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.

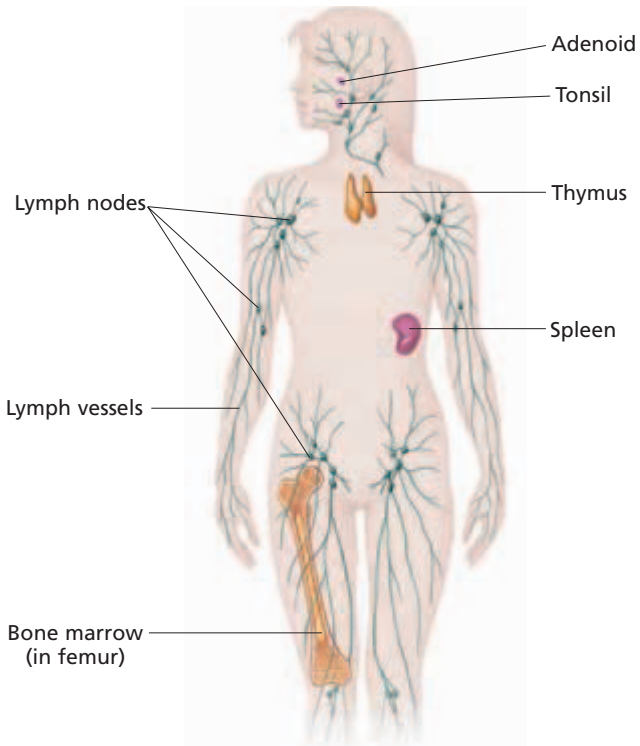


FIGURE 47-5
The cells and tissues of the immune system recognize and attack foreign substances in the body.

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

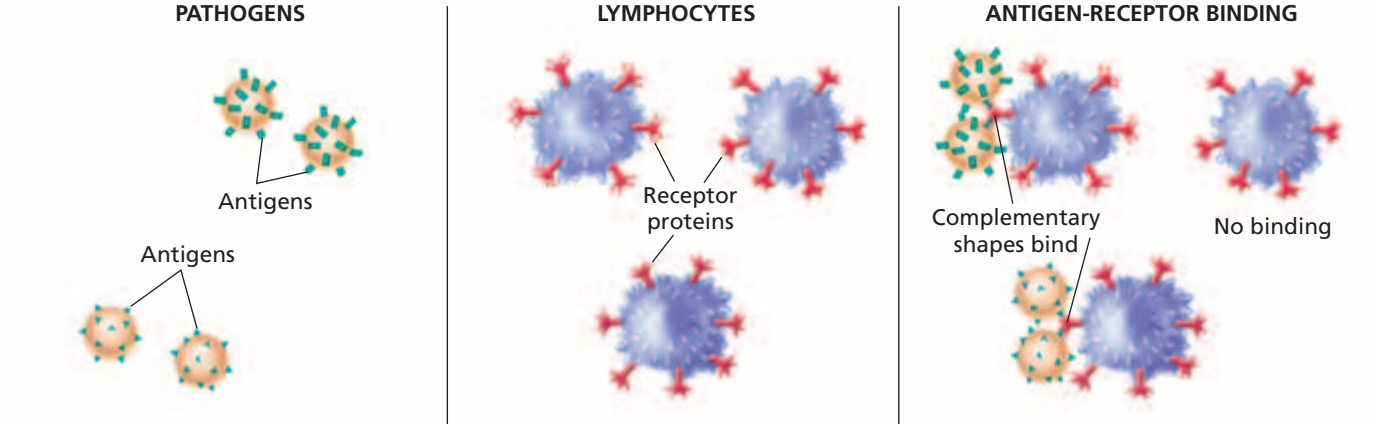
from the Greek *anti,* meaning "against," and *gen,* meaning "producing"

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.

