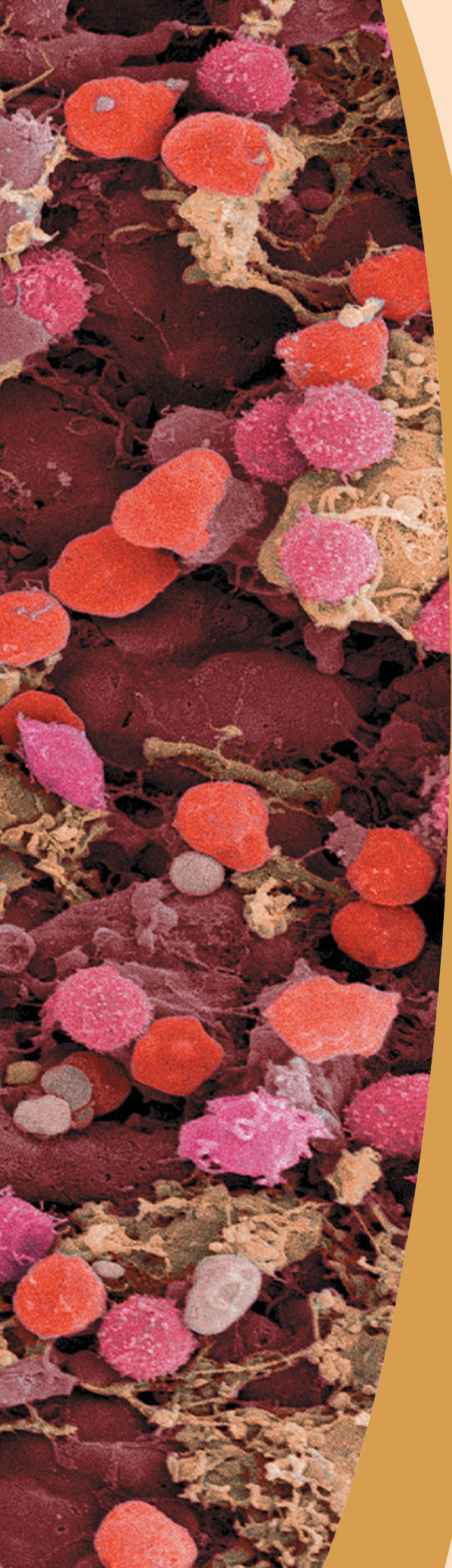


The Lymphatic and Immune Systems 21

After considering the cardiovascular system in the previous three chapters, we now turn to the closely related lymphatic and immune systems. The main function of the **lymphatic system** is to return excess tissue fluid back to the blood vascular system. The *lymphatic vessels* collect this fluid and transport it to the bloodstream. The **immune system** protects our bodies from foreign organisms by fighting infections and conferring immunity to disease. The main components of the immune system are *lymphocytes, lymphoid tissue,* and *lymphoid organs* (such as the spleen, lymph nodes, and thymus).

Freeze fracture section through the medullary sinus of a lymph node; dark red reticular cells are in the background (colored SEM).

The lymphatic and immune structures are of utmost importance to students entering the health professions: As you will see, the lymphatic vessels provide a route by which disease organisms travel throughout the body, and the lymphoid tissues and organs function to contain and destroy these organisms.

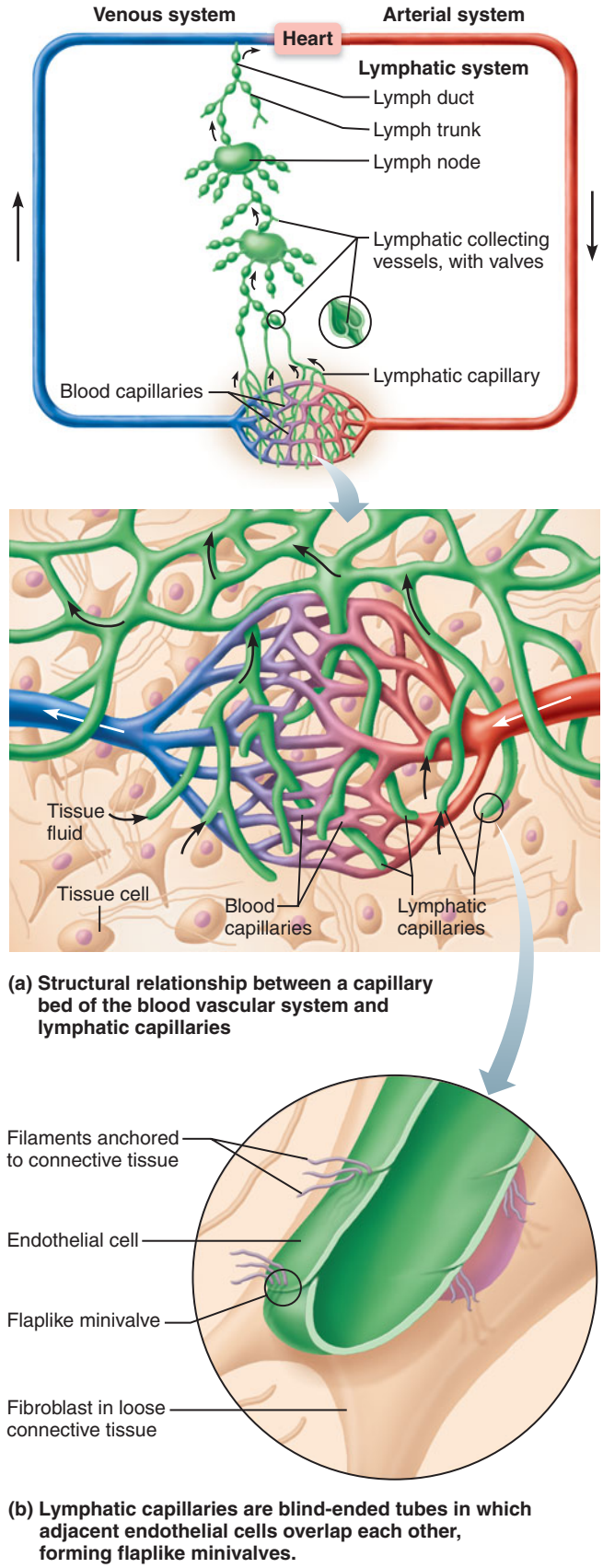
THE LYMPHATIC SYSTEM

- Describe the structure and distribution of lymphatic vessels.
- Explain how lymph forms and the mechanisms by which it is transported.
- List and explain the important functions of the lymphatic vessels.
- Describe how lymph nodes function as lymphatic organs.

Recall from Chapter 4 that all blood capillaries are surrounded by a loose connective tissue that contains tissue fluid **(Figure 21.1)**. Tissue fluid arises from blood filtered through the capillary walls and consists of the small molecules of blood plasma, including water, various ions, nutrient molecules, and respiratory gases. Even though fluid is continuously leaving and reentering the blood capillaries, for complex reasons slightly more fluid exits from the arteriole end of each capillary bed than reenters the blood at the venule end. The **lymphatic vessels** function to collect this excess tissue fluid from the loose connective tissue around blood capillaries and return it to the bloodstream. Once inside the lymphatic vessels, this fluid is called **lymph** (*lympha* = clear water). Any blockage of the lymphatic vessels causes the affected body region to swell with excess tissue fluid, a condition called *edema* (see p. 93).

The lymphatic vessels also perform another, related function. Blood proteins leak slowly but steadily from blood capillaries into the surrounding tissue fluid, and the lymphatic vessels return these leaked proteins to the bloodstream. Recall that the proteins in blood generate osmotic forces that are essential for keeping water in the bloodstream (see p. 540). If leaked proteins were not returned to the bloodstream, a massive outflow of water from the blood to the tissues would soon follow, and the entire cardiovascular system would collapse from insufficient volume.

Because lymph flows only *toward* the heart, the lymphatic vessels form a one-way system rather than a full circuit (Figure 21.1). There are several orders of lymphatic vessels. The smallest vessels, those that first receive lymph, are the *lymphatic capillaries.* These vessels drain into larger *lymphatic collecting vessels,* along which are scattered *lymph nodes.* The collecting vessels then drain into *lymph trunks,* which unite to form *lymph ducts,* which empty into the veins at the root of the neck. Each of these types of lymphatic vessels is discussed next.



(a) Structural relationship between a capillary bed of the blood vascular system and lymphatic capillaries

(b) Lymphatic capillaries are blind-ended tubes in which adjacent endothelial cells overlap each other, forming flaplike minivalves.

FIGURE 21.1 Distribution and special features of lymphatic capillaries. Arrows in (a) indicate direction of fluid movement.

Lymphatic Capillaries

Lymphatic capillaries, the highly permeable vessels that collect the excess tissue fluid, are located near blood capillaries in the loose connective tissue (Figure 21.1b). Like blood capillaries, their wall consists of a single layer of endothelial cells. Their permeability results from the structure and arrangement of the endothelial cells: They have few intercellular junctions, and the edges of adjacent cells overlap, forming easily opened minivalves. Bundles of fine collagen filaments anchor the endothelial cells to the surrounding connective tissue. As a result, any increase in the volume of the tissue fluid separates the minivalve flaps, opening gaps in the wall and allowing the fluid to enter. Once this fluid enters the lymphatic capillaries, it is called *lymph.* Lymph cannot leak out of the lymphatic capillary because backflow forces the minivalve flaps together.

Although the high permeability of lymphatic capillaries allows the uptake of large quantities of tissue fluid and large protein molecules, it also allows any bacteria, viruses, or cancer cells in the loose connective tissue to enter these capillaries with ease. These pathogenic agents can then travel throughout the body via the lymphatic vessels. However, this threat is averted in part by the lymph nodes, which destroy most pathogens in the lymph (see p. 628).

Lymphatic capillaries are widespread, occurring almost everywhere blood capillaries occur. However, lymphatic capillaries are absent from bone and teeth, from bone marrow, and from the entire central nervous system, where excess tissue fluid drains through the nervous tissue into the cerebrospinal fluid. The cerebrospinal fluid then returns this tissue fluid to the blood at the superior sagittal sinus (see pp. 408–409).

One set of lymphatic capillaries, called *lacteals* (lak′te-alz), has a unique function. Located in the villi of the mucosa of the small intestine, lacteals absorb digested fats from the intestine, which causes the lymph draining from the digestive viscera to become milky white (*lacte* = milk). This fatty lymph is called *chyle* (kīl; "juice"), and, like all lymph, it is carried to the bloodstream.

Lymphatic Collecting Vessels

From the lymphatic capillaries, lymph enters **lymphatic collecting vessels,** which accompany blood vessels: In general, the superficial lymphatic collecting vessels in the skin travel with superficial *veins,* whereas the deep lymphatic collecting vessels of the trunk and digestive viscera travel with the deep *arteries.*

Lymphatic collecting vessels are narrow and delicate, so they usually are not seen in the dissecting laboratory. They have the same tunics as blood vessels (tunica intima, tunica media, and tunica externa), but their walls are always much thinner. This reflects the fact that lymph flows under very low pressure, because lymphatic vessels are not connected to the pumping heart. To direct the flow of lymph, lymphatic collecting vessels contain more valves than do veins (Figure 21.1). At the base of each valve, the vessel bulges, forming a pocket in which lymph collects and forces the valve shut. Because of these bulges, each lymphatic collecting vessel resembles a string of beads. This distinctive appearance, which characterizes the larger lymph trunks and lymph ducts as well, allows physicians to recognize lymphatic vessels in X-ray films taken after these vessels are injected with radiopaque dye. This radiographic procedure is called **lymphangiography** (lim′fan″je-og′rah-fe; "lymph vessel picturing").

