The lymphatic and immune system

Al-Farabi Kazakh National University
Higher School of Medicine

LEARNING OUTCOMES

As a result of the lesson you will be able to:

- *List the functions and basic components of the lymphatic system;*
- *Explain how lymph is returned to the bloodstream;*
- *Describe and Identify the major lymphatic tissues and organs, and describe their location, structure, and functions.*
- *Define immune system, innate immunity, and adaptive immunity;*
- *Enumerate the defensive functions of each kind of white blood cell*

Lymphatic and Immune Systems

- the body harbors about 10,000 times as many bacterial cells as human cells
  - some beneficial
  - some potentially disease causing
- **immune system** – not an organ system, but a population of cells that inhabit all of our organs and defend the body from agents of disease
  - especially concentrated in the true organ system – **lymphatic system**
    - network of organs and vein-like vessels that recover fluid
    - inspect it for disease agents
    - activate immune responses
    - return the fluid to the bloodstream

Lymphatic and Immune Systems

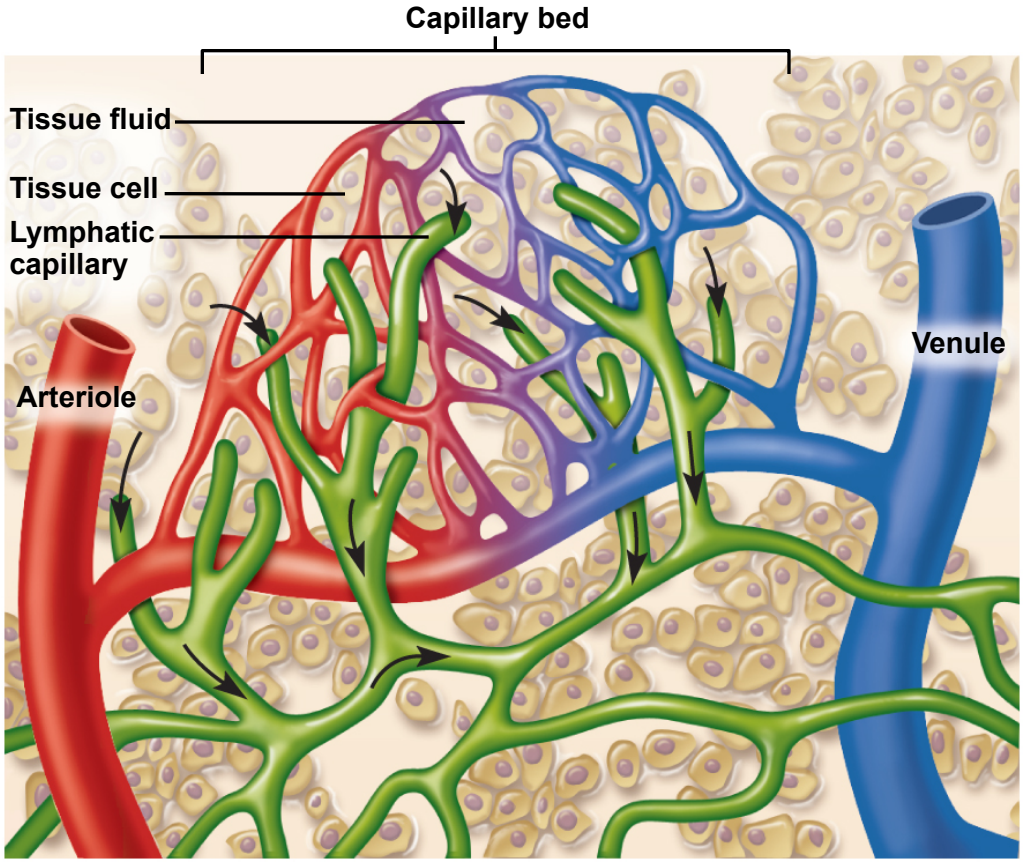


Figure 21.3a

- maintain fluid balance
- protect body from infection and disease

Functions of Lymphatic System

- **fluid recovery**
  - fluid continually filters from the blood capillaries into the tissue spaces
    - blood capillaries reabsorb 85%
    - 15% (2 – 4 L/day) of the water and about half of the plasma proteins enters lymphatic system and then returned to the blood
- **immunity**
  - excess filtered fluid picks up foreign cells and chemicals from the tissues
    - passes through lymph nodes where immune cells stand guard against foreign matter
    - activate a protective immune response
- **lipid absorption**
  - **lacteals** in small intestine absorb dietary lipids that are not absorbed by the blood capillaries

Components of the Lymphatic System

- **lymph**
  - the recovered fluid
- **lymphatic vessels**
  - transport the lymph
- **lymphatic tissues**
  - composed of aggregates of lymphocytes and macrophages that populate many organs in the body
- **lymphatic organs**
  - defense cells are especially concentrated in these organs
  - separated from surrounding organs by connective tissue capsules

Lymph and Lymphatic Capillaries

- **lymph**
  - clear, colorless fluid, similar to plasma, but much less protein
  - extracellular fluid drawn into lymphatic capillaries
- **lymphatic capillaries** (terminal lymphatics)
  - penetrate nearly every tissue of the body
    - absent from central nervous system, cartilage, cornea, bone and bone marrow
  - sacs of thin endothelial cells that loosely overlap each other
  - closed at one end
  - cells tethered to surrounding tissue by protein filaments
    - gaps between cells are large enough to allow bacteria and cells entrance to lymphatic capillary
  - endothelium creates valve-like flaps that open when interstitial fluid pressure is high, and close when it is low

Lymphatic Capillary

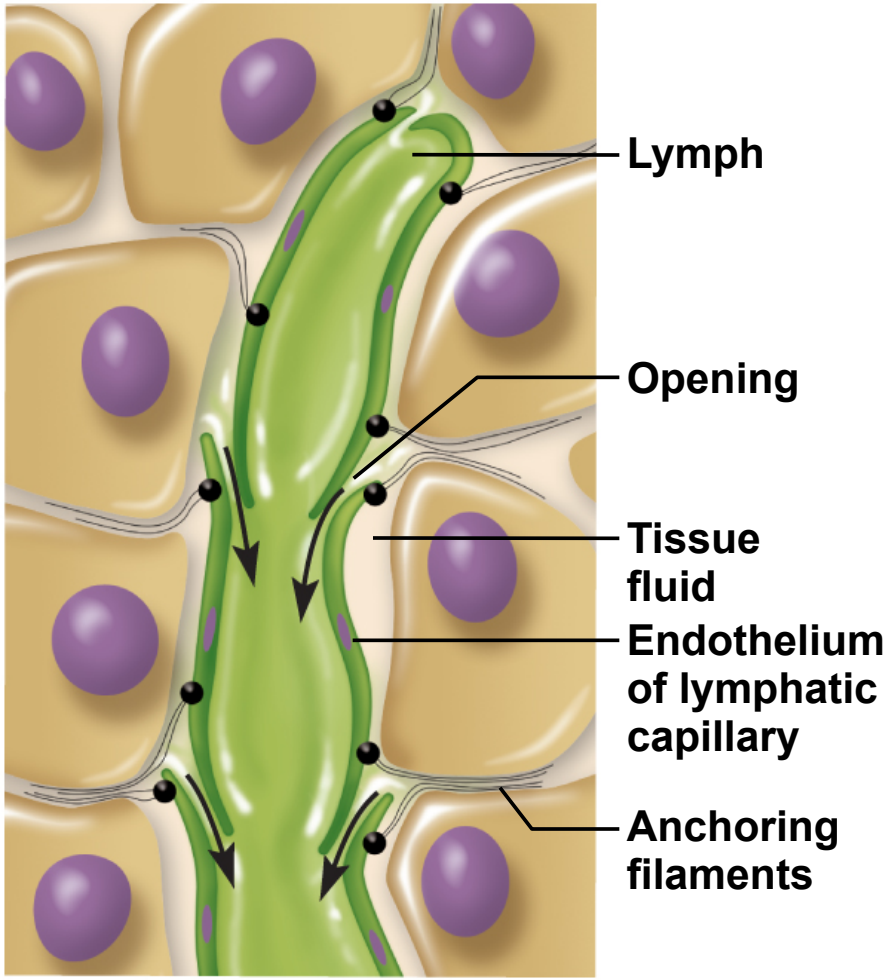


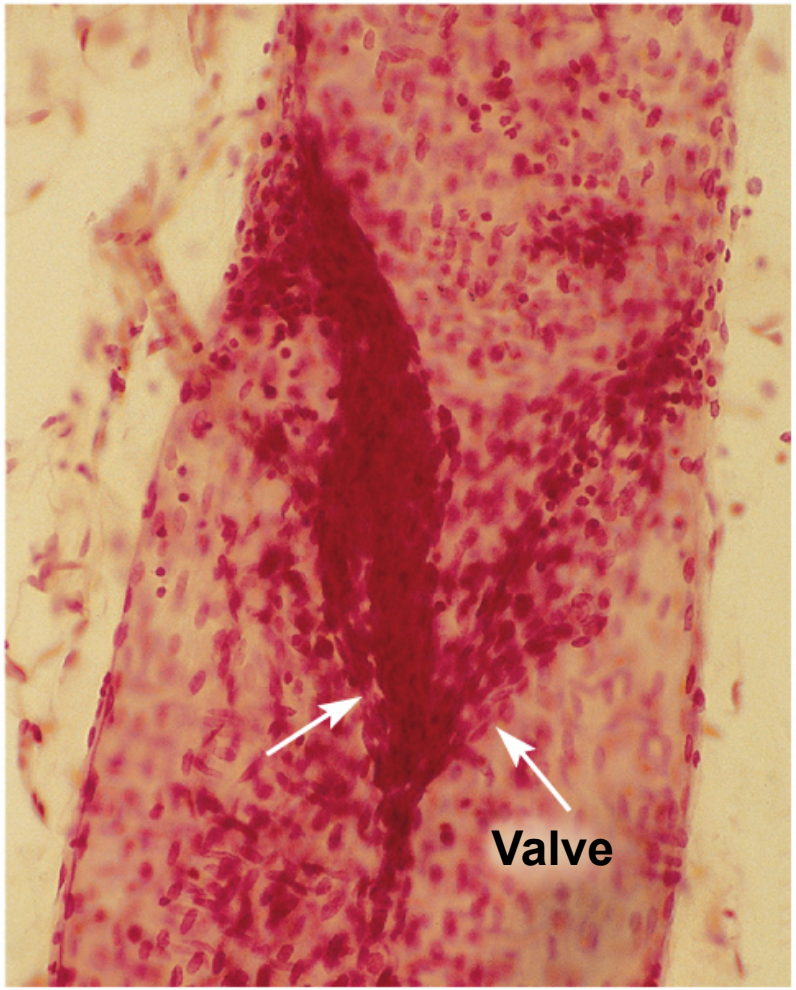
Figure 21.3b

Lymphatic Vessels

- larger ones composed of three layers
  - **tunica interna**: endothelium and valves
  - **tunica media**: elastic fibers, smooth muscle
  - **tunica externa**: thin outer layer

