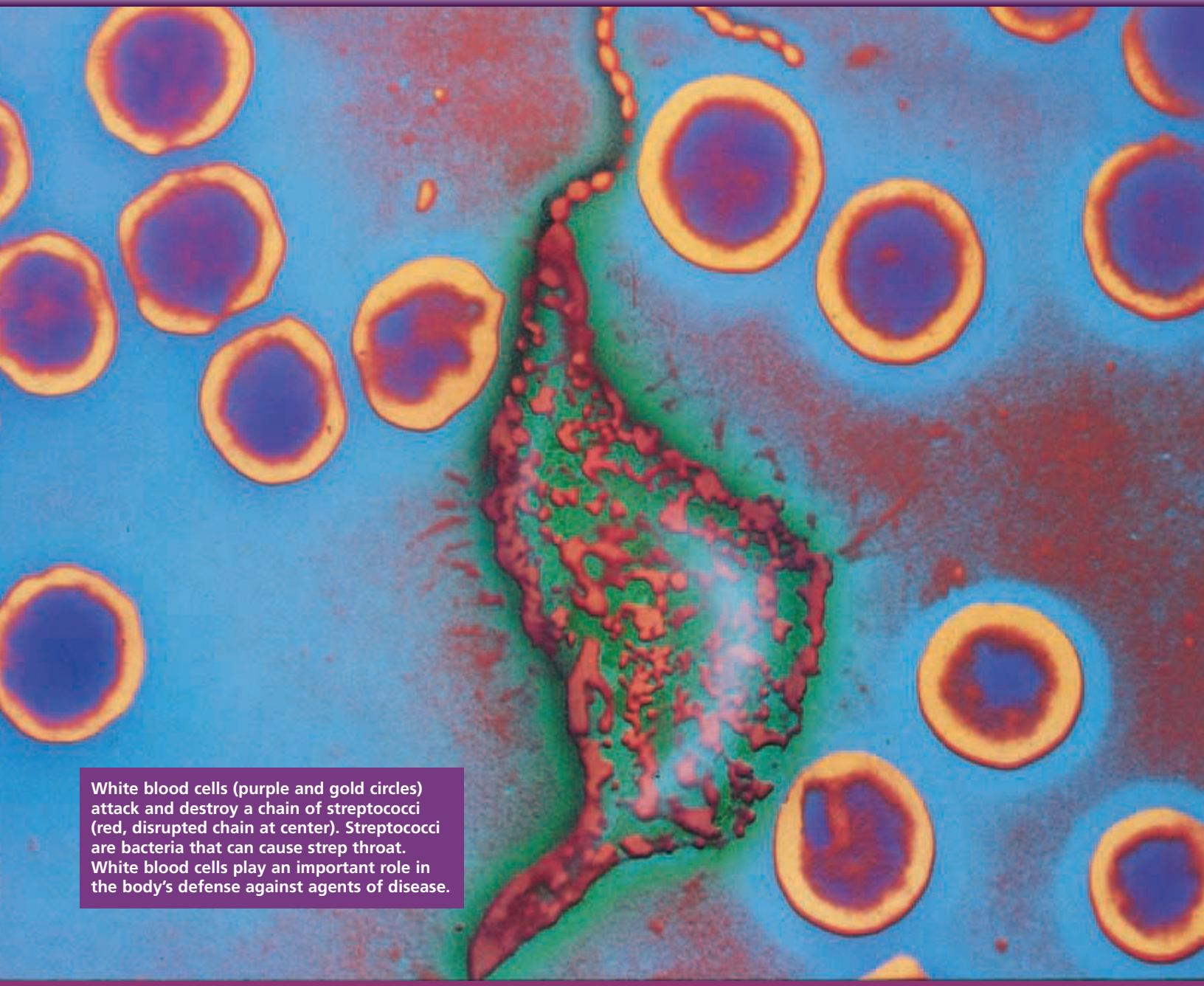
CHAPTER 47

THE BODY'S DEFENSE SYSTEMS



White blood cells (purple and gold circles) attack and destroy a chain of streptococci (red, disrupted chain at center). Streptococci are bacteria that can cause strep throat. White blood cells play an important role in the body's defense against agents of disease.

SECTION 1

NONSPECIFIC DEFENSES

When a type of virus called a rhinovirus enters the human body, it can cause the common cold. Diseases, such as colds, that are caused by agents that have invaded the body are called ***infectious diseases.*** *This section explains how the human body identifies the agents that cause infectious diseases and defends itself against these agents.*

OBJECTIVES

- **Summarize** Koch's postulates for identifying a disease-causing agent.
- **Describe** how the skin and mucous membranes protect the body against pathogens.
- **Describe** the steps of the inflammatory response.
- **Analyze** the roles of white blood cells in fighting pathogens.
- **Explain** the functions of fever and proteins in fighting pathogens.

VOCABULARY

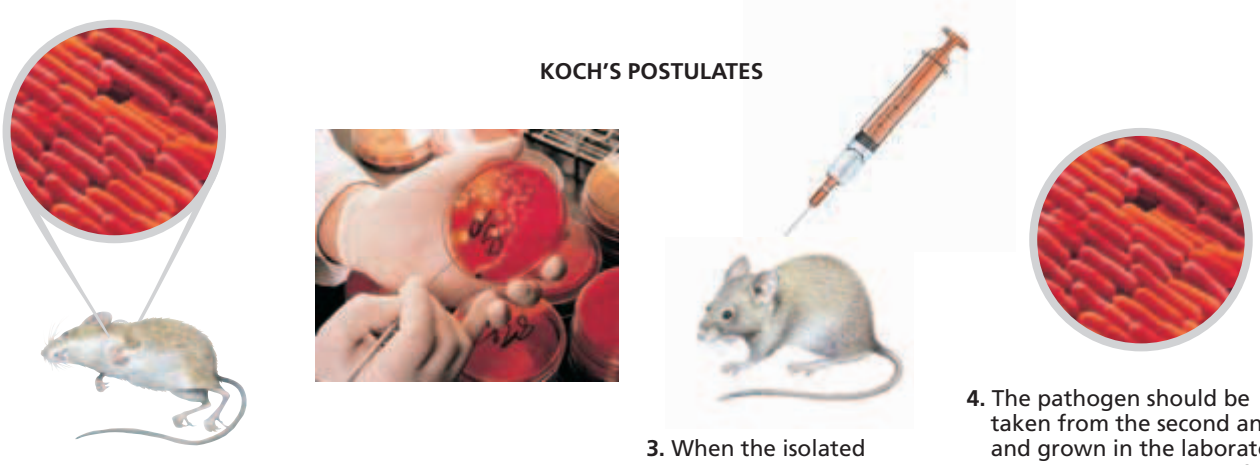
infectious disease
pathogen
Koch's postulates
mucous membrane
inflammatory response
histamine
phagocyte
neutrophil
macrophage
natural killer cell
complement system
interferon

IDENTIFYING PATHOGENS

A **pathogen** is any agent that causes disease. Robert Koch (KAWHK) (1843–1910), a German doctor, was the first person to establish a step-by-step procedure for identifying the particular pathogen that causes an infectious disease. In the 1870s, Koch studied anthrax, a disease of cattle that can spread to people. Koch observed that cattle with the illness had swarms of bacteria in their blood. He hypothesized that these bacteria caused anthrax.

To test his hypothesis, Koch isolated rod-shaped bacteria from a cow with anthrax and grew colonies of the bacteria to be sure he had isolated a single species. Then, he injected healthy cows with these bacteria. The cows developed anthrax. Koch found that the blood of these cows contained the same rod-shaped bacteria as the first cow. Furthermore, healthy cows that he had not injected lacked this type of bacteria. Koch concluded that the isolated species of bacterium causes anthrax. Through these studies, he developed **Koch's postulates,** which are "rules" for determining the cause of a disease. Figure 47-1 illustrates these postulates.

FIGURE 47-1
By applying the four principles of Koch's postulates, scientists can identify the pathogen that causes an infectious disease.



1. The pathogen must be present in an animal that has the disease and absent in healthy animals.

2. The pathogen must be isolated from the sick animal and grown in a laboratory.

3. When the isolated pathogen is injected into a healthy animal, the animal must develop the disease.

4. The pathogen should be taken from the second animal and grown in the laboratory. The pathogen cultured from the second animal should be the same as the pathogen cultured from the first animal.

TABLE 47-1 *Pathogens Responsible for Some Human Diseases*

Disease	Pathogen	Method of transmission
Botulism	*Clostridium botulinum* (bacterium)	contaminated food
Lyme disease	*Borrelia burgdorferi* (bacterium)	tick bites
AIDS	HIV (human immunodeficiency virus)	sexual contact, contaminated needles, contact with contaminated fluids from a mother to a fetus or infant
Severe acute respiratory syndrome (SARS)	coronavirus (virus)	person-to-person contact, indirect contact through pathogens in air or on objects (from coughs or sneezes)
Amebic dysentery	*Entamoeba histolytica* (protist)	contaminated food and water
Athlete's foot	*Tinea* (fungus)	contact with contaminated surfaces, person-to-person contact
Head lice	Lice (invertebrate parasite)	person-to-person contact, sharing personal items

Scientists have used Koch's postulates to identify thousands of pathogens. Many human diseases are caused by bacteria, viruses, protists, fungi, and invertebrates. Pathogens can spread to humans in five main ways—through air, food, water, person-to-person contact, and the bites of animals. Table 47-1 lists examples of pathogens that cause different human diseases and the means by which each is commonly transmitted.

