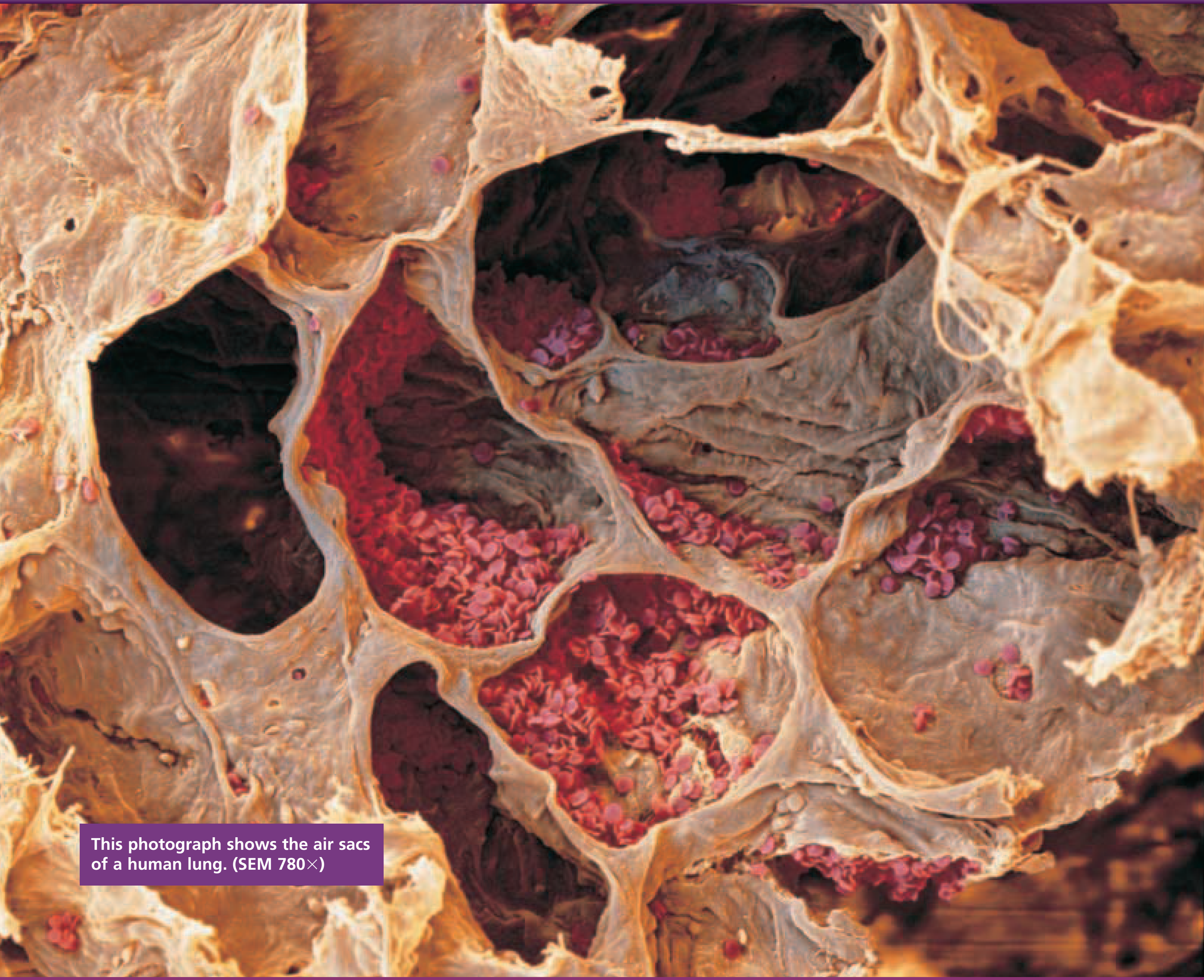
CHAPTER 46

CIRCULATORY AND RESPIRATORY SYSTEMS



This photograph shows the air sacs of a human lung. (SEM 780×)

THE CIRCULATORY SYSTEM

SECTION 1

Most of the cells in the human body are not in direct contact with the external environment. The circulatory system acts as a transport service for these cells. Two fluids move through the circulatory system: blood and lymph.

OBJECTIVES

- **Describe** the structure and function of the human heart.
- **Trace** the flow of blood through the heart and body.
- **Distinguish** between arteries, veins, and capillaries in terms of their structure and function.
- **Distinguish** between pulmonary circulation and systemic circulation.
- **Summarize** the functions of the lymphatic system.

VOCABULARY

cardiovascular system
lymphatic system
atrium
ventricle
valve
aorta
sinoatrial node
atrioventricular node
pulse
artery
blood pressure
hypertension
capillary
vein
pulmonary circulation
systemic circulation
atherosclerosis
lymph

THE HEART

The blood, heart, and blood vessels form the **cardiovascular system.** The lymph, lymph nodes, and lymph vessels form the **lymphatic system.** The cardiovascular system and lymphatic system collectively make up the *circulatory system.* The circulatory system transports nutrients, hormones, and gases; gets rid of wastes; and helps maintain a constant body temperature.

The central organ of the cardiovascular system is the heart, the muscular organ that pumps blood through a network of blood vessels. The heart beats more than 2.5 billion times in an average life span. Yet this organ is slightly larger than a fist. The heart lies within the thoracic (chest) cavity, behind the sternum (breastbone) and between the two lungs. A tough, saclike membrane called the *pericardium* surrounds the heart and secretes a fluid that reduces friction as the heart beats.

Notice in Figure 46-1 that a *septum* (wall) vertically divides the heart into two sides. The right side pumps blood to the lungs, and the left side pumps blood to the other parts of the body. Each side of the heart is divided into an upper and lower chamber. Each upper chamber is called an **atrium,** and each lower chamber is called a **ventricle.**