- converge into larger and larger vessels

Valve in a Lymphatic Vessel



(a)

Figure 21.4a

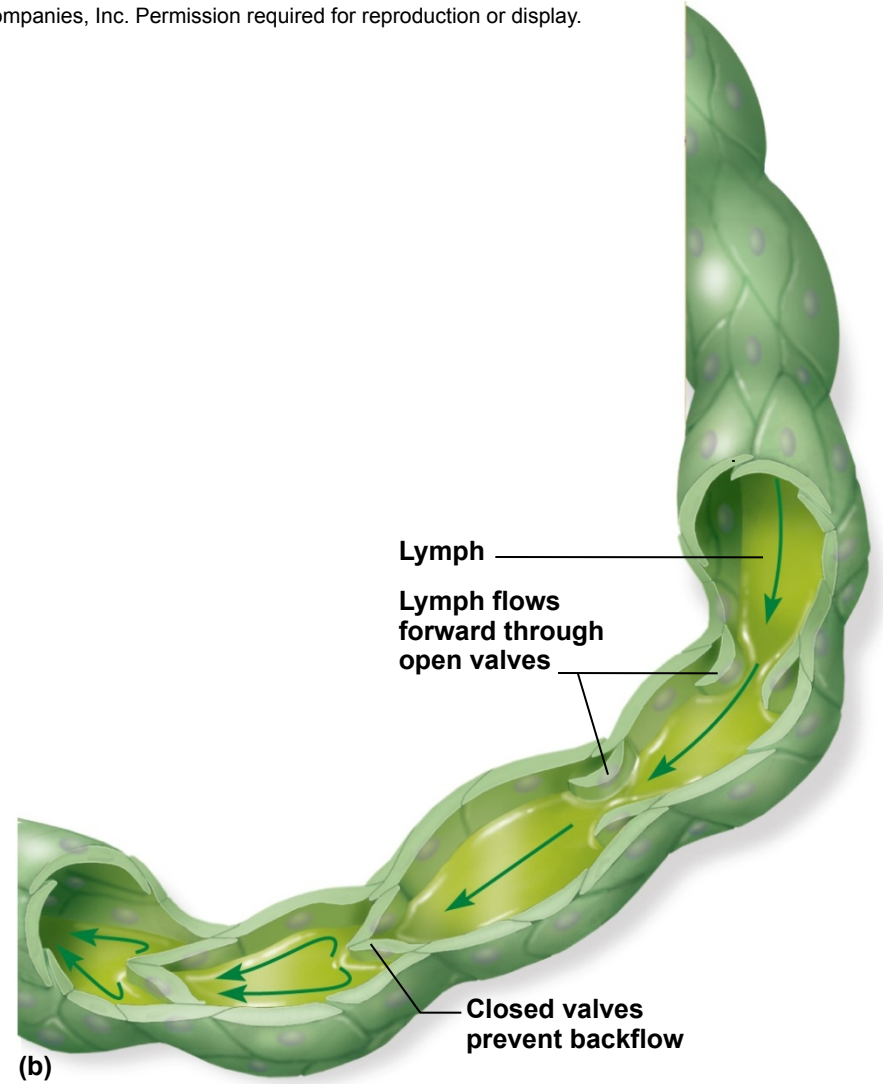


Figure 21.4b

Route of Lymph Flow

- **lymphatic capillaries**
- **collecting vessels**: course through many lymph nodes
- **six lymphatic trunks**: drain major portions of body
- **two collecting ducts**:
  - **right lymphatic duct** – receives lymph from right arm, right side of head and thorax; empties into right subclavian vein
  - **thoracic duct** - larger and longer, begins as a prominent sac in abdomen called the **cisterna chyli**; receives lymph from below diaphragm, left arm, left side of head, neck, and thorax; empties into left subclavian vein
- **subclavian veins**