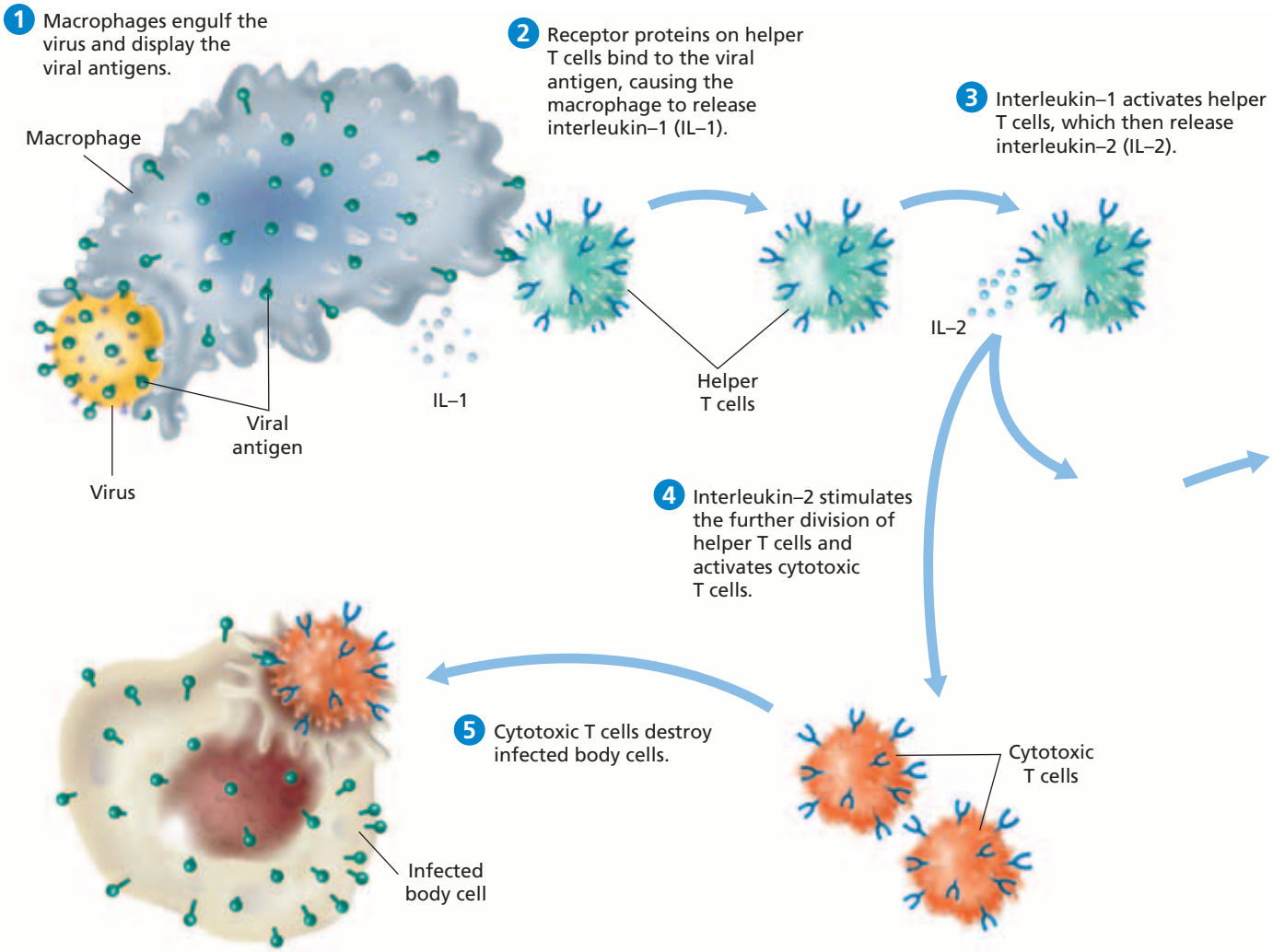


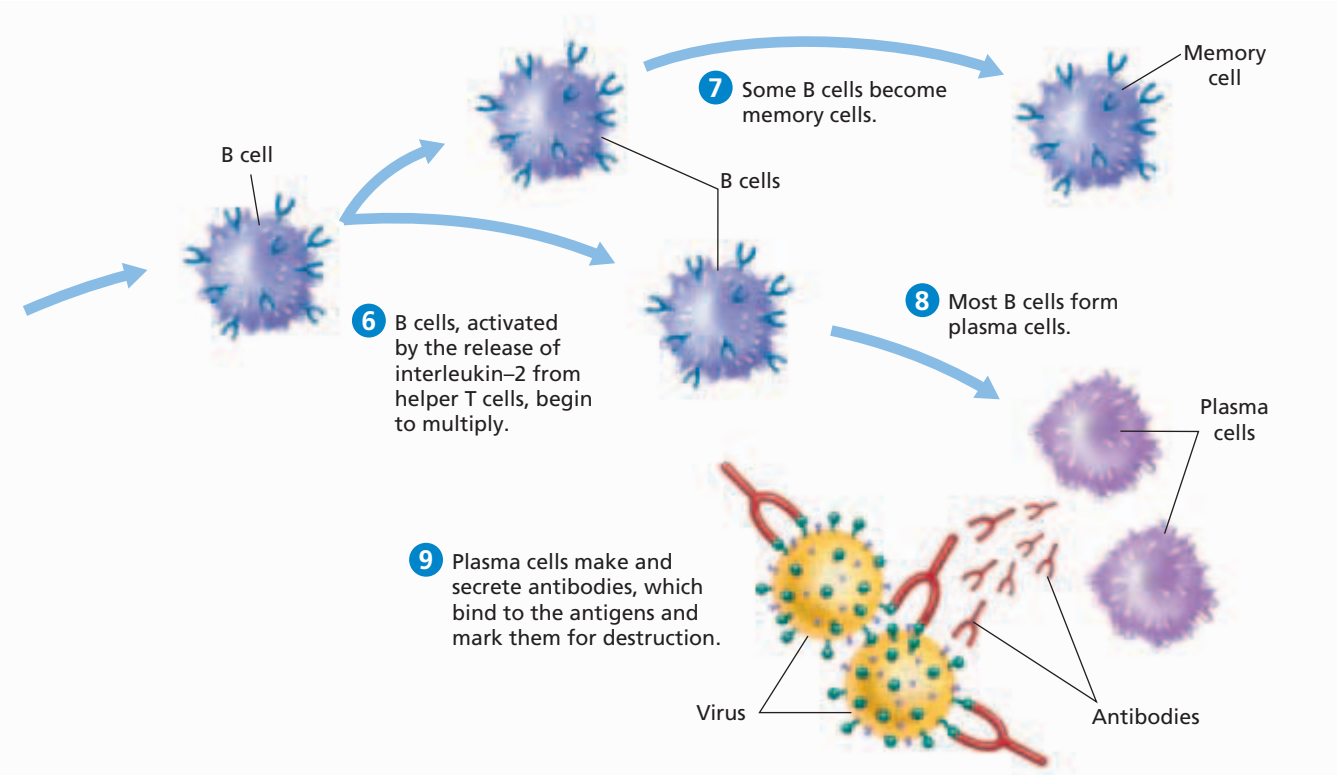
FIGURE 47-7

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.



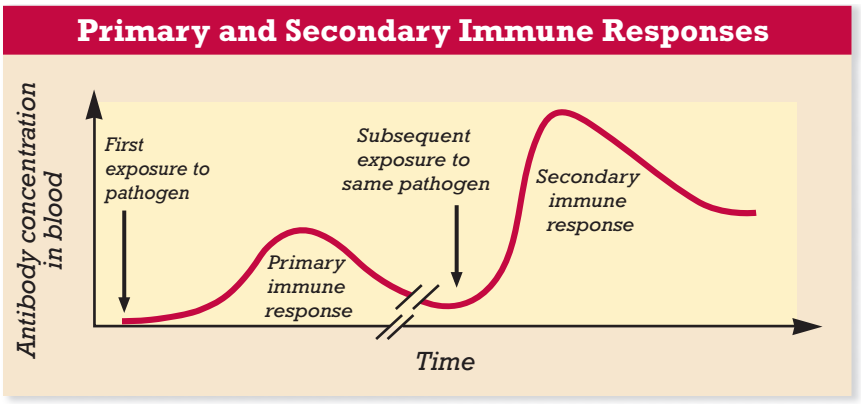
Antibodies bind to pathogens but do not destroy them directly. Instead, antibodies either inactivate the pathogen or cause its destruction by the nonspecific defenses. For example, by attaching to the surface proteins of a virus, antibodies prevent the virus from entering a cell, thereby blocking its 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

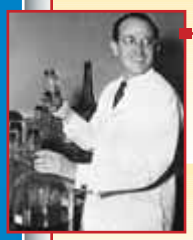
Timeline

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.