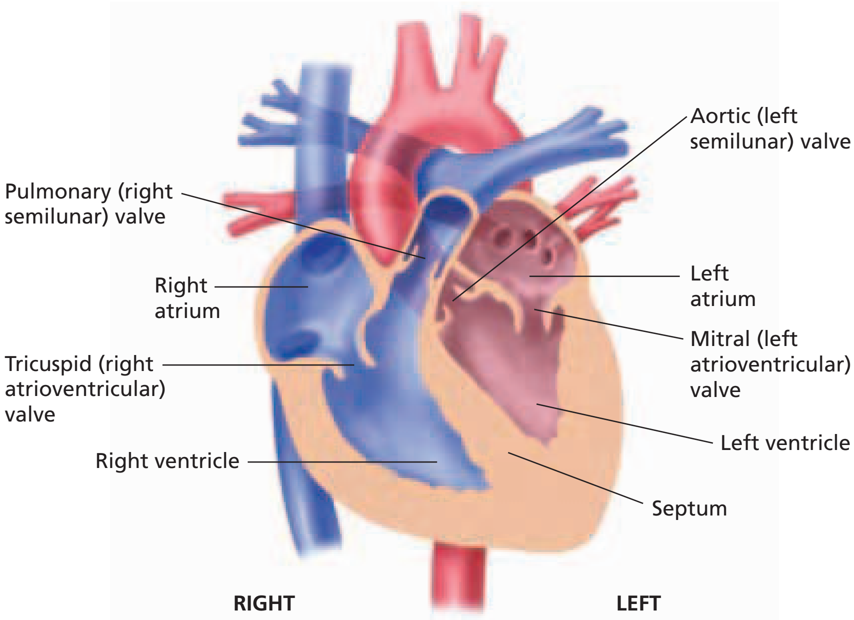


FIGURE 46-1

The septum prevents mixing of blood from the two sides of the heart, and the valves ensure that blood flows in only one direction.

Quick Lab

Determining Heart Rate

Materials stopwatch or clock with second hand

Procedure

1. Have your partner find the pulse in your wrist and count your heartbeats for 15 seconds while you are seated. Calculate your resting heart rate in beats per minute.
2. Have your partner count your heartbeats for 15 seconds while you are standing. Calculate your heart rate in beats per minute.
3. Have your partner count your heartbeats for 15 seconds after you jog or march in place for 1 minute. Calculate your heart rate in beats per minute.

Analysis What causes your pulse? What causes the change in your heart rate in each situation?

Valves are flaps of tissue that open in only one direction. The *atrioventricular* (AY-tree-oh-ven-TRIH-kyuh-luhr) *valve* (AV valve) on the right side of the heart is called the *tricuspid valve*. The *mitral valve*, also called the *bicuspid valve,* is on the left. As the ventricles pump, blood pressure closes the AV valves to prevent blood from flowing backward into the atria. From the ventricles, blood is pumped out of the heart into large vessels. A *semilunar* (SEM-ee-LOON-uhr) *valve* (SL valve) separates the ventricles from these large vessels on each side of the heart. The SL valve on the right side is known as the *pulmonary valve*, and the SL valve on the left side is known as the *aortic valve*. The SL valves prevent blood from flowing back into the ventricles when the heart relaxes.

Circulation in the Heart

Refer to Figure 46-2 to trace the path of the blood as it circulates through the heart. Blood returning to the heart from parts of the body other than the lungs has a high concentration of carbon dioxide and a low concentration of oxygen. 1 Deoxygenated (O_2-poor) blood enters the right atrium.

2 The right atrium sends deoxygenated blood into the right ventricle. 3 The muscles of the right ventricle contract and force the blood into the pulmonary arteries. 4 The pulmonary artery sends the blood to the lungs. In the lungs, the carbon dioxide diffuses out of the blood, and oxygen diffuses into the blood. 5 The oxygenated blood returns to the left atrium of the heart. Notice in Figure 46-2 that the flow of blood on the left side of the heart is illustrated with a red arrow representing oxygenated blood, which has a bright red color.

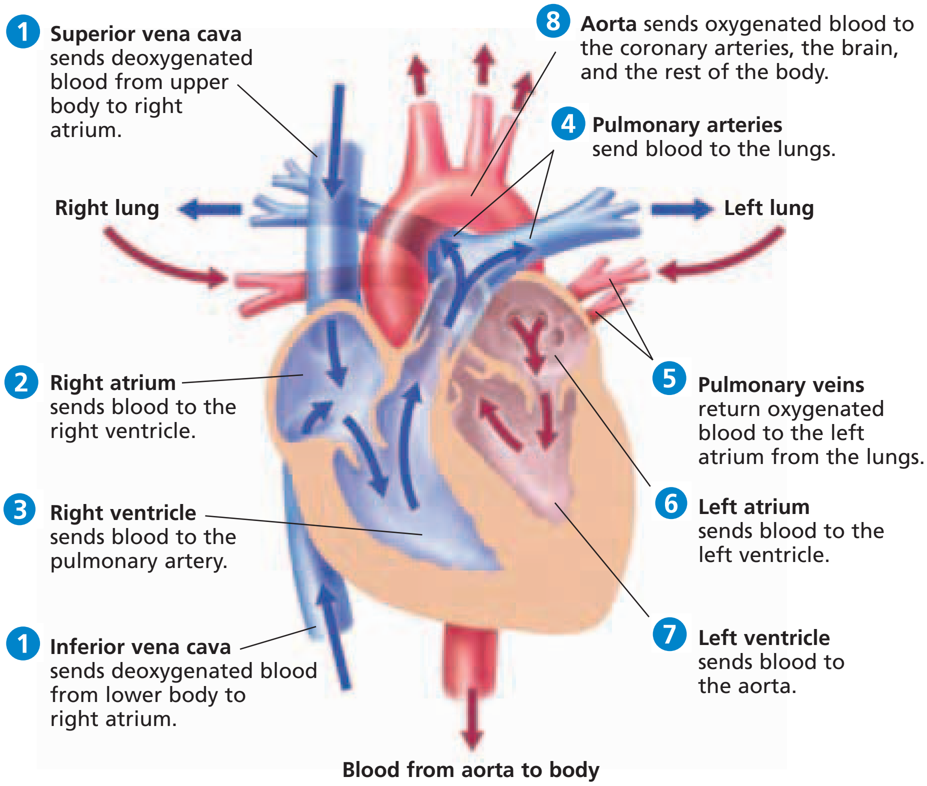


FIGURE 46-2

Trace the path of blood through the heart. Notice that illustrations of a heart are drawn as if the heart were in a person facing you. That is, the left side of the heart is shown on the right as you face the heart, and the right side of the heart is on the left as you face the heart.

6 The oxygenated blood is then pumped into the left ventricle. 7 Contraction of the muscular walls of the left ventricle forces the blood into a large blood vessel called the **aorta.** 8 From the aorta, blood is transported to all parts of the body. The left ventricle is the thickest chamber of the heart because it has to do the most work to pump blood to all parts of the body.

Deoxygenated blood is commonly represented with the color blue. However, it is a misconception that deoxygenated blood is blue. When oxygen is attached to hemoglobin, the blood is bright red. Without oxygen, blood is dark red. The dark red blood in veins appears blue when it shows through the vein walls and skin.