The Fluid Cycle

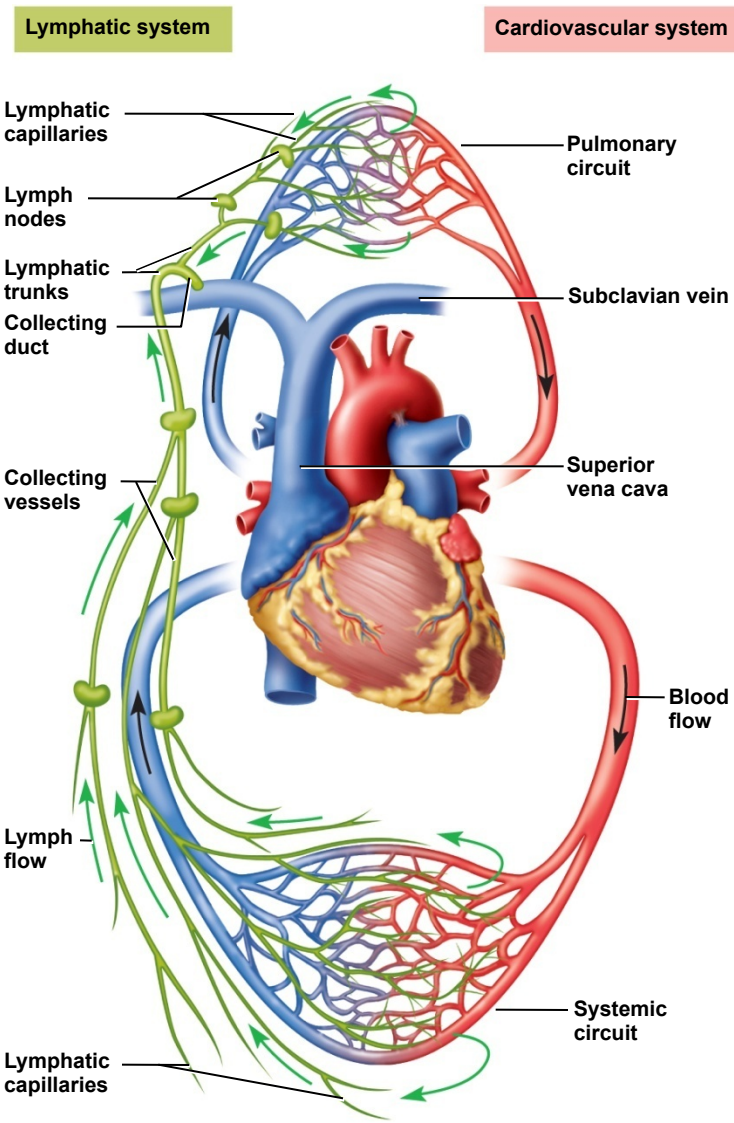


Figure 21.5

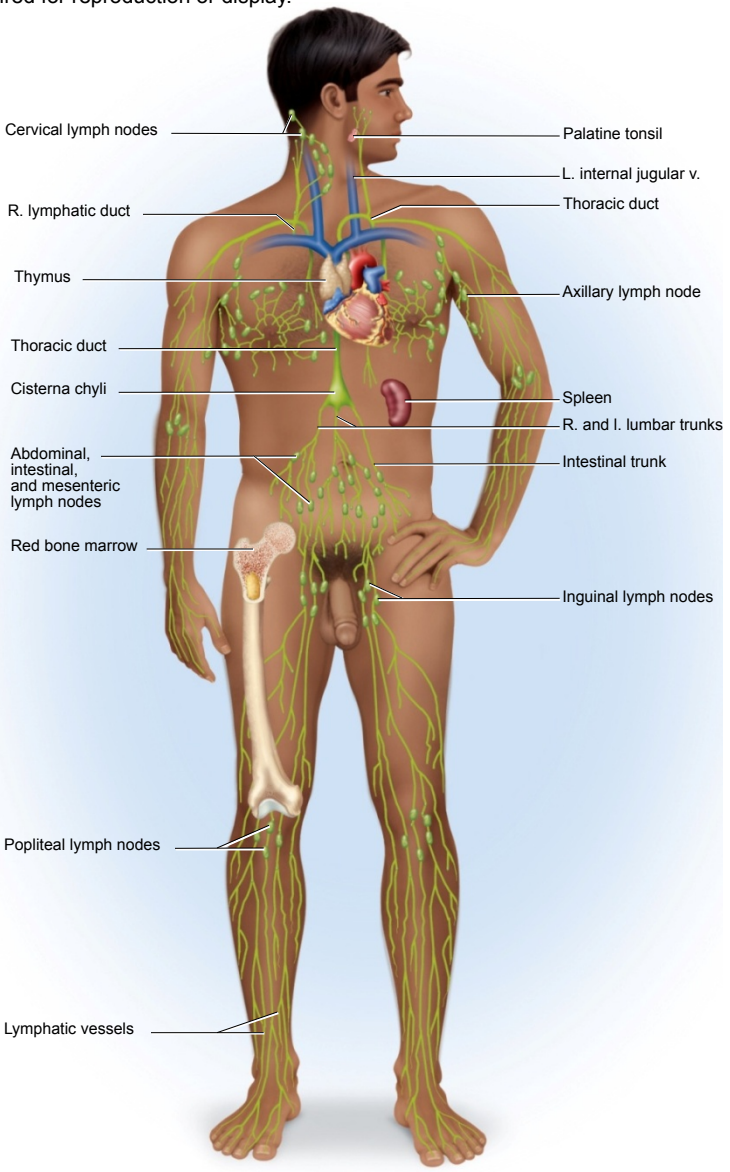


Figure 21.1

Lymphatic Drainage of Mammary and Axillary Regions

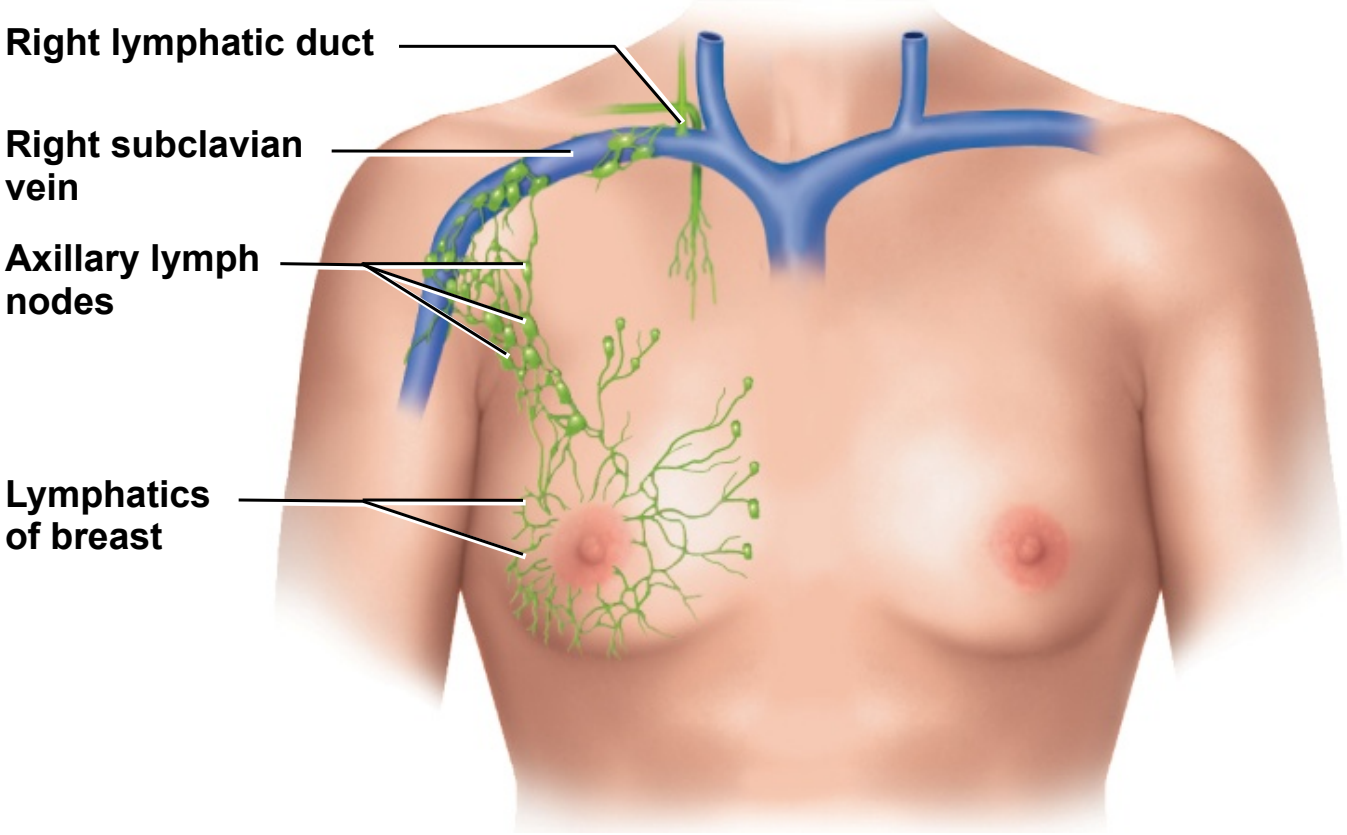


Figure 21.6b

Drainage of Thorax

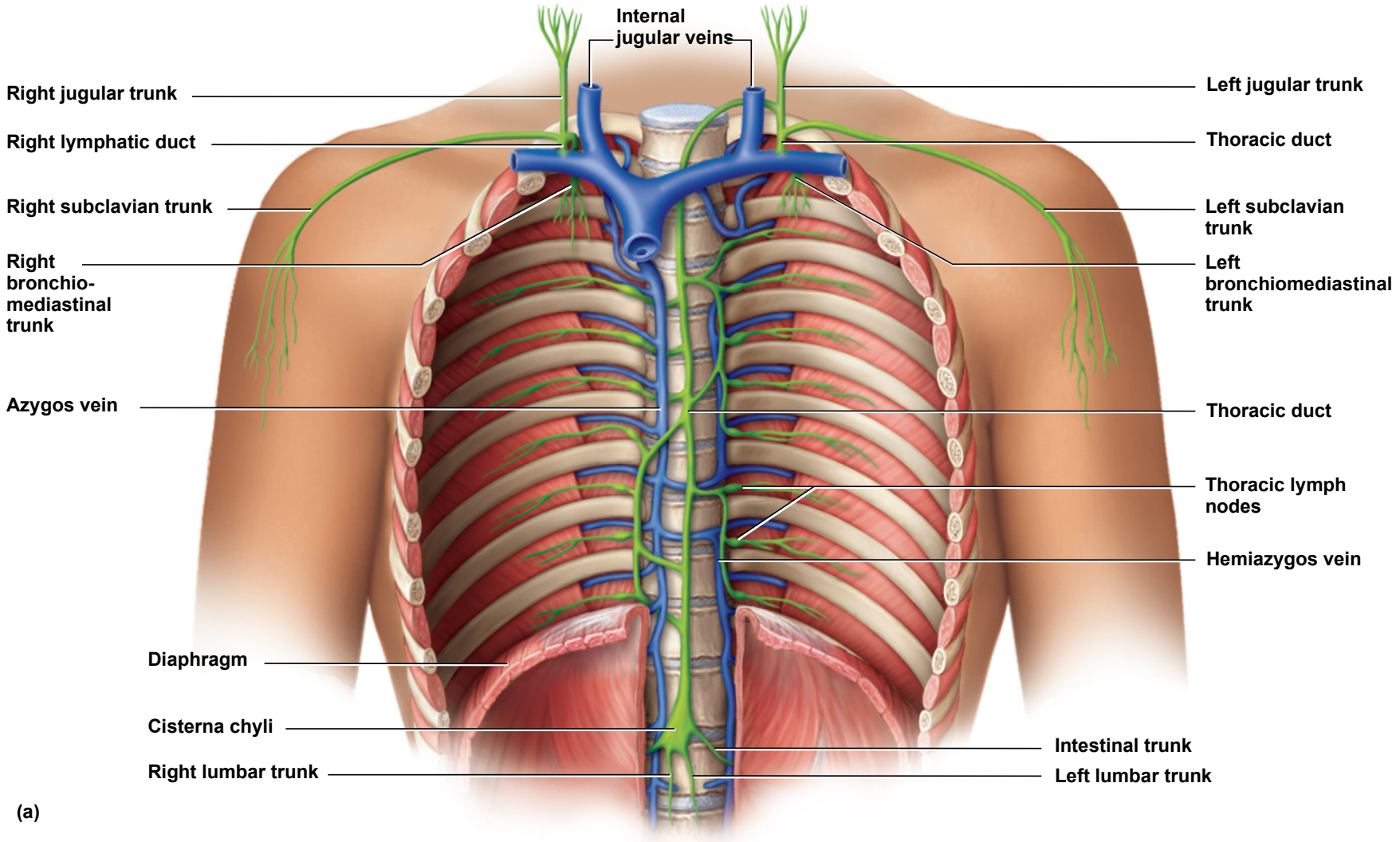


Figure 21.6a

Mechanisms of Lymph Flow

- lymph flows under forces similar to those that govern venous return, except no pump (heart)
- lymph flows at low pressure and slower speed than venous blood
- moved along by rhythmic contractions of lymphatic vessels
  - stretching of vessels stimulates contraction
- flow aided by skeletal muscle pump
- arterial pulsation rhythmically squeeze lymphatic vessels
- thoracic pump aids flow from abdominal to thoracic cavity
- valves prevent backward flow
- rapidly flowing blood in subclavian veins, draws lymph into it
- exercise significantly increases lymphatic return