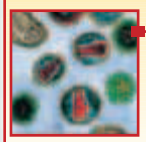


1955 An injectable polio vaccine is introduced by Jonas Salk.

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.

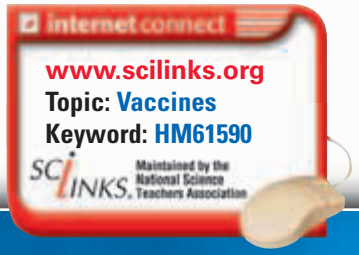
Science and medicine advanced slowly before the 20th century, and vaccination caught on only after scientists understood that germs cause disease. Louis Pasteur succeeded in vaccinating sheep against anthrax in 1881. In 1885, he injected a boy with killed rabies virus to save him from contracting the 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.

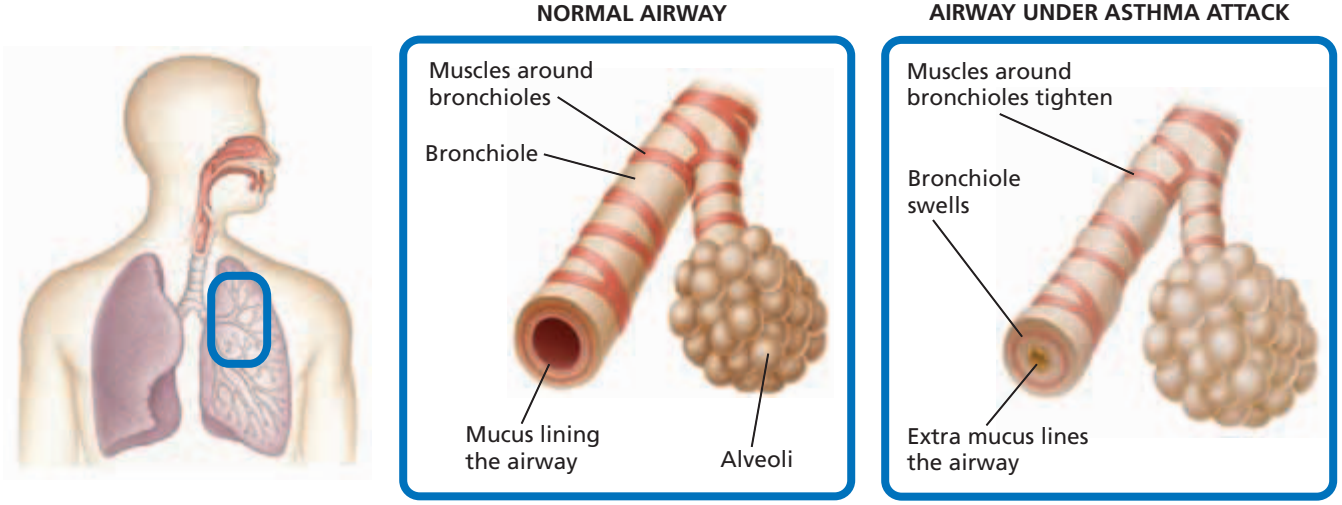


FIGURE 47-9

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.

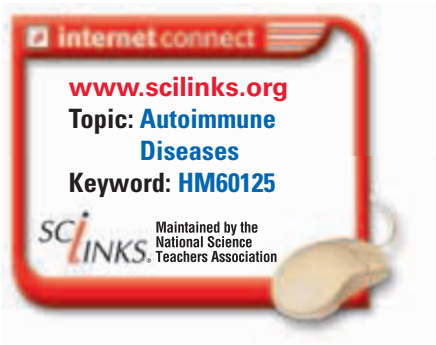
TABLE 47-2 *Autoimmune Diseases, Target Tissues, and Symptoms*

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.