includes dissolved foods, wastes, minerals, hormones, and various other substances that cells need or produce.

***Substances that regulate the blood.*** This group includes proteins and other substances that keep the blood chemicals balanced.

The substances carried in plasma enter and leave the plasma through the capillaries. The function of blood is to transport those substances, but if the blood is not carefully regulated, the substances that the blood transports are of little value.

For example, blood-clotting substances come from platelets and plasma. If the concentration of some of these substances is too high, the blood may clot too much. This could result in dangerous clots in the blood vessels. Regulators in the body work to keep the concentration of the blood-clotting substances in the blood at the proper levels. This is an example of the body working to maintain homeostasis.

## 20B Section Review

For Questions 1–6, tell whether each statement is true of (a) erythrocytes, (b) leukocytes, or (c) platelets. Some questions may have more than one answer; choose all that apply.

1. Do *not* have a nucleus
2. Function in blood clotting
3. Contain hemoglobin
4. Function in immunity
5. Transport oxygen to body tissues
6. Produced in bone marrow
7. How does blood become oxygenated? How does it become deoxygenated?
8. (True or False) A person whose blood cannot carry enough oxygen to his body cells has leukemia.
9. (F) If a person with blood type B receives a transfusion of blood type A, the donated blood will __________.
10. The fluid portion of the blood is the blood __________.
11. List three substances that are transported by blood and one substance that regulates blood.

# 20C The Blood Vessels and Heart

This year approximately one million people in the United States will die of *cardiovascular* (KAR dee oh VAS kyuh lur) malfunctions. Heart disease alone accounts for over one-third of all deaths in the United States. For various reasons the heart and blood vessels begin to wear out or become clogged.

Cardiovascular difficulties are often related to diet, exercise, and stress. A proper diet supplies the proper nutrients for good health. Regular vigorous exercise is necessary to keep the cardiovascular system functioning well. Many studies, however, point to stress as a major cause of cardiovascular problems in people. To understand how stress causes problems in the cardiovascular system, you will need to learn more about the heart and blood vessels.

### 20C Section Objectives

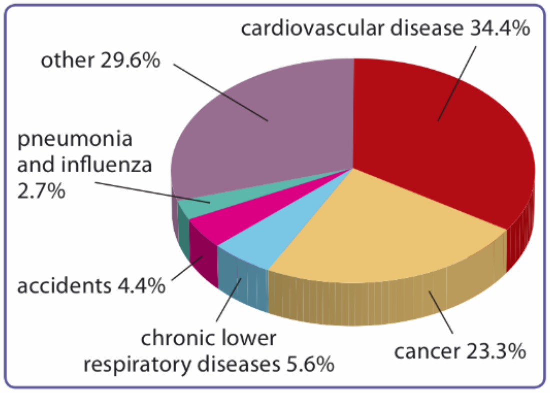
- ✓ Compare the anatomy and physiology of arteries, veins, and capillaries.
- ✓ Identify the structures of the heart.
- ✓ Trace the flow of oxygenated and deoxygenated blood through the heart.
- ✓ Compare the causes of high blood pressure and low blood pressure.
- ✓ Discuss common causes, symptoms, and treatments of heart attacks.

cardiovascular: cardio- (heart) + -vascular (little vessel)

## 20.6 The Structure of Blood Vessels

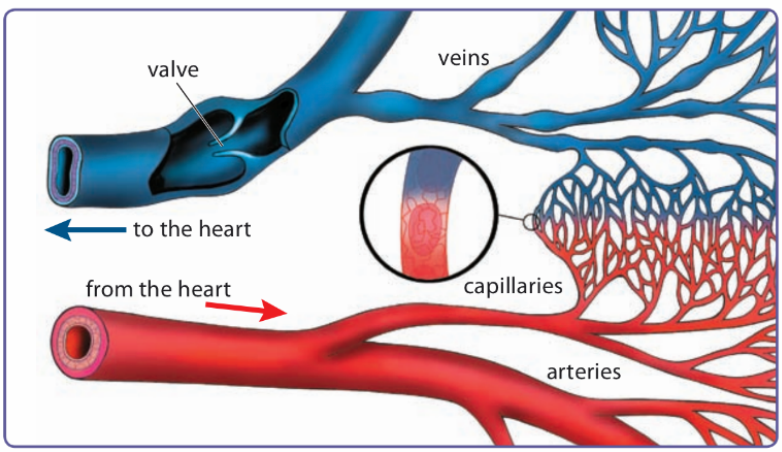
Humans have a *closed circulatory system*. Under normal circumstances blood travels from the heart and returns to the heart without ever leaving the blood vessels. Materials do enter and leave the blood, but most of the blood itself remains in the circulatory system.

**Arteries** are thick blood vessels that always carry blood *away from* the heart. They branch into smaller and smaller vessels until they become microscopic. The smallest vessels are called **capillaries**. Capillary walls are only one cell thick. Dissolved gases and small molecules can easily move through the capillary walls. While the blood is in the capillaries, materials are exchanged between the blood and the body's cells.




**20-9** Cardiovascular disease, which includes heart disease and stroke, is the leading cause of death in the United States. (National Vital Statistics Reports, vol. 59, no. 4, March 2011)

Capillaries merge to form larger vessels called **veins**, which carry blood *toward* the heart. Veins do not have walls as thick as arteries. They have one-way valves that allow blood to flow in only one direction—back to the heart. The pumping action of the heart forces blood through the arteries and on into the capillaries. After it has passed through the capillaries, there is little pressure to push it along in the veins. The return of blood to the heart is aided by body movements. As the muscles contract, they squeeze the veins, forcing the blood to move. The valves of the veins ensure that the blood flows toward the heart.




**20-10** The relationship between arteries, capillaries, and veins keeps the blood confined in a closed circulatory system.

Standing still for excessive periods of time may cause your feet to swell. Why? When there is no body movement, the blood in your vessels slows down and can begin to lose fluid into the surrounding tissues. This misplaced fluid causes swelling, or edema (ih DEE muh). Moving your legs helps prevent swelling. Muscles squeeze the veins, forcing the blood to return to your heart before the blood has a chance to lose its fluid.

### Think About It

In Figure 20-10, blue indicates deoxygenated blood. Does this mean that some of your blood is blue?

### Health Hint—Atherosclerosis

*Atherosclerosis* (ATH uh ro skluh RO sis) is a form of arteriosclerosis (ar TIHR ee o skluh RO sis; "hardening of the arteries") in which fatty material accumulates on the artery walls. This makes it difficult for blood to flow through the arteries and places greater stress on the heart. The damage caused by this buildup can lead to various types of heart and artery diseases or strokes. Heart disease and stroke kill more Americans each year than all the types of cancer combined.

It's easy to think of atherosclerosis as a disease of older people. But the habits that lead to the buildup of fatty material in the arteries can begin when you are young. In fact, physicians say that the disease can begin in childhood.

So how can you prevent atherosclerosis? Scientists believe that genetics and aging both play a role, but there are still things you can do to stay healthy. Avoiding cigarette smoke, eating a healthy diet (with the proper amount of fat), and exercising regularly are primary methods of prevention.

### Would You Believe?

Capillaries are so small that you need a microscope to see them. However, if all the capillaries from an adult were placed end to end, they would be between 25,000 and 60,000 miles long!

It is not just skeletal muscle movements that help move blood back to the heart. Smooth muscle plays a role as well. Blood vessels are lined with smooth muscle. Remember that smooth muscle is involuntary. As the smooth-muscle walls of the veins contract, blood is propelled toward the heart.

## 20.7 The Structure of the Heart

The **heart** is a muscular organ about the size of your fist. Its only function is to pump blood. When most of your body is resting, your heart continues to beat 60–80 times per minute, depending on your age and your physical condition. A person who is in good physical condition normally has a slower heart rate because his body is operating more efficiently.