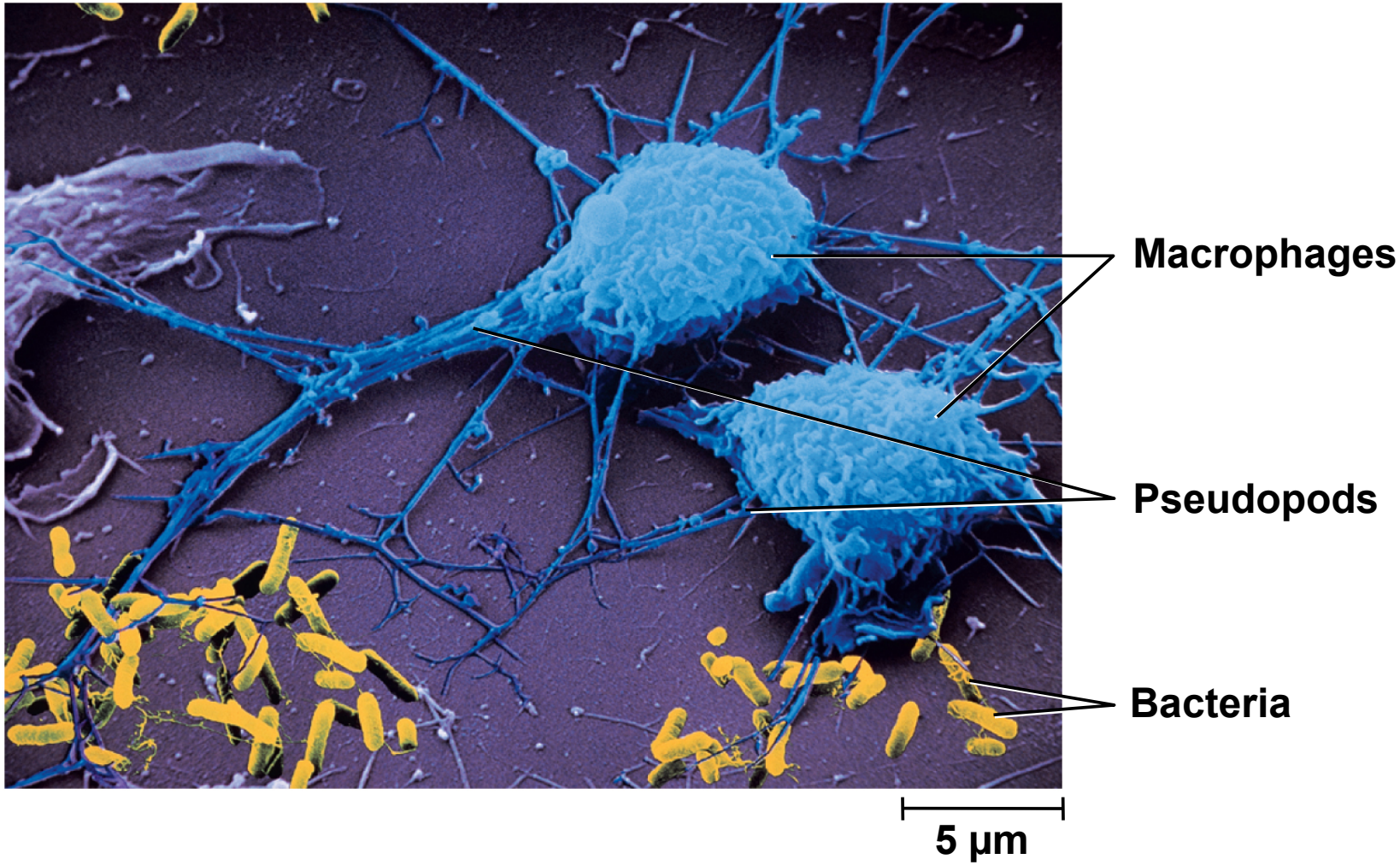
Lymphatic Cells

- **natural killer (NK) cells**
  - large lymphocytes that attack and destroy bacteria, transplanted tissue, host cells infected with viruses or have turned cancerous
  - responsible for immune surveillance
- **T lymphocytes (T cells)**
  - mature in thymus
- **B lymphocytes (B cells)**
  - activation causes proliferation and differentiation into **plasma cells** that produce **antibodies**

Lymphatic Cells

- **macrophages**
  - very large, avidly phagocytic cells of the connective tissue
  - develop from monocytes
  - phagocytize tissue debris, dead neutrophils, bacteria, and other foreign matter
  - process foreign matter and display antigenic fragments to certain T cells alerting the immune system to the presence of the enemy
  - antigen presenting cells (APCs)
- **dendritic cells**
  - branched, mobile APCs found in epidermis, mucous membranes, and lymphatic organs
  - alert immune system to pathogens that have breached their surface
- **reticular cells**
  - branched stationary cells that contribute to the stroma of a lymphatic organ
  - act as APCs in the thymus

Macrophages



Peter Arnold, Inc.

Figure 21.7

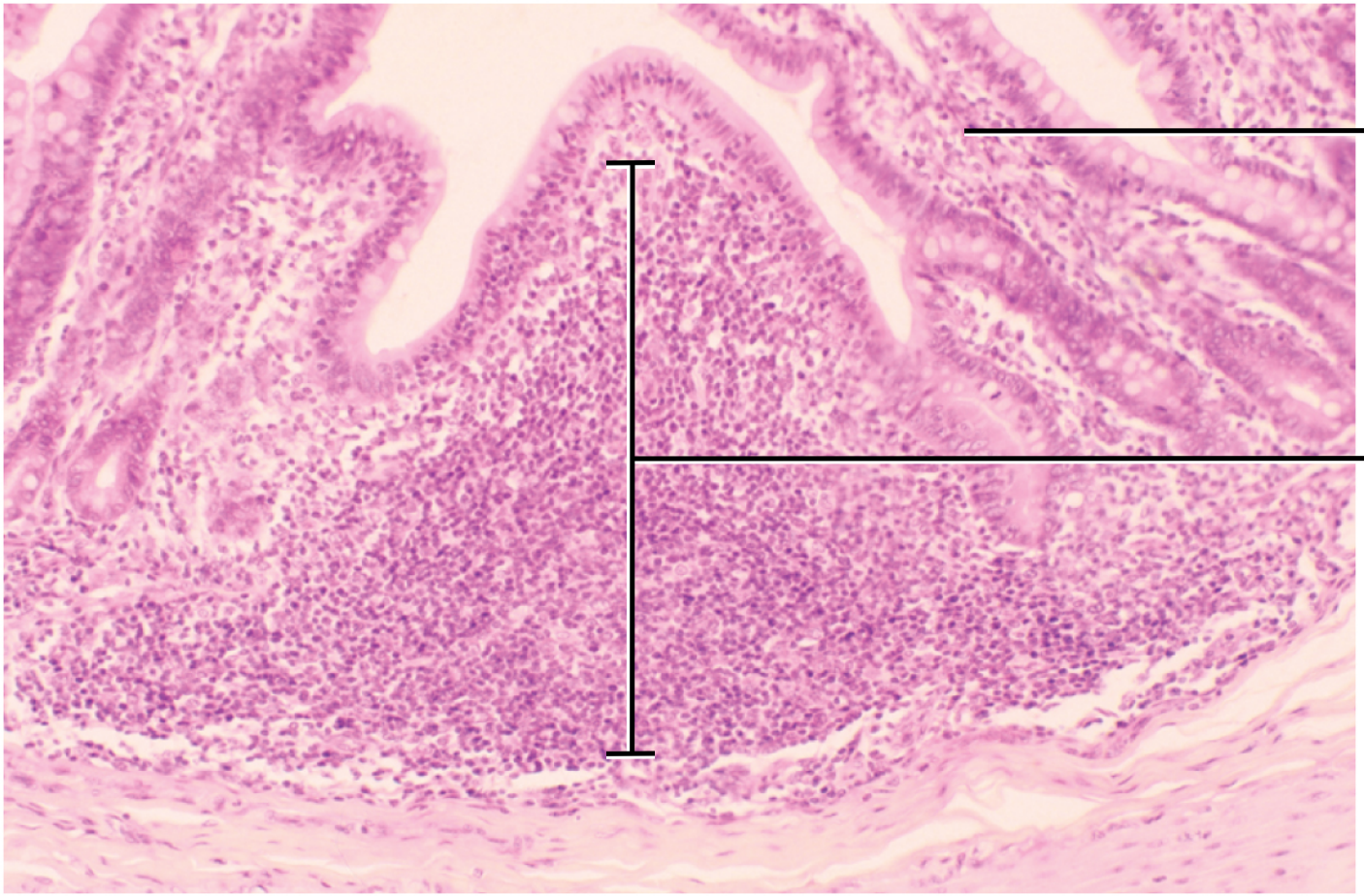
Lymphatic Tissue

- **lymphatic (lymphoid) tissue** – aggregations of lymphocytes in the connective tissues of mucous membranes and various organs

- **diffuse lymphatic tissue** – simplest form
  - lymphocytes are scattered, rather than densely clustered
  - prevalent in body passages open to the exterior
    - respiratory, digestive, urinary, and reproductive tracts
  - **mucosa-associated lymphatic tissue (MALT)**

- **lymphatic nodules (follicles)**
  - dense masses of lymphocytes and macrophages that congregate in response to pathogens
  - constant feature of the lymph nodes, tonsils, and appendix
  - **Peyer patches** – dense clusters in the ileum, the distal portion of the small intestine

Lymphatic Nodule



Custom Medical Stock Photo

Figure 21.8

Lymphatic Organs

- lymphatic organs have well-defined anatomical sites
  - have **connective tissue capsule** that separates the lymphatic tissue from neighboring tissues
- **primary lymphatic organs**
  - **red bone marrow** and **thymus**
  - site where T and B cells become **immunocompetent** – able to recognize and respond to antigens
- **secondary lymphatic organs**
  - **lymph nodes**, **tonsils**, and **spleen**
  - immunocompetent cells populate these tissues

Red Bone Marrow

- red bone marrow is involved in **hemopoiesis** (blood formation) and **immunity**
  - soft, loosely organized, highly vascular material
  - separated from osseous tissue by endosteum of bone
  - as blood cells mature, they push their way through the reticular and endothelial cells to enter the sinus and flow away in the blood stream