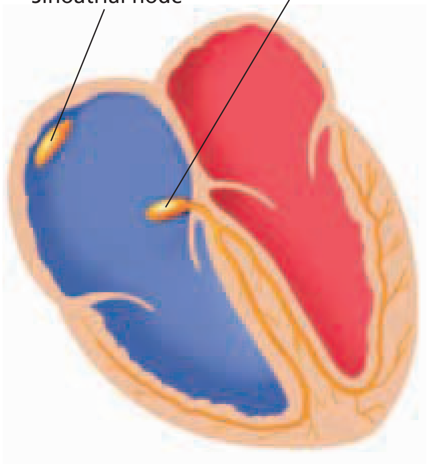


FIGURE 46-3

Two areas of specialized tissue, known as nodes, control the heartbeat. A person whose SA node is defective can have an operation to implant an artificial pacemaker. An artificial pacemaker can also help a defective AV node.

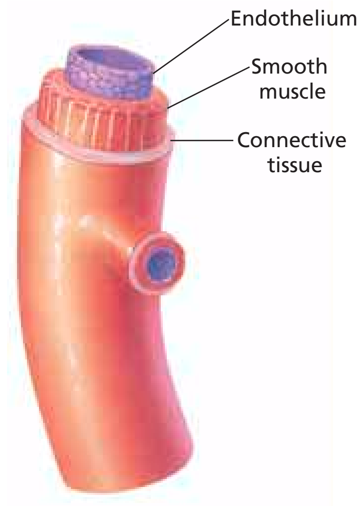
Control of the Heartbeat

The heart consists of muscle cells that contract in waves. When the first group of cells are stimulated, they in turn stimulate neighboring cells. Those cells then stimulate more cells. This chain reaction continues until all the cells contract. The wave of activity spreads in such a way that the atria and the ventricles contract in a steady rhythm. The first group of heart-muscle cells that get stimulated lie in an area of the heart known as the sinoatrial node, shown in Figure 46-3.

The **sinoatrial** (SIEN-oh-AY-tree-uhl) **(SA) node** is a group of specialized heart-muscle cells located in the right atrium. These muscle cells spontaneously initiate their own electrical impulse and contract. The SA node is often called the *pacemaker* because it regulates the rate of contraction of the entire heart. The electrical impulse initiated by the SA node subsequently reaches another special area of the heart, known as the **atrioventricular (AV) node.** The AV node is located in the septum between the atria, as shown in Figure 46-3. The AV node relays the electrical impulse to the muscle cells that make up the ventricles. As a result, the ventricles contract a fraction of a second after the atria, completing one full heartbeat. In an average adult at rest, the heart beats about 70 times each minute.

A heartbeat has two phases. Phase one, called *systole* (SIS-tohl), occurs when the ventricles contract, closing the AV valves and opening the SL valves to pump blood into the two major vessels that exit the heart. Phase two, called *diastole* (DIE-a-stohl), occurs when the ventricles relax, allowing the back pressure of the blood to close the SL valves and opening the AV valves. The closing of these two heart valves results in the characteristic *lub dup* sound we call a heartbeat. If one of the valves fails to close properly, some blood may flow backward, creating a different sound, which is known as a heart murmur.

A person's **pulse** is a series of pressure waves within an artery caused by the contractions of the left ventricle. When the ventricle contracts, blood surges through the arteries, and the elastic walls in the vessels expand and stretch. The most common site for taking a pulse is at a radial artery, on the thumb side of each wrist. The average pulse rate ranges from 70 to 90 beats per minute for adults.



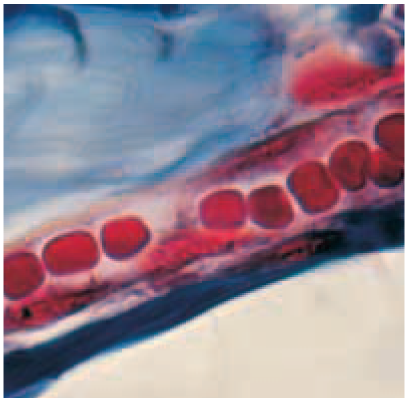
Artery
(carries blood away from the heart)

FIGURE 46-4

Notice the thick muscular layer of an artery. The layers of the artery wall are separated by elastic tissue. This tissue provides strength, preventing systolic pressure from bursting the artery.

FIGURE 46-5

The diameter of a capillary is so small that red blood cells must move single file through these vessels, as shown in this photograph (1,200×). All exchange of nutrients and waste between blood and cells occurs across the thin walls of the capillaries.



BLOOD VESSELS

The circulatory system is known as a closed system because the blood is contained within either the heart or the blood vessels at all times. This type of system differs from an open system, in which blood leaves the vessels and circulates within tissues throughout the organism's body. The blood vessels that are part of the closed circulatory system of humans form a vast network to help keep the blood flowing in one direction.

Arteries and Blood Pressure

The large, muscular vessels that carry blood away from the heart are called **arteries.** As shown in Figure 46-4, the thick walls of the arteries have three layers: an inner endothelial layer, a middle layer of smooth muscle, and an outer layer of connective tissue. This structure gives arteries a combination of strength and elasticity, which allows them to stretch as pressurized blood enters from the heart. You can feel this stretching of arteries—it is your pulse.

Contraction of the heart moves the blood through the arteries with great force. The force that blood exerts against the inside walls of a blood vessel is known as **blood pressure.** Blood pressure is highest in the two main arteries that leave the heart. It is usually measured in the artery that supplies blood to the arm. To measure blood pressure, a trained person inflates a cuff that is placed around a patient's arm, temporarily stopping the flow of blood through the artery. Connected to the cuff is a gauge containing a column of mercury (Hg) that rises as the pressure in the cuff increases. The trained person then releases the air in the cuff slowly while listening to the artery with a stethoscope and watching the column of mercury. The first sounds of blood passing through the artery indicates the *systolic pressure*, or the pressure of the blood when the ventricles contract. In a normal adult, the systolic pressure is about 120 mm of Hg for males and 110 mm of Hg for females. Continuing to release the air in the cuff, the trained person next listens for the disappearance of sound, which indicates a steady flow of blood through the artery in the arm. This indicates the *diastolic pressure*. In a normal adult, the diastolic pressure is about 80 mm of Hg for males and 70 mm of Hg for females.

High blood pressure, or **hypertension,** is a leading cause of death in many countries. Blood pressure that is higher than normal places a strain on the walls of the arteries and increases the chance that a vessel will burst.