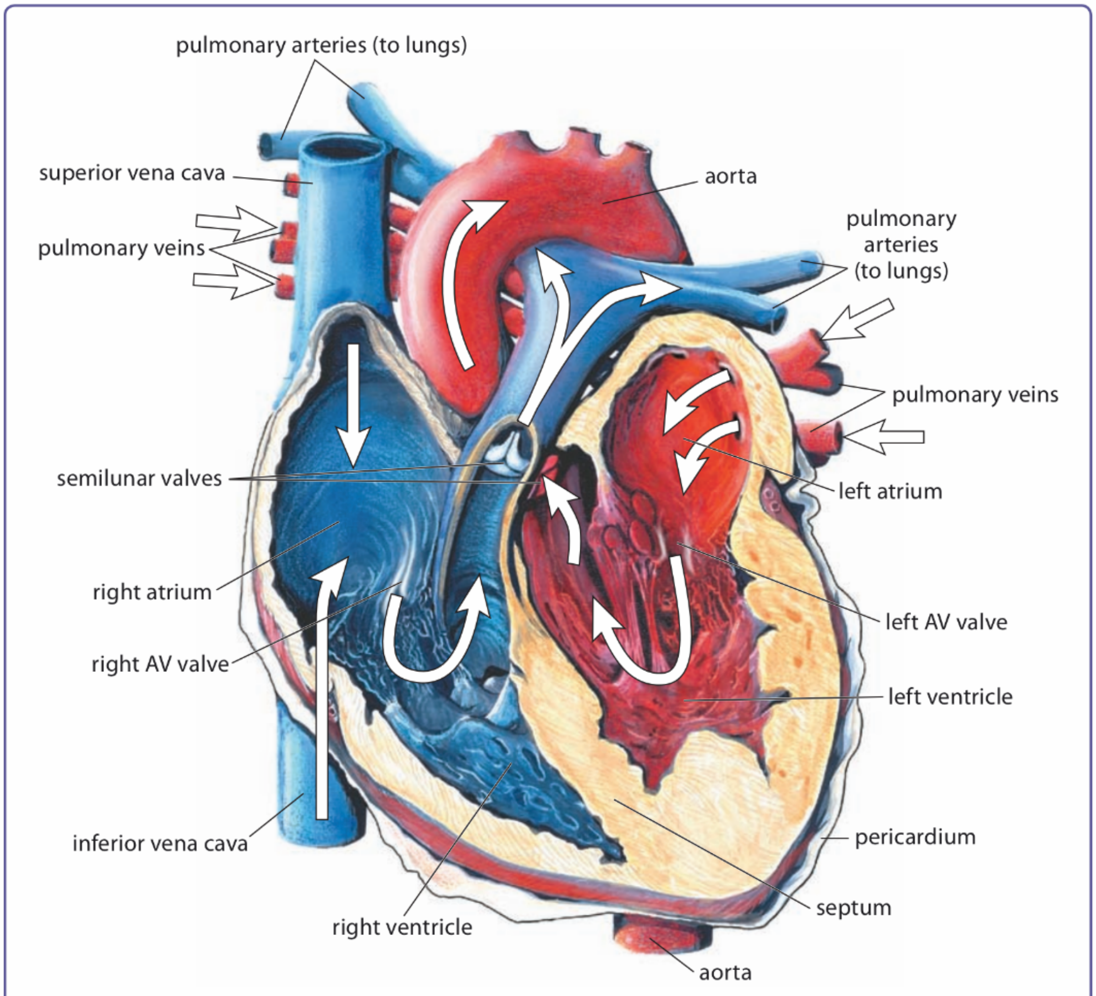
Inside the heart, a special tissue called the *pacemaker* uses electrical signals to make the heart beat automatically at your normal resting rate. When you are active, your heart beats faster because your brain and spinal cord send messages that increase your heart rate. When you are asleep, nerves can slow down the rate of your heart.

Not only is the heart a strong muscle, but it also has more endurance than any other muscle. Beating, on average, 72 times per minute, your heart will beat 2,650,838,400 times by your 70th birthday. All this movement could build up a lot of heat from friction (rubbing). Yet there is little friction because the heart is in a fluid-filled sac called the *pericardium* (PEHR ih KAR dee um). The fluid in this sac protects the heart as it beats.

pericardium: peri- (around) + -cardium (heart)

The heart has four hollow spaces called *chambers*. The upper, thin-walled chambers are called **atria** (sing., atrium). The larger, inferior, thick-walled chambers are **ventricles**. Blood that comes into the heart enters one of the atria. Blood leaves through one of the ventricles. The right side of the heart is separated from the left by a muscular wall called the *septum* (SEP tum).

Four valves in the heart direct the flow of blood. The atrium and ventricle on each side of the heart are separated by one-way valves called **atrioventricular** (AY tree o ven TRIK yuh lur) **valves** (**AV valves**). The AV valves are flaps of tissue that are attached to the inner surface of the ventricles by strong bands of connective tissue. These bands prevent the valves from swinging back into the atria. The AV valves allow blood to flow in only one direction—from the atria to the ventricles.




**20-11** Anatomy of the human heart

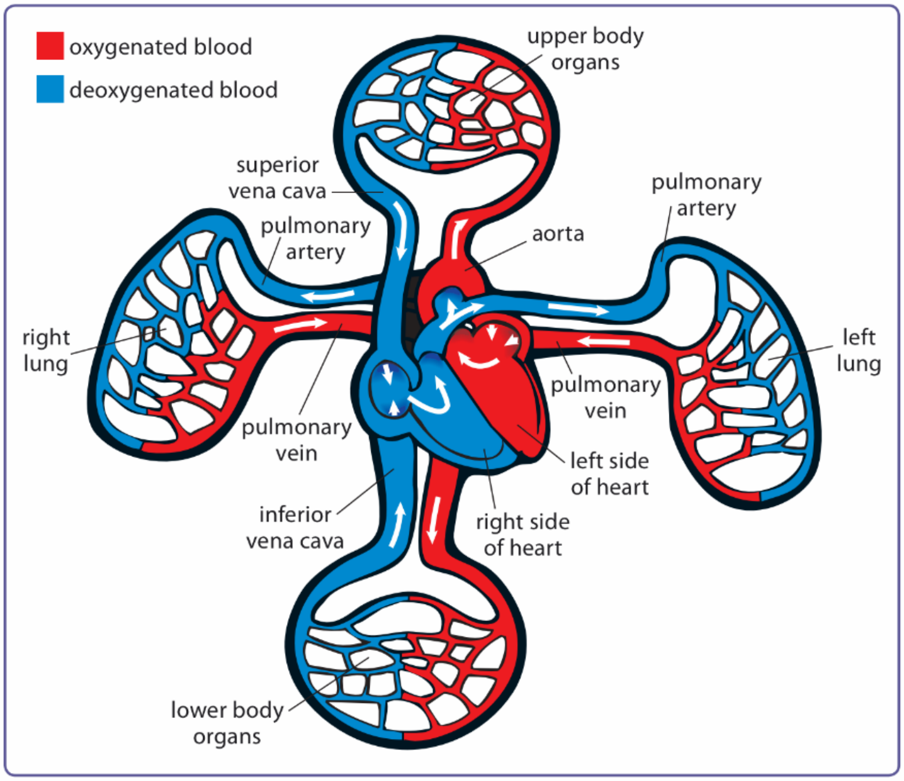
The **semilunar** (SEM ee LOO nur) **valves** are located at the exits of the ventricles. They allow blood to enter the large blood vessels that carry blood away from the heart. The semilunar valves are also one-way valves. They allow the blood to leave the ventricles and prevent it from returning.

## 20.8 *The Path of Blood*

Blood from all regions of the body (except the lungs) returns through two large veins that empty into the right atrium of the heart. The *superior vena cava* (VEE nuh • KAY vuh) returns blood from the upper body regions. The *inferior vena cava* returns blood from the lower body regions.

The blood coming from the body has already delivered oxygen to the body tissues. It has also picked up waste carbon dioxide from these tissues. Therefore, it is low in oxygen and high in carbon dioxide. It is called *deoxygenated blood*, and in most diagrams it is colored blue. The actual color of deoxygenated blood is a dull, purplish red.

After the right atrium fills with blood, it contracts and sends the blood through the right AV valve into the right ventricle. As the right ventricle contracts, the right AV valve closes




**20-12** The path of blood in the human body

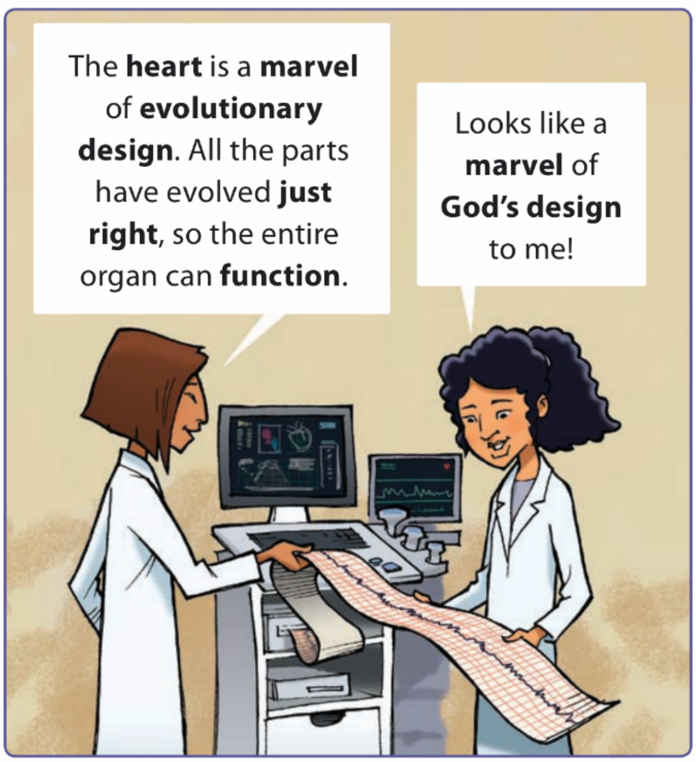
pulmonary: pulmon- (L. *pulmon*—lung) + -ary (L. *-arius*—relating to)

to prevent the blood from flowing back into the atrium. The blood moves through the semilunar valve into the *pulmonary* (POOL muh NEHR ee) *arteries*.

The pulmonary arteries carry deoxygenated blood to the lungs. As the blood flows through the lungs, carbon dioxide is released from the blood into the lungs to be exhaled. At the same time, oxygen moves from the air in the lungs into the blood. The oxygen-rich blood is called *oxygenated blood*, which is usually diagrammed red. The oxygenated blood returns to the left atrium through the *pulmonary veins*. (Remember that veins carry blood back to the heart.)

When the left atrium is filled with blood, it contracts. The blood flows through the left AV valve into the left ventricle. As the left ventricle contracts, the left AV valve closes, and the blood rushes through the semilunar valve into the aorta (ay OR tuh). The **aorta** is the largest artery in the body. It branches into many smaller arteries and capillaries to supply blood to the entire body.

As the blood passes through the capillaries, it delivers oxygen to the cells and absorbs carbon dioxide from them. By the time the blood enters the veins, it is deoxygenated. The veins collect the deoxygenated blood and return it to the heart. Scientists estimate that one drop of blood may circulate through the body once every 23 seconds.