Unaided by the force of the heartbeat, lymph is propelled through lymphatic vessels by a series of weaker mechanisms. Both the bulging of contracting skeletal muscles and the pulsations of nearby arteries push on the lymphatic vessels, squeezing lymph through them. Additionally, the muscular tunica media of the lymphatic vessels contracts to help propel the lymph, and the normal movements of the limbs and trunk keep the lymph flowing. Despite these propulsion mechanisms, the transport of lymph is sporadic and slow, which explains why people who stand for long times at work may develop severe edema around the ankles by the end of the workday. The edema usually disappears if the legs are exercised, as, for example, by walking home. The seemingly useless nervous habit of people who bounce and wiggle their legs while sitting actually performs the important function of moving lymph up the legs.

THE LYMPH VESSELS AND EDEMA A body region whose lymphatic collecting vessels have been blocked or removed will become swollen and puffy with edema. Edema of the arm often follows a mastectomy (removal of a cancerous breast) in which the lymphatic vessels and nodes that drain the arm are removed from the axilla. Severe edema may continue for several months until the lymphatic vessels grow back. (Lymphatic vessels regenerate quite well and can even grow through scar tissue.) Because this condition, called *lymphedema of the arm,* is very uncomfortable and difficult to treat, surgeons who perform mastectomies are now encouraged to abandon the standard, aggressive procedure of removing all the axillary lymph nodes, and instead to remove only those nodes to which the cancer is likely to have spread.

Lymph Nodes

Lymph nodes, which cleanse the lymph of pathogens, are bean-shaped organs situated along lymphatic collecting vessels (see Figure 21.1). The popular term "lymph glands" is not correct, because they are not glands at all. There are about 500 lymph nodes in the human body, ranging in diameter from 1 to 25 mm (up to 1 inch). Large clusters of superficial lymph nodes in the cervical, axillary, and inguinal regions, plus some important groups of deep nodes, are depicted in Figure 21.2.

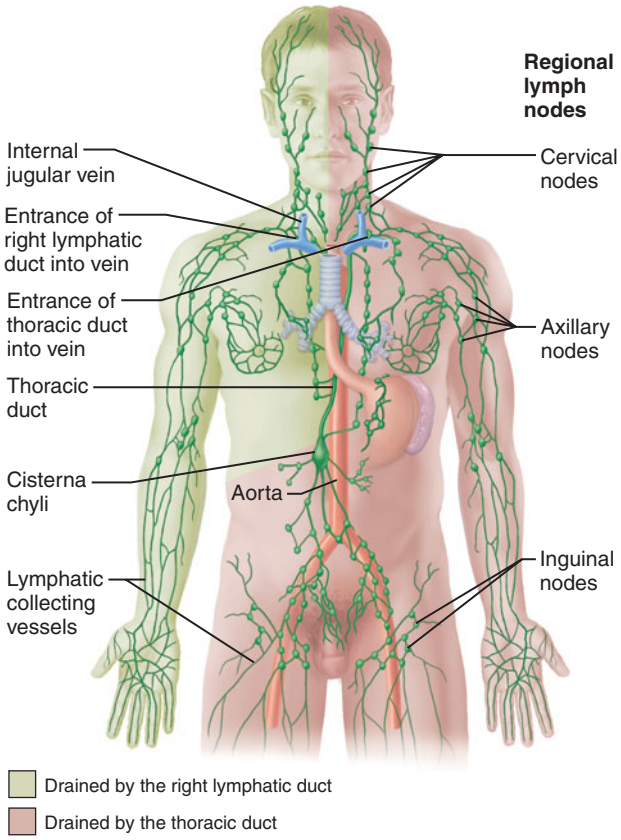


FIGURE 21.2 General distribution of lymphatic collecting vessels and regional lymph nodes.

The superficial *cervical nodes* along the jugular veins and carotid arteries receive lymph from the head and neck. *Axillary nodes* in the armpit and the *inguinal nodes* in the superior thigh filter lymph from the upper and lower limbs, respectively. Nodes in the mediastinum, such as the deep *tracheobronchial nodes,* receive lymph from the thoracic viscera. Deep nodes along the abdominal aorta, called *aortic nodes,* filter lymph from the posterior abdominal wall. Finally, deep nodes along the iliac arteries, called *iliac nodes,* filter lymph from pelvic organs and the lower limbs.

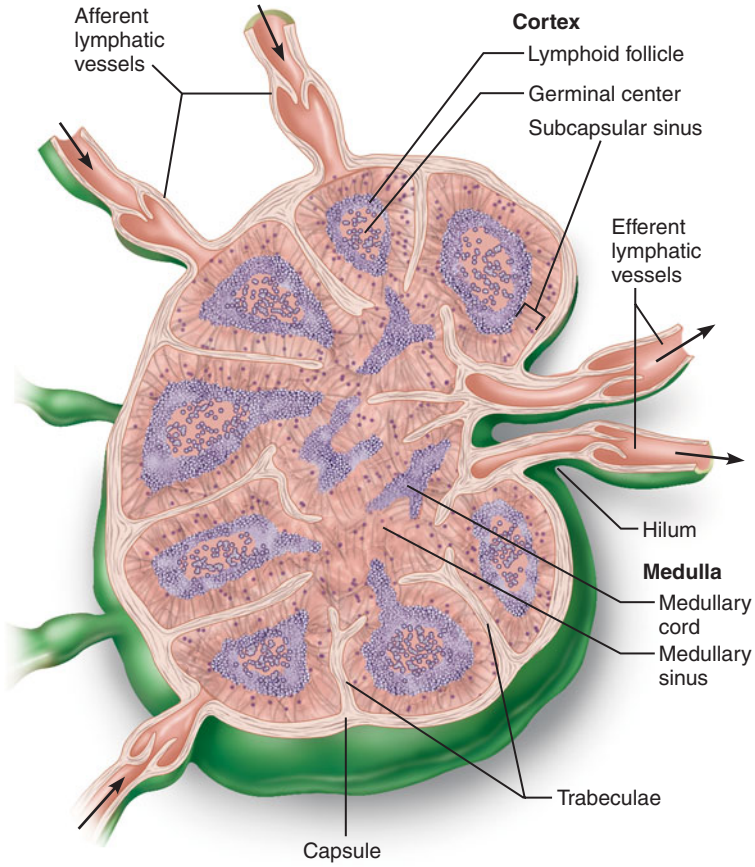
The microscopic anatomy of a lymph node is shown in Figure 21.3. The node is surrounded by a fibrous **capsule** of dense connective tissue, from which fibrous strands called **trabeculae** (trah-bek′u-le; "beams") extend inward to divide the node into compartments. Lymph enters the convex aspect of the node through several **afferent lymphatic vessels** and exits from the indented region on the other side, the **hilum** (hi′lum), through **efferent lymphatic vessels.** Within the node, between the afferent and efferent vessels, lymph percolates through **lymph sinuses** (*subcapsular, cortical,* and *medullary sinuses*). These large lymph sinuses are spanned internally by a crisscrossing network of reticular fibers covered by endothelial cells. Many macrophages live on this fiber network, consuming pathogens and foreign particles in the lymph that flows through the sinuses (Figure 21.3c). Because most lymph passes through several nodes, it is usually free of pathogens by the time it leaves its last node and enters the lymph trunks on its way to the great veins of the neck.

SWOLLEN LYMPH NODES Sometimes, lymph nodes are overwhelmed by the very agents they are trying to destroy. In one instance, when large numbers of undefeatable bacteria or viruses are trapped by the nodes but are not destroyed, the nodes become enlarged, inflamed, and very tender to the touch. Such infected lymph nodes are called *buboes* (bu′bōz). In bubonic plaque, buboes are the most obvious symptom. In another case, metastasizing cancer cells that enter lymphatic vessels and are trapped in the local lymph nodes continue to multiply there. The fact that cancer-infiltrated lymph nodes are swollen but not painful helps to distinguish cancerous nodes from those infected by microorganisms. (Pain results from inflammation, and cancer cells do not induce the inflammatory response.) Potentially cancerous lymph nodes can be located by palpation, as when a physician examining a patient for breast cancer feels for swollen axillary lymph nodes. Physicians can also locate enlarged, cancerous lymph nodes by using CT and MRI scans.

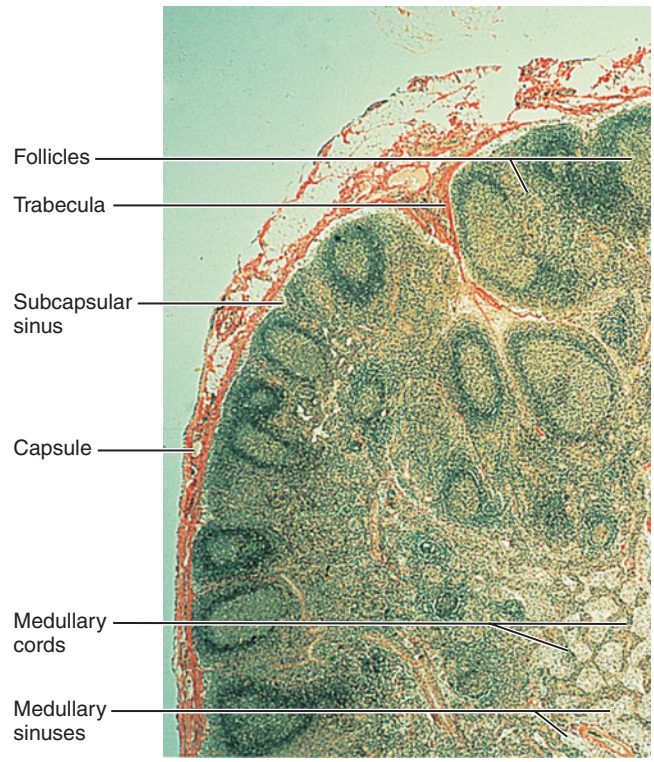
Lymph Trunks

After leaving the lymph nodes, the largest lymphatic collecting vessels converge to form **lymph trunks** (see Figure 21.2 and Figure 21.4). These trunks drain large areas of the body and are large enough to be found by a skilled dissector. The five major lymph trunks, from inferior to superior, are as follows:

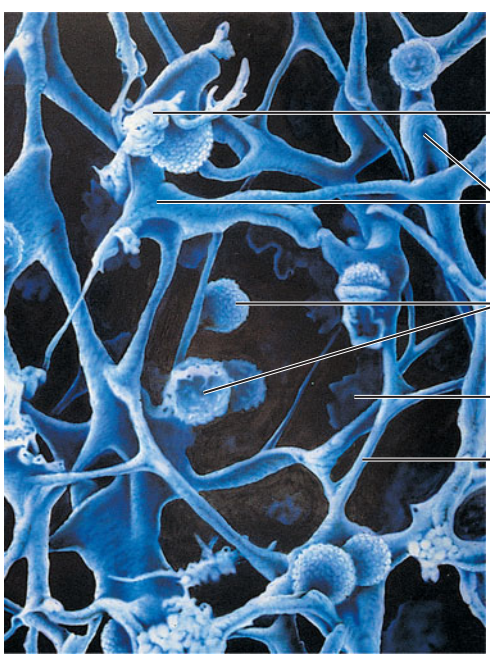
1. **Lumbar trunks.** These paired trunks, which lie along the sides of the aorta in the inferior abdomen, receive all lymph draining from the lower limbs, the pelvic organs, and from some of the anterior abdominal wall.
2. **Intestinal trunk.** This *unpaired* trunk, which lies near the posterior abdominal wall in the midline, receives fatty lymph (chyle) from the stomach, intestines, and other digestive organs.
3. **Bronchomediastinal** (brong″ko-me″de-ah-sti′nal) **trunks.** Ascending near the sides of the trachea, these paired trunks collect lymph from the thoracic viscera and thoracic wall.
4. **Subclavian trunks.** Located near the base of the neck, these paired trunks receive lymph from the upper limbs; they also drain the inferior neck and the superior thoracic wall.
5. **Jugular trunks.** Located at the base of each internal jugular vein, these paired trunks drain lymph from the head and neck.