FIGURE 47-2

The passages of the respiratory system are lined with cells that are covered with beating cilia (purplish strands). Pathogens (bluish circles) that become trapped in mucus secreted by these cells are swept upward, away from the lungs. (5,325×)

FIRST LINE OF DEFENSE: BARRIERS

The body's nonspecific defenses help protect the body against any pathogen, regardless of the pathogen's identity. Nonspecific defenses include the skin and mucous membranes. **Mucous** (MYOO-kuhs) **membranes** are epithelial tissues that protect the interior surfaces of the body that may be exposed to pathogens.

Most pathogens must enter the body to cause disease. The skin serves as a physical barrier to pathogens. Any break in the skin may allow pathogens to enter the body. In addition, the skin also releases sweat, oils, and waxes. These substances contain chemicals that are toxic to many pathogens. For example, sweat contains *lysozyme,* an enzyme that destroys some bacteria.

Mucous membranes serve as a barrier and secrete *mucus,* a sticky fluid that traps pathogens. Mucous membranes line the respiratory and digestive systems, the urethra, and the vagina. The passages of the respiratory tract are lined with cells that are covered with beating cilia, as shown in Figure 47-2. These cilia sweep mucus and pathogens up to the pharynx, where they are swallowed. Most swallowed pathogens are destroyed in the stomach by acids.

SECOND LINE OF DEFENSE: NONSPECIFIC IMMUNITY

If a pathogen gets past the skin and the mucous membranes, there is a second line of nonspecific defense inside the body—nonspecific immunity. Nonspecific immunity includes the inflammatory response, the temperature response, and proteins. Like the barriers of the first line of defense, these second-line defenses are nonspecific—they work the same way against any pathogen.

Inflammatory Response

Any pathogen that gets past the skin or mucous membranes will stimulate the **inflammatory response,** a series of events that suppress infection and speed recovery. An example is shown in Figure 47-3. When cells are damaged, whether through a cut on the skin or invasion by pathogens, some of the damaged cells release histamine (HIS-tuh-MEEN), as described in step 1. **Histamine** is a substance that increases blood flow to the injured area and increases the permeability of surrounding capillaries. The changes caused by histamine result in redness, swelling, warmth, and pain. If blood vessels have been damaged, platelets begin the blood-clotting process, sealing off surrounding tissues and stopping pathogens from entering the rest of the body.

White blood cells fight pathogens that have entered the body. In step 2, fluids and white blood cells called *phagocytes* pass through the capillary walls to the injured area. **Phagocytes** ingest and destroy pathogens and foreign matter, as shown in step 3. Phagocytes and some other types of white blood cells are attracted to the site of injury by histamine.

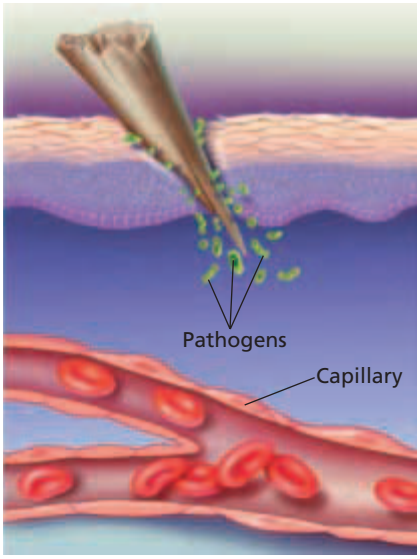
Eco Connection

Agriculture and Human Diseases

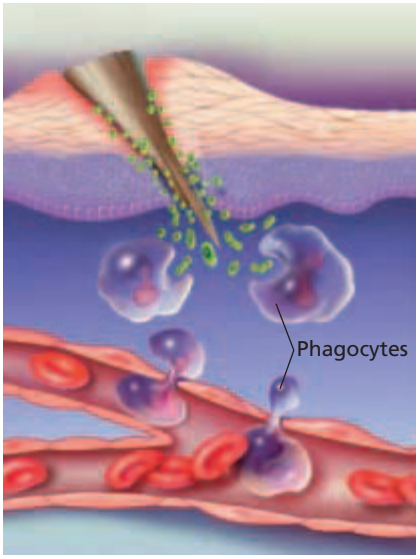
The beginning of farming and herding about 10,000 years ago changed the nature of human diseases. When humans began to keep herds of domesticated animals, such as cattle and sheep, humans were exposed to the pathogens that infect these animals. Some of these pathogens then began infecting humans. Measles, tuberculosis, smallpox, and flu are among the diseases that may have been transmitted to humans from domesticated animals.

FIGURE 47-3

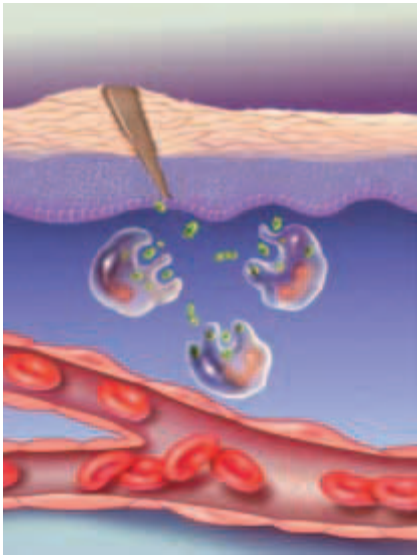
Injury to cells triggers an inflammatory response.



1 An injury may allow pathogens to get past the barrier of the skin. Injured cells release chemical messengers, such as histamine.



2 Nearby capillaries respond by swelling and leaking fluid. Phagocytes pass through capillary walls and attack the pathogens.



3 Phagocytes destroy the pathogens, and the injury begins to heal.

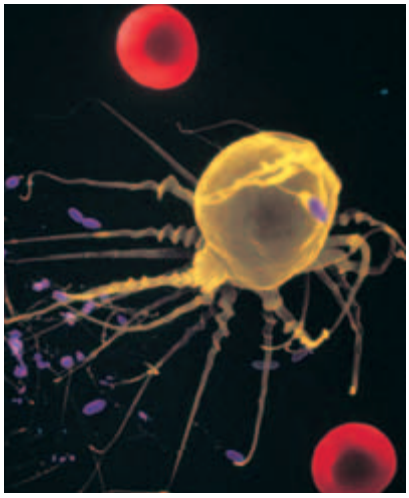


FIGURE 47-4

This macrophage (shown in yellow) is using cytoplasmic extensions to capture bacteria (shown in purple). (SEM 17,400×)

The **neutrophil** (NOO-troh-fil) is the most abundant type of phagocyte in the body. Neutrophils circulate through blood vessels, and they can squeeze through capillary walls to reach the infection site. Once there, neutrophils ingest pathogens they encounter. Another type of phagocyte is the **macrophage** (MAK-roh-FAYJ), shown in Figure 47-4. Macrophages engulf pathogens and cellular debris. Some are stationed in body tissues, waiting for pathogens, while others seek out pathogens.

Natural killer cells are large white blood cells that attack pathogen-infected cells—not the pathogens themselves. Natural killer cells are effective at killing cancer cells and virus-infected cells. A natural killer cell pierces the cell membrane of its target cell, allowing water to rush in and causing the cell to burst.

Temperature Response

When the body begins to fight pathogens, body temperature may increase several degrees. A rise in body temperature above the normal 37°C (98.6°F) is called a *fever.* Fever is a symptom of illness that shows the body is responding to an infection. Some pathogens trigger fever, as do chemicals released by macrophages. A moderate fever may slow bacterial and viral growth and promote white blood cell activity. However, very high fever is dangerous because extreme heat can destroy important cellular proteins. Temperatures greater than 39°C (103°F) can be dangerous, and those greater than 41°C (105°F) can lead to death.

Word Roots and Origins

macrophage

from the Greek *makros,* meaning "large," and *phagein,* meaning "to eat"

Proteins

Proteins also provide nonspecific defenses. About 20 different proteins make up the **complement system.** Complement proteins circulate in the blood and become active when they encounter certain pathogens. Some of these proteins form a ring-shaped structure that punctures the membranes of infected cells, causing the cells to die. Another nonspecific defense is **interferon,** a protein released by cells infected with viruses. Interferon causes nearby cells to make a protein that helps them resist viral infection.

SECTION 1 REVIEW

1. Explain how Koch tested his hypothesis about the cause of anthrax.
2. How does the body's first line of defense function?
3. What role does greater permeability of capillaries play in the inflammatory response?
4. How do natural killer cells differ from macrophages?
5. What is the role of interferon?

CRITICAL THINKING

6. **Analyzing Information** Scientists can't always apply all of Koch's postulates to determine the cause of a disease. Explain why.
7. **Forming Reasoned Opinions** Should a fever always be treated? Why or why not?
8. **Inferring Relationships** Explain how cold symptoms show that the body is using both lines of nonspecific defenses to fight pathogens.

SECTION 2

SPECIFIC DEFENSES: THE IMMUNE SYSTEM

Although the nonspecific defenses usually keep pathogens from harming the body, a pathogen sometimes breaks through. In response, the body begins its third line of defense—a response aimed specifically at the pathogen.

OBJECTIVES

- **Identify** and describe the parts of the immune system.
- **Explain** how the immune system recognizes pathogens.
- **Compare** the actions of T cells and B cells in the immune response.
- **Relate** vaccination to immunity.
- **Distinguish** between allergy, asthma, and autoimmune disease.