**20-13**

## 20.9 *The Workings of the Heart*

The walls of the left ventricle are about three times thicker than the walls of the right ventricle. The right ventricle has to pump blood only to the lungs, but the left ventricle has to push blood to all other body regions.

The muscle of the heart receives almost no nourishment from the blood that flows through its chambers. The heart's nourishment is supplied primarily by two *coronary arteries*. These arteries branch off the aorta and enter the heart muscle. In time, the blood from the heart muscle enters a vein on the back side of the heart and flows into the right atrium.

When the heart contracts, both atria function together, and then both ventricles function together. Both the right and left atria receive blood at the same time. When they contract, both AV valves open and blood flows into the ventricles. After a brief pause both ventricles contract, the AV valves close, and the semilunar valves open. The blood is then pumped into the pulmonary arteries and aorta at the same time.

A physician uses a *stethoscope* (STETH uh skope) to listen to your heart. The normal sounds of a heartbeat are a soft *lubb-dubb*. The *lubb* sound is produced by the AV valves shutting as the ventricles contract. Shortly after this, the semilunar valves close, producing the *dubb*. The first sound is longer and louder than the second. One *lubb-dubb* indicates one complete beat of the heart.

Unusual heart sounds may indicate a heart disorder. A *heart murmur* is an abnormal sound usually caused by defective heart valves. If the valves do not close properly, blood may leak backward, causing a gurgling sound, or murmur. *Arrhythmia* (uh RITH mee uh) is another problem that can often be detected by listening to the heart. Arrhythmia occurs when the heart beats out of rhythm.

**20-14** The way your heart sounds can reveal its health.

## 20.10 *Blood Pressure*

As the heart pumps, the blood passes into the arteries with such force that they swell slightly. You feel this force when you take your **pulse**. By pressing an artery against a bone, you can feel the force of blood pushing against the pressure caused by your finger. Your pulse rate tells you how fast your heart is beating. A normal resting pulse rate is about 70 beats per minute.

The pressure of circulating blood against the walls of the arteries is called **blood pressure**. Even between heartbeats there is some pressure in the arteries. This pressure forces the blood through the arteries and on into the capillaries of the body.

Often a person with low blood pressure does not have enough blood passing through his capillaries to nourish his cells properly. If the blood pressure goes too low, the person may become unconscious.

**20-15** The pulse is commonly measured by using two fingertips to press the radial artery against the radius.

When you exercise, your cells use more nutrients and oxygen and produce more wastes. By increasing the blood

# Facets of Life Science: Beating Heart Attacks

Each year over one million people in the United States have a heart attack. Close to half of them die. Anyone at any age may have a heart attack. Physical exercise or emotional problems do not necessarily cause heart attacks. Many people suffer heart attacks when they are relaxing or sleeping.

## *Signs of a Heart Attack*

The most common warning sign of a heart attack is a squeezing type of pain in the center of the chest. This painful sensation may also spread to the shoulders, neck, and arms. It may last for two minutes or longer, and it may come and go. The pain may be sharp, stabbing, and quite severe, especially in men. The person may not appear ill, but he may feel weak, nauseated, short of breath, and sweaty.

The symptoms of a heart attack are sometimes different in women. Women often feel breathless, and they do not always experience chest pain. Instead, they may have pain in the upper back, shoulders, and neck, or a dull ache that radiates down the back and arms. They often have flu-like symptoms, such as nausea, tiredness, dizziness, and a cold sweat.

## *Causes of a Heart Attack*

So what exactly is a heart attack? The term actually means that something has gone wrong rather suddenly with the heart, stopping it from working properly. Heart attacks are caused by a decreased supply of blood to the hard-working cardiac muscle. Many factors can contribute to heart attacks. Two common ones are a coronary embolism and a coronary thrombosis.

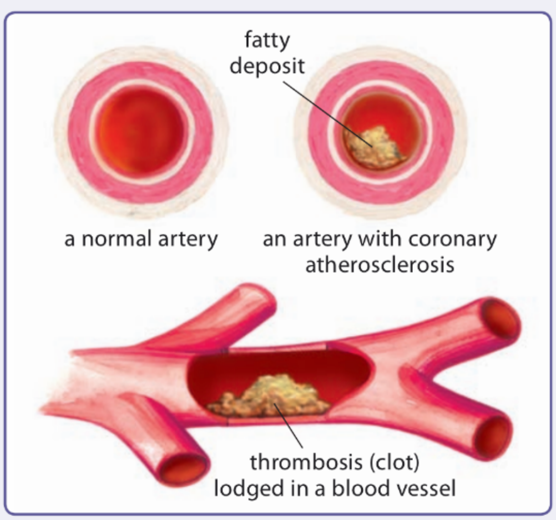
Coronary arteries, which supply the heart muscle with oxygen-rich blood, are sometimes clogged by clots floating in the blood, called *emboli* (EM buh LYE) (sing., embolus). This is called a *coronary embolism* and can cause a heart attack. The heart muscle fed by the blocked coronary artery no longer receives its share of blood. The area quickly becomes damaged and stops working. The rest of the heart may continue working, but the damaged section reduces the heart's efficiency.

Coronary atherosclerosis (see box on p. 448) can also contribute to heart attacks. Smaller passageways in the arteries reduce the amount of oxygenated blood pumped to the heart muscle. If the blood flows too slowly, a clot can form that completely blocks the artery. This is called a *coronary thrombosis* (thrahm BO sis), and it can also cause a heart attack. Without enough oxygen the muscle tissue may function irregularly, eventually die, and be replaced by scar tissue.

## *Recovering from a Heart Attack*

A person suffering a heart attack should receive medical attention immediately. While waiting for medical help to arrive, the victim should lie down and try to relax. It is important to put as little strain as possible on the weakened heart.

Sometimes the heart itself can repair some of the damage caused by a coronary embolism or thrombosis. Nearby blood vessels can grow into the damaged section to resupply the area with blood. The damaged area is replaced with new tissue, although a section of nonfunctioning scar tissue will usually remain. The blood works to dissolve clots. If a clot is small, it may be completely dissolved.




Defibrillation is used to treat some heart attack victims.

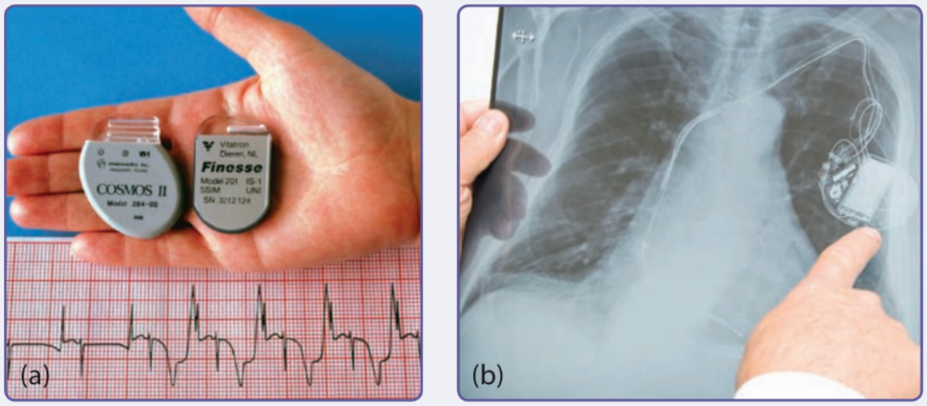
It is also possible for surgeons to remove blood clots from arteries. They can also take sections of blood vessels from another part of the body and use them to restore circulation to the heart. Such sections are attached to the blocked vessels of the heart, forming a bypass around the clot.

A nonsurgical treatment that is often used is the "clot buster." Given to a patient through the veins, a clot buster is an enzyme that dissolves clots. Once in the bloodstream, the drug circulates to the blocked artery. It dissolves the clot quickly, allowing oxygenated blood to flow to the affected part of the heart. Patients treated in this way have a higher survival rate and usually recover faster. In fact, a few patients recover so quickly that in just a few minutes they seem totally recovered.

Some sudden heart attacks may be associated with irregular heartbeats. A heart that is not beating properly is said to have an *arrhythmia*. *Ventricular fibrillation* (FIB ruh LAY shun) is an arrhythmia in which the ventricles quiver vigorously but do not pump blood. Ventricular fibrillation and some other arrhythmias can often be restored to a normal rhythm by a *defibrillator* (dee FIB ruh LAY tur), which shocks the heart with a direct electrical current. This causes the heart to contract all at once and temporarily stops its electrical activity. When the heart's natural pacemaker begins functioning again, the heart should beat normally.

### Pacemakers

Some heart attacks damage the heart's natural pacemaker, often causing a slow heartbeat (less than 60 beats per minute). An artificial pacemaker may need to be implanted to help the heart beat regularly. Sometimes only a temporary pacemaker is needed to help the heart while it recovers. If the heart is severely damaged and cannot maintain a normal heart rate, a permanent artificial pacemaker may be necessary.



Pacemakers (a) and an x-ray (b) showing a pacemaker in a person's chest

Permanent pacemakers are usually small battery-powered units implanted under a person's skin. An electrode runs from the unit through a vein and passes into the heart. The pacemaker controls the rate of the person's heartbeat by sending out regular electrical impulses. Some models may last from three to fifteen years before the batteries need to be replaced.

Years ago pacemakers were preset to beat at a fixed rate. A patient using this type of pacemaker was unable to participate in much physical exercise. The preset heart rate did not pump enough blood to supply the body's increased needs. Today's pacemakers are able to sense increased body movement and increase the heart rate to deliver more blood to the body. There are also implantable defibrillators that can detect an arrhythmia and deliver a shock to the heart if needed.