Capillaries and Veins

Recall that when the left ventricle contracts, it forces blood into the aorta, the body's largest artery. From the aorta, blood travels through a network of smaller arteries, which in turn divide and form even smaller vessels, called *arterioles*. The arterioles branch into a network of tiny vessels, called **capillaries.** A capillary is shown in Figure 46-5.

The network formed by capillaries is so extensive that all of the approximately 100 trillion cells in the body lie within about 125 μm of a capillary. This close association between capillaries and cells allows for rapid exchange of materials. Capillary walls are only one cell thick; gases and nutrients can diffuse through these thin walls. Wherever the concentration of oxygen or nutrients is higher in the blood than in the surrounding cells, the substance diffuses from the blood into the cells. Wherever the concentrations of carbon dioxide and wastes are higher in the cells than in the blood, these substances diffuse from the cells into the blood.

Blood flows through capillaries that merge to form larger vessels called *venules* (VEN-yoolz). Several venules in turn unite to form a **vein,** a large blood vessel that carries blood to the heart. Veins returning deoxygenated blood from the lower parts of the body merge to form the *inferior vena cava*. Veins returning deoxygenated blood from the upper parts of the body merge to form the *superior vena cava*. Refer back to Figure 46-2, and locate the inferior vena cava and the superior vena cava.

As you can see in Figure 46-6, although the walls of the veins are composed of three layers, like those of the arteries, they are thinner and less muscular. By the time blood reaches the veins, it is under much less pressure than it was in the arteries. With less pressure being exerted in the veins, the blood could flow backward and disrupt the pattern of circulation. To prevent that, valves in the veins help keep the blood flowing in one direction. Many veins pass through skeletal muscle. When these muscles contract, they are able to squeeze the blood through the veins. When these muscles relax, the valves can close, thus preventing the blood from flowing backward. Figure 46-6 shows the structure of a valve in a vein.

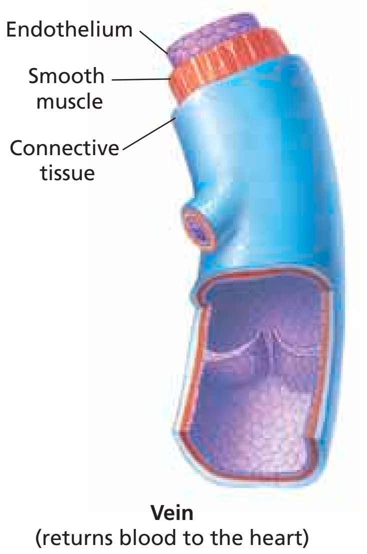


FIGURE 46-6

Like an artery, a vein has three layers: the outer layer of connective tissue, the middle layer of smooth muscle, and the inner layer of endothelial tissue.

PATTERNS OF CIRCULATION

The English scientist William Harvey (1578–1657) first showed that the heart and the blood vessels form one continuous, closed system of circulation, as shown in Figure 46-7. He also reasoned that this system consists of two primary subsystems: **pulmonary circulation,** in which the blood travels between the heart and lungs, and **systemic circulation,** in which the blood travels between the heart and all other body tissues.

Pulmonary Circulation

Deoxygenated blood returning from all parts of the body except the lungs enters the right atrium, where it is then pumped into the right ventricle. When the right ventricle contracts, the deoxygenated blood is sent through the pulmonary artery to the lungs. The pulmonary artery is the only artery that carries deoxygenated blood. The pulmonary artery branches into two smaller arteries, with one artery going to each lung. These arteries branch into arterioles and then into capillaries in the lungs.

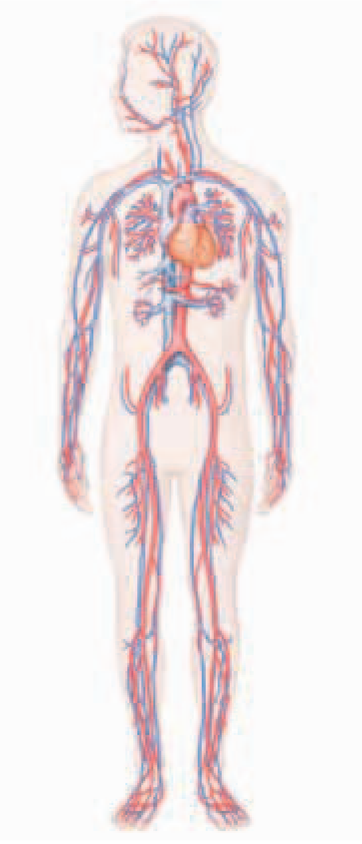
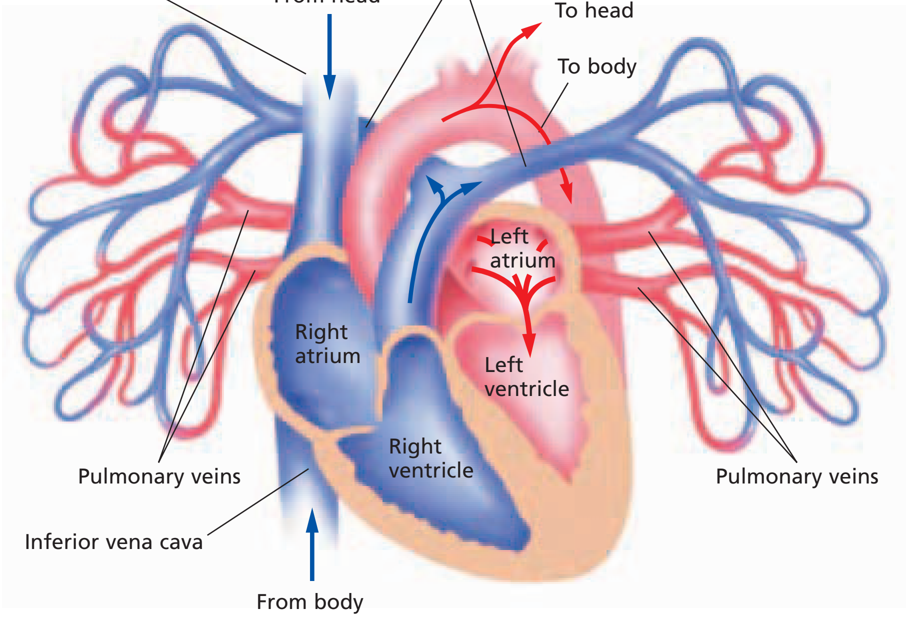


FIGURE 46-7

The cardiovascular system transports materials throughout the body and distributes heat.