(a) Longitudinal view of the internal structure of a lymph node and associated lymphatics



(b) Photomicrograph of part of a lymph node (14×)



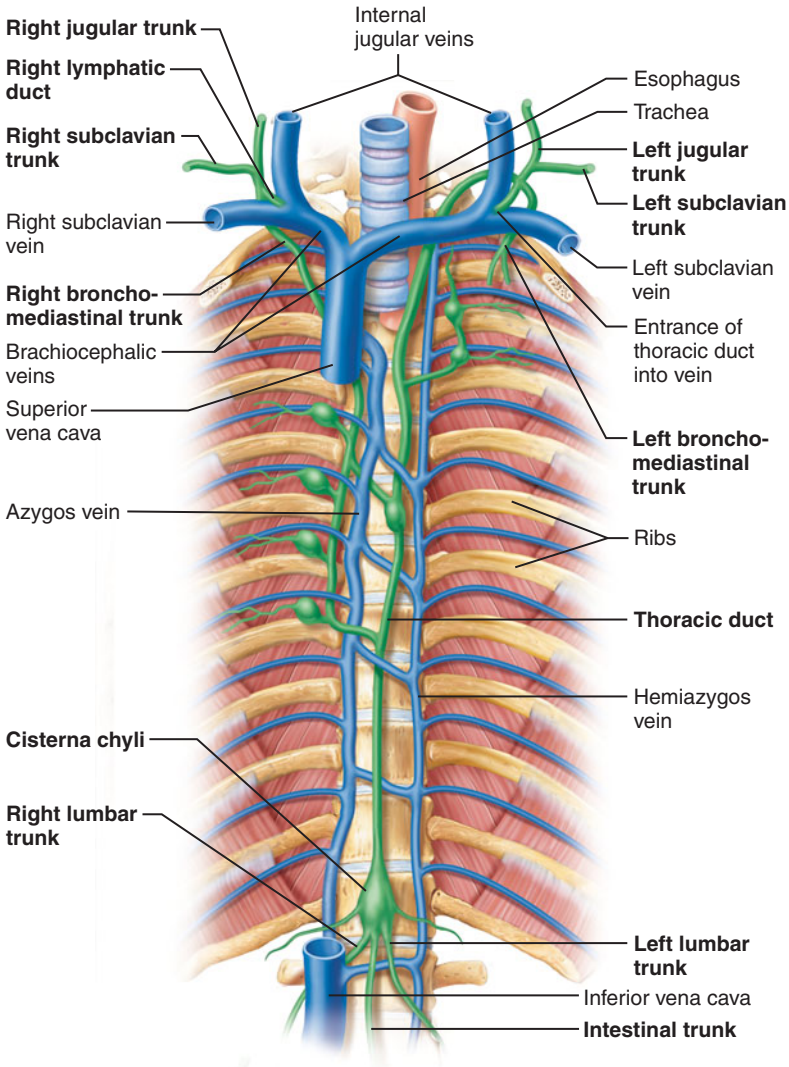
(c) Reticular tissue within the medullary sinus (540×)

FIGURE 21.3 Structure of a lymph node. In (a), arrows indicate the direction of the lymph flow into, through, and out of the node.

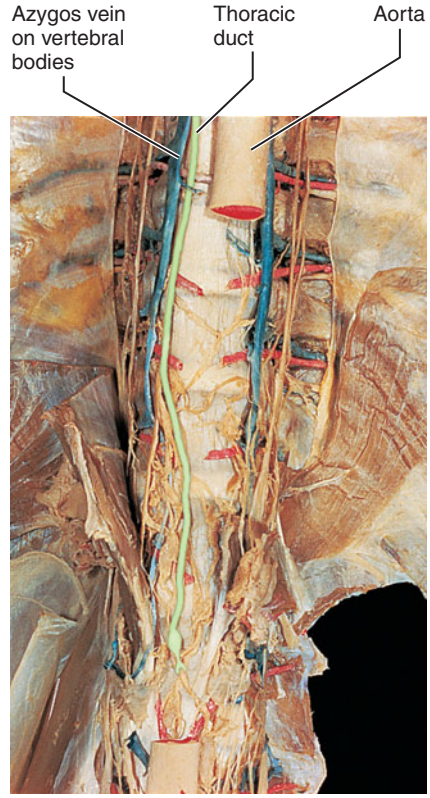
Lymph Ducts

The lymph trunks drain into the largest lymphatic vessels, the **lymph ducts** (Figures 21.2 and 21.4). Whereas some individuals have two lymph ducts, others have just one.

1. **Thoracic duct.** The *thoracic duct* is present in all individuals. Its most inferior part, located at the union of the lumbar and intestinal trunks, is the **cisterna chyli** (sis-ter′nah ki′li; "sac of chyle"), which lies on the bodies of vertebrae L_1 and L_2 (Figure 21.4a). From there, the thoracic duct ascends along the vertebral bodies. In the superior thorax, it turns left and empties into the venous circulation at the junction of the left internal jugular and left subclavian veins. The thoracic duct is often joined by the left jugular, subclavian, and/or bronchomediastinal trunks just before it joins with the venous circulation. Alternatively, any or all of these three lymph trunks can empty separately into the nearby veins. When it is joined by the three trunks, the thoracic duct drains three-quarters of the body: the left side of the head, neck, and thorax; the left upper limb; and the body's entire lower half (see Figure 21.2).
2. **Right lymphatic duct.** The upper right quadrant of the body is drained by the right jugular, subclavian, and bronchomediastinal trunks. In about 20% of people, these ducts join to form a short *right lymphatic duct.* When present, this duct empties into the neck veins at or



(a) Major lymphatic trunks and ducts in relation to veins and surrounding structures, anterior view



(b) Thoracic duct (colored green) along the posterior thoracic wall

FIGURE 21.4 The lymph trunks and ducts.

near the junction of the right internal jugular and subclavian veins (Figure 21.2). More commonly, the three trunks open independently into the neck veins.

This completes the description of the lymphatic vessels. To summarize their functions, they (1) return excess tissue fluid to the bloodstream, (2) return leaked proteins to the blood, and (3) carry absorbed fat from the intestine to the blood (through lacteals). Moreover, in addition to their roles as lymph filters, the lymph nodes along lymphatic collecting vessels fight disease in their roles as lymphoid organs of the immune system.

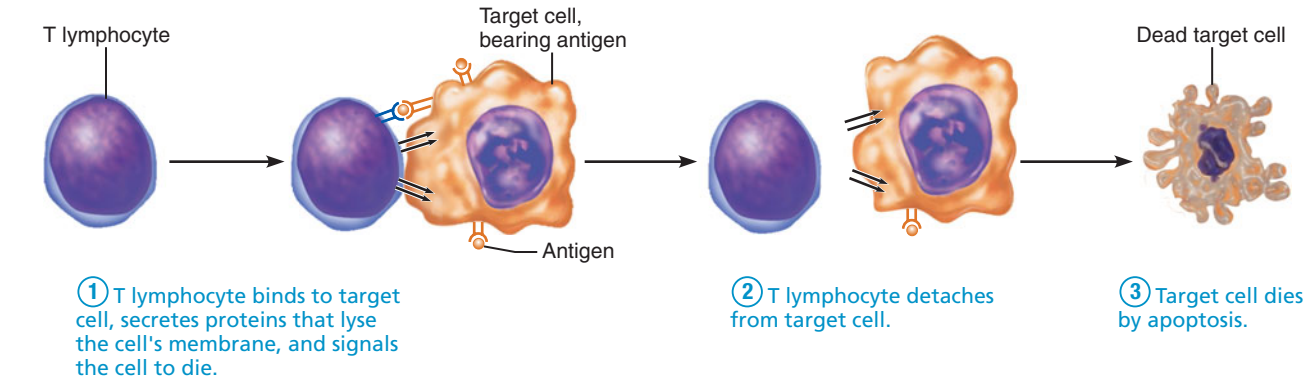
check your understanding

1. What structural feature of lymphatic capillaries makes them permeable to tissue fluid? How does this differ from the features that make blood capillaries permeable?
2. A sentinel lymph node is the first lymph node to receive drainage from the site of a tumor. This lymph node is tested to determine whether a cancer has spread from its initial location. In what group of lymph nodes would the sentinel node be located in a patient with throat cancer? A patient with breast cancer? A patient with cervical cancer?
3. Fatty lymph, picked up by the lacteals in the small intestine, travels through the _____ trunk into the _____ duct and empties into venous circulation at the junction of the _____ and _____ veins.

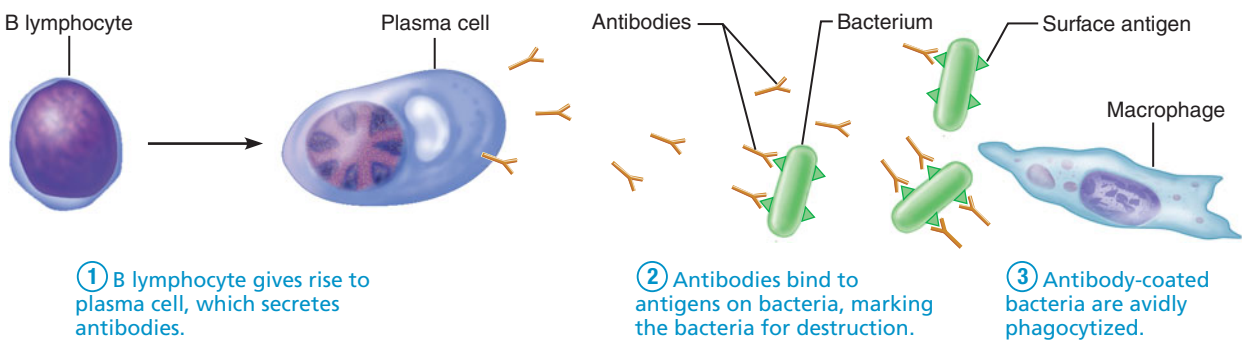
For answers, see Appendix B.

THE IMMUNE SYSTEM

The **immune system** is central to the body's fight against disease. Unlike the body's other defense systems, it recognizes and attacks *specific* foreign molecules, and it destroys pathogens more and more effectively with each new exposure. The immune system centers around the key defense cells called



(a) Action of cytotoxic T lymphocyte



(b) Differentiation and activity of B lymphocyte

FIGURE 21.5 Lymphocyte function.

lymphocytes, but it also includes *lymphoid tissue* and the *lymphoid organs,* which contain lymphocytes. Lymphoid organs include *lymph nodes, spleen, thymus, tonsils,* and *aggregated lymphoid nodules in the small intestine* and *appendix.* The following sections consider these immune components one by one, from the cellular level to the organ level.

Lymphocytes

- Describe the function, recirculation, and activation of lymphocytes.
- Relate the structure of lymphoid tissue to its infection-fighting function.

Infectious microorganisms that penetrate the epithelial barriers of the body enter the underlying loose connective tissues. These infectious agents trigger an inflammatory response (described on p. 93) and are attacked by macrophages and by **lymphocytes** of the immune system. Recall from Chapter 18 (p. 545) that lymphocytes are a type of white blood cell. Lymphocytes are effective in fighting infectious organisms because each lymphocyte recognizes and acts against a *specific* foreign molecule. Any such molecule that induces a response from a lymphocyte is called an *antigen.* Most antigens are either proteins or glycoproteins in the plasma membranes of foreign cells or in the cell walls of bacteria, or proteins secreted by foreign cells (bacterial toxins, for example).