If a person is going to die of a heart attack, death usually occurs in the first few hours following the attack. If the victim survives, the heart gradually repairs itself. Many victims are able to increase physical activity in a few days to a few weeks, depending on the amount of damage to the heart. Many then undergo physical therapy to increase the strength of their heart.

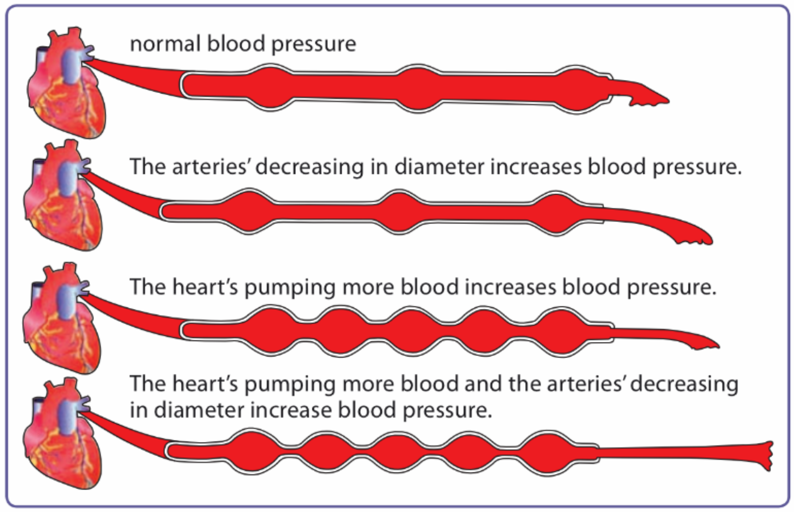
pressure, your body forces more blood through the capillaries. This increases the food and oxygen supply to the cells and removes the extra amounts of wastes.

One way the body increases blood pressure is by having the heart pump more blood. This is what happens when your heart beats faster. Another way the body increases blood pressure when necessary is by constricting the blood vessels. Smooth muscles in artery walls contract, reducing the diameter of the vessel. Increasing blood pressure is beneficial when your body needs it. However, continually high blood pressure can overwork the heart and blood vessels and cause them to wear out sooner.

Various diseases of the heart, liver, and kidneys can cause high blood pressure. Several other factors, such as old age, lead to high blood pressure. As blood vessels get older, they lose their ability to expand. If they are unable to expand as blood is pumped into them, the blood pressure increases. Scientists believe that genetics can also play a role in the development of high blood pressure.

### Think About It

Look at Figure 20-16. What effect do you think an increase in blood vessel diameter would have on blood pressure?




**20-16** Many factors affect blood pressure.

One of the major factors that contributes to high blood pressure is tension. Tension is often caused by worries, frustrations, guilt, anxiety, and similar problems. In a fallen world plagued with wars, social and economic problems, and sin, it is easy to see how tension can become a major problem, especially for non-Christians. Christians, however, have a heavenly Father Who has promised to never leave or forsake them (Ps. 23; Heb. 13:5–6). Christians should expect testings and trials, but they should take heart; God is in control and has promised that He will use everything that happens for a good purpose (Gen. 50:20; Rom. 8:28).

## 20C Section Review

1. What is the leading cause of death in the United States?
2. (True or False) Arteries carry blood away from the heart.
3. The blood vessels where gases and nutrients are exchanged between the blood and body tissues are called
   a. arteries. c. capillaries.
   b. aortas. d. veins.
4. What makes blood return to your heart from your feet, against the force of gravity?
5. What structure protects the heart from friction as it beats?
6. The heart chambers that receive blood from other parts of the body are the ___________.
7. What two organs do the pulmonary arteries and pulmonary veins connect?
8. The valves that control the *exits* of the ventricles are called ___________ valves.
9. Blood from the lungs returns to the heart through the
   a. superior vena cava. c. inferior vena cava.
   b. aorta. d. pulmonary veins.
10. (F) Why would someone get an artificial pacemaker?
11. Is it a sin for a Christian to have high blood pressure? Explain.

# 20D The Immune System and Defense Against Disease

At the end of the sixth day when God had finished His creation, "God saw every thing that he had made, and, behold, it was very good" (Gen. 1:31). All that God had created lived in harmony. There was no disease and no death. However, two events changed the relationship between man and all other organisms.

The first event was the disobedience of Adam and Eve. The second event was the curse God placed on them and the earth because of this sin. Though Adam and Eve were placed in the Garden of Eden "to dress it and to keep it" (Gen. 2:15), the earth would now resist them and their work. Adam and Eve's disobedience also resulted in death. God had said, "Thou shalt surely die" (Gen. 2:17). Physical death is a constant reminder of sin and of the spiritual death that came upon all people that day.

The environment changed as a result of sin. Death and disease became commonplace. Many microorganisms that originally caused no harm are now pathogens, which cause sickness and death. But God knew that the human body would be attacked in a sin-cursed world. From the beginning He designed us with bodily defenses to help us survive in this flawed environment.

### 20D Section Objectives

- ✓ Defend a biblical view of disease.
- ✓ Describe the body's nonspecific defense mechanisms.
- ✓ Describe the body's specific defense mechanisms.
- ✓ Differentiate between an antigen and an antibody, between T cells and B cells, and between active and passive immunity.
- ✓ Discuss the causes and effects of allergies, autoimmune diseases, and HIV.

### Function of the Immune System

- Protection from pathogens

## 20.11 Nonspecific Defenses

The body's nonspecific defenses protect against all different kinds of pathogens. These defenses include the skin, mucous membranes, inflammation, and fever.

### Skin

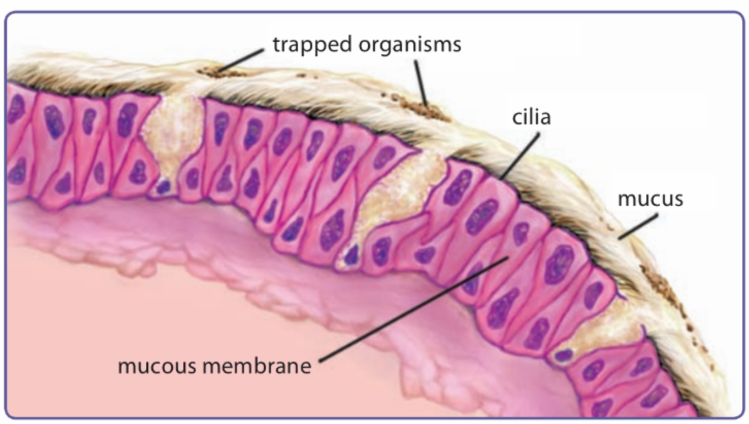
The body's first line of defense against invaders is its covering—the skin. As you learned in Chapter 19, your integumentary system provides a protective covering for the outside of your body. Although the skin is thin, the connections between these epithelial cells are very strong. The skin also produces some chemicals that kill microorganisms on its surface. Usually the only way an organism can get through is when the skin is cut or scraped.

### Think About It

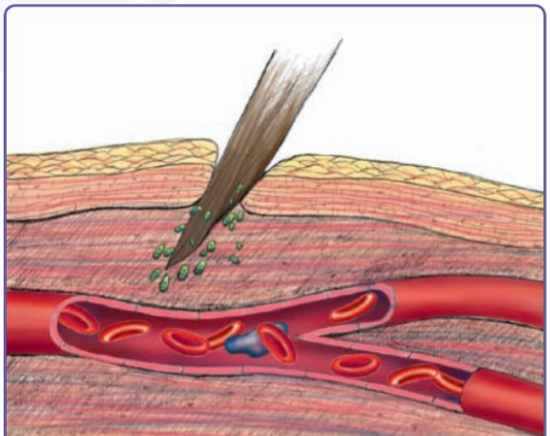
Is the presence of bacteria in your body always harmful?

### Mucous Membranes

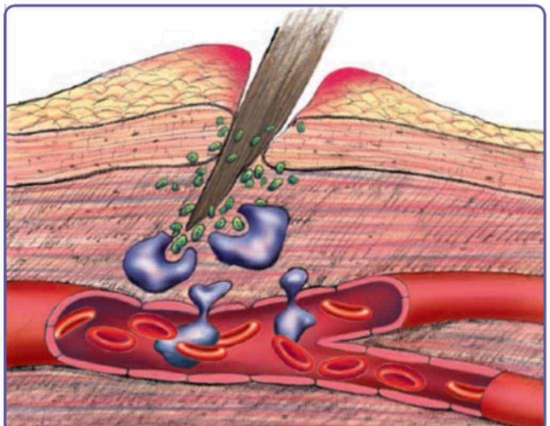
Mucous membranes are also made of epithelial tissue, but they are usually not as thick as skin. They line the inside of the body. For example, your mouth and nose are lined with mucous membranes. Mucous membranes produce sticky mucus that traps foreign materials. Some mucous membranes have tiny fingerlike projections called cilia that beat back and forth. These wavelike movements move the mucus and trapped materials to the throat where they are swallowed. Hydrochloric (HY druh KLOR ik) acid



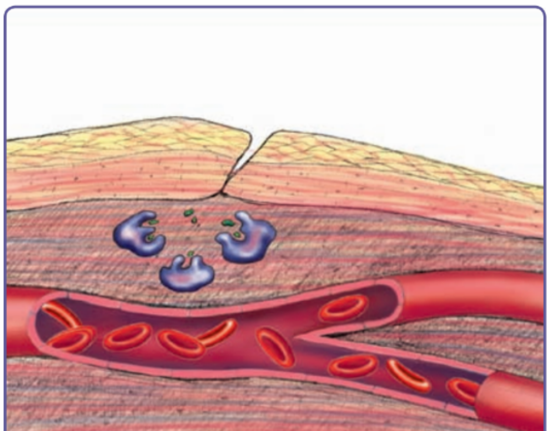

**20-17** Mucous membranes are an important part of the body's first line of defense.



Bacteria (green) enter the body on the end of a splinter.