FIGURE 46-8

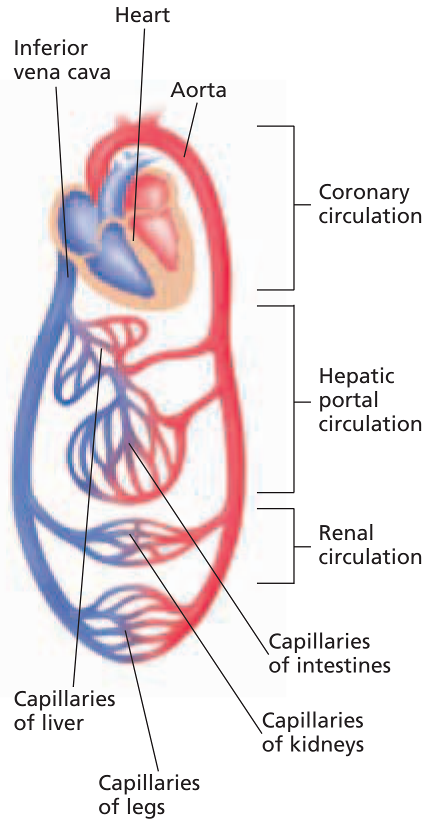
The pulmonary circulation between the heart and the lungs involves the pulmonary arteries and the pulmonary veins. Deoxygenated blood flows from the right side of the heart to the lungs. Oxygenated blood is returned to the left side of the heart from the lungs. This is the opposite of systemic and coronary blood flow, in which oxygen-rich blood flows from the heart and oxygen-poor blood is returned to the heart.



In the lungs, carbon dioxide diffuses out of the capillaries and oxygen diffuses into the capillaries. The oxygenated blood then flows into venules, which merge into the *pulmonary veins* that lead to the left atrium of the heart. From the left atrium, blood is pumped into the left ventricle and then to the body through the aorta. In Figure 46-8, trace the path blood takes as it passes through pulmonary circulation.

FIGURE 46-9

Notice three subsystems of systemic circulation. Other subsystems transport blood between the heart and the head, arms, and other organs.



Systemic Circulation

Systemic circulation is the movement of blood between the heart and all parts of the body except the lungs. Trace the path blood follows in systemic circulation in Figure 46-9. Notice that oxygenated blood is pumped out of the left ventricle and into the aorta. From the aorta, blood flows into other subsystems of systemic circulation.

Coronary circulation is the subsystem of systemic circulation that supplies blood to the heart itself. If blood flow in the *coronary arteries,* which supply blood to the heart, is reduced or cut off, muscle cells will die. This can happen when an artery is blocked by a blood clot or by **atherosclerosis** (ATH-uhr-oh-skler-OH-sis), a disease characterized by the buildup of fatty materials on the interior walls of the coronary arteries. Either type of blockage can lead to a *heart attack*.

Hepatic portal circulation is a subsystem of systemic circulation. Nutrients are picked up by capillaries in the small intestine and are transported by the blood to the liver. Excess nutrients are stored in the liver for future needs. The liver receives oxygenated blood from a large artery that branches from the aorta.

Renal circulation, another subsystem of systemic circulation, supplies blood to the kidneys. Nearly one-fourth of the blood that is pumped into the aorta by the left ventricle flows to the kidneys. The kidneys filter waste from the blood.

LYMPHATIC SYSTEM

In addition to the cardiovascular system, the circulatory system also includes the lymphatic system. One function of the lymphatic system is to return fluids that have collected in the tissues to the bloodstream. Fluids diffuse through the capillary walls just as oxygen and nutrients do. Some of these fluids pass into cells, some return to the capillaries, and some remain in the intercellular spaces.

Excess fluid in the tissues moves into the tiny vessels of the lymphatic system; this fluid is called **lymph.** Lymph vessels merge to form larger vessels. The lymph vessels are similar in structure to capillaries, and the larger lymph vessels are similar in structure to veins. However, an important difference exists between blood vessels and lymph vessels. Blood vessels form a complete circuit so that blood passes from the heart to all parts of the body and then back again to the heart. In contrast, lymph vessels form a one-way system that returns fluids collected in the tissues back to the bloodstream. In addition, the lymphatic system has no pump. Like the blood in veins, lymph must be moved through the vessels by the squeezing of skeletal muscles. Like veins, the larger lymph vessels have valves to prevent the fluid from moving backward.

Notice in Figure 46-10 that lymph vessels form a vast network that extends throughout the body. The lymph that travels in these vessels is a transparent yellowish fluid, much like the liquid part of the blood. As the lymph travels through these vessels on its way to the heart, it passes through small organs known as lymph nodes. Notice in Figure 46-10 that lymph nodes are like beads on a string. These nodes filter the lymph as it passes, trapping foreign particles, microorganisms, and other tissue debris. Lymph nodes also store *lymphocytes*, white blood cells that are specialized to fight disease. When a person has an infection, the nodes may become inflamed, swollen, and tender because of the increased number of lymphocytes.

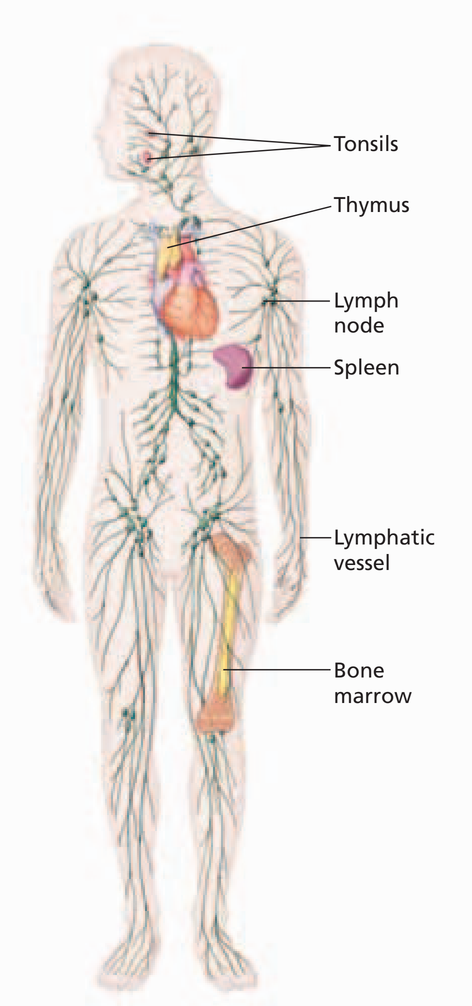


FIGURE 46-10

Like the cardiovascular system, the lymphatic system forms a vast network. Concentrated in certain regions of this network are lymph nodes that contain some of the disease-fighting cells of the immune system.