The two main classes of lymphocytes—T cells and B cells—attack antigens in different ways. A major type of T cell, called a **cytotoxic, killer,** or **$CD8^+$ T lymphocyte,** attacks foreign cells directly (Figure 21.5a). It does so by binding to such an antigen-bearing cell, secreting proteins that perforate the foreign cell's membrane, then signaling the cell to undergo programmed cell death (apoptosis; see p. 43). **T cells** bind to antigens that are presented by special proteins that occur only on the membranes of eukaryotic cells (cells that are complex enough to have a nucleus and organelles). These proteins are called the *major histocompatibility complex (MHC).* T cells recognize and respond only to foreign antigens. Thus, T cells target "alien" cells—they reject transplanted organs, destroy our own cells that have been infected with viruses or other pathogens, and kill some cancer cells. All these cells are treated as foreign because they have altered (antigenic) proteins on their surfaces.

B cells, by contrast, differentiate into **plasma cells** that secrete **antibodies** (Figure 21.5b). Antibodies are proteins that bind to specific antigens and mark them for destruction by, for example, making them more recognizable to phagocytic cells. In this way, B cells "flag" cells for destruction by macrophages. B lymphocytes and antibodies respond primarily to bacteria and bacterial toxins in our body fluids. T and B lymphocytes, despite their different actions, cannot be distinguished from one another structurally, even under the electron microscope.

A third class of lymphocytes, **natural killer cells,** do not recognize specific antigens, but instead act when they detect a lack of "self" cell surface molecules or the presence of certain sugars on a target cell. They then rapidly attack tumor cells

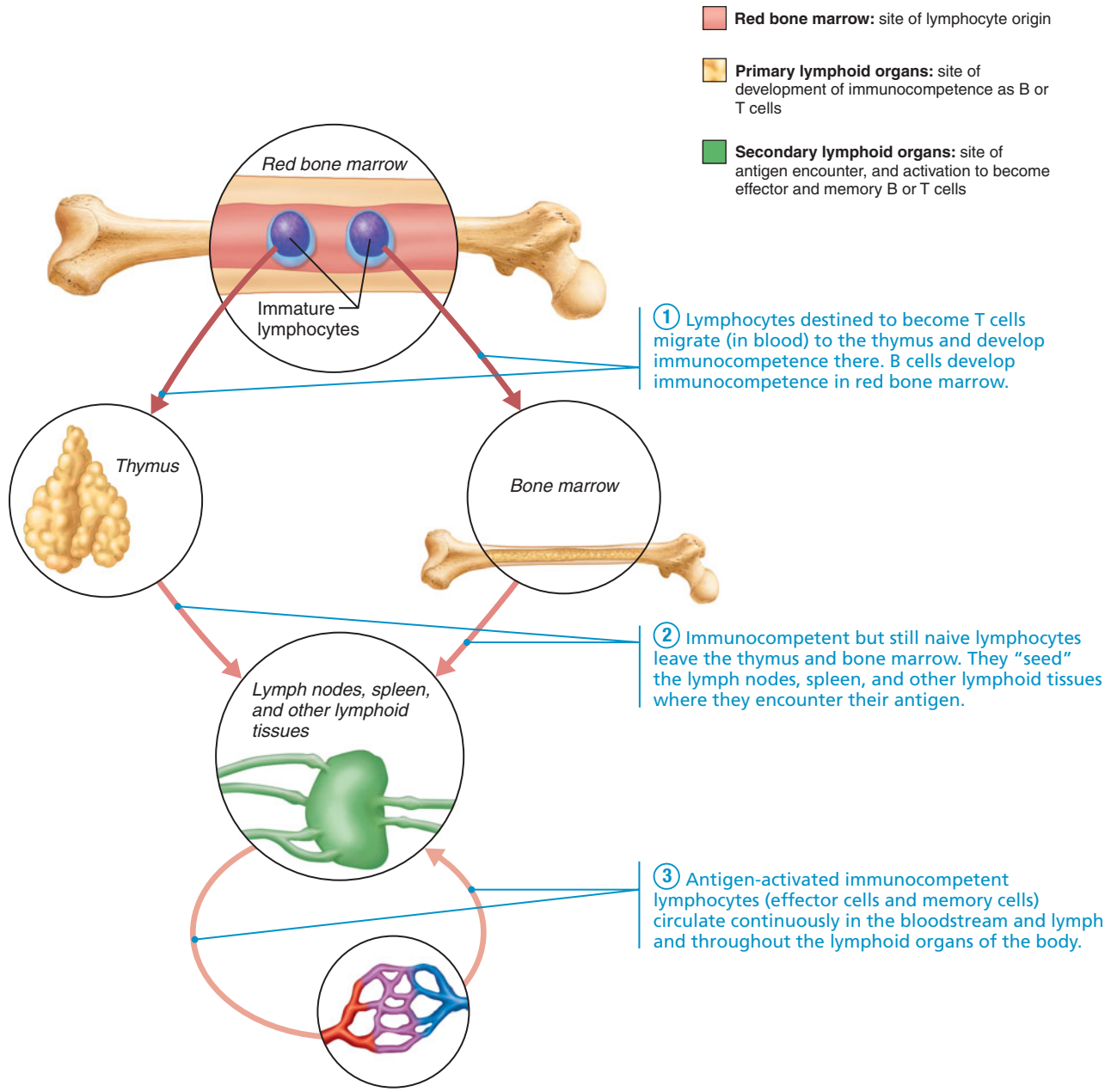


FIGURE 21.6 Differentiation, activation, and recirculation of lymphocytes. Immature lymphocytes arise in red bone marrow. (Note that red bone marrow is not found in the medullary cavity of the diaphysis of long bones in adults.) Plasma cells (antibody-secreting effector B cells) usually do not circulate.

and virus-infected cells before the immune response is activated. They destroy cells in the same way that cytotoxic T cells do, that is, they lyse them (see Figure 21.5a).

B and T cells continuously travel in the blood and lymph streams to reach infected connective tissues throughout the body, where they fight infection. They repeatedly enter and exit these connective tissues, including the often-infected lymphoid tissue, by squeezing through the walls of capillaries and venules. This repeated movement of activated lymphocytes between the circulatory vessels and the connective tissues, called *recirculation,* ensures that lymphocytes reach all infection sites quickly.

Lymphocyte Activation

Immature lymphocytes go through several stages before they are able to attack antigens. Most lymphocytes pass through these stages during a person's infancy and childhood, but many do so in adulthood as well.

Figure 21.6 provides an overview of lymphocyte development and activation. All lymphocytes originate in the red bone marrow from lymphoid stem cells. Some lymphocytes leave the bone marrow and travel in the bloodstream to the thymus in the thorax and become T lymphocytes (*T* stands for *thymus*). Others stay in the bone marrow and become B lymphocytes.

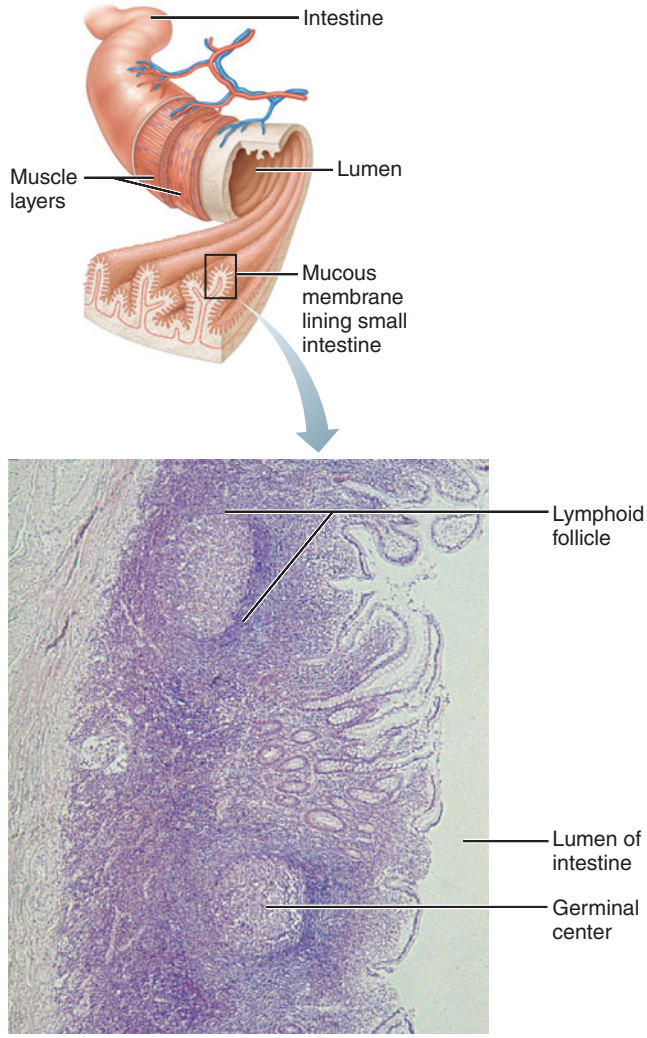
These new T and B lymphocytes divide rapidly and generate many lymphocyte families, each of which has surface receptors able to recognize one unique type of antigen. This is called gaining *immunocompetence.* Next, the young T or B lymphocyte travels through the bloodstream and establishes itself in the lymphoid tissue, where it may ultimately meet and bind to its specific antigen, an encounter called *antigenic challenge.* Upon this encounter, the lymphocyte becomes fully activated (gains the ability to attack its antigen). It proliferates rapidly and produces mature lymphocytes that recirculate throughout the body seeking the same pathogens to attack.

During the activation process, a lymphocyte is presented its antigen by a cell such as a macrophage that has recently phagocytized the antigen, or by a **dendritic cell,** a "professional" antigen gatherer that patrols the body seeking antigens. The dendritic cell or macrophage carries the antigen to the lymphoid tissues where lymphocytes are established. The specific response of the activating lymphocyte to the antigen differs for each type of lymphocyte; however, both activating B and T cells produce clones of *effector cells* and *memory cells.*

Effector lymphocytes are short-lived lymphocytes that respond to the pathogen immediately and then die. B cells divide rapidly to produce plasma cells. These plasma cells secrete antibodies that bind with soluble antigens, marking them for phagocytosis. The two types of T cells interact with cellular antigens differently: *Cytotoxic ($CD8^+$) T cells* directly lyse the "foreign" cell (for example, a virus-infected cell or cancer cell), and **helper ($CD4^+$) T cells** stimulate the various cells of the immune system by secreting chemicals called cytokines. Cytokines stimulate the proliferation of activated B cells, cytotoxic T cells, and macrophages and amplify and fine-tune the immune response. The importance of helper T cells is illustrated by *acquired immune deficiency syndrome (AIDS),* a viral disease in which a drastic decline in the body's helper T cells greatly weakens the immune system. AIDS is considered in more detail in A Closer Look on p. 626.

The other clones produced during activation, **memory lymphocytes,** also called **memory cells,** wait within the lymphoid tissues until the body encounters the specific antigen again—maybe decades later. When a memory lymphocyte finally encounters its antigen, its proliferative response and its attack are most vigorous and rapid. Memory lymphocytes are the basis of acquired immunity; that is, they guard against subsequent infections and prevent people from getting certain diseases more than once.

VACCINATION Vaccination mimics acquired immunity by presenting the body with a weakened or inactive dose of a pathogen or toxin. The result of exposure to the infectious agent is the activation of lymphocytes specific to that pathogen and the development of memory lymphocytes. Thus if the body is infected by the same agent again, it can produce a rapid response to eliminate the pathogen before it can cause illness.



Lymphoid tissue from mucosa of small intestine (14×)

FIGURE 21.7 Mucosa-associated lymphoid tissue (MALT).