VOCABULARY

immune system
lymphocyte
thymus
spleen
B cell
T cell
antigen
immune response
helper T cell
cell-mediated immune response
cytotoxic T cell
humoral immune response
plasma cell
antibody
memory cell
immunity
vaccination
allergy
asthma
autoimmune disease

THE IMMUNE SYSTEM

The **immune system,** the cells and tissues that recognize and attack foreign substances in the body, provides the body's specific defenses. The immune system fights pathogens and helps to stop the growth and spread of cancers. The immune system is made up of several tissues and white blood cells. The components of the immune system, shown in Figure 47-5, are found throughout the body. The tissues include the bone marrow, thymus, lymph nodes, spleen, tonsils, and adenoids. The white blood cells of the immune system are called **lymphocytes** (LIM-foh-sietz).

Each part of the immune system plays a special role in defending the body against pathogens. *Bone marrow,* the soft material found inside long bones, such as the femur, makes the billions of new lymphocytes needed by the body every day. The **thymus,** a gland located above the heart, helps produce a special kind of lymphocyte.

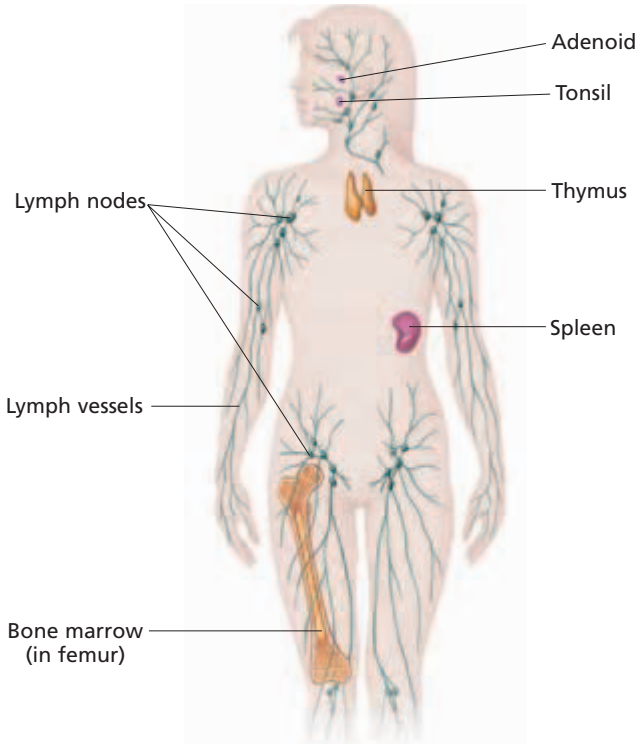


FIGURE 47-5
The cells and tissues of the immune system recognize and attack foreign substances in the body.

Lymph nodes, located throughout the body along the vessels of the lymphatic system, contain lymphocytes. (Recall that the lymphatic system gathers and filters the fluid, called *lymph,* that leaks from the circulatory system.) Lymph nodes collect pathogens from the lymph and expose them to lymphocytes. The **spleen,** the largest lymphatic organ in the body, stores healthy blood cells, breaks down aging red blood cells, and helps develop lymphocytes and other types of white blood cells. The spleen also collects pathogens from the blood, and the lymphocytes in the spleen attack these trapped pathogens. The *adenoids* and *tonsils* are masses of lymph tissue found in the nose and throat.

There are two types of lymphocytes: B cells and T cells. **B cells** are made in the bone marrow and complete their development there. **T cells** are also made in the bone marrow but complete their development only after traveling to the thymus.

Word Roots and Origins

antigen

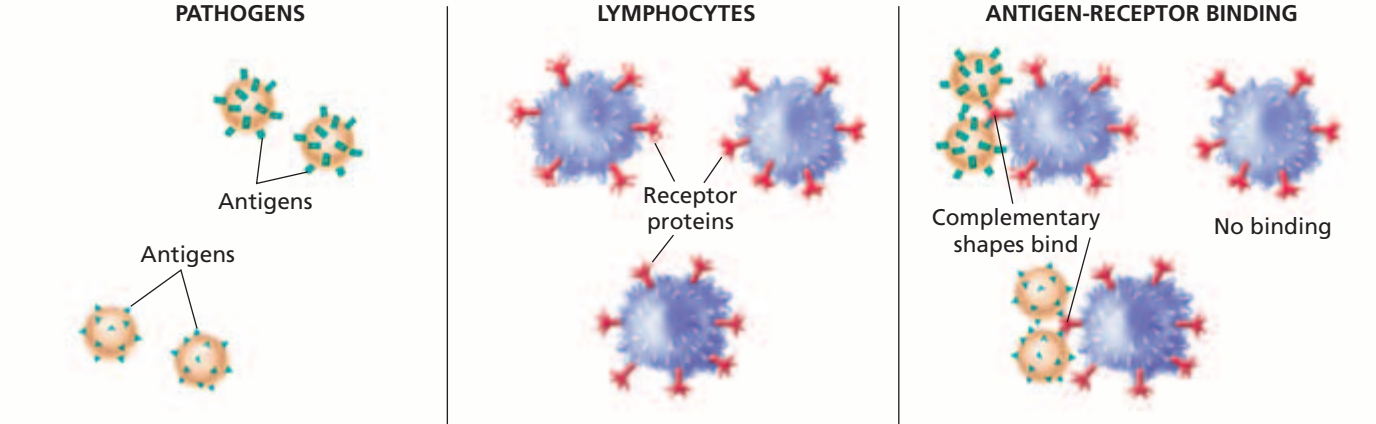
from the Greek *anti,* meaning "against," and *gen,* meaning "producing"

RECOGNIZING PATHOGENS

Lymphocytes can provide specific defenses because they recognize foreign invaders. An **antigen** (AN-tuh-juhn) is any substance that the immune system can recognize and react with. Antigens, as shown in Figure 47-6a, cause lymphocytes to react. A wide variety of substances can be antigens, including pathogens or parts of pathogens, bacterial toxins, insect venom, and pollen. In addition, almost any molecule that is not a natural part of an individual's body, such as that from transplanted tissue or transfused blood of an incompatible type, can act as a foreign antigen. When lymphocytes recognize an antigen, they bind to the antigen to start a specific attack. The reaction of the body against an antigen is known as an **immune response.**

FIGURE 47-6

(a) Antigens are found on a pathogen's surface. (b) The receptor proteins on the surface of lymphocytes (such as B cells, shown here) have a complex, three-dimensional structure. (c) The receptors can bind to antigens that have a complementary shape.



(a) Many pathogens are covered with molecules that function as antigens and cause lymphocytes to react.

(b) A lymphocyte has receptor proteins all over its surface. Note the different shapes of receptor proteins on the different lymphocytes. All of the receptor proteins on an individual lymphocyte are the same unique shape.

(c) The receptor proteins on each lymphocyte bind to antigens with complementary shapes. If a lymphocyte does not have a complementary receptor protein, it will not bind to an antigen (upper right).

How do lymphocytes identify antigens? A lymphocyte has unique receptor proteins all over the surface of its cell membrane, as shown in Figure 47-6b. These receptor proteins recognize and bind to antigens that match their three-dimensional shape, as shown in Figure 47-6c. The surface of a bacterial cell, for instance, can be covered with many different kinds of molecules, each of which can function as an antigen and cause lymphocytes to react. All of the receptors on an individual lymphocyte are the same shape or type and thus bind to the same type of antigens.

The body can defend itself against an enormous number of different pathogens, because the immune system makes billions of different kinds of lymphocytes. Each kind of lymphocyte carries unique receptors. The specificity of the immune response is due to the specificity of the antigen receptors on the lymphocytes. For example, when a cold virus enters the body, lymphocytes with receptors that match the antigens of that cold virus respond. Lymphocytes with other kinds of receptors, such as those that bind to a flu virus, do not respond.

IMMUNE RESPONSE

An immune response is a two-part assault on a pathogen. Both parts, the cell-mediated immune response and the humoral immune response, occur at the same time and require a specialized lymphocyte called a **helper T cell.** Steps ❶, ❷, and ❸ of Figure 47-7 on the next page show how an immune response is initiated. The first step occurs when a macrophage engulfs a pathogen. The macrophage then displays fragments of the pathogen's antigens on the surface of its own cell membrane. When the macrophage binds to a helper T cell with a receptor matching this antigen, the macrophage releases a cytokine called *interleukin-1* (in-tuhr-LOO-kin). *Cytokines* are proteins that can affect the behavior of other immune cells. The release of interleukin-1 by the macrophage activates more helper T cells, which then release a second cytokine, interleukin-2.

Word Roots and Origins

cytokine

from the Greek *kytos,* meaning "hollow vessel" or "cell," and *kinesis,* meaning "movement"

Cell-Mediated Immune Response

More than one type of T cell carries out the **cell-mediated immune response.** Interleukin-2 stimulates the further production of helper T cells. The increase in helper T cells produces an increase in interleukin-2, which allows T cells to divide even faster. Interleukin-2 is also responsible for stimulating the production of **cytotoxic** (siet-oh-TAHKS-ik) **T cells** (sometimes called killer T cells), which recognize and destroy cells that have been infected by the pathogen. Invaded cells are recognizable because they usually have some of the pathogen's antigens on their surface, as shown in Figure 47-7. The cytotoxic T cells produced have receptors that match the antigen. Cytotoxic T cells usually kill by making a hole in the cell membrane of their target. Cytotoxic T cells can also kill cancer cells and attack parasites and foreign tissues.