Macrophages (purple) squeeze through the capillary walls.



As the wound heals, the macrophages finish destroying the bacteria.

**20-18** Inflammation

produced by the stomach kills any organisms trapped in the mucus. Like the skin, this barrier can be penetrated by organisms only through small tears or scrapes.

### *Inflammation*

If a pathogen gets through the skin or mucous membranes, the next line of defense is activated—inflammation. **Inflammation** is a local response to invaders. When cells are damaged, they release special chemicals that cause changes in nearby blood vessels.

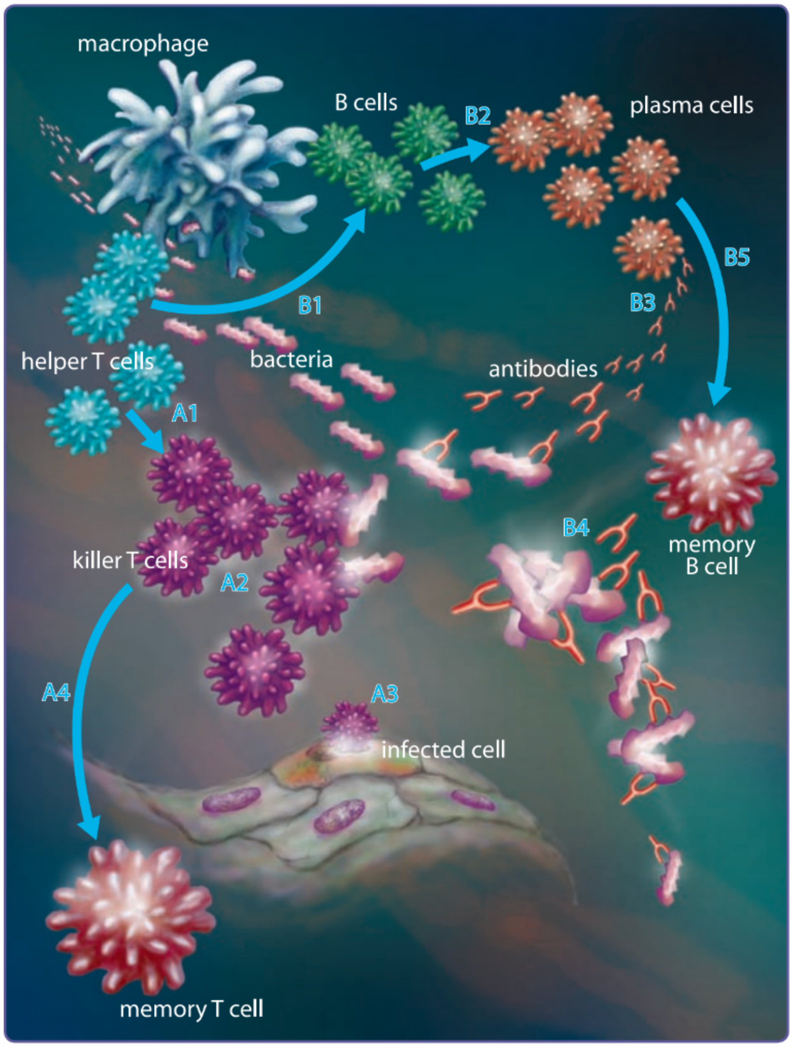
- First, the blood vessels in the area dilate (increase in size) to supply more blood to the area.
- Second, the walls of the capillaries become "leaky" so that plasma can reach the site. If the area where the inflammation is occurring is close to the surface of the skin, the area may be swollen, red, painful, and slightly warmer than the surrounding skin. The plasma brings nutrients and other substances to fight the invaders.
- Third, special leukocytes called *macrophages* slip through the capillary walls. The macrophages attack the foreign organisms and kill them. How do the macrophages know what to attack? All organisms contain chemicals called **antigens** on their cell membranes. The body recognizes antigens from other organisms as "foreign." Macrophages recognize foreign antigens as not belonging in the body and attack them.

### *Fever*

If more help is needed, the body responds by causing a fever. A fever is an increase in the body's normal temperature of 37 °C (98.6 °F). You might think that a fever is bad. However, the increase in temperature often slows the rate of bacterial reproduction. Remember from Chapter 9 (p. 187) that different bacteria have very specific temperature ranges in which they grow best. A fever can also increase many of the body's defenses to fight the invaders. Special chemicals released at the site of inflammation travel to the brain, which triggers the increase in temperature. Of course, if the body's temperature goes too high or is raised for too long, the body's tissues may be damaged.

## 20.12 *Specific Defenses*

The body's final line of defense is the **immune system**. Cells in the immune system respond to and attack *specific* pathogens. The body's nonspecific defenses could be compared to a garbage disposal; they will attack and protect the body against all different kinds of pathogens. The cells of the immune system, however, are picky eaters; they have specific pathogens to which they respond. The white blood cells used by the immune system are called *lymphocytes* (LIM fuh SITES). There are two major kinds of lymphocytes—T cells and B cells.




**20-19** The immune response. When macrophages identify a foreign substance (such as bacteria), two series of events happen simultaneously.

- Helper T cells activate killer T cells (A1) as well as B cells (B1). Some killer T cells attack the bacteria (A2), and others attack infected cells (A3).
- Meanwhile, the activated B cells produce plasma cells (B2), which in turn produce antibodies (B3). The antibodies attack the invading bacteria (B4).
- After the bacteria have been destroyed, some T cells (A4) and some B cells (B5) become memory cells to guard against future infections. Leftover antibodies also remain in the bloodstream, enhancing the body's immunity.

## T Cells and B Cells

Millions of T cells circulate in the blood. Once a macrophage identifies a foreign antigen, the macrophage releases a chemical that causes T cells to spring into action. First, they rapidly multiply to make more T cells that recognize the foreign antigen. Some of the T cells called *helper T cells* activate *killer T cells*. The killer T cells begin to attack either the pathogen or body cells that have been infected with the pathogen. Helper T cells also notify B cells that a foreign antigen has been found.

Once the B cells have been notified, or activated by the helper T cells, they begin producing *plasma cells*. The plasma

## Facets of Life Science: Organ Transplants

Occasionally people are born with defective organs that surgery cannot repair. In other cases, injury or disease makes an organ useless. Illegal drug use or complications due to prescribed drugs can destroy an organ's ability to function. For people in these circumstances, organ transplants may be necessary if they are to lead normal lives.

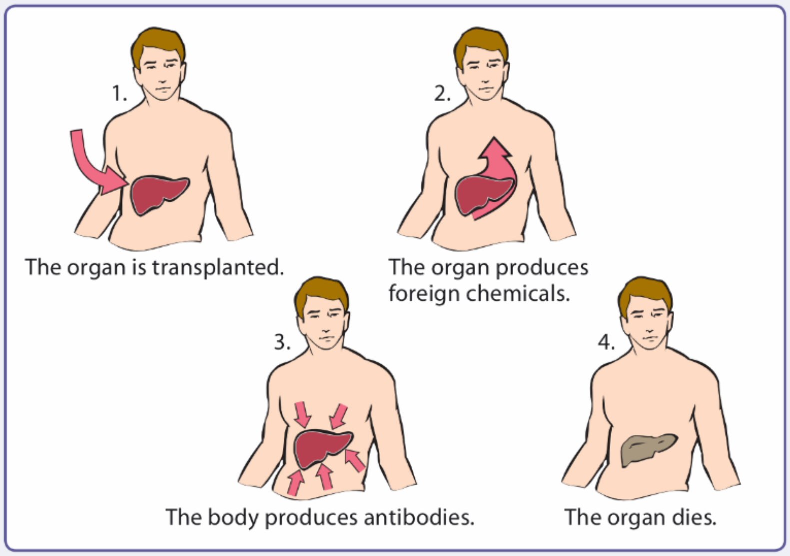
The major problem with organ transplants is rejection. The human body's immune system produces white blood cells and antibodies to fight off infection caused by foreign substances—normally bacteria and viruses. If the immune system recognizes an antigen on the transplanted organ as foreign, it produces antibodies that attack the organ, and the body then rejects the organ. Sometimes rejection is immediate, and the person dies soon after the transplant is completed. In other instances, the organ functions well for several years; then it gradually slows down as the immune system destroys it. Rejection is becoming less of a problem because of anti-rejection drugs.

Anti-rejection drugs slow or stop the activity of the immune system. However, drugs used to inhibit the immune system cause the body to tolerate not only the foreign organ but also foreign bacteria and viruses. Sometimes the patient dies not because the transplanted organ is rejected, but because his immune system could not fight off an infection that it easily could have if it had been working properly.

In 1954 a kidney became the first organ ever to be successfully transplanted in humans. The kidney was donated by a young boy to his twin brother, who was dying of kidney failure. (Humans have two kidneys but usually can lead a normal life with only one.) Because the boys had the same genetic makeup, there was little problem with rejection. Both boys grew up to be healthy men. Since 1954, kidney transplants have added years to the lives of many people.