Lymphoid Tissue

Lymphoid tissue, the most important tissue of the immune system, is a specialized type of connective tissue in which vast quantities of lymphocytes gather to fight invading microorganisms. This tissue has two general locations: (1) in the frequently infected mucous membranes (p. 89) of the digestive, respiratory, urinary, and reproductive tracts, where it is called **mucosa-associated lymphoid tissue,** or **MALT (Figure 21.7)**; and (2) in all lymphoid organs except the thymus. Besides serving as the main battleground in the fight against infection, lymphoid tissue is also where most lymphocytes become activated and most effector and memory lymphocytes are generated.

The structural features of lymphoid tissue (see Figure 21.3c) serve its infection-fighting role. It is a reticular connective tissue whose basic framework is a network of reticular fibers secreted by reticular cells (fibroblasts). Within the

a closer look

AIDS: The Modern-Day Plague?

AIDS is a viral disease that progresses through three stages: (1) An acute stage, which develops within several weeks of infection and lasts about 2 weeks, is characterized by flulike symptoms such as fever, fatigue, rash, headache, sore throat, swollen lymph nodes, muscle and joint pain, night sweats, and diarrhea. (2) Next comes a long period without symptoms that lasts an average of 10 years. (3) Finally, full-blown AIDS develops, characterized by collapse of the immune system that results in increasingly frequent opportunistic infections. These can include tuberculosis, a rare type of pneumonia, and the distinctive purple skin lesions of *Kaposi's sarcoma* (see p. 632). Furthermore, there is wasting (weight loss) accompanied by diarrhea. About 10% to 15% of AIDS patients develop dementia. Untreated AIDS ends in death from wasting or overwhelming infection. This final stage lasts a few months to several years.

Cause

The agent that causes AIDS, the human immunodeficiency virus (HIV), is transmitted solely through body secretions—blood, semen, and possibly vaginal secretions. It is not transmitted by casual contact, because the virus dries and dies when exposed to air. Most commonly, HIV enters the body (1) during sexual contact in which the mucosa is torn and bleeds, or where open lesions due to other sexually transmitted diseases give the virus access to the blood; or (2) through blood-contaminated needles.

After entering the body, HIV travels to the lymphoid tissues, where it infects and destroys helper ($CD4^+$) T cells, severely depressing immunity. Helper T cells are the cornerstone of the immune system, because they regulate the populations of B cells and cytotoxic T cells, and without them these lymphocytes cannot be activated or maintained. HIV also enters dendritic cells, macrophages, and microglia cells, all of which share a surface protein called CD4, to which HIV attaches. The virus invades the brain, probably in infected microglia, and induces destruction of neurons, accounting for the dementia of some AIDS patients.

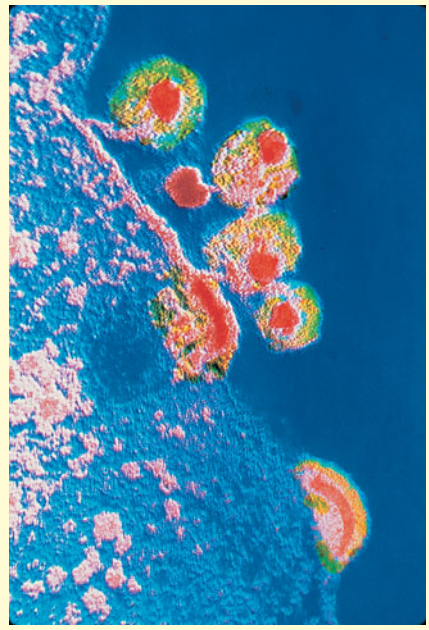
In the initial, acute stage, rapid virus multiplication stimulates the immune system. Antibody levels rise, and cytotoxic ($CD8^+$) T cells fight the infection. During the long, asymptomatic stage, HIV replicates and mutates rapidly, producing deadly strains that evade the immune system by hiding in the $CD4^+$ cells of lymphoid tissues. Ultimately, the immune system is so weakened that the exhausted $CD8^+$ cells can no longer contain the virus. The number of helper T cells declines, and the terminal AIDS stage begins.

Today, AIDS is entering its third decade as a global epidemic. In 2007, the number of people worldwide with HIV infection or AIDS reached 33 million. Of the 2.7 million newly infected individuals, 1.9 million (50%) are in sub-Saharan Africa.

Treatment

Until recently, researchers and clinicians had hoped that new antiviral drugs might effectively treat HIV. A combination of drugs that prevent viral replication and assembly diminished viral loads to undetectable levels. For many AIDS patients, their disease went into remission. Unfortunately, this treatment does not eliminate HIV from the body, and short breaks in treatment allow viral levels to soar.

Another complication is HIV's ability to mutate. Since 1996, when antiviral drugs were first used against it, HIV has developed resistance to every antiviral medication tested. The quest for a vaccine against HIV, either as prevention or treatment, has been equally challenging as viral mutations form new resistant subtypes.



New HIV viruses (red and yellow dots) emerge from an infected human cell.

Despite the grim outlook for a cure, clinicians note a trend in many countries toward high-risk sexual practices, such as casual encounters with multiple partners and falling rates of condom use. The Centers for Disease Control and Prevention estimates that 1.1 million U.S. residents are infected with HIV. The only certain way to avoid AIDS is to avoid contact with HIV-infected body fluids and to practice abstinence. Short of that, the best defense is to practice safe sex by using latex condoms and to know one's sexual partner well.

spaces of this network reside the many T and B lymphocytes that arrive continuously from venules coursing through this tissue. Macrophages on the fiber network kill invading microorganisms by phagocytosis and, along with dendritic cells, activate nearby lymphocytes by presenting them with antigens.

Evident within lymphoid tissue are scattered, spherical clusters of densely packed lymphocytes, called **lymphoid follicles** or **nodules** (Figure 21.7). These follicles often exhibit lighter-staining centers, called **germinal centers,** of dividing lymphocytes. Each follicle derives from the activation of a single B cell, whose rapid proliferation generates the thousands of lymphocytes in the follicle. Newly produced B cells migrate away from the follicle to become plasma cells.

check your understanding

4. Where do cytotoxic T lymphocytes gain immunocompetence?
5. Which immune cells will respond to an infection caused by a bacterial agent?
6. What type of lymphocytes are found in lymphoid follicles? What occurs at the germinal center of a lymphoid follicle?

For answers, see Appendix B.

Lymphoid Organs

➤ Describe the locations, histological structure, and immune functions of the following lymphoid organs: lymph nodes, spleen, thymus, tonsils, aggregated lymphoid nodules in the intestine and appendix.

The **lymphoid organs** (Figure 21.8) include the primary lymphoid organs, which are the bone marrow and thymus, and the secondary lymphoid organs, which are the lymph nodes, spleen, tonsils, and aggregated lymphoid nodules in the small intestine and appendix. The bone marrow and the thymus function to produce B and T lymphocytes, respectively. The other lymphoid organs are elaborately designed to store lymphocytes and gather and destroy infectious microorganisms within their lymphoid tissue. The structure of bone marrow is discussed in Chapter 18, p. 546. The remaining lymphoid organs are examined here, beginning with the thymus and continuing with the secondary lymphoid organs.

Thymus

The two-lobed **thymus** lies in the superior thorax and inferior neck, just posterior to the sternum (Figure 21.9a). As noted earlier, the thymus is the site at which immature lymphocytes develop into T lymphocytes. Specifically, it secretes thymic hormones such as thymosin and thymopoietin, which cause T lymphocytes to gain immunocompetence. Prominent in newborns, the thymus continues to increase in size during childhood, when it is most active. During late adolescence, it begins to atrophy gradually as its functional

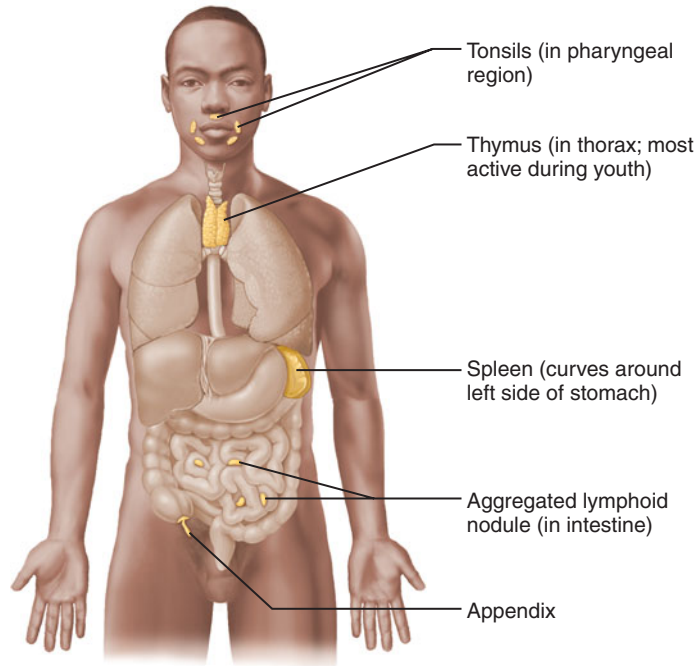
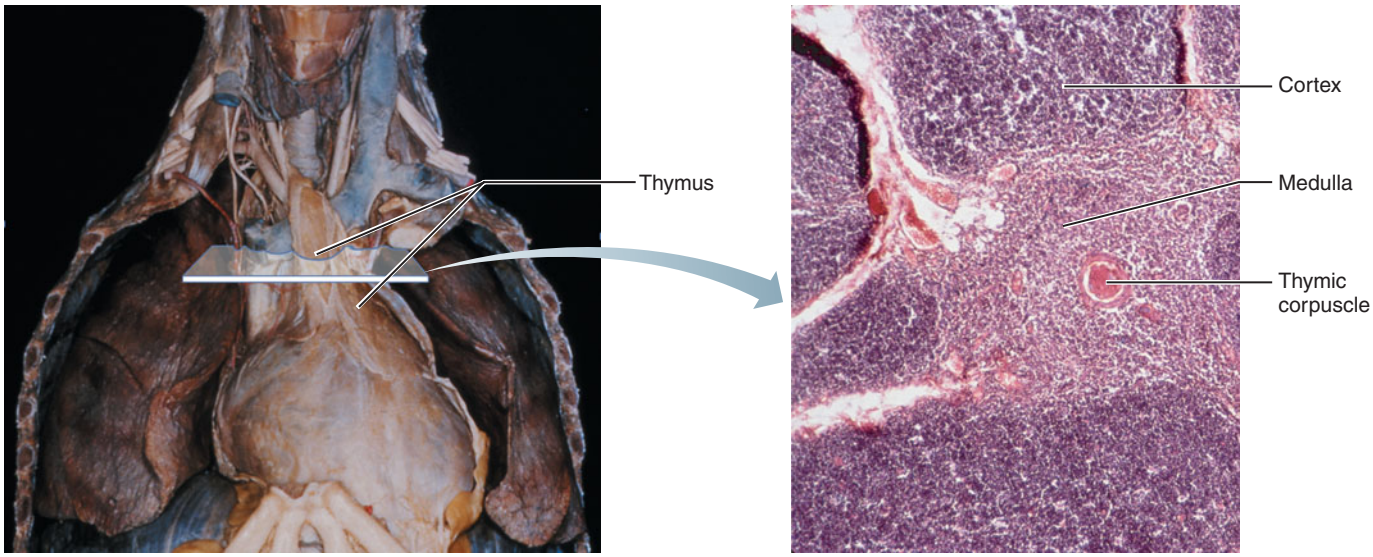


FIGURE 21.8 Lymphoid organs.

tissue is slowly replaced with fibrous and fatty tissue. At age 20 it still has about 80% of its functional tissue, but at age 40 it typically retains only 5%. By old age, only 2% remains, and the thymus is a fatty mass that is difficult to distinguish from the surrounding connective tissue. Even as it atrophies over time, the thymus continues to produce immunocompetent cells throughout adulthood at a reduced rate.