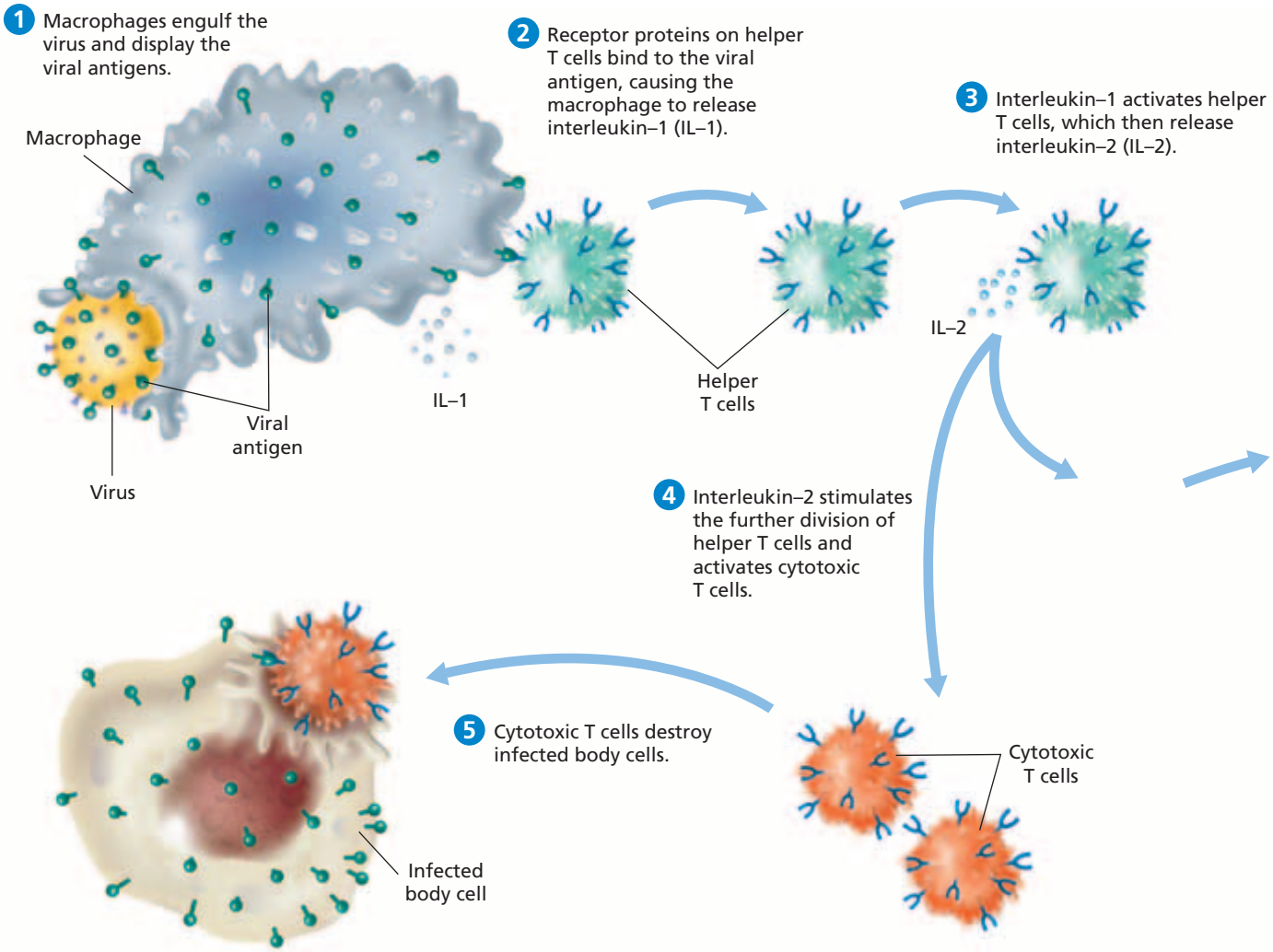


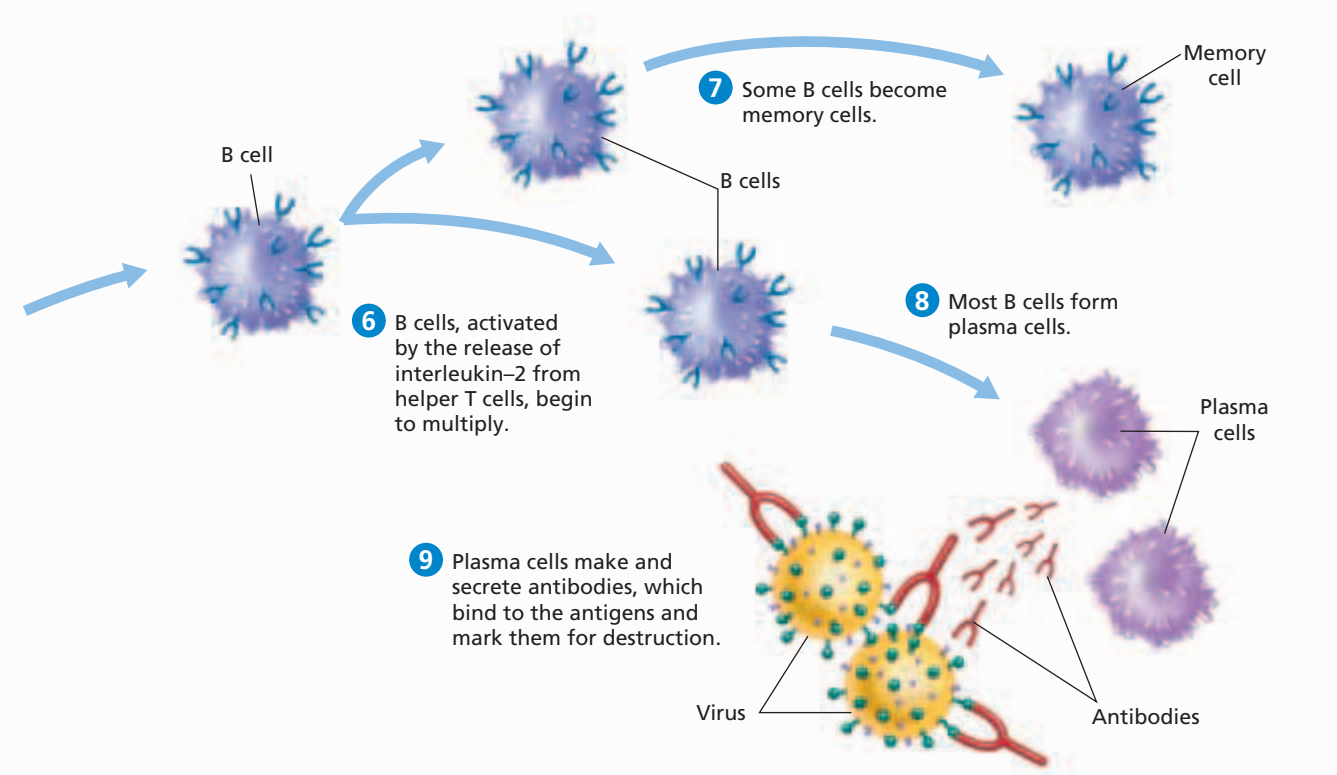
FIGURE 47-7

The immune response is a two-part assault on a pathogen: the cell-mediated immune response and the humoral immune response. Both responses occur at the same time and are triggered when a macrophage engulfs a pathogen, thus activating helper T cells (steps 1 through 3). The cell-mediated immune response is shown in steps 4 and 5, and the humoral immune response is shown in steps 6 through 9 on the next page.

One other type of T cell that plays a part in cell-mediated immunity is *suppressor T cells*. Suppressor T cells are not well understood but are thought to help shut down the immune response after the pathogen has been cleared from the body. The cell-mediated immune response is shown in steps 4 and 5 in Figure 47-7 above.

Humoral Immune Response

The **humoral** (HYOO-muhr-uhl) **immune response** involves the action of B cells and occurs at the same time the cell-mediated immune response occurs. Like the cell-mediated immune response, the humoral immune response is triggered when macrophages engulf pathogens, stimulating helper T cells. The release of interleukin-2 stimulates B cells that have receptors that are complementary to the antigen to divide and change into plasma cells. **Plasma cells** are highly specialized cells that make defensive proteins called *antibodies* that are released into the blood. An **antibody** binds to a specific antigen or inactivates or destroys toxins. Antibodies are Y-shaped molecules. The two arms of each Y are identical, and each arm has a receptor that can attach to a specific antigen. A plasma cell can make up to 30,000 antibody molecules per second.