Histology of Red Bone Marrow

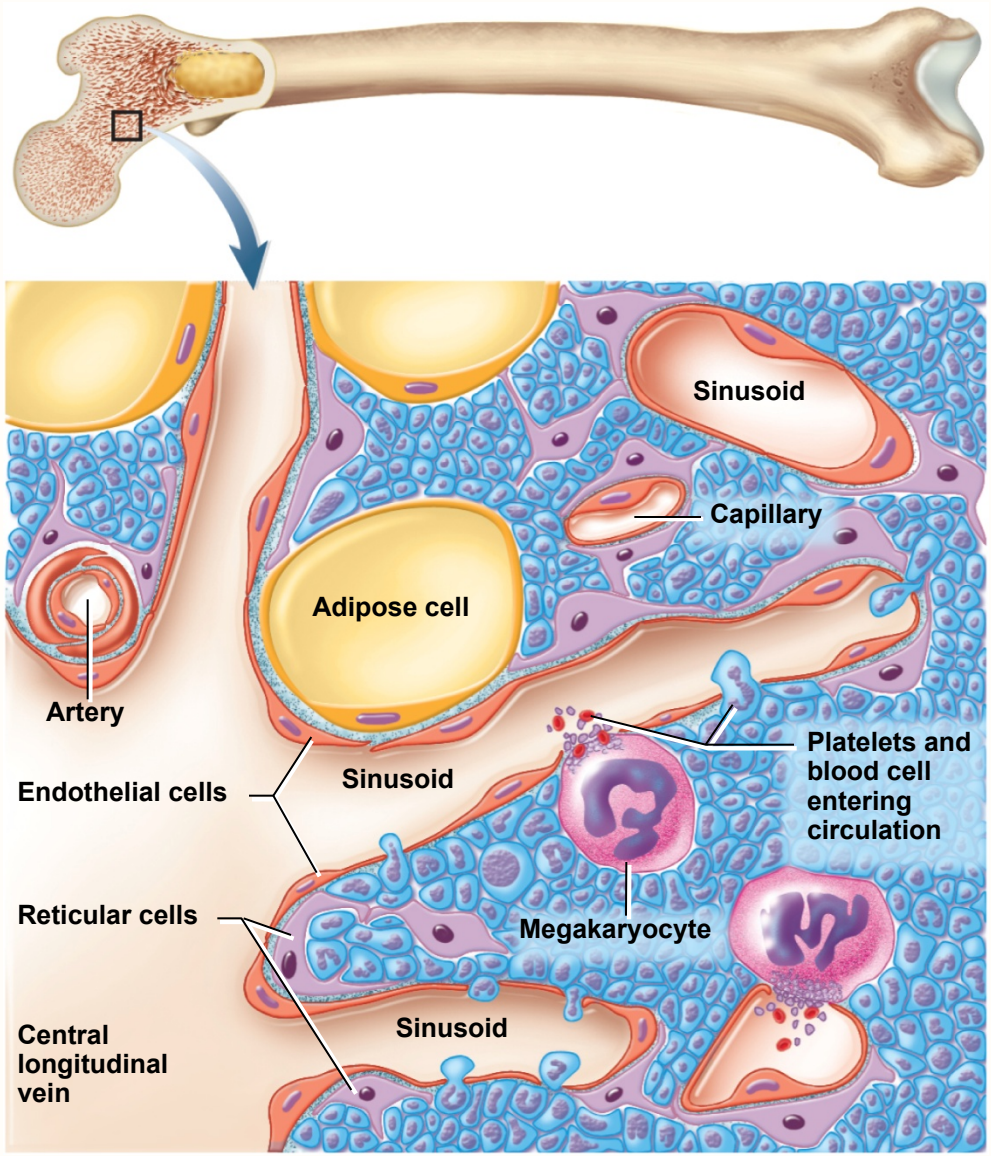
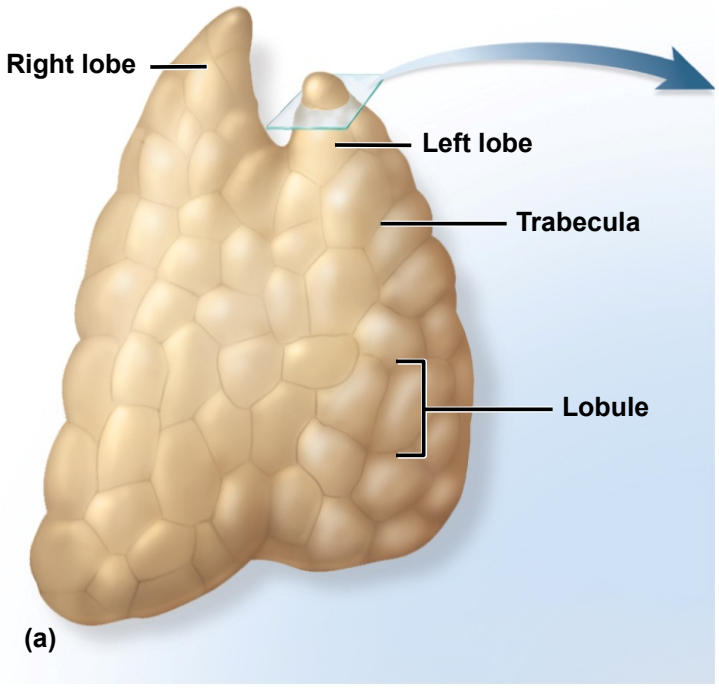


Figure 21.9

Thymus

- **thymus** – member of the endocrine, lymphatic, and immune systems
  - houses developing lymphocytes
  - secretes hormones regulating their activity
  - bilobed organ located in superior mediastinum between the sternum and aortic arch
  - degeneration or involution with age
  - fibrous capsule gives off **trabeculae (septa)** that divide the gland into several lobes
    - lobes have cortex and medulla populated by T lymphocytes
  - **reticular epithelial cells** seal off cortex from medulla forming **blood-thymus barrier**
    - produce signaling molecules **thymosin**, **thymopoietin, thymulin**, **interleukins**, and **interferon**