The thymus contains numerous **lobules** arranged like the florets in a head of cauliflower. Each lobule in turn contains an outer cortex and an inner medulla (Figure 21.9b). The **cortex** stains dark because it is packed with rapidly dividing T lymphocytes gaining immunocompetence; the **medulla** contains fewer lymphocytes and stains lighter. Also in the medulla are **thymic (Hassall's) corpuscles,** which are composed of clusters of epithelial cells. The thymic corpuscles function in the development of regulatory T cells, a type of T lymphocyte that prevents autoimmune responses.

The thymus differs from the other lymphoid organs in two basic ways: First, it functions strictly in lymphocyte maturation and thus is the only lymphoid organ that does not directly fight antigens. In fact, the *blood-thymus barrier,* analogous to the blood-brain barrier, keeps bloodborne antigens from leaking out of thymic capillaries and prematurely activating the immature thymic lymphocytes. Second, the tissue framework of the thymus is not a true lymphoid connective tissue. Because the thymus arises like a gland from the epithelium lining the embryonic pharynx, its basic tissue framework consists of star-shaped epithelial cells rather than reticular fibers. These *epithelial reticular cells* secrete the thymic hormones that stimulate T cells to become immunocompetent. Note as well that the thymus has no lymphoid follicles because it lacks B cells.



(a) Thymus located in the superior mediastinum

(b) Micrograph of thymic tissue showing part of a lobule

FIGURE 21.9 The thymus. (a) Dissection showing the location of the thymus in the superior thorax. **(b)** Photomicrograph of thymic tissue, showing part of a lobule with cortex and medulla regions, and thymic (Hassall's) corpuscles (35×).

Lymph Nodes

The lymph-filtering components of lymph nodes have already been considered (pp. 619–620), but lymph nodes are more than just lymph filters. The lymph nodes are the organs at which the lymphatic and immune systems intersect. Between the lymph sinuses are masses of lymphoid tissue (see Figure 21.3). As the lymph percolates through the lymph sinuses, some of the contained antigens leak out through the sinus walls into this lymphoid tissue. Most antigenic challenges in the human body occur here in the lymph nodes, where the antigens not only meet their destruction but also activate B and T lymphocytes, adding to the body's valuable supply of memory lymphocytes that offer long-term immunity.

As shown in Figure 21.3, lymph nodes have two histologically distinct regions, an external **cortex** ("outer bark") and a **medulla** ("middle") near the hilum. All the lymphoid follicles and most B cells occupy the lymphoid tissue of the most superficial part of the cortex. Deeper in the cortex, the lymphocytes are primarily T cells, especially helper T cells that increase the activity of B cells in the nearby follicles. Clusters of lymphocytes within the medulla, called the medullary cords, contain T and B lymphocytes and plasma cells.

Spleen

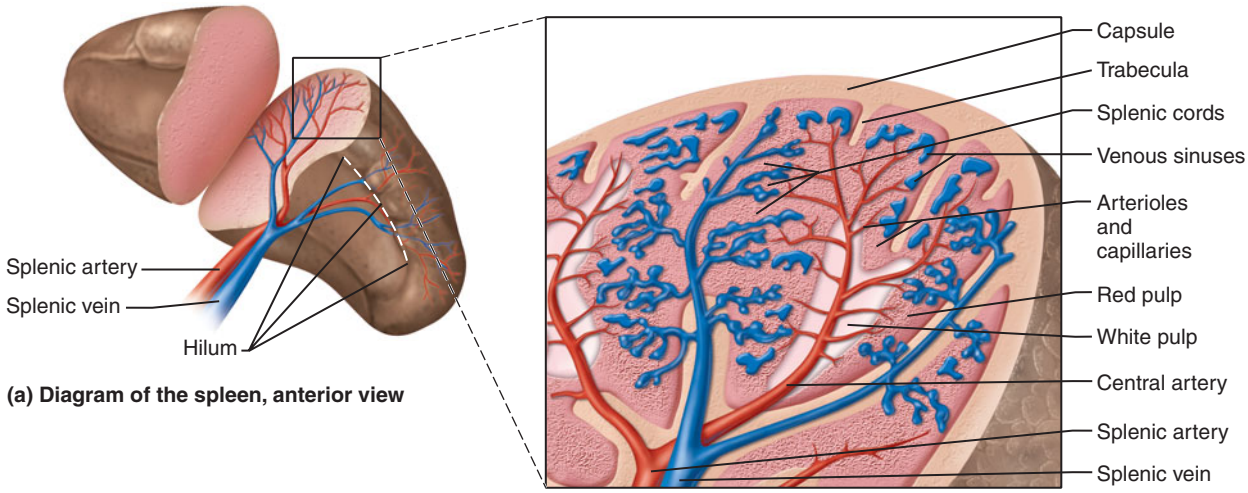
The soft, blood-rich **spleen** (Figure 21.10) is the largest lymphoid organ. Its size varies greatly among individuals, but on average it is the size of a fist. This unpaired organ, which lies in the left superior quadrant of the abdominal cavity just posterior to the stomach (see Figure 21.8), is shaped like a jellyfish and has a concave anterior surface. The large *splenic vessels* enter and exit the anterior surface along a line called the **hilum** (Figure 21.10a).

The spleen has two main blood-cleansing functions: (1) the removal of bloodborne antigens (its immune function), and (2) the removal and destruction of aged or defective blood cells. Additionally, the spleen is a site of hematopoiesis in the fetus and stores blood platelets throughout life.

The spleen, like lymph nodes, is surrounded by a fibrous capsule from which trabeculae extend inward (Figure 21.10b). The larger branches of the splenic artery run in the trabeculae and send smaller arterial branches into the substance of the spleen. These branches are called **central arteries** because they are enclosed by (lie near the *center* of) thick sleeves of lymphoid tissue that collectively constitute the **white pulp** of the spleen. Bloodborne antigens enter this lymphoid tissue and are destroyed as they activate the immune response. The white pulp provides the immune function of the spleen.

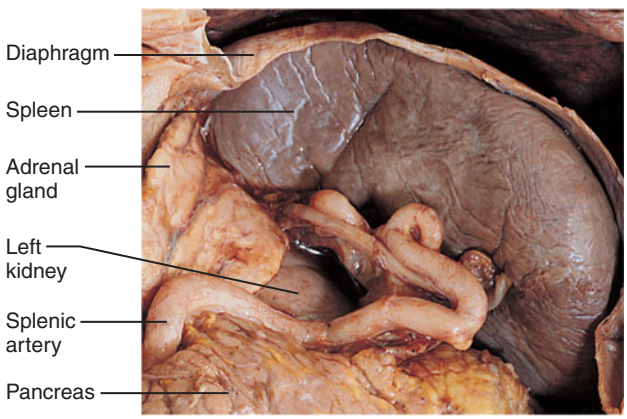
Surrounding the white pulp is **red pulp,** which has two parts: (1) **venous sinuses,** blood sinusoids that arise from the distal branches of the central arteries outside of the white pulp; and (2) **splenic cords,** which consist of a reticular connective tissue that is exceptionally rich in macrophages. Whole blood leaks from the sinuses into this connective tissue, where macrophages then phagocytize any defective blood cells. Hence, red pulp is responsible for the spleen's ability to dispose of worn-out blood cells.

In histological sections (Figure 21.10d), the white pulp appears as islands in a sea of red pulp. Note that the naming of the pulp regions reflects their appearances in fresh spleen tissue rather than in stained histological sections; with many stains, the white pulp actually appears darker than the red pulp.

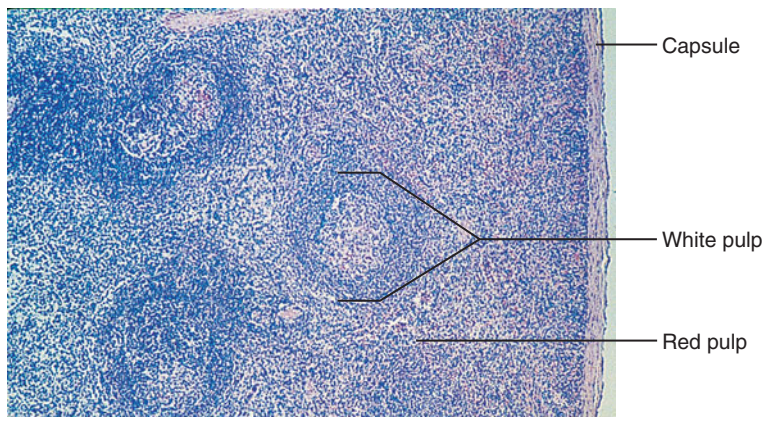


(a) Diagram of the spleen, anterior view

(b) Diagram of spleen histology



(c) Photograph of the spleen in its normal position in the abdominal cavity, anterior view



(d) Photomicrograph of spleen tissue (7×). The white pulp, a lymphoid tissue with many lymphocytes, is surrounded by red pulp containing abundant erythrocytes.

FIGURE 21.10 Structure of the spleen. (See *A Brief Atlas of the Human Body,* Second Edition, Plate 39.)

SPLENECTOMY Because the capsule of the spleen is relatively thin, physical injury or a serious infection may cause the spleen to rupture, leading to severe loss of blood due to hemorrhage into the peritoneal cavity. In such cases, the spleen must be removed quickly and its artery tied off, a surgical procedure called a **splenectomy.** A person can live a relatively healthy life without a spleen, because macrophages in the bone marrow and liver can take over most of the spleen's functions. Such a person will be more susceptible to infections, however, so surgeons performing splenectomies now leave some of the spleen in place whenever possible. Alternatively, healthy fragments of the spleen are surgically reattached immediately after the operation. In some such cases, the spleen can regenerate.

Tonsils

The **tonsils,** perhaps the simplest lymphoid organs, are mere swellings of the mucosa lining the pharynx. There are four groups of tonsils, whose precise locations are indicated in Figure 22.3 in the following chapter. The **palatine tonsils** lie directly posterior to the mouth and palate on the lateral sides of the pharyngeal wall. These are the largest tonsils and the ones most often infected and removed during childhood, in a surgical procedure called *tonsillectomy.* The **lingual tonsil** lies on the posterior surface of the tongue, the **pharyngeal tonsil** (adenoids) lies on the pharyngeal roof, and the **tubal tonsils** are just behind the openings of the pharyngotympanic tubes into the pharynx. The four groups of tonsils are arranged in a ring around the entrance to the pharynx to gather and remove many pathogens that enter the pharynx in inspired air and swallowed food. The tonsils process the antigens and then initiate immune responses.

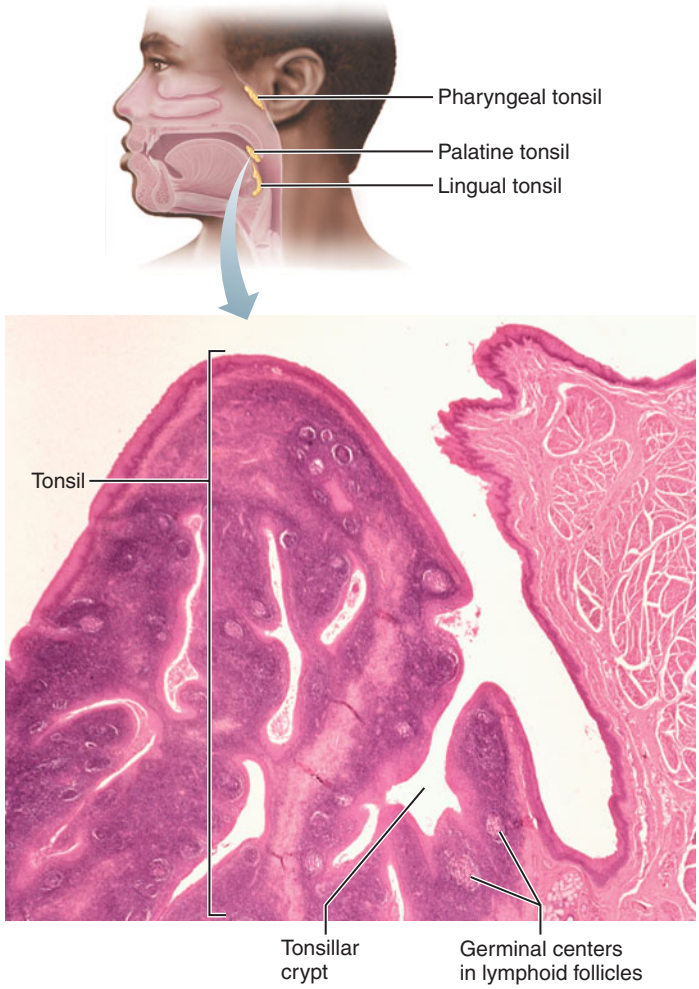


FIGURE 21.11 Histology of the palatine tonsil. The exterior surface of the tonsil is covered by epithelium, which invaginates deeply to form tonsillar crypts.