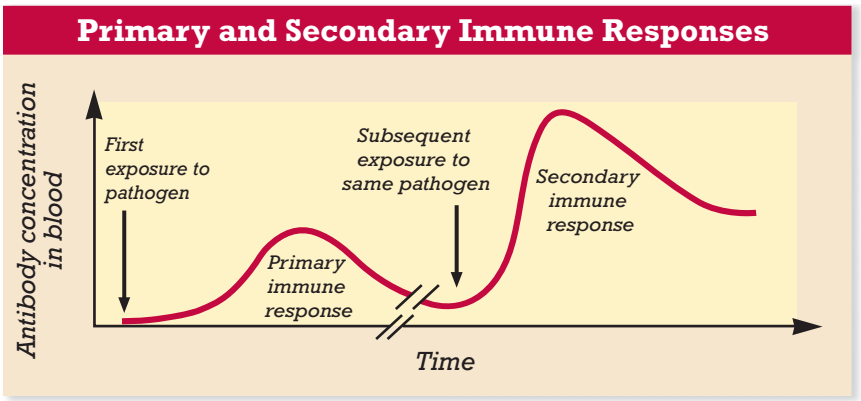
Antibodies bind to pathogens but do not destroy them directly. Instead, antibodies either inactivate the pathogen or cause its destruction by the nonspecific defenses. For example, by attaching to the surface proteins of a virus, antibodies prevent the virus from entering a cell, thereby blocking its reproduction. Antibodies also cause pathogens to clump together, which helps macrophages to engulf the pathogens. Antigen-antibody binding also activates the complement system. The complement proteins can then create holes in the membranes of the pathogen's cells, causing them to burst. The humoral immune response is shown in steps 6 through 9 in Figure 47-7 above.

Primary and Secondary Immune Responses

Although the immune response stops once the body has overcome an infection, some memory cells remain in the body. **Memory cells** are lymphocytes that will not respond the first time that they meet with an antigen or an invading cell but will recognize and attack that antigen or invading cell during later infections.

Memory cells are the body's long-term protection against reinfection by a pathogen. Memory cells often remain effective throughout an individual's life. Because of memory cells, a person will get most diseases only once. When exposed to a pathogen a second time, memory cells immediately recognize it and begin to divide rapidly. They eliminate the pathogen before it can produce serious illness.

(a)



(b)

FIGURE 47-8

(a) Vaccinations take advantage of the production of memory cells and the secondary immune response. (b) Compare the production of antibodies during the primary and secondary immune responses that are shown on the graph.

The first time the body encounters an antigen, the immune response is called a *primary immune response*. The response of memory cells to a later infection by the same pathogen is called a *secondary immune response*. The secondary immune response is much faster and more powerful, producing many more antibodies, as shown in the graph above. Recall that memory cells protect only against pathogens already encountered. Colds and flu are an exception, because rhinoviruses and flu viruses mutate at a high rate. Therefore, these viruses are always presenting new antigens.

IMMUNITY AND VACCINATION

Immunity is the ability to resist an infectious disease. A person who is resistant to a pathogen is said to be immune to it. One way for the body to gain immunity to a pathogen is to be infected by it, undergo a primary immune response, and survive the disease it causes. Another, safer way is through **vaccination** (vak-suh-NAY-shuhn), the introduction of antigens into the body to cause immunity. Vaccination usually involves an injection of a vaccine under the skin, as shown in Figure 47-8a.

Vaccines

A *vaccine* is a solution that contains a dead or weakened pathogen or material from a pathogen. However, the antigens are still present, so the body produces a primary immune response to the antigens in the vaccine. The memory cells that remain after the primary immune response can provide a quick secondary immune response if the antigen ever enters the body again.

Some of the diseases that have been controlled through the use of vaccines are polio, measles, mumps, tetanus, and diphtheria. An intensive worldwide vaccination campaign has eliminated smallpox. Sometimes, the protection provided by vaccines wears off over time. So, doctors recommend *booster shots* to restore immunity against some diseases, such as tetanus and polio.

Quick Lab

Organizing the Immune Response

Materials paper, pencil

Procedure Create a diagram or a flowchart that outlines the steps involved in an immune response. Label the cells and the steps.

Analysis What are helper T cells? How is a cell-mediated response different from a humoral response?

MILESTONES IN Vaccine Development

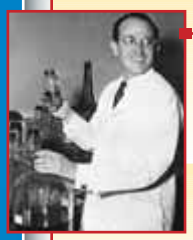
Timeline

Before 1700 Asian physicians use variolation.

1796 Jenner uses cowpox to immunize against smallpox.

1885 Pasteur treats rabies with vaccination.

1940s Vaccines for diphtheria, pertussis, tetanus, and smallpox are used routinely.

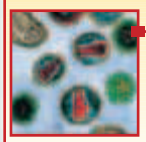


1955 An injectable polio vaccine is introduced by Jonas Salk.

1964 A vaccine for measles is released.

1967 A mumps vaccine is introduced.

1986 Recombinant vaccines are developed.



1990s and later Researchers seek an effective vaccine for HIV and other pathogens.

Centuries ago, Asian physicians sought to understand immunity by exposing healthy people to material from the sores of smallpox victims. This technique, called variolation, *had limited success but a huge historical impact. In the early 1700s, a British woman saw the technique being used in Turkey and described it to British doctors, who tried it on children. One of those children was Edward Jenner, the inventor of vaccination.*

As a country doctor in the late 1700s, Edward Jenner was investigating cowpox, a relatively harmless disease. He knew that milkmaids often contracted cowpox from cows. He had also heard that milkmaids who had cowpox were immune to smallpox. Jenner saw a connection, and he hypothesized that exposure to the pathogen that causes cowpox would give a person immunity to the smallpox pathogen also. In 1796, Jenner tested his hypothesis.

Jenner took matter from the cowpox sore of a milkmaid and injected it into an 8-year-old boy. Two months later, Jenner injected material from a sore of a smallpox patient. The boy remained healthy, even after several more injections. Jenner's experiment would be considered unethical today, but his observations led to millions of lives being saved through vaccination.

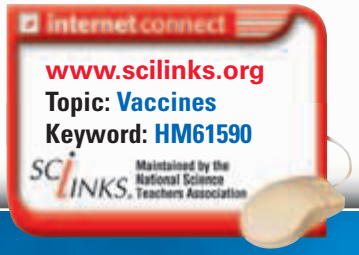
Science and medicine advanced slowly before the 20th century, and vaccination caught on only after scientists understood that germs cause disease. Louis Pasteur succeeded in vaccinating sheep against anthrax in 1881. In 1885, he injected a boy with killed rabies virus to save him from contracting the disease. This event helped explain vaccination, and soon scientists around the world began searching for the agents of disease and creating vaccines. By the early 1970s, vaccines had been developed for diphtheria, pertussis, tetanus, mumps, polio, measles, and rubella. In the United States, these illnesses have been virtually eliminated through vaccination.

Researchers soon discovered that the immune system can recognize a tiny piece of a pathogen and still form antibodies. By 1986, scientists had developed a recombinant hepatitis B vaccine by using harmless organisms altered to make a protein from the virus. The new vaccine cannot actually cause the disease, a rare but dangerous side effect of previous vaccines.

Vaccine research now focuses on conquering pathogens that have caused new outbreaks of disease around the world. These pathogens include HIV, the West Nile virus, the Ebola virus, and the coronavirus that causes SARS. In addition, researchers are working to improve existing vaccines, such as those for smallpox and anthrax.

Review

1. Why is it unnecessary for a vaccine to contain a whole pathogen?
2. **Critical Thinking** How can a person be immune to smallpox after exposure to cowpox?
3. **Critical Thinking** Do you think Pasteur's injection of rabies virus into a child would be considered unethical today?



PROBLEMS OF THE IMMUNE SYSTEM

Sometimes, the immune system reacts to otherwise harmless antigens in ways that can be harmful. Three examples of such problems of the immune system are allergies, asthma, and autoimmune diseases.

Allergies

An **allergy** is a physical response to an antigen. The antigen can be a common substance that produces little or no response in the general population. Antigens that can trigger allergic reactions include pollen, animal dander (flakes of skin), dust mites, food, and fungal spores. Allergic symptoms are generally mild, including a runny nose, sneezing, watery eyes, or itchy swellings of the skin. However, some people have extreme and life-threatening reactions to allergies. Many of the symptoms of allergy result from the release of histamine by cells that are exposed to the antigen. Drugs called *antihistamines* help counteract the effects of histamine and can relieve some symptoms of allergies.

Asthma

Allergies can also trigger **asthma,** a respiratory disorder that causes the bronchioles (airways of the lungs) to narrow. Asthma attacks occur when the muscles covering the bronchioles overreact to substances in the air, as shown in Figure 47-9. Substances that can cause asthma attacks include cigarette smoke and allergens such as animal dander. During an asthma attack, the lining of the bronchioles and other respiratory tissues may also swell and become inflamed, making breathing difficult. Other symptoms of asthma include shortness of breath, wheezing, and coughing. Asthma attacks are serious. Thousands of people in the United States die from asthma each year.