SECTION 1 REVIEW

1. Describe the structure of the heart.
2. Outline the path that blood follows through the heart and body, starting at the superior vena cava.
3. Describe the process by which the heartbeat is regulated.
4. How are the structures of arteries, veins, and capillaries related to their function?
5. Compare oxygenation levels in pulmonary circulation and systemic circulation.
6. Explain how the lymphatic system works with the cardiovascular system.

CRITICAL THINKING

7. **Analyzing Information** Some babies are born with a hole in the septum between the two atria. Based on what you know about blood flow through the heart, explain why this condition would be harmful to the baby.
8. **Forming Reasoned Opinions** In which blood vessels would you expect to find the lowest average blood pressure? Explain your answer.
9. **Applying Information** A man's arm is cut by a piece of glass. Blood comes out of the wound in rapid spurts. Which type of vessel was cut?

SECTION 2

OBJECTIVES

- **List** the components of blood.
- **Distinguish** between red blood cells, white blood cells, and platelets in terms of their structure and function.
- **Summarize** the process of blood clotting.
- **Explain** what determines the compatibility of blood types for transfusion.

VOCABULARY

plasma
red blood cell (erythrocyte)
hemoglobin
white blood cell (leukocyte)
phagocyte
antibody
platelet
fibrin
blood type
antigen
Rh factor

BLOOD

Blood is a liquid connective tissue. The two main functions of the blood are to transport nutrients and oxygen to the cells and to carry carbon dioxide and other waste materials away from the cells. Blood also transfers heat to the body surface and plays a major role in defending the body against disease.

COMPOSITION OF BLOOD

Blood is composed of a liquid medium and blood solids (formed elements). Formed elements include red blood cells, white blood cells, and platelets. The liquid makes up about 55 percent of the blood, and formed elements make up the remaining 45 percent. A healthy adult has about 4 to 5 L of blood in his or her body.

Plasma

Plasma, the liquid medium, is a sticky, straw-colored fluid that is about 90 percent water and includes metabolites, nutrients, wastes, salts, and proteins. Cells receive nourishment from dissolved substances carried in the plasma. These substances, which may include vitamins, minerals, amino acids, and glucose, are absorbed from the digestive system and transported to the cells. Plasma also carries hormones and brings wastes from the cells to the kidneys or the lungs to be removed from the body.

A variety of proteins are carried in the plasma. The plasma proteins have various functions. Some of the proteins in the plasma are essential for the formation of blood clots. Another protein, called albumin, plays an important role in the regulation of osmotic pressure between plasma and blood cells and between plasma and tissues. Other proteins, called antibodies, help the body fight disease.

FIGURE 46-11
Notice that a mature red blood cell (RBC) is disk-shaped and is concave on both sides. A red blood cell is little more than a cell membrane filled with hemoglobin. How is this structure related to its function?

Red Blood Cells

Red blood cells, or **erythrocytes** (uh-RITH-ruh-siets), shown in Figure 46-11, transport oxygen to cells in all parts of the body. Red blood cells are formed in the red marrow of bones. Immature red blood cells synthesize large amounts of an iron-containing protein called **hemoglobin.** Hemoglobin is the molecule that actually transports oxygen and, to a lesser degree, carbon dioxide. During the formation of a red blood cell, its cell nucleus and organelles disintegrate. The mature red blood cell is little more than a membrane containing hemoglobin.

Because red blood cells lack nuclei, they cannot divide and they have a limited survival period, usually 120 to 130 days. Of the more than 30 trillion red blood cells circulating throughout the body at one time, 2 million disintegrate every second. To replace them, new ones form at the same rate in the red marrow of bones. Some parts of the disintegrated red blood cells are recycled. For example, the iron portion of the hemoglobin molecule is carried in the blood to the marrow, where it is reused in new red blood cells.

White Blood Cells

White blood cells, or **leukocytes** (LOO-kuh-siets), help defend the body against disease. They are formed in the red marrow, but some must travel to lymph nodes, tonsils, the thymus, or the spleen to mature. White blood cells are larger than red blood cells and significantly less plentiful. Each cubic millimeter of blood normally contains about 4 million red blood cells and 7,000 white blood cells. White blood cells can squeeze their way through openings in the walls of blood vessels and into the intercellular fluid. In that way, white blood cells can reach the site of infection and help destroy invading microorganisms.

Notice in Figure 46-12 that a white blood cell has a very different structure from that of a red blood cell. For instance, a white blood cell may be irregularly shaped and may have a rough outer surface. There are other differences between red blood cells and white blood cells as well. In contrast with the short-lived red blood cells, white blood cells may function for years. And while there is only one type of red blood cell, there are several types of white blood cells.

The white blood cell shown in Figure 46-12 is the type of white blood cell known as a **phagocyte** (FA-guh-siet). Phagocytes are cells that engulf invading microorganisms. Locate the microorganisms that are being engulfed by the phagocyte in Figure 46-12. Another type of white blood cell produces **antibodies.** Antibodies are proteins that help destroy substances, such as bacteria and viruses, that enter the body and can cause disease. When a person has an infection, the number of white blood cells can double.

Word Roots and Origins

leukocyte

from the Greek *leuco*, meaning "white," and *cyte*, meaning "cell"

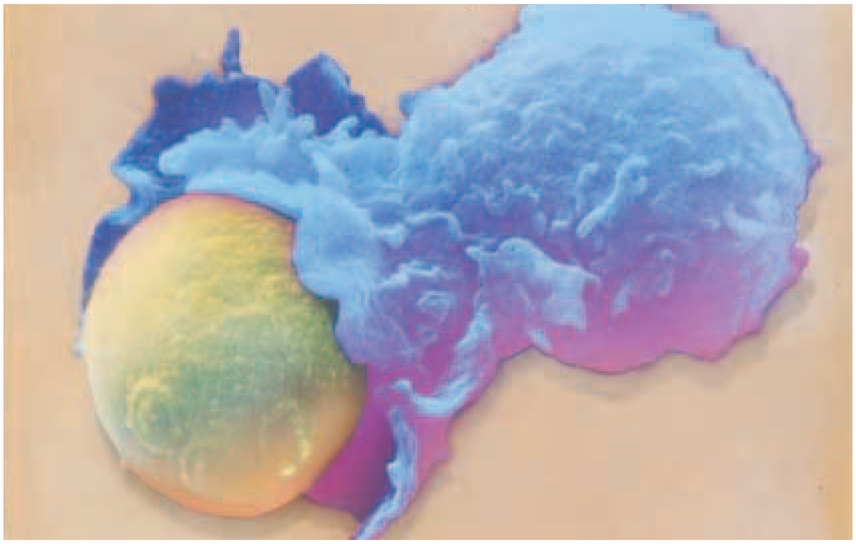


FIGURE 46-12
Some white blood cells, like the phagocyte shown in blue, engulf and destroy invading microorganisms.