The techniques for transplanting kidneys are not as complicated as those for transplanting other organs. In a kidney transplant only one artery, one vein, and one ureter must be cut and attached. The ideal kidney donor is a close, living relative of the patient. Most donors, however, are people who have just died but had signed up to become organ donors. A kidney taken from a dead donor must be transplanted within 24 hours; otherwise, the rejection rate increases.

If a kidney transplant is successful, it allows a patient to lead a nearly normal life. The alternative to a kidney transplant is to be attached to an artificial kidney machine several times a week for several hours at a time. This process is called dialysis (dy AL ih sis).




Both dialysis and organ transplants are expensive. Transplants and additional medications range anywhere from $50,000 to over $500,000 during the first year after the transplant. Understandably most patients are unable to pay all the costs. In the past, many patients were rejected for treatment due to their inability to pay. In 1972 an amendment to the Social Security Act authorized the federal government to pay almost all expenses related to dialysis machines and kidney transplants. This has not reduced the costs but has merely shifted the payment of these costs to all Americans by way of taxes.

Many other organ and tissue transplants are now possible. Bones, cartilage, tendons, eardrums, middle-ear bones, corneas, bone marrow, lungs, livers, intestines, pancreases, and hearts have been transplanted successfully.

cells, in turn, begin producing antibodies. *Antibodies* are proteins that react against a specific antigen. The antibodies destroy the pathogen or inactivate it so that other cells can destroy it. They are so specific that an antibody that destroys one pathogen may have no effect on a different pathogen.

Once the pathogen has been destroyed, the leftover antibodies remain in the bloodstream in case they are needed again. Also, some of the T cells and B cells "remember" the antigen so that if it ever returns, the body can quickly respond.

### *Would You Believe?*

Plasma cells live for four or five days. During that time, they can produce up to 2000 antibodies per second!

## Frequently Transplanted Organs (U.S. Hospitals)

***Cornea.*** A cornea transplant is the most frequent transplant operation. Few corneas are rejected by the recipients' bodies. Cornea transplants improve the vision of over 90% of the people who have this operation.

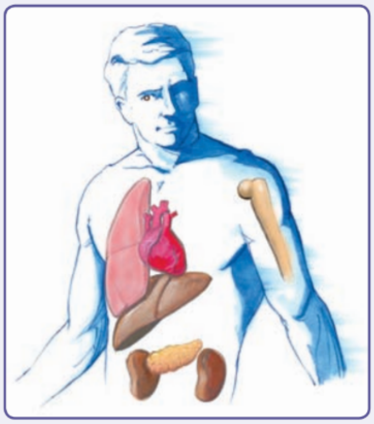
***Kidney.*** Over 17,000 kidneys are transplanted each year; around 6000 of these are from living donors. Approximately 96% of transplanted kidneys still function after one year. This is the most frequent organ transplant. (The cornea is only part of an organ.) If the transplanted kidney fails, the person can survive by using a dialysis machine.

***Liver.*** Approximately 6000 liver transplants are performed each year. About 75% of the people who receive a transplant are alive after five years.

***Heart.*** Over 2000 people receive heart transplants each year. More than 85% of heart-transplant patients are alive a year after the transplant. About 70% are alive after five years.

***Heart-lung.*** Patients needing only a lung transplant often receive a heart-lung transplant. The combined transplant operation has a better success rate than lung transplants alone. Fewer than a hundred such operations are attempted each year. Statistics indicate that around 80% of the patients receiving heart-lung transplants are alive after one year. This number drops to less than 50% after five years.

***Pancreas.*** Around 1000 pancreas transplants are performed each year. About 90% of the recipients are alive after five years. A person whose transplanted pancreas fails can receive injections of insulin to remain alive.



***Bone marrow.*** The success rate for marrow transplants varies greatly (between 10% and 90%). Survival depends on which disease the patient has and how well matched the donor and patient are. Bone marrow produces the white blood cells used by the immune system. Thus, sometimes the marrow transplant rejects the new body, rather than the body rejecting the transplant.

These remaining B cells and T cells are called *memory cells*. The body's ability to remember a specific foreign antigen and respond to it before getting sick is called *immunity*.

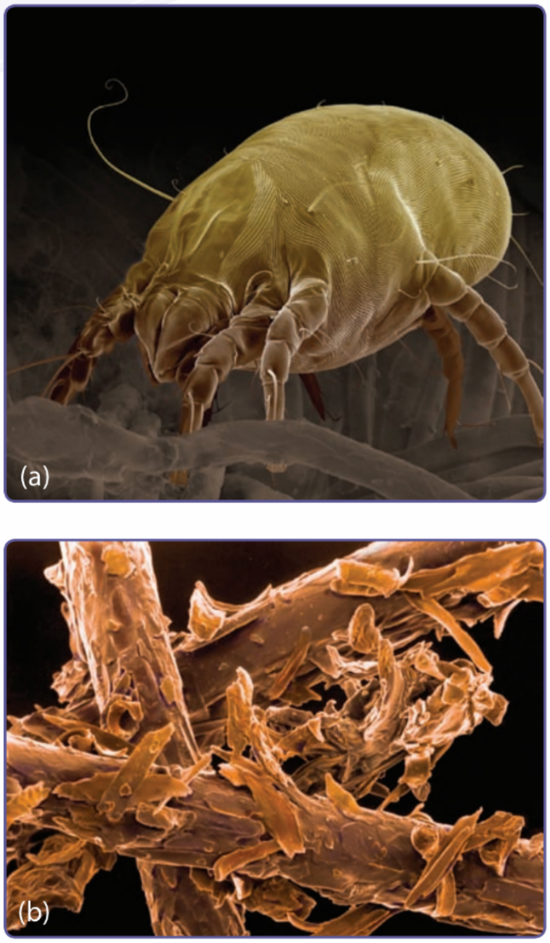
### Active and Passive Immunity

When your body produces its own antibodies, it is called *active immunity*. Active immunity occurs when there has been an infection and the immune system has responded. Another way to develop active immunity is by receiving a vaccine (vak SEEN). A *vaccine* contains a weakened form of the virus or bacterium that still contains the antigens. Your body recognizes the antigens as foreign and produces antibodies and memory cells to be ready in case they are needed in the future. Since the vaccine is a weakened form of the pathogen, you do not experience the symptoms of the disease. If you ever encounter the pathogen in the future, your body can respond quickly to fight it off before you become sick.

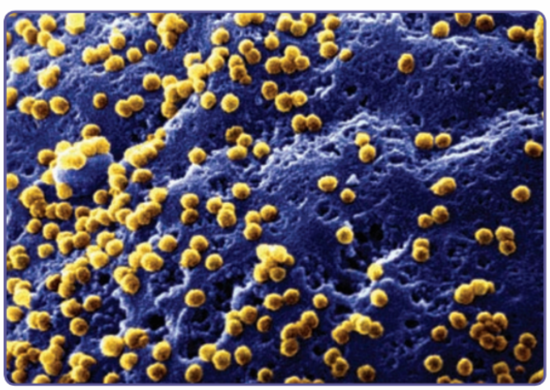
*Passive immunity* occurs when you receive already-made antibodies. A newborn baby receives antibodies from his mother. Since these antibodies do not last long, infants can be vaccinated so they can develop their own antibodies. People can also receive antibodies from animals or other organisms. These antibodies can be injected just like a vaccine, providing passive immunity. Since these antibodies do not last long, booster injections are needed to maintain the immunity.

**Think About It**

Why does active immunity last longer than passive immunity?




**20-20** Dust mites (a) and pet dander (flakes of dried skin on hair) (b) can cause allergic reactions.



**20-21** The human immunodeficiency virus is the virus that causes AIDS.

## 20.13 *Defense Malfunctions*

God designed a marvelous immune system, but because of the effects of the Fall, problems can occur. Some pathogens cause the immune system to react against normal body tissues. Others prevent the immune system from working effectively. Also, the immune system sometimes overreacts to substances that are not pathogens.

### *Allergies*

Has freshly mown grass ever caused your nose to run or your eyes to itch? Do some foods make you break out in a rash? If so, you probably have an allergy. An **allergy** is an overreaction of the immune system to a foreign substance that normally is not a pathogen. The substance, such as pollen or mold, that causes such a response is called an *allergen*. The response may be just a runny nose, or it can cause life-threatening breathing difficulties.

### Autoimmune Diseases

In an *autoimmune disease*, the immune system is unable to tell the difference between pathogens and some of the body's normal cells. When this happens, the immune system attacks the body's own cells. Doctors and scientists are not sure why this occurs. Examples of autoimmune diseases include rheumatoid arthritis, lupus, multiple sclerosis, and some types of diabetes.

### AIDS

AIDS is caused by the human immunodeficiency virus (HIV). HIV destroys the body's ability to respond to pathogens by destroying helper T cells. Without helper T cells, killer T cells and B cells are not activated. Thus, they cannot respond to HIV or other pathogens that might infect the body. The result is that many HIV-infected people develop AIDS (acquired immune deficiency syndrome). Since their bodies cannot properly respond to infections, they often die from infections that a healthy immune system could easily overcome.

HIV infections have spread rapidly over the world primarily through immoral sexual relations. Before HIV was fully understood, it was sometimes spread through blood transfusions. Sadly, many innocent people were infected. In 1985 a screening test was designed to test donated blood for the presence of HIV. Blood collection centers now screen for HIV.

What should be our response to a person suffering from HIV or AIDS? It should be the same as our response to other disease victims—compassion and love. We should not assume that a person got the disease because of immoral activity or because God is judging that person for some sin he has committed (Luke 13:4–5). We should treat him the same way we would want to be treated. If you meet someone with AIDS who is not a believer in Jesus Christ, this could be a great chance to share with him that we are all sinners (Rom. 3:23), but "Christ Jesus came into the world to save sinners" (1 Tim. 1:15).