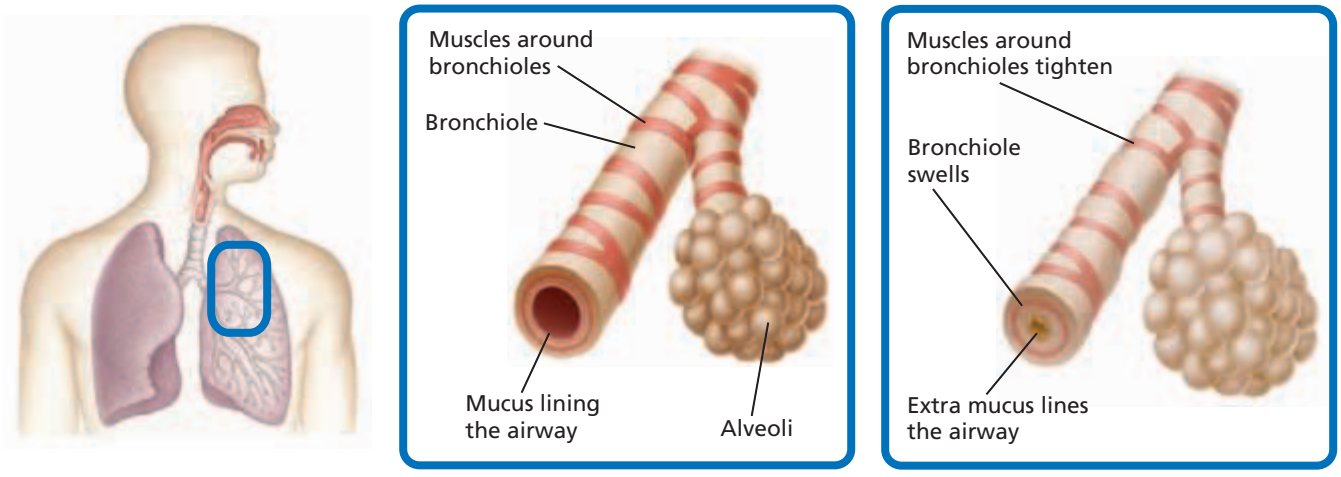


FIGURE 47-9

During an asthma attack, the muscles that encircle the airways of the lung (bronchioles) constrict, and inflammation of the respiratory tissues causes swelling and extra mucus to be produced in the airways. These reactions can make breathing difficult.

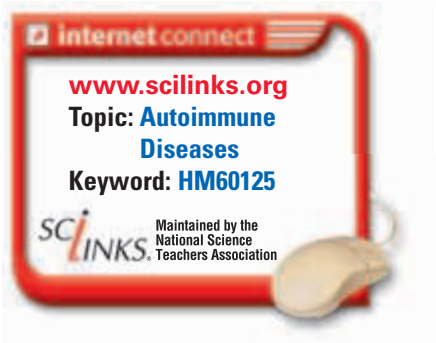
TABLE 47-2 *Autoimmune Diseases, Target Tissues, and Symptoms*

Disease	Tissues affected	Symptoms
Systemic lupus erythematosus	Connective tissue throughout the body	Facial rash, painful joints, fever, fatigue, kidney problems, weight loss
Type 1 diabetes	Insulin-producing cells in pancreas	Excessive urine production, excessive thirst, weight loss, fatigue, confusion
Rheumatoid arthritis	Joints	Painful, crippling inflammation of the joints
Psoriasis	Skin	Dry, scaly, red skin patches
Scleroderma	Multiple organs	Hardening and stiffening of the skin
Crohn's disease	Digestive system	Abdominal pain, nausea, vomiting, weight loss

Autoimmune Diseases

A disease in which the immune system attacks the organism's own cells is called an **autoimmune** (awt-oh-i-MYOON) **disease.** Lymphocytes that recognize and react to the body's own cells are usually eliminated during development, before they become functional. This removal of certain lymphocytes prevents an attack directed at the body's own tissues. However, in rare cases the immune system does respond to the body's own cells, attacking them as if they were pathogens. An autoimmune disease results.

Autoimmune diseases affect organs and tissues in various areas of the body. Multiple sclerosis is an autoimmune disease of the nervous system that affects mainly young adults. In this disease, T cells attack and slowly destroy the insulating material surrounding nerve cells in the brain, in the spinal cord, and in the nerves leading from the eyes to the brain. Symptoms include weakness, unsteadiness, tingling or burning sensations, and blurred vision. In severe cases, paralysis, blindness, and even death can result. Scientists are still searching for the causes of multiple sclerosis and other autoimmune diseases. Table 47-2 lists some other autoimmune diseases and describes their effects on the body.



SECTION 2 REVIEW

1. Describe the functions of the spleen and of the bone marrow.
2. What is an antigen?
3. How does the role of B cells in the immune response differ from that of helper T cells?
4. Explain how vaccination stimulates immunity to a disease.
5. Name one similarity and one difference between autoimmune diseases and allergies.

CRITICAL THINKING

6. **Recognizing Relationships** Explain how B cells depend on T cells.
7. **Evaluating an Argument** "A person who has just recovered from a cold cannot get the flu." Is this statement true? Explain your reasoning.
8. **Forming Reasoned Opinions** Would vaccine research be useful in preventing autoimmune diseases? Explain your reasoning.

SECTION 3

OBJECTIVES

- **Describe** the relationship between HIV and AIDS.
- **Distinguish** between the three phases of HIV infection.
- **Identify** the two main ways that HIV is transmitted.
- **Determine** how the evolution of HIV affects the development of vaccines and treatment.

VOCABULARY

AIDS
HIV
opportunistic infection

HIV AND AIDS

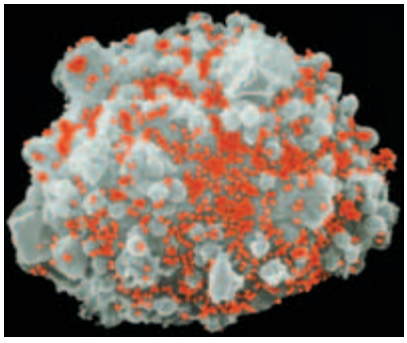
The immune system normally provides protection against infectious diseases. The importance of the immune system can be seen in diseases in which the immune system does not function properly. One of the deadliest of these diseases is ***AIDS*** *(acquired immunodeficiency syndrome), in which the immune system loses its ability to fight off pathogens and cancers. AIDS was recognized as a disease in 1981. Since then, it has killed more than 22 million people worldwide.*

THE COURSE OF HIV INFECTION

AIDS results from infection by the human immunodeficiency virus, or **HIV.** Once HIV has entered the bloodstream, HIV binds to CD4, a receptor protein on the surface of some cells. To enter a cell, HIV must also bind to an associated protein, or co-receptor. Macrophages, which have the CD4 receptor and a co-receptor called CCR5, are often the first cells of the immune system infected with HIV. The virus replicates inside the macrophages, and new viruses are released through "budding." This process does not destroy the macrophages. Viral replication of HIV results in many mutations. Eventually, a mutation may enable the virus to recognize other co-receptors, such as those found on helper T cells.

After release from macrophages, HIV attaches to and enters helper T cells. After viral replication, the new viruses are released from the T cell, as shown in Figure 47-10. These viruses then attach to other helper T cells, where the process repeats. Unlike macrophages, helper T cells are destroyed. Eventually, HIV kills enough helper T cells to cripple the immune system, leading to AIDS. HIV infection doesn't progress to AIDS on a specific timetable, but people tend to go through three phases of infection.

FIGURE 47-10
An HIV-infected helper T cell (grey mass) releases hundreds of new virus particles (red dots). (SEM 5,600×)



Phase I

Phase I of HIV infection is called the *asymptomatic stage,* because there are few or no symptoms. However, the amount of virus increases due to replication, as shown in Figure 47-11. The immune system begins an attack, and plasma cells make antibodies to fight the virus. However, it may take several weeks for the amount of anti-HIV antibodies to become large enough to result in a positive HIV test. HIV-infected people may feel well during phase I but can still infect other people. Phase I can last for up to 10 years or more.

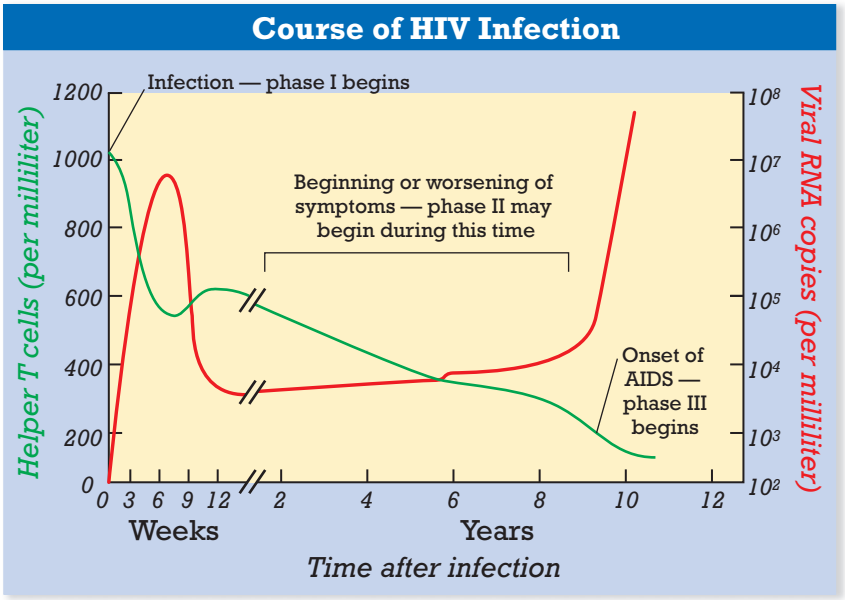


FIGURE 47-11

This graph shows an example of how the course of HIV infection can proceed. The course of HIV infection depends on both the numbers of virus particles and the numbers of helper T cells in the blood.

Phase II

The beginning or worsening of symptoms marks the start of the second phase of HIV infection. B cells continue to make a large amount of antibody against HIV. However, as shown in Figure 47-11, the number of T cells drops steadily as the virus continues to replicate. As the immune system fails, lymph glands become swollen, and fatigue, weight loss, fever, or diarrhea develop or worsen. Some infected people may notice mental changes, such as forgetfulness and abnormal thinking patterns.