FIGURE 46-13

Inactive platelets, such as the yellow object shown in (a), derive their name from the fact that they look like little plates. Platelets are colorless and contain chemicals that are involved in the clotting process. (b) The platelets change shape during the clotting process. When activated, the platelets settle and spread on the substrate.

(a)

(b)

Eco Connection

Vampire Bats Help Save Stroke Victims

Vampire bats have an anticoagulant in their saliva that prevents blood clotting when it flows from a wound. In 1995, this enzyme was isolated and named *Draculin*.

Researchers have developed a clot-dissolving agent called *Desmodus rotundus salivary plasminogen activator* (DSPA), which is based on the salivary enzyme Draculin. DSPA targets and destroys fibrin. The current treatment must be given within three hours of the onset of a stroke (a sudden loss of consciousness or paralysis that occurs when the blood flow to the brain is interrupted). Otherwise, brain-cell death and brain damage may occur. According to research, DSPA could be a safe treatment for longer periods of time and appears to have no detrimental effect on brain cells.

Platelets

Platelets are essential to the formation of a blood clot. A blood clot is a mass of interwoven fibers and blood cells that prevents excess loss of blood from a wound. Platelets are not whole cells. They are fragments of very large cells that were formed in the bone marrow. As you can see in Figure 46-13a, platelets get their name from their platelike structure. Platelets lack a nucleus and have a life span of 7 to 12 days. A cubic micrometer of blood may contain as many as half a million platelets.

When a blood vessel tears or rips, platelets congregate at the damaged site, sticking together and forming a small plug. The vessel constricts, slowing blood flow to the area. Then, special clotting factors are released from the platelets and the damaged tissue. These factors begin a series of chemical reactions that occur at the site of the bleeding. The last step in this series brings about the production of a protein called **fibrin.** Fibrin molecules consist of long, sticky chains. As you can see in Figure 46-14, these chains form a net that traps red blood cells, and the mass of fibrin and red blood cells hardens into a clot, or scab.

Hemophilia is a disorder caused by the absence of one or more of the proteins required for blood clotting. When a person with hemophilia is injured, bleeding continues for much longer than it would in a person without hemophilia. Large cuts or internal injuries can be life threatening. Today, people with hemophilia are treated with injections of the missing clotting factors.

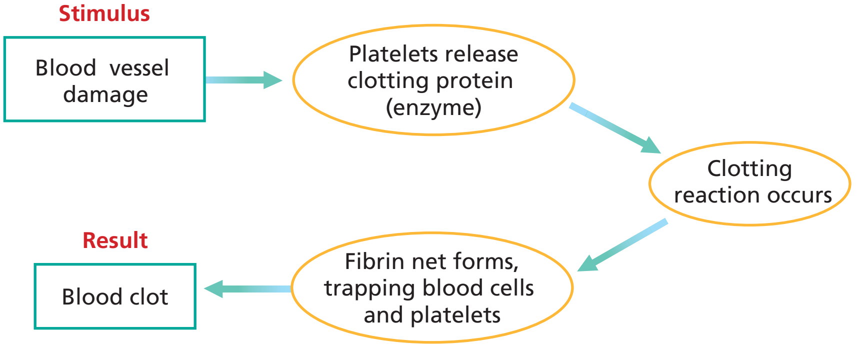


FIGURE 46-14

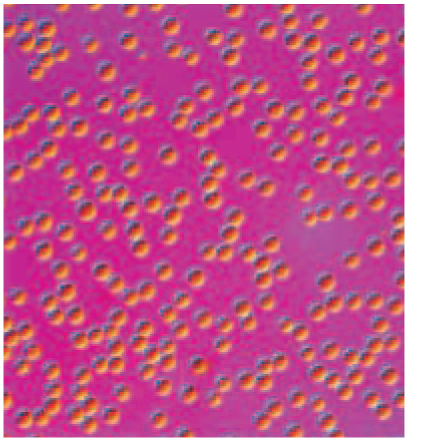
The release of enzymes from platelets at the site of a damaged blood vessel initiates a "clotting cascade."

BLOOD TYPES

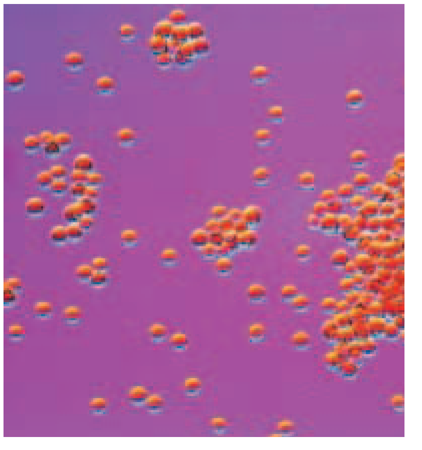
Blood type is determined by the type of antigen present on the surface of the red blood cells. An **antigen** is a substance that stimulates an immune response. Antigens that are normally present in a person's body provoke no response. However, when foreign antigens enter the body, cells respond by producing antibodies. In fact, the word *antigen* is an abbreviation for "antibody-generating substance."

In the early 1900s, Karl Landsteiner used blood taken from his laboratory workers and made observations similar to those you see in Figure 46-15. He noticed that mixing blood samples from two people sometimes resulted in the cells clumping together, or *agglutinating*. When samples of two different blood types are mixed together, reactions occur between the antigens on the red blood cells and the antibodies in the plasma, causing the cells to agglutinate. When samples of the same blood type are mixed, no reaction occurs, and the blood cells do not agglutinate.

Landsteiner's observations led to the classification of human blood by blood types. Three of the most important human antigens are called A, B, and Rh. The A-B-O system of blood typing, described below, is based on the A and B antigens.



(a)



(b)

FIGURE 46-15

Notice that there is no agglutination of red blood cells in the slide in (a), where blood samples from two people with the same blood type were mixed. Compare this with the slide in (b), where blood samples from two people with different blood types were mixed.