The histological structure of tonsils is shown in Figure 21.11. These swellings of mucosa, like all mucosae, consist of an epithelium underlain by a connective tissue lamina propria. In the tonsils, the underlying lamina propria consists of abundant mucosa-associated lymphoid tissue (MALT) packed with lymphocytes and scattered lymphoid follicles. The overlying epithelium invaginates deep into the interior of the tonsil, forming blind-ended **crypts** that trap bacteria and particulate matter. The trapped bacteria work their way through the epithelium to the underlying lymphoid tissue, causing the activation of lymphocytes. Such trapping of bacteria leads to many tonsil infections during childhood, but it also generates a great variety of memory lymphocytes for long-term immunity.

Aggregated Lymphoid Nodules and the Appendix

Many bacteria permanently inhabit the hollow interior of the intestines and are constantly infecting the intestinal walls. To fight these invaders, MALT is especially abundant in the intestine. In fact, in two parts of the intestine, MALT is so large, permanent, and densely packed with lymphocytes that it is said to form lymphoid organs: the aggregated lymphoid nodules and the appendix.

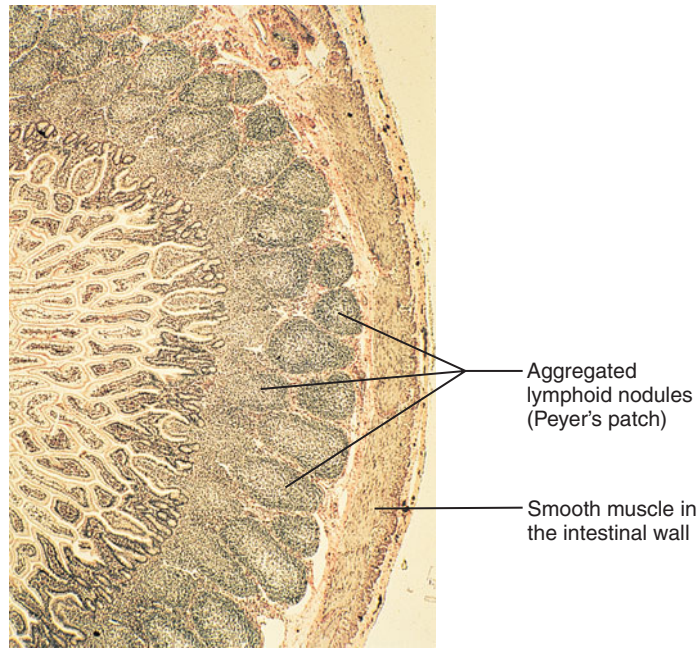


FIGURE 21.12 Aggregated lymphoid nodule. The photomicrograph shows the histological structure of the aggregated lymphoid nodules (Peyer's patches) in the wall of the ileum of the small intestine. The lumen of the intestine is seen at the left of the photomicrograph (6×).

Aggregated lymphoid nodules *(Peyer's patches)* are clusters of lymphoid follicles in the walls of the distal part (ileum) of the small intestine (Figure 21.12). About 40 of these nodules are present, averaging about a centimeter long and a centimeter wide.

Lymphoid tissue is also heavily concentrated in the wall of the **appendix,** a tubular offshoot of the first part (cecum) of the large intestine (see Figure 21.8). Histological sections reveal that dense lymphoid tissue uniformly occupies over half the thickness of the appendix wall.

Besides destroying the microorganisms that invade them, the aggregated lymphoid nodules and appendix sample many different antigens from within the digestive tube and generate a wide variety of memory lymphocytes to protect the body.

check your understanding

7. What is the function of red pulp in the spleen?
8. Where are T lymphocytes located in lymph nodes?
9. Which part of the intestine contains aggregated lymphoid nodules?

For answers, see Appendix B.

DISORDERS OF THE LYMPHATIC AND IMMUNE SYSTEMS

➤ Describe the basic characteristics of two disorders of lymphatic vessels: chylothorax, lymphangitis; and three disorders of lymphocytes and lymphoid organs: mononucleosis, Hodgkin's disease, and non-Hodgkin's lymphoma.

Chylothorax ("chyle in the thorax") is the leakage of the fatty lymph, chyle, from the thoracic duct into a pleural cavity in the thorax. It is caused by tearing or a blockage of the thoracic duct due to chest trauma or to compression by a nearby tumor. Complications can result from (1) large amounts of lymph in the pleural cavity compressing and collapsing the lungs, (2) metabolic problems caused by the loss of fatty nutrients from the circulation, or (3) diminished blood volume following the loss of fluid from the circulation. Treatment involves draining the lymph from the pleural cavity and surgically repairing any damage to the thoracic duct.

Lymphangitis (lim′fan-ji′tis; "lymph vessel inflammation") is inflammation of a lymphatic vessel. Like the large blood vessels, the lymphatic vessels are supplied with blood by the vasa vasorum. When lymphatic vessels are infected and inflamed, the vasa vasorum become congested with blood. The superficial lymphatic vessels then become visible through the skin as red lines that are tender to the touch.

Mononucleosis is a viral disease common in adolescents and young adults. Its symptoms include fatigue, fever, sore throat, swollen lymph nodes, and enlargement of the spleen. It is caused by the Epstein-Barr virus, which specifically attacks B lymphocytes. This attack leads to a massive activation of T lymphocytes, which in turn attack the virus-infected B cells. The large numbers of oversized T lymphocytes that circulate in the bloodstream were originally misidentified as monocytes (*mononucleosis* = condition of monocytes). Mononucleosis is transmitted in saliva ("kissing disease") and usually lasts 4 to 6 weeks. The most serious risk of this disease is rupture of the enlarged spleen, which can cause massive hemorrhaging.

Hodgkin's disease is a malignancy of the lymph nodes characterized by swollen, nonpainful nodes; fatigue; and often, persistent fever and night sweats. It is characterized by distinctive giant cells in the nodes called Reed-Sternberg cells, which are of uncertain origin but may be modified lymphocytes or macrophages. Hodgkin's disease is treated with radiation therapy, and the cure rate is high relative to that of other cancers.

Non-Hodgkin's lymphoma includes all cancers of lymphoid tissues except Hodgkin's disease. It involves the uncontrolled multiplication and metastasis of undifferentiated lymphocytes, usually B cells but sometimes T cells. Lymph nodes become swollen, the spleen may enlarge, gut-lymphoid tissue may be affected, and many organs may eventually be involved. Non-Hodgkin's lymphoma is increasing in frequency and is now the fifth most common type of cancer. A low-grade type, which affects the elderly and grows slowly, is often fatal because it is resistant to chemotherapy. An intermediate or high-grade type, which affects young people and grows quickly, can respond to chemotherapy with a 30% to 60% remission rate.

THE LYMPHATIC AND IMMUNE SYSTEMS THROUGHOUT LIFE

➤ Outline the development of the lymphatic vessels and lymphoid organs.

The lymphatic system develops from a number of sources. Both lymphatic vessels and the main clusters of lymph nodes grow from *lymphatic sacs,* which are projections from the large veins in the embryo. The thymus originates as an outgrowth of the endoderm lining the embryonic pharynx (see Figure 17.12, p. 533). It detaches from the pharynx and migrates caudally into the thorax. Starting early in the fetal period, the thymus receives the first progenitors of T lymphocytes from the blood-forming organs (yolk sac, liver, then bone marrow). The first B lymphocytes are produced in the bone marrow at this time. All the nonthymic lymphoid organs and tissues (spleen, lymph nodes, and MALT) arise from mesodermal mesenchyme. The spleen and tonsils develop before birth. The other secondary lymphoid organs, however, are poorly developed before birth. Shortly after birth, they become heavily populated by circulating lymphocytes and start to gain their functional properties.

The immune system of newborns was long thought to be too immature to attack invading pathogens. However, new experiments show that newborns respond to new antigens just as vigorously as do adults, with both T cells and antibodies. Throughout infancy and childhood, many memory lymphocytes are formed, and a wide range of immunity is attained. After childhood, some immune organs become less active and begin to shrink. The tonsils are regressing by age 14 (except the lingual tonsil, which does not shrink until about age 30). As previously mentioned, the thymus regresses after late adolescence but keeps producing T cells throughout life.

The lymphoid organs and immune system normally serve people well until late in life, when their efficiency begins to wane and their ability to fight infection declines. This reduced effectiveness seems mostly due to a decrease in the production and responsiveness of T cells, which in turn causes similar declines in B cells. Old age is accompanied by an increased susceptibility to disease. The greater incidence of cancer in the elderly is assumed to be another example of the declining ability of the immune system to destroy harmful cells.

check your understanding

10. A few days after a cat scratched his hand, John noticed thin red lines extending from his hand up through his forearm. What is the cause of these marks?
11. From which embryonic layer is the thymus derived? From which embryonic layer are the tonsils, spleen, and lymph nodes derived?

For answers, see Appendix B.

RELATED CLINICAL TERMS

KAPOSI'S SARCOMA Tumorlike lesions of the skin and some internal organs, seen in some AIDS patients. The lesions are vascularized and arise from proliferating capillary endothelial cells. The capillaries are so permeable that they leak erythrocytes, giving the lesions a purple color. Kaposi's sarcoma is now known to be caused by a previously unrecognized type of herpes virus that infects the endothelium. Confusion exists as to whether the lesions are merely due to cellular hyperplasia or are true tumors. Treatment is with chemotherapy.

LYMPHADENOPATHY (lim-fad′ĕ-nop-ah-the) (*adeno* = gland; *pathy* = disease) Any disease of the lymph nodes.

LYMPHOMA Any neoplasm (tumor) of the lymphoid tissue, whether benign or malignant.

SENTINEL LYMPH NODE IN CANCER The first node that receives lymph draining from a body area suspected of having a tumor. When examined for the presence of cancer cells, this node gives the best indication of whether metastasis (spread) through the lymph vessels has occurred.

SPLENOMEGALY (sple″no-meg′ah-le; "spleen big") Enlargement of the spleen, usually resulting from blood diseases such as mononucleosis, malaria, leukemia, or polycythemia vera. A way that physicians diagnose spleen enlargement is by feeling for the spleen's notched superior border through the skin of the abdominal wall just anterior to the costal margin. A healthy spleen never reaches this far anteriorly.

TONSILLITIS Congestion of the tonsils, typically with infecting bacteria, which causes them to become red, swollen, and sore.

CHAPTER SUMMARY

You can use the following media study tool for additional help when you review specific key topics in Chapter 21.

PAL = **Practice Anatomy Lab™**

1. The lymphatic system consists of lymphatic circulatory vessels that carry lymph. The immune system contains the lymphocytes, lymphoid tissue, and lymphoid organs, which are involved in the body's fight against disease.