Anatomy of Thymus



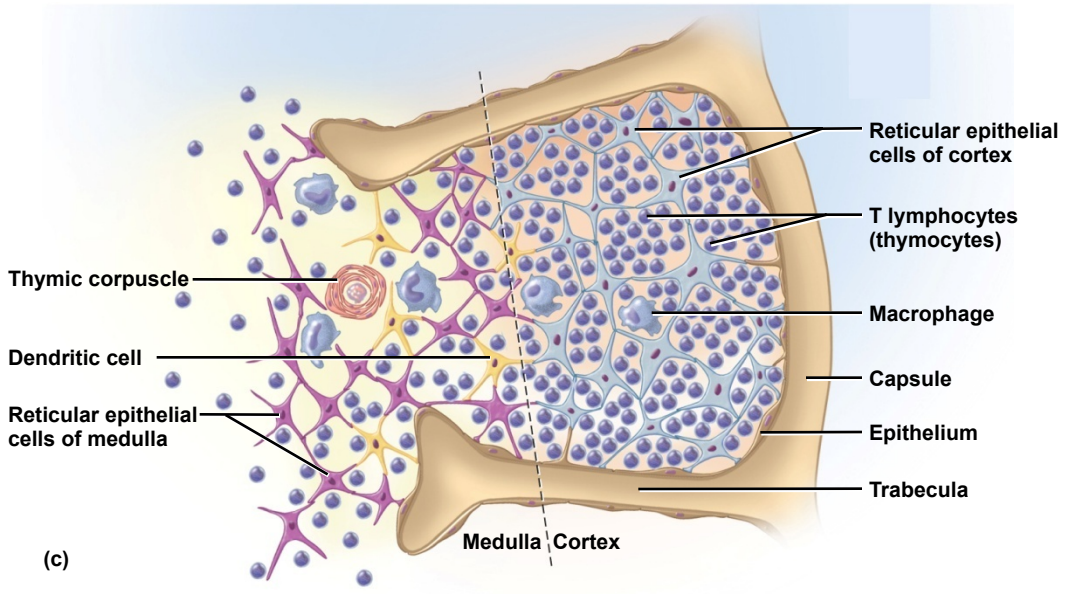


Figure 21.10a,c

Histology of Thymus

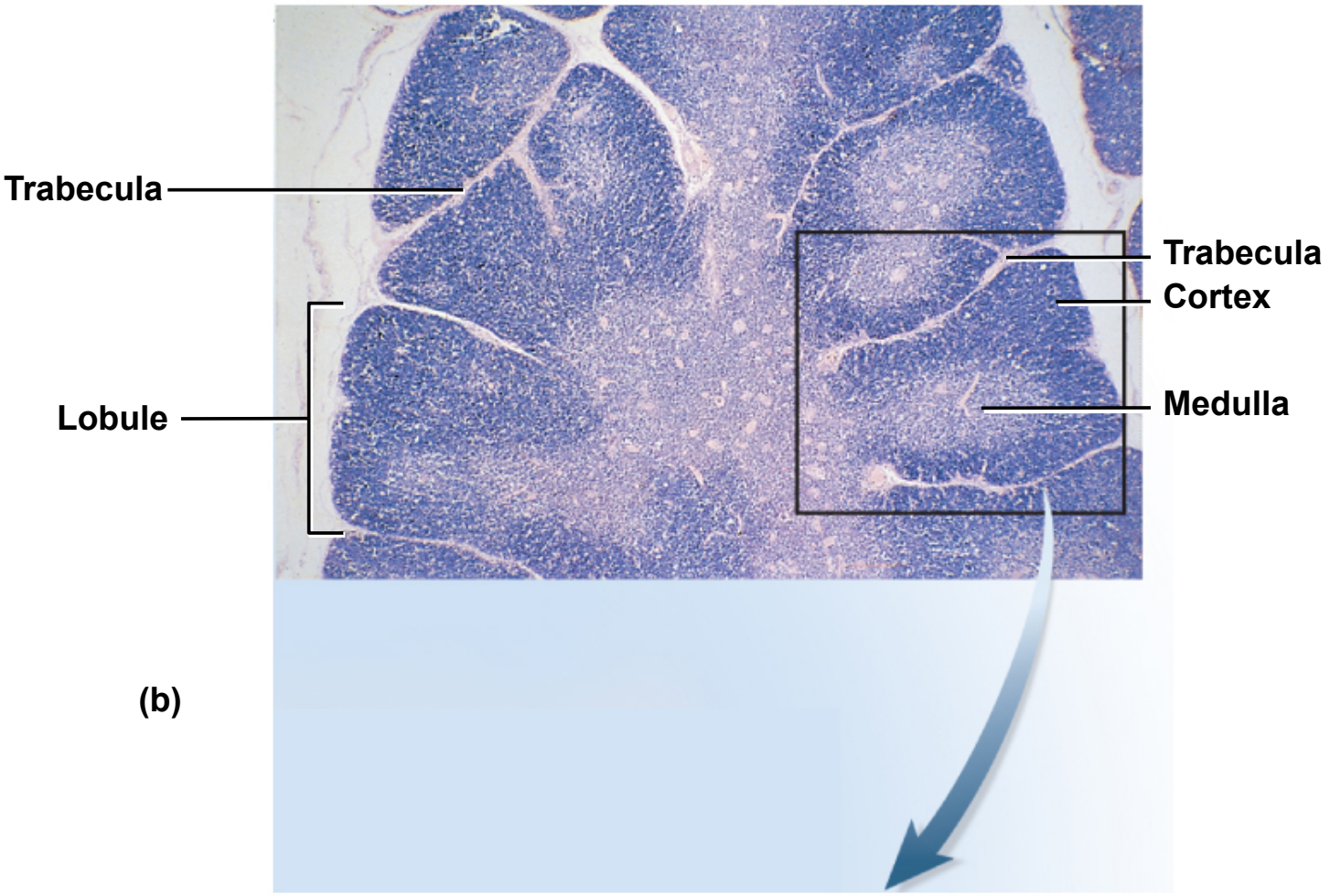


Figure 21.10b

Lymph Node

- **lymph nodes** – the most numerous lymphatic organs
  - about 450 in typical young adult
  - serve two functions:
    - cleanse the lymph
    - act as a site of T and B cell activation
- elongated, bean shaped structure with **hilum**
- enclosed with **fibrous capsule** with **trabeculae** that divide interior into compartments
  - stroma of reticular fibers and reticular cells
- **parenchyma** divided into **cortex** and **medulla**
  - **germinal centers** where B cells multiply and differentiate into plasma cells
- several **afferent lymphatic vessels** lead into the node along its convex surface
  - lymph leaves the node through one to three **efferent lymphatic vessels** that leave the hilum

Lymph Node

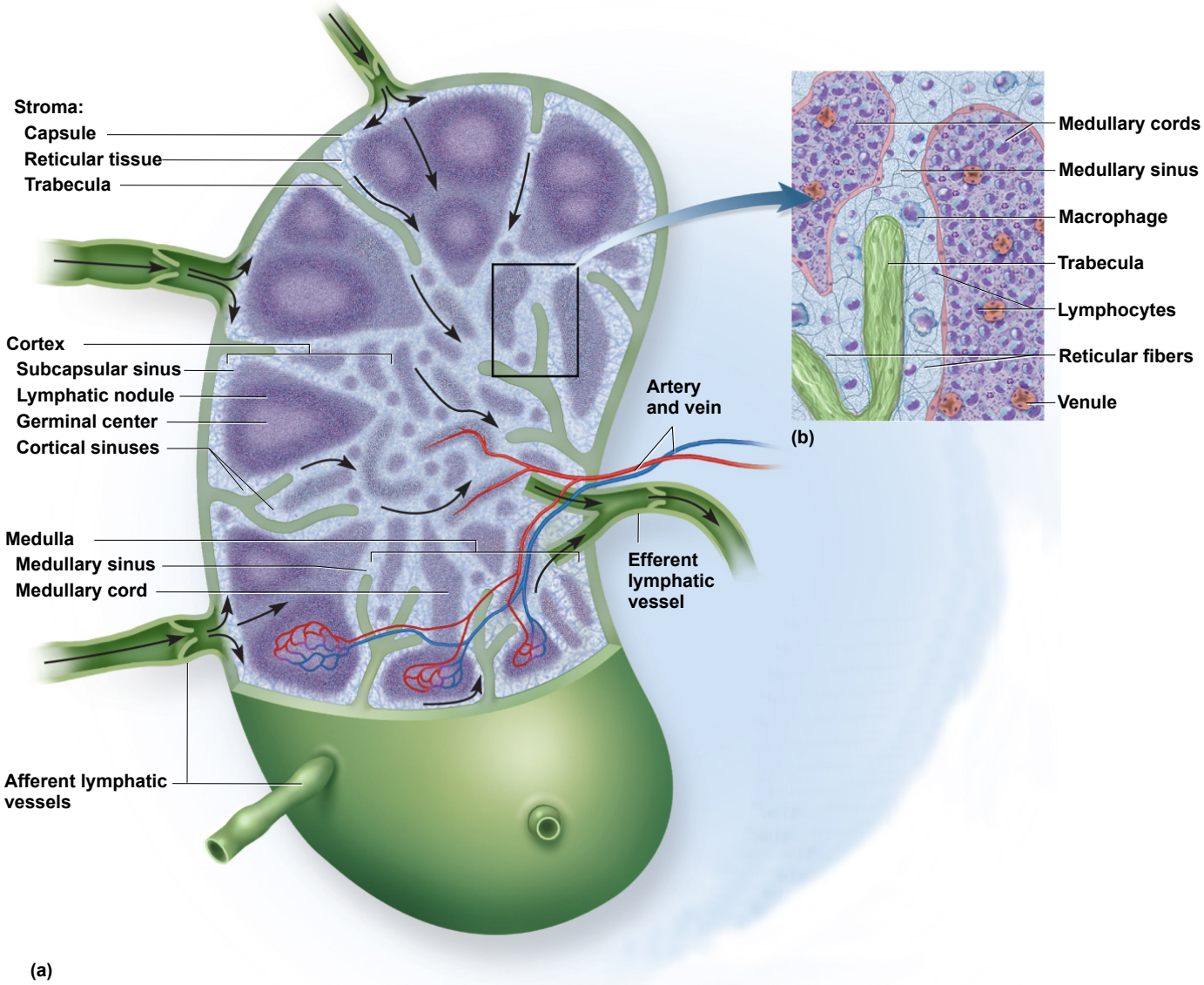


Figure 21.12a,b

Lymph Node Locations

- **cervical lymph nodes**
  - deep and superficial group in the neck
  - monitor lymph coming from head and neck
- **axillary lymph nodes**
  - concentrated in armpit
  - receive lymph from upper limb and female breast
- **thoracic lymph nodes**
  - in thoracic cavity especially embedded in mediastinum
  - receive lymph from mediastinum, lungs, and airway

Lymph Node Locations

- **abdominal lymph nodes**
  - occur in posterior abdominopelvic wall
  - monitor lymph from the urinary and reproductive systems
- **intestinal and mesenteric lymph nodes**
  - found in the mesenteries, adjacent to the appendix and intestines
  - monitor lymph from the digestive tract
- **inguinal lymph nodes**
  - in the groin and receive lymph from the entire lower limb
- **popliteal lymph nodes**
  - occur on the back of the knee
  - receive lymph from the leg proper

Lymph Node Areas of Concentration

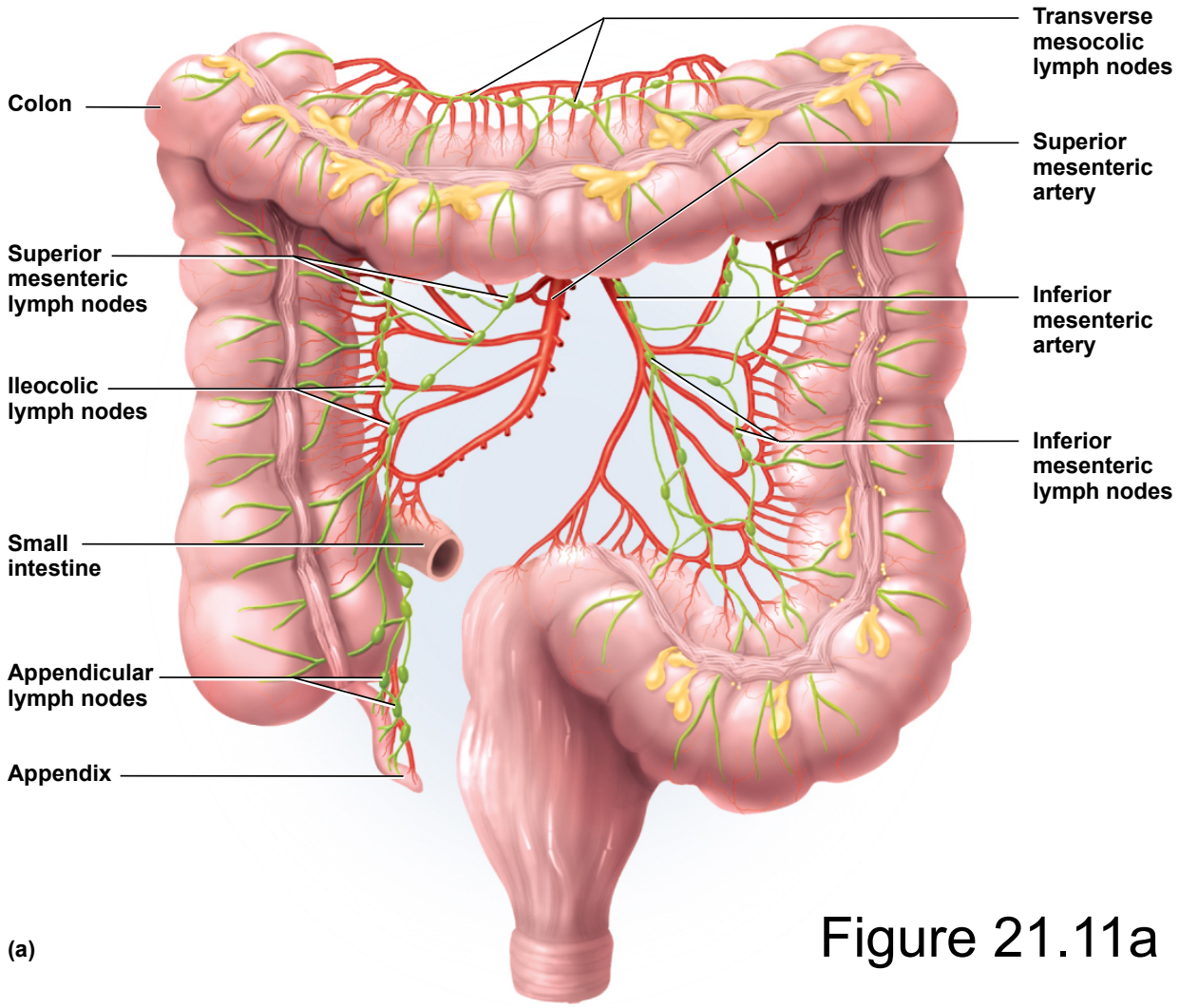


Figure 21.11a

Lymphadenopathy

- **lymphadenopathy** - collective term for all lymph node diseases
- **lymphadenitis** - swollen, painful node responding to foreign antigen
- lymph nodes are common sites for **metastatic cancer**
  – swollen, firm and usually painless