## 20D Section Review

1. What two major events changed God's creation?
2. How are the integumentary system and the immune system related?
3. Which affects the entire body, inflammation or fever?
4. What prevents macrophages from attacking the body's own cells?
5. Explain the similarities and differences between T cells and B cells.
6. Plasma cells produce __________ that destroy or inactivate pathogens.
   a. antigens c. antibodies
   b. allergies d. B cells
7. What is the function of a memory cell?
8. (F) How is rejection in a bone marrow transplant different from rejection with other transplants?
9. What kind of immunity is produced by an injection of preformed antibodies?
10. (True or False) An overreaction of the immune system to a nonpathogenic substance is called an allergy.

# 20E The Excretory System

The primary functions of the excretory system are to remove wastes from the blood and to eliminate them from the body in order to maintain the body's homeostasis. The main organs of the excretory system are the **kidneys**. The kidneys are reddish brown, bean-shaped organs about 11 cm (4.3 in.) long and 6 cm (2.4 in.) wide. They are located in the lower back, one on each side of the vertebral column.

Attached to each kidney is a ureter. The **ureters** (YUR ih turz) are tubes that carry the wastes and water filtered out of the blood down to the urinary bladder. The **urinary bladder** is a muscular bag that temporarily stores the fluid wastes from the kidneys. From the urinary bladder a muscular tube called the **urethra** (yoo REE thruh) leads to the outside of the body.

### *20E Section Objectives*

- ✓ Describe the functions of the major organs of the excretory system.
- ✓ Explain how kidneys remove waste materials from the blood and how these materials are removed from the body.
- ✓ Identify several usual and unusual substances in urine.

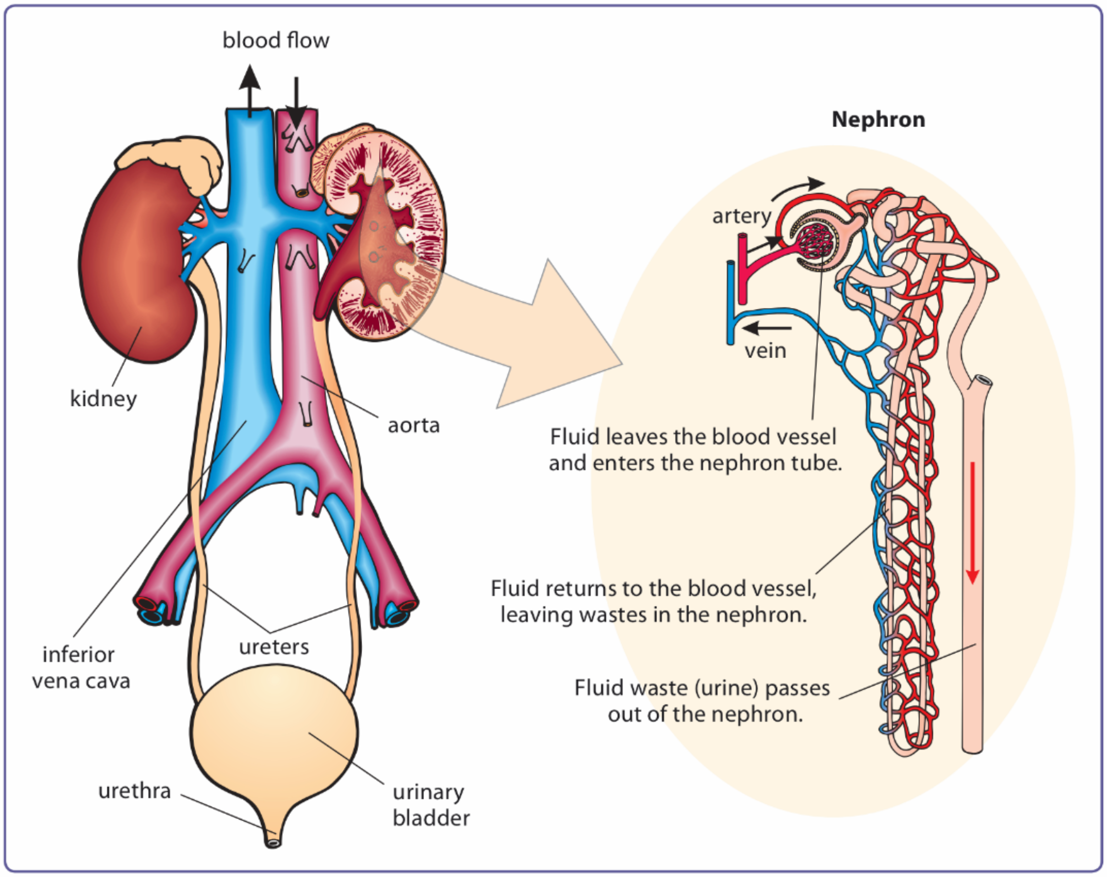
### *Functions of the Excretory System*

- Removal of wastes, foreign substances, and excess substances from the blood
- Temporary collection and storage of these substances
- Elimination of these substances from the body

## 20.14 *How the Kidneys Function*

Inside each kidney are about one million nephrons (NEF rahnz). A **nephron** is the unit in the kidney that filters the blood. The filtering takes place in two steps. First, a large portion of the water from the plasma leaves the blood capillaries and enters the nephrons. This water contains many dissolved substances. The water then flows along the nephron tubule.

The second step involves the return of substances to the blood. Most of the water and normal substances of blood plasma, such as salts, calcium, vitamins, hormones, pigments, and amino acids, return to the blood through capillaries that surround the nephron tubule. If the plasma has too much of any of these substances, some will remain in the nephrons. Also, substances that




**20-22** Human excretory system

are not normal to the blood, such as drugs and waste products, remain in the nephrons. The fluid that remains in the nephrons is called **urine**. The urine from the nephrons collects in the kidney and then passes into the ureter.

## 20.15 *Usual and Unusual Substances in Urine*

Normally urine contains a small amount of each of the substances found in blood plasma. However, urine may contain larger quantities of these substances if unusually large amounts of them are present in the blood. For example, if you consume more vitamin C than your body can use, your urine will contain some vitamin C.

Urine contains mostly water (95%) and waste products. When blood flows through the body tissues, it picks up the waste products produced by normal cellular processes. For example, protein digestion produces ammonia as a waste product. Ammonia is changed to another waste product, *urea* (yoo REE uh), by the liver. When blood containing urea passes through the kidneys, much of the urea is left in the nephrons. Thus the blood is much cleaner after it passes through the kidneys.

One substance that should not be present in the urine in large quantities is sugar (glucose). The pancreas is one of the key regulators of the level of sugar in the blood. (See pp. 481, 507–8.) If this organ fails, there may be too much sugar in the

## Connections in Science: Artificial Kidneys

Occasionally a person's kidneys fail to operate properly. This failure may be caused by injury, disease, or overworking of the kidneys. If one kidney stops operating, there is usually little problem. People can function normally with only one kidney. People can also function with only a part of one kidney working, but they must be under careful supervision. However, if a person loses the use of both kidneys, a *dialysis machine* (often called an artificial kidney) can help filter his blood.

Dialysis removes from the blood the wastes that the kidneys would normally remove. Dialysis patients are usually connected to the machine several times a week for several hours each time. The artificial kidney contains thin tubes submerged in warm, circulating fluid. After a patient's blood vessels are connected to the artificial kidney, his blood flows through these tubes. As the blood flows through the tubes, wastes are removed in much the same way that they are in a nephron. The cleansed blood then returns from the dialysis machine into the patient's blood vessels through other plastic tubes.

Scientists are working to develop artificial kidneys that allow greater time between dialysis treatments. This would help the dialysis patients live more normal lives. It could also reduce the cost of the procedure. Some researchers are even trying to develop synthetic kidneys that could be transplanted into patients and function just as well as natural human kidneys.

Dialysis filters wastes from a person's blood.

blood. This condition is called *diabetes mellitus* (see p. 75). The excess sugar in the blood causes the kidneys to filter out sugar and put it in the urine. Various other diseases and disorders account for the presence of other unusual substances or abnormal amounts of substances in a person's urine. A *urinalysis* (a process for determining what is in urine) can often tell a physician a great deal about a patient's health.

## 20E Section Review

1. The tubes that carry wastes from the kidneys to the bladder are the
   a. ureters. c. urethras.
   b. nephrons. d. ureas.
2. The microscopic structures in the kidneys that filter wastes from the blood are called ___________.
3. Which structure is most inferior?
   a. kidney c. ureter
   b. urethra d. bladder
4. List two substances *normally* found in urine.
5. What could excessive sugar in the urine indicate?
6. (True or False) Dialysis can be used to remove wastes from the blood of people whose kidneys do not function properly.