The Lymphatic System (pp. 618–622)

2. Lymph is excess tissue fluid, which originates because slightly more fluid leaves blood capillaries than returns there. Lymphatic vessels pick up this excess fluid and return it to the great veins at the root of the neck.
3. Lymphatic vessels also retrieve blood proteins that leak from capillaries and return these proteins to the bloodstream.
4. The vessels of the lymphatic system, from smallest to largest, are lymphatic capillaries, lymphatic collecting vessels (with lymph nodes), lymph trunks, and lymph ducts.

Lymphatic Capillaries (p. 619)

5. Lymphatic capillaries weave through the loose connective tissues of the body. These closed-end tubes are highly permeable to entering tissue fluid and proteins because their endothelial cells are loosely joined. Disease-causing microorganisms and cancer cells also enter the permeable lymphatic capillaries and spread widely through the lymph vessels.
6. Lymphatic capillaries called lacteals absorb digested fat from the small intestine.

Lymphatic Collecting Vessels (p. 619)

7. Lymphatic collecting vessels run alongside arteries and veins but have thinner walls and many more valves than do veins. The collecting vessels resemble a string of beads.
8. Lymph flows very slowly through lymphatic collecting vessels. Flow is maintained by normal body movements, contractions of skeletal muscles, arterial pulsations, and contraction of smooth muscle in the wall of the lymphatic vessel. Lymphatic valves prevent backflow.

Lymph Nodes (pp. 619–620)

9. Clustered along the lymphatic collecting vessels, bean-shaped lymph nodes remove infectious agents and cancer cells from the lymph stream. Lymph enters the node via afferent lymphatic vessels and exits via efferent vessels at the hilum. In between, the lymph percolates through lymph sinuses, where macrophages remove lymph-borne pathogens. For a diagram of the body's main groups of lymph nodes, see Figure 21.2.

Lymph Trunks (p. 620)

10. The lymph trunks (lumbar, intestinal, bronchomediastinal, subclavian, and jugular) each drain a large body region. All except the intestinal trunk are paired.

Lymph Ducts (pp. 621–622)

11. The right lymphatic duct (and/or the nearby trunks) drains lymph from the superior right quarter of the body. The thoracic duct (and/or the nearby trunks) drains lymph from the rest of the body. These two ducts empty into the junction of the internal jugular and subclavian veins. The thoracic duct starts at the cisterna chyli at L_1–L_2 and ascends along the thoracic vertebral bodies.

PAL **Human Cadaver/Lymphatic System**

The Immune System (pp. 622–630)

12. Lymphoid organs and lymphoid tissues house millions of lymphocytes, important cells of the immune system that recognize specific antigens.

Lymphocytes (pp. 623–624)

13. B and T lymphocytes fight infectious microorganisms in the loose and lymphoid connective tissues of the body—B cells by producing antibody-secreting plasma cells, and cytotoxic ($CD8^+$) T cells by directly killing antigen-bearing cells. B cells and antibodies are best at destroying bacteria and bacterial products, whereas T cells are best at destroying eukaryotic cells that express surface antigens, such as virus-infected cells and grafted and tumor cells.

Natural killer lymphocytes do not recognize specific antigens but rapidly attack and kill tumor cells and virus-infected cells.

14. Mature lymphocytes patrol connective tissues throughout the body by passing in and out of the circulatory vessels (recirculation).

Lymphocyte Activation (pp. 624–625)

15. Lymphocytes arise from stem cells in the bone marrow. T cells develop immunocompetence in the thymus, whereas B cells develop immunocompetence in the bone marrow. Immunocompetent lymphocytes then circulate to the loose and lymphoid connective tissues, where antigen binding (the antigen challenge) leads to lymphocyte activation.

16. The antigen challenge involves an interaction among the lymphocyte being activated, an antigen-presenting cell (dendritic cell or macrophage), and a helper ($CD4^+$) T lymphocyte. A newly activated T or B cell divides quickly to produce many short-lived effector lymphocytes and some long-lived memory lymphocytes. Recirculating memory lymphocytes provide long-term immunity.

Lymphoid Tissue (pp. 625–627)

17. Lymphoid tissue is an often-infected reticular connective tissue in which many B and T lymphocytes gather to fight pathogens or become activated. It is located in the mucous membranes (as MALT) and in the lymphoid organs (except the thymus).

18. Lymphoid tissue contains lymphoid follicles (nodules) with germinal centers. Each follicle contains thousands of B lymphocytes, all derived from one activated B cell.

Lymphoid Organs (pp. 627–630)

19. The thymus, located in the superoanterior thorax and neck, is a primary lymphoid organ that is most active during youth. Its hormones, secreted by epithelial reticular cells, signal the contained T lymphocytes to gain immunocompetence.

20. The thymus has lobules, each with an outer cortex packed with maturing T cells and an inner medulla containing fewer T cells and degenerative thymic (Hassall's) corpuscles.

21. Within a lymph node, masses of lymphoid tissue lie between the sinuses. This lymphoid tissue receives some of the antigens that pass through the node, leading to lymphocyte activation and memory-lymphocyte production. The masses help divide each node into an outer cortex and an inner medulla.

22. The spleen lies in the superior left part of the abdominal cavity. The splenic vessels enter and exit the hilum on the anterior surface.

23. The spleen has two main functions: (1) removing antigens from the blood and (2) destroying worn-out blood cells. The first function is performed by the white pulp; the second, by the red pulp. White pulp consists of sleeves of lymphoid tissue, each surrounding a central artery. Red pulp consists of venous sinuses and strips of blood-filled reticular connective tissue called splenic cords, whose macrophages remove worn-out blood cells.

24. The tonsils in the pharynx, aggregated lymphoid nodules in the small intestine, and the wall of the appendix are parts of MALT in which the lymphoid tissue contains an exceptionally high concentration of lymphocytes and follicles.

Disorders of the Lymphatic and Immune Systems (p. 631)

25. Chylothorax is the leakage of chyle from the thoracic duct into the pleural cavity. Lymphangitis is inflammation of a lymphatic vessel. Mononucleosis is a viral infection of B lymphocytes, which are attacked by T lymphocytes, leading to flulike symptoms. Hodgkin's disease is a type of lymph node cancer, and non-Hodgkin's lymphoma includes all other cancers of lymphoid tissue.

The Lymphatic and Immune Systems Throughout Life (p. 631)

26. Lymphatic vessels develop from lymphatic sacs attached to the embryonic veins. The thymus develops from pharyngeal endoderm, and the other lymphoid organs derive from mesenchyme.

27. Lymphoid organs become populated by lymphocytes, which arise from hematopoietic tissue.

28. With aging, the immune system becomes less responsive. Thus, the elderly suffer more often from infections and cancer.

REVIEW QUESTIONS

Multiple Choice/Matching Questions

For answers, see Appendix B.

1. Lymphatic capillaries (a) are open-ended like drinking straws, (b) have continuous tight junctions like those of the capillaries of the blood-brain barrier, (c) have endothelial cells separated by flaplike minivalves that open wide, (d) have special barriers that stop cancer cells from entering, (e) all of the above.

2. The basic structural framework of most lymphoid organs consists of (a) areolar connective tissue, (b) hematopoietic tissue, (c) reticular connective tissue, (d) adipose tissue.

3. Lymph nodes cluster in all the following body areas except the (a) brain, (b) axillae, (c) groin, (d) neck.

4. The germinal centers in lymph nodes are sites of (a) the lymph sinuses, (b) proliferating B lymphocytes, (c) T lymphocytes, (d) a and c, (e) all of the above.

5. The red pulp of the spleen (a) contains venous sinuses and a macrophage-rich connective tissue, (b) is another name for the fibrous capsule, (c) is lymphoid tissue containing lymphocytes, (d) is the part of the spleen that destroys worn-out erythrocytes, (e) a and d.

6. Lymphocytes that develop immunocompetence in the thymus are (a) B lymphocytes, (b) T lymphocytes.

7. Which of the following lymphoid organs have a cortex and a medulla? (More than one choice is correct.) (a) lymph nodes, (b) spleen, (c) thymus, (d) aggregated lymphoid nodules, (e) tonsils.

8. Which one of the following lymphoid organs does *not* contain lymphoid follicles or germinal centers? (a) lymph nodes, (b) spleen, (c) thymus, (d) aggregated lymphoid nodules, (e) tonsils.

9. Developmentally, the embryonic lymphatic vessels are most closely associated with the (a) veins, (b) arteries, (c) nerves, (d) thymus.

10. It sometimes is difficult to distinguish the different lymphoid organs from one another in histological sections. How would you tell the thymus from a lymph node? (a) Only the thymus has a cortex and medulla; (b) lymphocytes are far less densely packed in the thymus than in the lymph node; (c) the thymus contains no blood

vessels; (d) only the thymus has distinct lobules and thymic (Hassall's) corpuscles.

11. In some people, the thoracic duct does not receive any of the lymph trunks at the base of the neck (jugular, subclavian, or bronchomediastinal). In such people, what part of the body does the thoracic duct drain? (a) upper right quarter, (b) upper left quarter, (c) upper half, (d) lower half.

Short Answer Essay Questions

12. Compare the basic functions of a lymph node to those of the spleen.

13. If you saw a blood vessel and a lymphatic collecting vessel running side by side, how could you tell them apart?

14. Trace the entire course of the thoracic duct. Name the locations of all the lymph trunks.

15. List and briefly explain three important functions of the lymphatic vessels.

16. Which three of the six groups of lymph nodes described on p. 620 are easily felt (palpated) through the skin during a physical examination?

17. Explain the basic functional differences between B and T lymphocytes.

18. As George was reading this chapter for the second time, he suddenly had an insight, exclaiming, "Lymph comes from the blood, and then it returns to the blood!" Is this insight correct? Explain.

19. Billie Jo is looking at histological slides of the spleen under a microscope. She says that she sees lymphoid follicles in the white pulp. Is she correct? Explain.

20. Aparna, a gross anatomist who has been teaching human anatomy for 35 years, told her class that in adults the thymus is atrophied and has no function. Is she correct? Explain.

CRITICAL REASONING & CLINICAL APPLICATION QUESTIONS

1. A friend tells you that he has tender, swollen "glands" along the left side of the front of his neck. You notice that he has a bandage on his left cheek that is not fully hiding a large infected cut there. The glands are not really glands. Exactly what are his swollen "glands," and how did they become swollen?

2. When young Joe went sledding, the runner of a friend's sled hit him in the left side and ruptured his spleen. Joe almost died before he got to a hospital. What is the immediate danger of a ruptured spleen?

3. The man in the hospital bed next to Joe is an alcoholic with cirrhosis of the liver and portal hypertension. His spleen is seriously enlarged. Based on what you learned in Chapter 20 (p. 608), how could portal hypertension lead to splenomegaly?

4. Mrs. Roselli has undergone a left radical mastectomy. Her left arm is severely swollen and painful, and she is unable to raise it higher than her shoulder. (a) Explain the origin of her signs and symptoms. (b) Is she likely to have relief from these symptoms in time? Explain.

5. Traci arrives at the clinic complaining of pain and redness of her right ring finger. The finger and the dorsum of her hand have edema, and red streaks are apparent on her right forearm. Antibiotics are prescribed, and the nurse applies a sling to the affected arm. Why is it important that Traci not move the affected arm excessively?

6. Simi realized she was very ill. During a recent trip to the tropics, she had contracted both malaria and tuberculosis, diseases whose microorganisms travel throughout the bloodstream. Back home for only a week, she then contracted mononucleosis. When she went to the doctor, he was able to feel the notched superior border of her spleen projecting far anterior to the left costal margin in her abdominal wall. Was something wrong with her spleen? Explain.