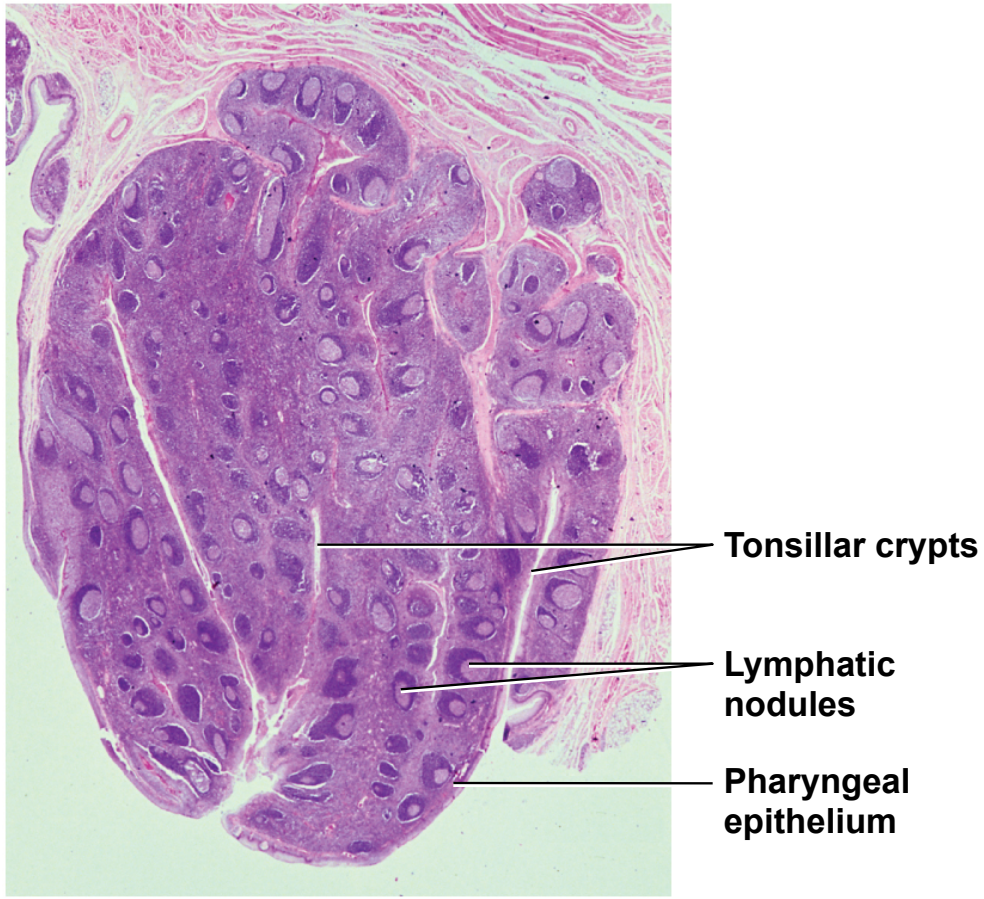
Lymph Nodes and Metastatic Cancer

- **metastasis** – phenomenon in which cancerous cells break free from the original, primary tumor, travel to other sites in the body, and establish new tumors.
  - metastasizing cancer cells can easily enter the lymphatic vessels
  - tend to lodge in the first lymph node they encounter
  - multiply there and eventually destroy the node
    - swollen, firm, and usually painless
  - tend to spread to the next node downstream
  - treatment of breast cancer is lumpectomy, mastectomy along with removal of nearby axillary nodes

Tonsils

- **tonsils** – patches of lymphatic tissue located at the entrance to the pharynx
  - guard against ingested or inhaled pathogens
  - each covered with epithelium
  - have deep pits – **tonsillar crypts** lined with lymphatic nodules – **tonsillitis** and **tonsillectomy**
- **three main sets of tonsils**
  - **palatine tonsils**
    - pair at posterior margin of oral cavity
    - most often infected
  - **lingual tonsils**
    - pair at root of tongue
  - **pharyngeal tonsil (adenoid)**
    - single tonsil on wall of nasopharynx

pharyngeal tonsil



(b)

Figure 21.13b

- covered by epithelium
- pathogens get into tonsillar crypts and encounter lymphocytes

The Tonsils

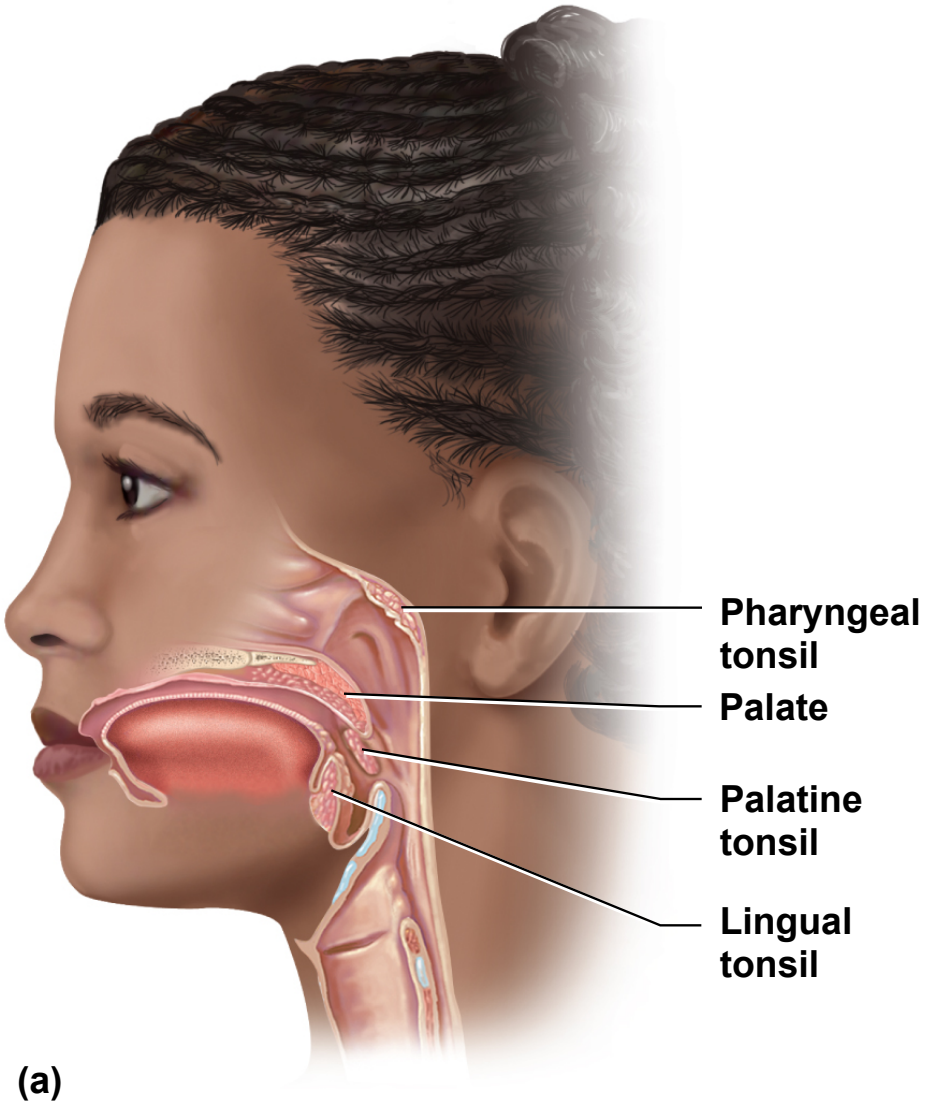


Figure 21.13 a

Spleen

- **spleen** – the body's largest lymphatic organ
- **parenchyma** exhibits two types of tissue:
  - **red pulp** - sinuses filled with erythrocytes
  - **white pulp** - lymphocytes, macrophages surrounding small branches of splenic artery
- functions
  - blood production in fetus
  - blood reservoir
  - 'erythrocyte graveyard' - RBC disposal
  - white pulp monitors blood for foreign antigens
- spleen highly vascular and vulnerable to trauma and infection
  - ruptured spleen - **splenectomy**