Phase III

In phase III, the number of helper T cells drops so low that they can no longer stimulate B cells and cytotoxic T cells to fight invaders. As a consequence, the amount of anti-HIV antibody falls, and HIV levels rise dramatically. The virus continues destroying the few helper T cells remaining. AIDS is diagnosed when the helper T-cell count drops to 200 cells per milliliter of blood or lower (a normal amount is 600 to 700 helper T cells per milliliter).

AIDS may also be diagnosed if an opportunistic infection has developed. **Opportunistic infections** are illnesses caused by pathogens that produce disease in people with weakened immune systems. These organisms usually do not create problems in people with a healthy immune system. Opportunistic infections include pneumocystis pneumonia, tuberculosis, and a rare infection of the brain called *toxoplasmosis*. Rare cancers such as Kaposi's sarcoma, which causes purplish-red blotches on the skin, can also signal the onset of AIDS.

Drug therapy can slow the progress from HIV infection to AIDS. But AIDS is fatal. Few individuals live more than two years after an AIDS diagnosis. It is important to note that HIV itself does not cause death. Rather, death results from the weakened immune system's inability to fight opportunistic infections and cancers.

TRANSMISSION OF HIV

HIV is transmitted by the transfer of body fluids containing HIV or HIV-infected cells. The most common means of infection is sexual contact with an infected person. The second most common means is the use of syringes and hypodermic needles that have been contaminated with blood containing HIV. People who inject intravenous drugs and who share needles are at very high risk of infection. HIV can also be transmitted from an infected mother to her infant before or during birth or through breast-feeding.

HIV is not transmitted through casual contact, such as shaking hands. HIV is apparently not transmitted through the air, in water, on toilet seats, or through insect bites. The likelihood of infection through a blood transfusion is extremely low.

VACCINES AND TREATMENTS

FIGURE 47-12

A scientist studies blood samples as part of the search for a treatment or vaccine for HIV.

Scientists trying to create vaccines and treatments for HIV, such as the scientist shown in Figure 47-12, must contend with its rapid rate of evolution. The genes that code for the virus's surface proteins mutate frequently. As a result, new variants of the virus with slightly different surface proteins are constantly appearing. To produce effective immunity, a vaccine against HIV must stimulate the immune system to respond to many variants of the virus. Although researchers are developing and testing several vaccines against HIV, none has yet proven effective.

In addition, HIV can quickly become resistant to drugs. Scientists now treat patients with a combination of three drugs. Because mutations are random, mutations that create resistance to all three drugs are not likely to occur. However, this therapy often requires patients to take 50 or more pills a day. Many HIV-infected patients find the plan difficult and expensive. Nevertheless, the multidrug treatment is the most effective plan currently available. Because there is not yet a vaccine or cure for HIV infection, the only way to prevent HIV infection is to avoid high-risk behaviors.

SECTION 3 REVIEW

1. Describe the relationship between HIV and AIDS.
2. State the developments during the course of HIV infection that can lead to a diagnosis of AIDS.
3. List two ways that HIV can be transmitted and two ways that it cannot.
4. Why have scientists been unable to develop an effective vaccine for HIV?

CRITICAL THINKING

5. **Recognizing Factual Accuracy** Evaluate the statement "HIV infection causes death."
6. **Analyzing Current Research** Explain how research on co-receptor blocking might affect the search for a treatment for HIV infection.
7. **Comparing Concepts** Identify one similarity and one difference between HIV and a cold virus.

CHAPTER HIGHLIGHTS

SECTION 1 Nonspecific Defenses

- A pathogen is any agent that causes a disease. Robert Koch developed four basic steps, or postulates, for identifying the pathogen responsible for a disease.
- The skin and mucous membranes are nonspecific defenses that keep pathogens out of the body.
- The skin acts as an external barrier to pathogens and also releases substances that are toxic to pathogens.
- The mucous membranes protect the interior surfaces of the body and secrete mucus, a sticky fluid that traps pathogens.
- Injury to cells triggers an inflammatory response. Injured cells release chemical messengers that attract phagocytes through the capillary walls. Phagocytes then destroy the pathogens.
- White blood cells fight pathogens. Two types of phagocytes (neutrophils and macrophages) ingest pathogens. Natural killer cells pierce the cell membranes of infected cells.
- Nonspecific defenses also include an elevation in temperature (fever) and the activation of proteins such as the complement system and interferon.

Vocabulary

infectious disease (p. 957)
pathogen (p. 957)
Koch's postulates (p. 957)
mucous membrane (p. 958)
inflammatory response (p. 959)
histamine (p. 959)
phagocyte (p. 959)
neutrophil (p. 960)
macrophage (p. 960)
natural killer cell (p. 960)
complement system (p. 960)
interferon (p. 960)

SECTION 2 Specific Defenses: The Immune System

- The immune system consists of the cells and tissues that recognize and attack foreign substances in the body.
- Lymphocytes must be able to recognize foreign invaders and tell them apart from the cells of the body. Receptor proteins on a lymphocyte's plasma membrane allow the lymphocyte to recognize the invaders' antigens.
- The reaction of the body against an antigen is called an *immune response.* An immune response is a two-part assault on a pathogen: the cell-mediated immune response and the humoral immune response.
- Memory cells that remain after a primary response to an antigen allow a rapid secondary immune response if that antigen appears again. Vaccinations take advantage of the production of memory cells and the secondary immune response.
- An allergy is a physical response to an antigen that causes little or no response in the general population. Allergies can trigger asthma, a respiratory disorder that causes the bronchioles to narrow. An autoimmune disease is a disease in which the immune system attacks the organism's own cells.

Vocabulary

immune system (p. 961)
lymphocyte (p. 961)
thymus (p. 961)
spleen (p. 962)
B cell (p. 962)
T cell (p. 962)
antigen (p. 962)
immune response (p. 962)
helper T cell (p. 963)
cell-mediated immune response (p. 963)
cytotoxic T cell (p. 963)
humoral immune response (p. 964)
plasma cell (p. 964)
antibody (p. 964)
memory cell (p. 965)
immunity (p. 966)
vaccination (p. 966)
allergy (p. 968)
asthma (p. 968)
autoimmune disease (p. 969)

SECTION 3 HIV and AIDS

- AIDS results from infection by HIV. HIV can replicate inside macrophages and helper T cells.
- The course of HIV infection usually has three phases: phase I, the asymptomatic phase; phase II, the beginning or worsening of symptoms; and phase III, AIDS.
- HIV is transmitted mainly through sexual contact and the use of HIV-contaminated needles.
- Because its genes mutate often, HIV can quickly become resistant to medication. The rapid evolution of HIV also makes it difficult to develop an effective vaccine.

Vocabulary

AIDS (p. 970)
HIV (p. 970)
opportunistic infection (p. 971)

CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *macrophage* and *natural killer cell*
   b. *B cell* and *T cell*
   c. *antigen* and *antibody*
   d. *allergy* and *asthma*
2. Explain the relationship between HIV and AIDS.
3. Use the following terms in the same sentence: *cell-mediated immune response, helper T cell, cytotoxic T cell,* and *interleukin-2*.
4. **Word Roots and Origins** The word *pathogen* is derived from the Greek *pathos,* which means "suffering" or "disease," and *-gen,* which means "to produce." Using this information, explain why the term *pathogen* is a good name for an infectious agent.

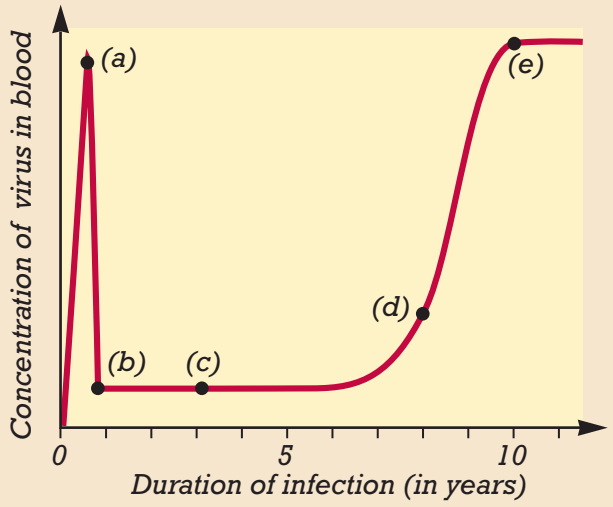
UNDERSTANDING KEY CONCEPTS

5. **Describe** the steps that must be followed to prove that a particular pathogen is responsible for a disease.
6. **Compare** the function of the mucous membranes with that of the skin.
7. **Summarize** the steps of the inflammatory response.
8. **Name** the chemical messenger that increases the permeability of the capillaries surrounding an injury.
9. **Identify** the roles that white blood cells play in the second line of nonspecific defenses.
10. **Explain** how fever and protein production help defend against infection.
11. **Name** one function of the thymus.
12. **Describe** how lymphocytes recognize and bind to pathogens.
13. **Explain** the role that helper T cells play in the immune response.
14. **Name** the type of cell that produces antibodies and releases them into the blood.
15. **Explain** the function of antibodies.
16. **State** the role that memory cells play in providing immunity against disease.
17. **Relate** vaccination to immunity.
18. **Describe** the cause of autoimmune diseases.
19. **Name** the point at which phase III in the course of HIV infection begins.
20. **List** two main ways HIV is usually transmitted.
21. **Identify** the problem scientists have encountered when trying to develop a vaccine against HIV.
22.  **CONCEPT MAPPING** Use the following terms to create a concept map: *pathogen, macrophage, helper T cell, cytotoxic T cell, B cell, plasma cell,* and *antibody*.