A-B-O System

The A-B-O system is a means of classifying blood by the antigens located on the surface of the red blood cells and the antibodies circulating in the plasma. As shown in Table 46-1, an individual's red blood cells may carry an A antigen, a B antigen, both A and B antigens, or no antigen at all. These antigen patterns are called blood types A, B, AB, and O, respectively.

Notice in Table 46-1 that an individual with type A blood also has anti-B antibodies against type B blood. If type B blood is given to a recipient with type A blood, the recipient's anti-B antibodies will react with the B antigens on the donated red blood cells and the blood will agglutinate. In addition, the donor's type B blood has anti-A antibodies. Their presence will compound the antigen-antibody reaction. The result will be agglutinated blood that will block the flow of blood through the vessels. For this reason, transfusion recipients must receive blood that is compatible with their own.

TABLE 46-1 ***Blood Types, Antigens, and Antibodies***

Blood types	Antigen on the red blood cells	Antibodies in the plasma	Can get blood from	Can give blood to
A	A	anti-B	O, A	A, AB
B	B	anti-A	O, B	B, AB
AB	A and B	none	A, B, AB, O	AB
O	none	anti-A, anti-B	O	A, B, AB, O

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People who have type AB blood are *universal recipients.* They can receive A, B, AB, or O blood because they do not have anti-A or anti-B antibodies. People who have type O blood are *universal donors.* They can donate blood to people who have A, B, AB, or O blood because the blood cells of people who have type O blood do not have A or B antigens.

Rh System

An antigen that is sometimes present on the surface of red blood cells is the **Rh factor,** named after the rhesus monkey in which it was first discovered. Eighty-five percent of the United States' population is Rh-positive (Rh^+), meaning that Rh antigens are present. People who do not have Rh antigens are called Rh-negative (Rh^-).

If an Rh^- person receives a transfusion of blood that has Rh^+ antigens, antibodies may react with the antigen and agglutination will occur. The most serious problem with Rh incompatibility occurs during pregnancy. If the mother is Rh^- and the father is Rh^+, the child may inherit the dominant Rh^+ allele from the father. During delivery, a small amount of the fetus's Rh^+ blood may reach the mother's bloodstream. If this happens, the mother will develop antibodies to the Rh factor. If a second Rh^+ child is conceived later, the mother's antibodies can cross the placenta and attack the blood of the fetus. This condition is called *erythroblastosis fetalis.* The fetus may die as a result of this condition, or if the child is born alive, he or she may need an immediate transfusion of Rh^+ blood.

To prevent this condition, an Rh^- mother of an Rh^+ child can be given antibodies to destroy any Rh^+ cells that have entered her bloodstream from the fetus. The mother is, in effect, immunized against the Rh antigen before her immune system has a chance to develop its own antibodies. The antibody treatment prevents Rh sensitization in Rh^- women only if their bodies have not already produced Rh antibodies. If an Rh^- mother has not yet been sensitized, she receives the antibody treatment in the 28th week of pregnancy and again immediately after delivery.

SECTION 2 REVIEW

1. Identify the four main components of blood.
2. Explain how the structure of red blood cells, white blood cells, and platelets relates to the function of these cells.
3. Identify the stages and structures involved in the clotting process.
4. What factors determine the compatibility of blood types for transfusion?
5. Which blood types, in terms of the A-B-O and Rh antigens, can be donated to somebody with type AB^- blood?

CRITICAL THINKING

6. **Analyzing Information** Hemophilia is a disorder in which there is a failure in one of the steps of clot formation. What might be some advantages and disadvantages of this disorder?
7. **Evaluating Results** A patient's blood has an elevated count of leukocytes. What does this most likely indicate?
8. **Relating Concepts** Explain why a pregnant woman should know her blood type and the blood type of her baby's father.

MILESTONES IN Blood Transfusions

Timeline

1628 William Harvey describes the circulation of blood.

1667 Jean-Baptiste Denis successfully transfuses blood from a lamb to a human.

1818 First human-to-human blood transfusion.

1901 Karl Landsteiner determined three of four blood types (A, B, and O).

1914 Blood is stored for the first time.

1937 Bernard Fantus formed the first blood bank.

1939 Charles Drew set up collection centers for blood to fill World War II needs.

1950 Carl Walter and W.P. Murphy, Jr. introduced the plastic bag to collect blood.

1985 Blood is screened for HIV and other diseases.

Every three seconds someone needs a blood transfusion—blood, plasma, or saline is introduced into the body. Blood and blood products are used to treat accident and burn victims, cancer patients, and patients undergoing surgeries and medical treatments. The development of safe blood transfusion techniques was an important achievement in modern medicine.

In 1665, Richard Lower, an English physician, transferred blood between two dogs. Jean-Baptiste Denis, a French physician and astrologer, transfused blood from a lamb to a human in 1667. The first successful human-to-human blood transfusions were performed in 1818 by James Blundell, a British physician, but these were followed by many failures.

In 1901, Austrian-born American physiologist Karl Landsteiner determined the first three blood types—A, B, and O—and that incompatible types will clot. This discovery explained why the outcome of transfusions had been so unpredictable in the past. For his work, Landsteiner received the Nobel Prize in medicine or physiology in 1930.

During World War I, scientists began to study how to preserve and transport blood for wounded soldiers. They found that the addition of sodium citrate prevented clotting, making the storage of blood possible for the first time.

In 1937, Bernard Fantus, a physician, established the first nonprofit blood bank at Cook County Hospital in Chicago. The next year, Charles Drew, a medical doctor, found that blood plasma (the liquid component of blood) could substitute for whole blood in emergency situations.

Germany's attack on France in 1940 created a great need for blood. Based on Drew's findings, the United States began to provide liquid plasma and whole blood for France. Working with the National Research Council and the American Red Cross, Drew set up blood collection centers.

Early in the 1980s, some transfused blood was found to carry the human immunodeficiency virus (HIV), the virus that causes acquired immune deficiency syndrome (AIDS). Since 1985, careful screening for HIV, hepatitis, and other diseases has almost entirely removed the risk of receiving contaminated blood.

Today, many people bank their own blood for later use in surgery. Blood can also be collected during surgery and returned to the patient later. The AIDS epidemic has triggered a race to create artificial blood. Several companies have begun testing blood substitutes from chemically treated animal blood and outdated human blood.

Review

1. What type of patients can benefit from blood transfusions?
2. **Critical Thinking** How might safe blood transfusion techniques affect you?
3. **Critical Thinking** Use the Web site below to research the latest progress on creating artificial blood. Write a short report to describe your findings.

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