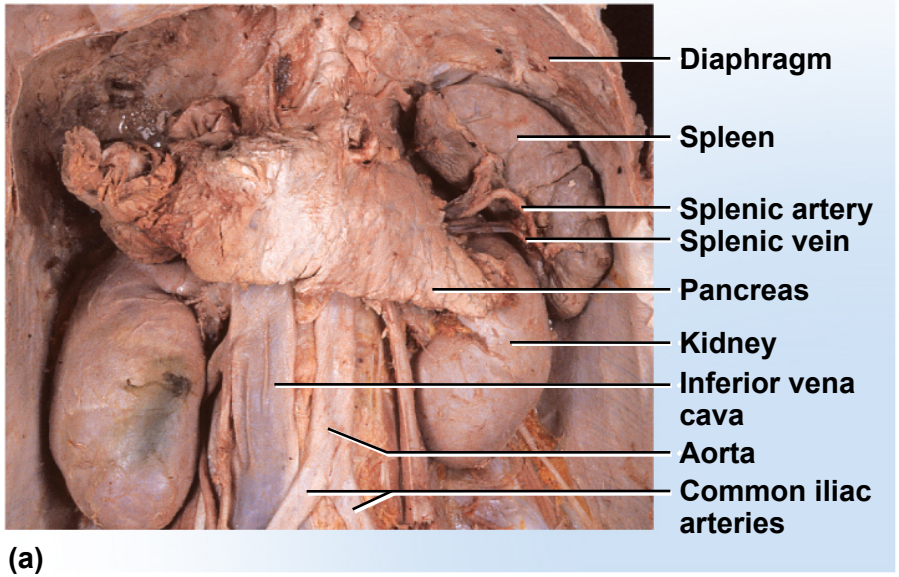


Figure 21.14a

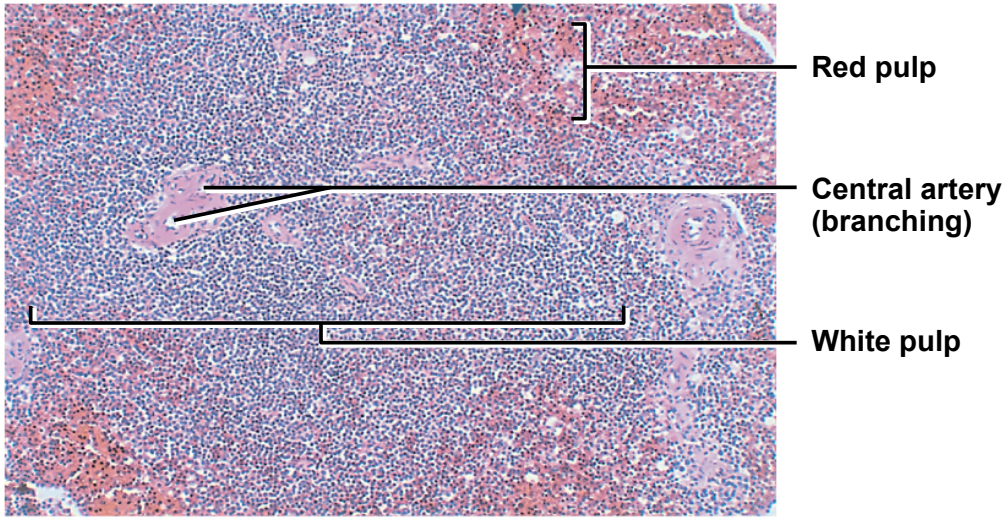


Figure 21.14c

Spleen

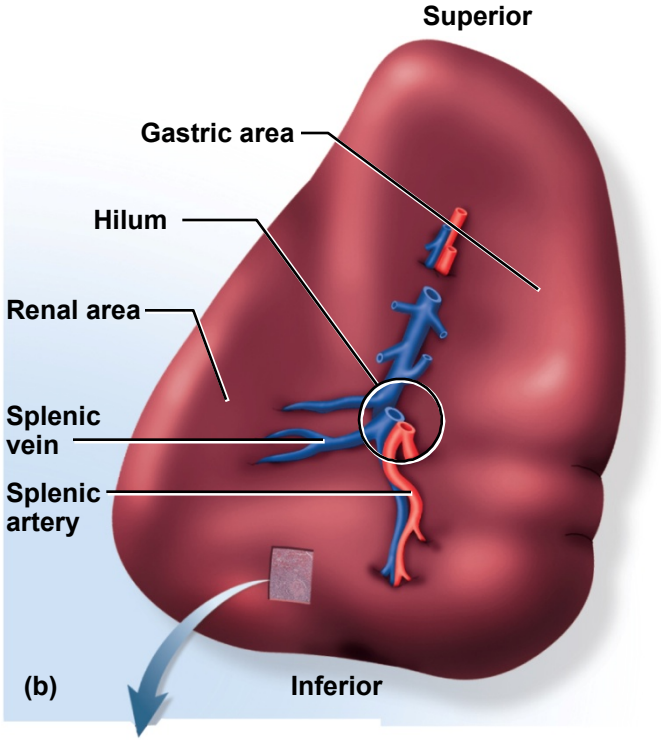


Figure 21.14b

Defenses Against Pathogens

- **pathogens** – environmental agents capable of producing disease
  - infectious organisms, toxic chemicals, and radiation
- **three lines of defenses** against pathogens:
  - **first line of defense** – external barriers, skin and mucous membranes
  - **second line of defense** – several nonspecific defense mechanisms
    - leukocytes and macrophages, antimicrobial proteins, immune surveillance, inflammation, and fever
    - effective against a broad range of pathogens
  - **third line of defense** – the immune system
    - defeats a pathogen, and leaves the body of a ‘memory’ of it so it can defeat it faster in the future

Nonspecific Resistance and Immunity

- **nonspecific resistance** – guards equally against a broad range of pathogens
  - their effectiveness does not depend on prior exposure
  - skin and mucous membranes
  - leukocytes and macrophages, antimicrobial proteins, immune surveillance, inflammation, and fever

- **immunity** – specific defense because it results from prior exposure to a pathogen
  - usually provides future protection only against that particular one

External Barriers

- **skin**
  - makes it mechanically difficult for microorganisms to enter the body
  - toughness of keratin
  - too dry and nutrient-poor to support microbial growth
  - **defensins** – peptides that kill microbes by creating holes in their membranes
  - **acid mantle** – thin film of lactic acid from sweat which inhibits bacterial growth
- **mucous membranes**
  - digestive, respiratory, urinary, and reproductive tracts are open to the exterior and protected by mucous membranes
  - mucus physically traps microbes
  - **lysozyme** - enzyme destroys bacterial cell walls
- **subepithelial areolar tissue**
  - viscous barrier of **hyaluronic acid**
    - **hyaluronidase** - enzyme used by pathogens to make hyaluronic acid less viscous

Leukocytes and Macrophages

- **phagocytes** – phagocytic cells with a voracious appetite for foreign matter

- five types of leukocytes
  - **neutrophils**
  - **eosinophils**
  - **basophils**
  - **monocytes**
  - **lymphocytes**

Neutrophils

- wander in connective tissue killing bacteria
  - phagocytosis and digestion
  - produces a cloud of bactericidal chemicals
- create a **killing zone**
  - degranulation
    - lysosomes discharge into tissue fluid
  - **respiratory burst** – neutrophils rapidly absorb oxygen
    - **toxic chemicals** are created ($O_2^{\bullet -}$, H_2O_2, HClO)
  - kill more bacteria with toxic chemicals than phagocytosis

Eosinophils

- found especially in the mucous membranes
- stand guard against **parasites**, **allergens** (allergy causing agents), and other pathogens
- kill tapeworms and roundworms by producing superoxide, hydrogen peroxide, and toxic proteins
- promote action of **basophils** and **mast cells**
- phagocytize **antigen-antibody complexes**
- limit action of **histamine** and other inflammatory chemicals

Basophils

- secrete chemicals that aid mobility and action of WBC other leukocytes
  - **leukotrienes** – activate and attract neutrophils and eosinophils
  - **histamine** – a vasodilator which increases blood flow
    - speeds delivery of leukocytes to the area
  - **heparin** – inhibits the formation of clots
    - would impede leukocyte mobility
- **mast cells** also secrete these substances
  - type of connective tissue cell very similar to basophils

Lymphocytes

- three basic categories
- circulating blood contains
  - 80% **T cells**
  - 15% **B cells**
  - 5% **NK cells**
- many diverse functions

Monocytes

- **monocytes** - emigrate from the blood into the connective tissue and transform into **macrophages**

- **macrophage system** – all the body's avidly phagocytic cells, except leukocytes
  - **wandering macrophages** – actively seeking pathogens
    - widely distributed in loose connective tissue
  - **fixed macrophages** – phagocytize only pathogens that come to them
    - **microglia** – in central nervous system
    - **alveolar macrophages** – in lungs
    - **hepatic macrophages** – in liver

Antimicrobial Proteins

- proteins that inhibit microbial reproduction and provide short-term, nonspecific resistance to pathogenic bacteria and viruses

- two families of antimicrobial proteins:
  - **interferons**
  - **complement system**

Interferons

- **interferons** - secreted by certain cells infected by viruses
  - of no benefit to the cell that secretes them
  - alert neighboring cells and protect them from becoming infected
  - bind to surface receptors on neighboring cells
    - activate second-messenger systems within
  - alerted cell synthesizes various proteins that defend it from infection
    - breaks down viral genes or preventing replication
  - also activates NK cells and macrophages
    - destroy infected cell before they can liberate a swarm of newly replicated viruses
  - activated NK cells destroy malignant cells

Passive and Active Immunity

- **natural active immunity**
  - production of one's own antibodies or T cells as a result of infection or natural exposure to antigen
- **artificial active immunity**
  - production of one's own antibodies or T cells as a result of vaccination against disease
  - **vaccine** – consists of dead or attenuated (weakened) pathogens that stimulate the immune response without causing the disease
  - **booster shots** – periodic immunizations to stimulate immune memory to maintain a high level of protection
- **natural passive immunity**
  - temporary immunity that results from antibodies produced by another person
    - fetus acquires antibodies from mother through placenta, milk
- **artificial passive immunity**
  - temporary immunity that results from the injection of immune serum (antibodies) from another person or animal
    - treatment for snakebite, botulism, rabies, tetanus, and other diseases

Lymphocytes

- major cells of the immune system
  - lymphocytes
  - macrophages
  - dendritic cells
- especially concentrated in strategic places such as lymphatic organs, skin, and mucous membranes
- three categories of lymphocytes
  - **natural killer (NK) cells** – immune surveillance
  - **T lymphocytes (T cells)**
  - **B lymphocytes (B cells)**