### Learning the Lingo


| | |
|---|---|
| homeostasis | 439 |
| erythrocyte | 441 |
| hemoglobin | 441 |
| leukocyte | 441 |
| antibody | 443 |
| platelet | 443 |
| blood plasma | 446 |
| artery | 447 |
| capillary | 447 |
| vein | 447 |
| heart | 448 |
| atrium | 448 |
| ventricle | 448 |
| atrioventricular valve (AV valve) | 448 |
| semilunar valve | 449 |
| aorta | 450 |
| pulse | 451 |
| blood pressure | 451 |
| inflammation | 456 |
| antigen | 456 |
| immune system | 456 |
| allergy | 460 |
| kidney | 461 |
| ureter | 461 |
| urinary bladder | 461 |
| urethra | 461 |
| nephron | 461 |
| urine | 462 |


# Pulling It All Together

## Gathering the Data

- Maintaining the internal balance of an organism is called homeostasis. The circulatory, immune, and excretory systems all function to maintain homeostasis.
- Blood cells develop in the bone marrow. Erythrocytes are red blood cells. They contain hemoglobin, which carries oxygen to body tissues. They do not have nuclei. Hemoglobin disorders include anemia and carbon monoxide poisoning.
- Leukocytes are white blood cells; they function in immunity. Some destroy bacteria and other foreign matter, and others produce antibodies, which are chemicals that attack invading organisms. A rise in the number of leukocytes indicates an infection. Platelets are small cell fragments that help in blood clotting.
- The fluid portion of the blood is called blood plasma. It is mostly water. The rest of the plasma contains substances that are transported by the blood (such as foods, wastes, minerals, and hormones) and substances that regulate the blood (such as proteins).
- Arteries carry blood away from the heart, and veins carry blood toward the heart. Capillaries are the smallest blood vessels, through which materials are exchanged with the body tissues.
- The heart is protected by a fluid-filled sac called the pericardium. Inside the heart are four chambers. The upper chambers are atria, and the lower chambers are ventricles. The septum divides the right and left sides of the heart.
- Deoxygenated blood from the body enters the right atrium through the superior vena cava and inferior vena cava. The right atrioventricular (AV) valve opens to allow blood into the right ventricle. The right ventricle contracts, sending blood through a semilunar valve, into the pulmonary arteries, and to the lungs to receive oxygen. Oxygenated blood returns to the heart through the pulmonary veins into the left atrium. The left AV valve opens to allow blood into the left ventricle. The left ventricle contracts, sending blood through another semilunar valve and into the aorta to be pumped throughout the body. The coronary arteries supply the heart with blood.
- The pressure of circulating blood against the artery walls is called blood pressure. Various factors can cause blood pressure to increase or decrease. You can measure your heart rate by taking your pulse.
- The body's immune system defends against pathogens. Nonspecific defenses include the skin, mucous membranes, inflammation, and fever. Macrophages are special white

blood cells that attack foreign organisms. They recognize them as foreign by the antigens on their cell membranes.

- The body's specific defenses are T cells and B cells, which are lymphocytes, another type of white blood cell. When a macrophage recognizes a foreign antigen, it stimulates T cells. T cells activate helper T cells, which activate killer T cells. Killer T cells attack the pathogen. Helper T cells also activate B cells, which make plasma cells that produce antibodies to fight the pathogen. After an infection, the body produces memory B cells and memory T cells. The body's ability to remember a pathogen and respond quickly is called immunity.
- Active immunity is obtained when the body produces antibodies itself. This can happen by experiencing the disease or by receiving a vaccine. Passive immunity occurs when a person receives antibodies from another source, such as an infant from his mother. Passive immunity does not last as long as active immunity.
- An allergy is an overreaction of the immune system to a nonpathogenic substance. Other malfunctions of the immune system include autoimmune diseases and AIDS.
- The excretory system removes wastes from the blood and eliminates them from the body. The kidneys are the main excretory organs. Ureters carry urine from the kidneys to the urinary bladder, where the urine is stored. The urethra carries urine from the bladder to the outside of the body.
- Each kidney contains millions of microscopic structures called nephrons, which filter wastes as blood plasma flows through them. The fluid that remains after filtration is called urine.
- Urine usually contains mostly water and waste products, such as urea. An excessive amount of sugar in the blood can indicate diabetes mellitus.

## Sorting the Data

Note: For True/False questions that are false, explain why the statement is false or suggest a way to make it true.

1. (True or False) An organism's maintaining an internal balance is called homeostasis.
2. Which blood cells are not complete cells? Explain.
3. Where are blood cells produced?
4. The pigment in red blood cells that is used for carrying oxygen is ___________.
5. Some white blood cells produce chemicals that are called ___________ and that attack foreign organisms.
   a. antigens c. antibodies
   b. platelets d. macrophages
6. (True or False) Platelets function in blood clotting.
7. What is the function of blood plasma?


8. Which of these vessels carry blood *toward* the heart?
   a. cardiac veins
   b. pulmonary arteries
   c. renal arteries
   d. the aorta
9. What is the function of your natural pacemaker?
10. Where does blood go after leaving the right ventricle?
11. (True or False) The largest artery in the body is the superior vena cava.
12. What is an arrhythmia?
13. What kind of energy does a defibrillator use to restore normal heart functions?
14. Describe two ways the body can increase blood pressure.
15. Since God declared His creation "very good" (Gen. 1:31), why do we have pathogens?
16. Describe several nonspecific defenses the body uses to protect itself from pathogens.
17. Tell whether each of the following statements are true of (a) T cells, (b) B cells, (c) both, or (d) neither.
    a. a type of lymphocyte
    b. produce plasma cells, which produce antibodies
    c. one of the body's specific defenses
    d. a type of leukocyte
    e. a type of erythrocyte
18. (True or False) Experiencing a disease gives a person passive immunity.
19. What is an autoimmune disease?
20. What body structure temporarily stores urine?
21. What are nephrons? How do they maintain homeostasis?
22. A common waste substance in urine that is produced during protein digestion is __________.

## Outside the Lab

23. Research a disease or disorder of one of the human body systems discussed in this chapter. Prepare a short report about the disease. Include information about causes, symptoms, statistics, and treatments.

## Analyzing the Data

24. Why is carbon monoxide so dangerous?
25. What type(s) of blood could a person with type B blood receive in a transfusion? Why?
26. Describe the relationship between arteries, veins, and capillaries.
27. Why are the ventricle walls thicker than the atrium walls?
28. How are semilunar valves and atrioventricular valves different? How are they similar?
29. Do arteries ever carry deoxygenated blood? If so, when?
30. Why is the immune system described as a *specific* defense?
31. Why is a temperature of 100 °F considered beneficial during an illness, but a temperature of 105 °F is dangerous?

32. Why does a vaccine provide active immunity instead of passive immunity?

## Drawing Conclusions

In 3–5 sentences, summarize the main ideas from the chapter in your own words.

# Standardized-Test Prep Questions

Use Diagram A to answer Questions 1–4.

1. What is the function of Structure 5?
   a. pumps blood to the left atrium
   b. returns blood to the body tissues
   c. returns blood to the heart
   d. pumps blood to the left lung
2. How is the blood in Structure 6 different from the blood in the other arteries of the body?
   a. It is saturated with carbon monoxide.
   b. It contains deoxygenated blood.
   c. It connects to the heart.
   d. It has a high plasma content.
3. Where will blood go immediately after leaving Structure 4?
   a. to the left atrium c. to the lungs
   b. to the body d. to the aorta
4. Which structure contains oxygenated blood?
   a. 1 c. 6
   b. 4 d. 10

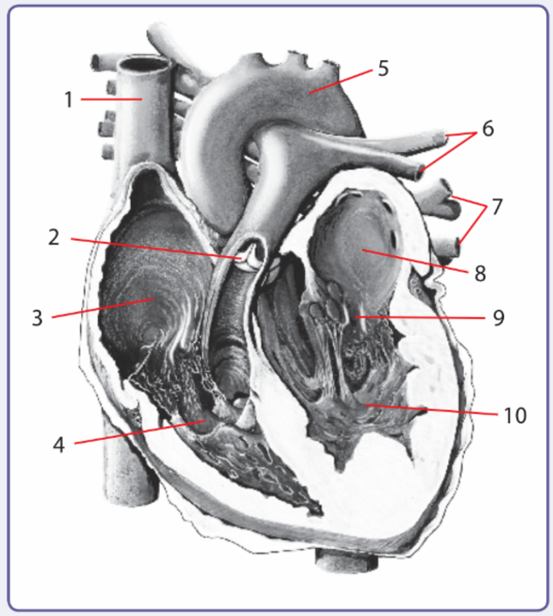


Diagram A

5. Which of these blood vessels would you expect to carry blood from the aorta to the kidneys?
   a. cephalic vein c. inferior vena cava
   b. renal artery d. femoral vein
6. A large number of white blood cells could indicate
   a. immunity. c. too much hemoglobin.
   b. an infection. d. anemia.
7. What blood type(s) could a person with type AB blood safely receive in a transfusion? (Select all that apply.)
   a. type A c. type AB
   b. type B d. type O
8. What type of blood cell is indicated in Diagram B?
   a. erythrocyte c. platelet
   b. antibody d. leukocyte

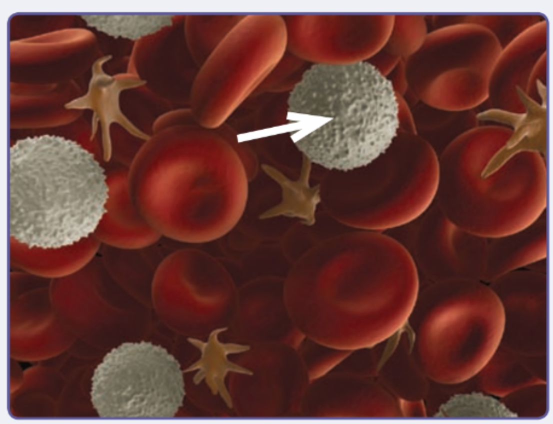


Diagram B

9. People with AIDS often die from other infections because HIV
   a. destroys T cells. c. inactivates hemoglobin.
   b. causes fever. d. produces antibodies.
10. If you receive a vaccine for measles, you will develop __________ against this disease.
    a. active immunity c. passive immunity
    b. autoimmunity d. antigens