CRITICAL THINKING

23. **Making Comparisons** Scientists created an effective vaccine for smallpox but have not been able to do so for HIV. What does this suggest about the rate of evolution of the smallpox virus?
24. **Relating Concepts** Cytotoxic T cells attack and destroy some kinds of cancer cells. What can you conclude about the surface proteins of these cancer cells?
25. **Interpreting Graphics** The graph below shows the amount of HIV in the blood of an infected person over time. Use the graph to answer the following questions:
   a. What caused the peak in viral concentration at point a?
   b. Why did the level of virus drop between points a and b?
   c. Describe what is happening to both the virus and the immune system at points c and d.

Virus Concentration in HIV Infection



26. **Inferring Relationships** People who are severely burned often die from infection. Use what you know about disease transmission to explain why this situation is common.

Standardized Test Preparation

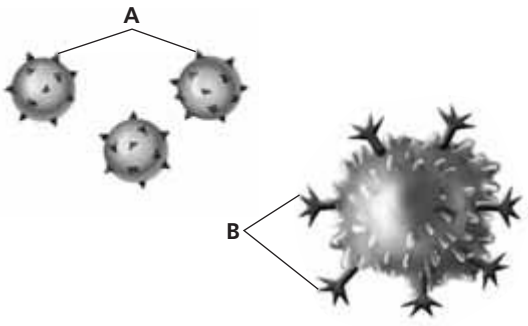
DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. Which of the following is part of the nonspecific defenses?
- **A.** the inflammatory response
- **B.** the primary immune response
- **C.** the humoral immune response
- **D.** the secondary immune response

2. Which of the following statements is false?
- **F.** Autoimmune diseases can be fatal.
- **G.** Autoimmune diseases are a type of cancer.
- **H.** Multiple sclerosis is an autoimmune disease.
- **J.** Autoimmune diseases target the body's cells.

3. Which of the following is the most common means of HIV transmission?
- **A.** receiving a blood transfusion
- **B.** performing experiments with HIV
- **C.** shaking hands with a person who has AIDS
- **D.** having sexual contact with an HIV-infected person

INTERPRETING GRAPHICS: The image below shows two kinds of structures involved in an immune response. Use the image to answer the questions that follow.



4. What are the structures labeled *A*?
- **F.** antigens
- **G.** interferons
- **H.** interleukins
- **J.** receptor proteins

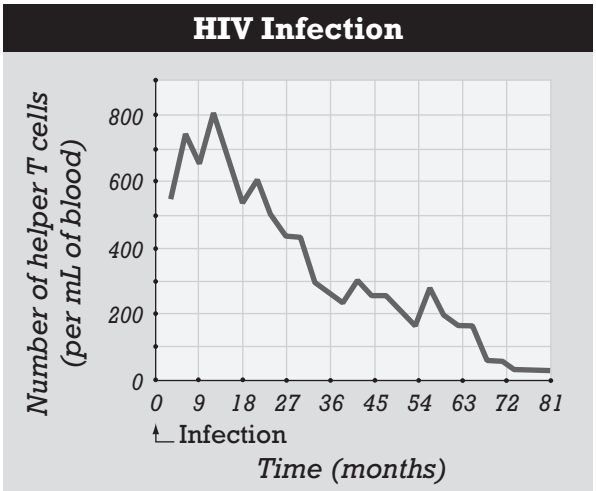
5. What are the structures labeled *B*?
- **A.** antigens
- **B.** interferons
- **C.** interleukins
- **D.** receptor proteins

6. Why do structures *A* and *B* interact with each other?
- **F.** Both are viral proteins.
- **G.** Both are "nonself" structures.
- **H.** They are complementary shapes.
- **J.** They are produced by the same cells.

DIRECTIONS: Complete the following analogy.

7. T cell : cell-mediated :: B cell :
- **A.** humoral
- **B.** infectious
- **C.** secondary
- **D.** inflammatory

INTERPRETING GRAPHICS: The graph below shows the number of helper T cells over time from the onset of HIV infection. Use the graph to answer the question that follows.



8. About how many months after infection did the number of T cells first drop below 200/mL?
- **F.** 18
- **G.** 39
- **H.** 51
- **J.** 58

SHORT RESPONSE

A person infected with HIV today might not test positive for HIV antibodies for up to 6 months.

Explain why an HIV antibody test may not be positive until several weeks after a person's exposure to HIV.

EXTENDED RESPONSE

The inflammatory response results from cell injury.

Part A Explain the role of histamine in the inflammatory response.

Part B Explain the usefulness of having more than one type of white blood cell respond in the inflammatory response.

Test TIP Whenever possible, highlight or underline numbers or words that are critical to correctly understanding a question.

Simulating Disease Transmission

OBJECTIVES

- Simulate the transmission of a disease.
- Determine the original carrier of the disease.

PROCESS SKILLS

- organizing data
- analyzing data
- identifying
- modeling

MATERIALS

- lab apron
- safety goggles
- disposable gloves
- dropper bottle of unknown solution
- large test tube
- indophenol indicator

Background

1. What are the five main ways that human diseases can be transmitted?
2. How does a cold or flu spread from person to person?
3. How does the body fight invading viruses?
4. Why has the transmission of HIV become a great concern worldwide?
5. Why is a person with AIDS less able to combat infections than a person who does not have AIDS?

PART A Simulating the Transmission of a Disease

1. This investigation will involve the class in a simulation of disease transmission. After the simulation, you will try to identify the original infected person in the closed class population.
2. In your lab report, construct a data table similar to Table A.
3.  **CAUTION Put on a lab apron, goggles, and disposable gloves.**
4.  **CAUTION If you get any solution used in this investigation on your skin or clothing, wash it off at the sink while calling to your teacher. If you get any solution used in this investigation in your eyes, immediately flush your eyes with water at the eyewash station while calling to your teacher.** You have been given a dropper bottle of unknown solution and a clean test tube. The solution in the dropper bottle represents the pathogens that you carry. Handle the unknown solution with care because it is not simply water.
5. When your teacher says to begin, transfer three dropperfuls of your solution to your clean test tube. Then, replace the lid on the dropper bottle, and do not re-open it until Part B of this investigation.
6. Select one person to be your partner. Let one partner pour the contents of his or her test tube into the other partner's test tube. Then, pour half the solution back into the first test tube. You and your partner now share pathogens of any possible transmittable disease that either of you might have had. Record the name of your first partner (Round 1) in your data table in your lab report.
7. For Round 2, wait for your teacher's signal, and then find a different partner and exchange solutions in the same manner as you did in step 6. Record the name of your second partner (Round 2) in your lab report. Do not exchange solutions with the same person more than once. Repeat this procedure again for Round 3.
8. After all rounds are finished, your instructor will ask you to add one dropperful of indophenol indicator to your test tube to see if the fluids in your test tube have become infected. Infected solutions will be colorless or light pink. All uninfected solutions will appear blue. Record the outcome of your tests in your lab report.

TABLE A *LIST OF PARTNERS' NAMES*

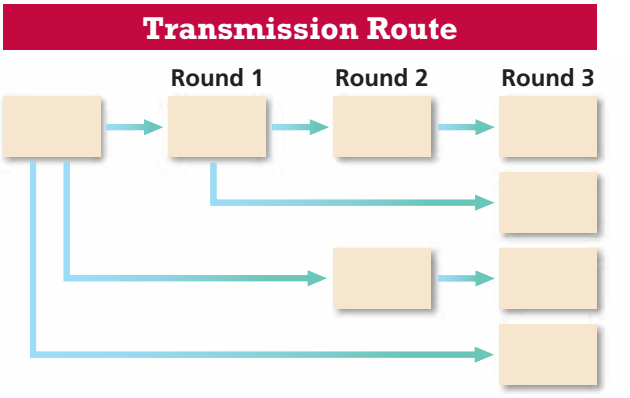
Round number	Partner's name
1	
2	
3	

TABLE B *PATH OF DISEASE TRANSMISSION*

Name of infected person	Names of infected person's partners		
	Round 1	Round 2	Round 3

PART B Tracing the Source of the Disease

9. If you are an infected person, give your name to your teacher. As names of infected people are written on the chalkboard or on the overhead projector, record them in your lab report in a table similar to Table B shown above.
10. Try to trace the original source of the infection, and then determine the transmission route of the disease. In your table, cross out the names of all the uninfected partners in Rounds 1, 2, and 3. There should be only two people in Round 1 who were infected. One of these people was the original carrier.
11. Draw a diagram that shows the transmission route of the disease through all three rounds. Your diagram may look something like the chart below. Include your diagram in your lab report.



12. In your diagram, insert the names of the two people in Round 1 who were infected and the names of their partners in Rounds 2 and 3.
13. To test whether a person was the original disease carrier, pour a sample from his or her dropper bottle into a clean test tube, and add indophenol indicator.
14.  Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. What might the clear fluid in each student's dropper bottle represent?
2. Does the simulated disease have any apparent symptoms?
3. What chemical is added to the test tubes when the rounds are completed?
4. What color indicates a positive result?
5. What color indicates a negative result?
6. Who was the original disease carrier?
7. After the three rounds, how many students were infected? Express this as a percentage of the number of students in the class.
8. If an epidemic occurred in your community, how might public-health officials work to stop the spread of the disease?

Further Inquiry

A public-health official is sent to investigate an outbreak of a new disease. Devise an experiment to allow the official to determine whether the disease has been caused by the passing of pathogens from person to person or by environmental conditions.