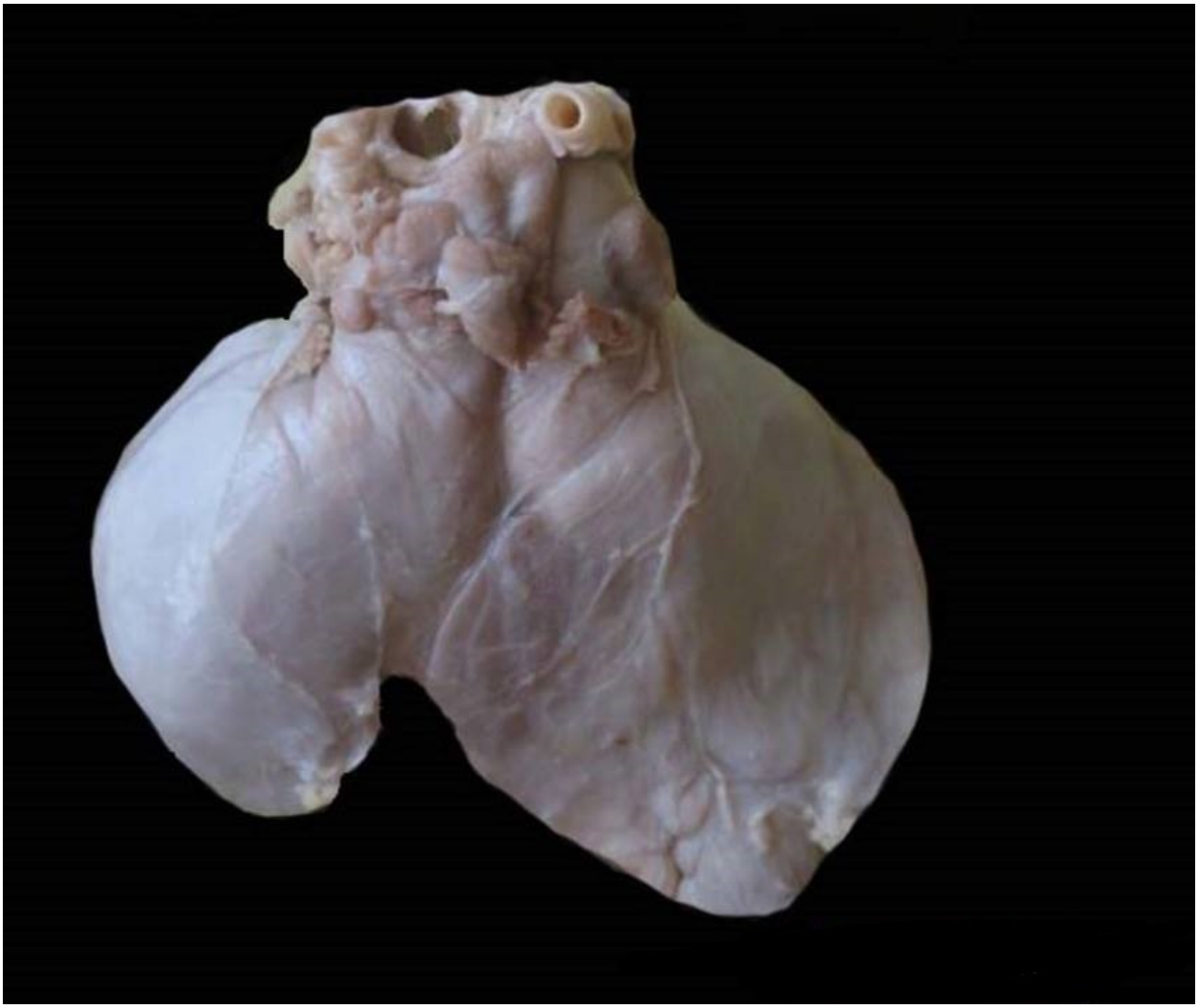
Exercise 7: Lymphatic System and Immune Response



https://upload.wikimedia.org/wikipedia/commons/1/1a/Human_thymus.jpg

Figure 7.1 The above diagram is an anterior view of a dissected human thymus. The thymus is an important lymphatic structure and part of the lymphatic system.

At the end of this lab, you will be able to:

- Describe the structure and function of the lymphatic tissue
- Describe the structure and function of primary and secondary lymphatic organs
- Discuss the cells of the immune system, how they function, and their relationship with the lymphatic system
- Identify the specific cells of the immune system
- Differentiate between innate and adaptive immunity
- Locate and identify major lymph vessels and organs

Pre-lab activity 7.1: Describe Structures of the Lymphatic System

Use your textbook or other resources to complete all activities in this lab exercise.

Term	Definition
Lymphatic system	
Lymph	
Lymphatic capillaries	
Lymphatic trunks	
Thoracic duct	
Cisterna chyli	
Lymph node	
Bone marrow	
Lymphoid nodules	
MALT	
Spleen	
Thymus	

Anatomy of the Lymphatic and Immune Systems

The immune system is a complex collection of cells and organs that destroy or neutralize pathogens that would otherwise cause disease or death. The lymphatic system, is associated with the immune system to such a degree that the two systems are virtually indistinguishable. The lymphatic system is a subsystem of the circulatory system in that consists of a complex network of vessels, tissues, and organs. The lymphatic system carries excess fluids to the bloodstream and filters pathogens from the blood. The swelling of lymph nodes during an infection and the transport of lymphocytes via the lymphatic vessels are but two examples of the many connections between these critical organ systems.

Functions of the Lymphatic System

A major function of the lymphatic system is to drain tissue fluids and return them to the bloodstream. Blood pressure causes leakage of fluid from the capillaries, resulting in the accumulation of fluid in the interstitial space—that is, spaces between individual cells in the tissues. In humans, 20 liters of plasma is released into the interstitial space of the tissues each day due to capillary filtration. Once this filtrate is out of the bloodstream and in the tissue spaces, it is referred to as interstitial fluid. Of this, 17 liters is reabsorbed directly by the blood vessels. But what happens to the remaining three liters? This is where the lymphatic system comes into play. It drains the excess fluid and empties it back into the bloodstream via a series of vessels, trunks, and ducts. Lymph is the term used to describe interstitial fluid once it has entered the lymphatic system. When the lymphatic system is damaged in some way, such as by cancer cells or destroyed through injury, protein-rich interstitial fluid accumulates in the tissue spaces. This inappropriate accumulation of fluid referred to as lymphedema may lead to serious medical conditions.

Lymphatic capillaries are vessels where interstitial fluid enters the lymphatic system to become lymph fluid (Figure 7.3). Located in almost every tissue in the body, these vessels are interlaced among the arterioles and venules of the circulatory system in the soft connective tissues of the body. Lymphatic capillaries are formed by a one cell-thick layer of endothelial cells and represent the open end of the system, allowing interstitial fluid to flow into them via overlapping cells. When interstitial fluid pressure is low, the endothelial flaps close to prevent “backflow.” As interstitial fluid pressure increases, the spaces between the cells open-up, allowing the fluid to enter. Entry of fluid into lymphatic capillaries is also enabled by the collagen filaments that anchor the capillaries to surrounding structures. As interstitial fluid pressure increases, the filaments pull on the endothelial cell flaps, opening them even further to allow easy entry of fluid.

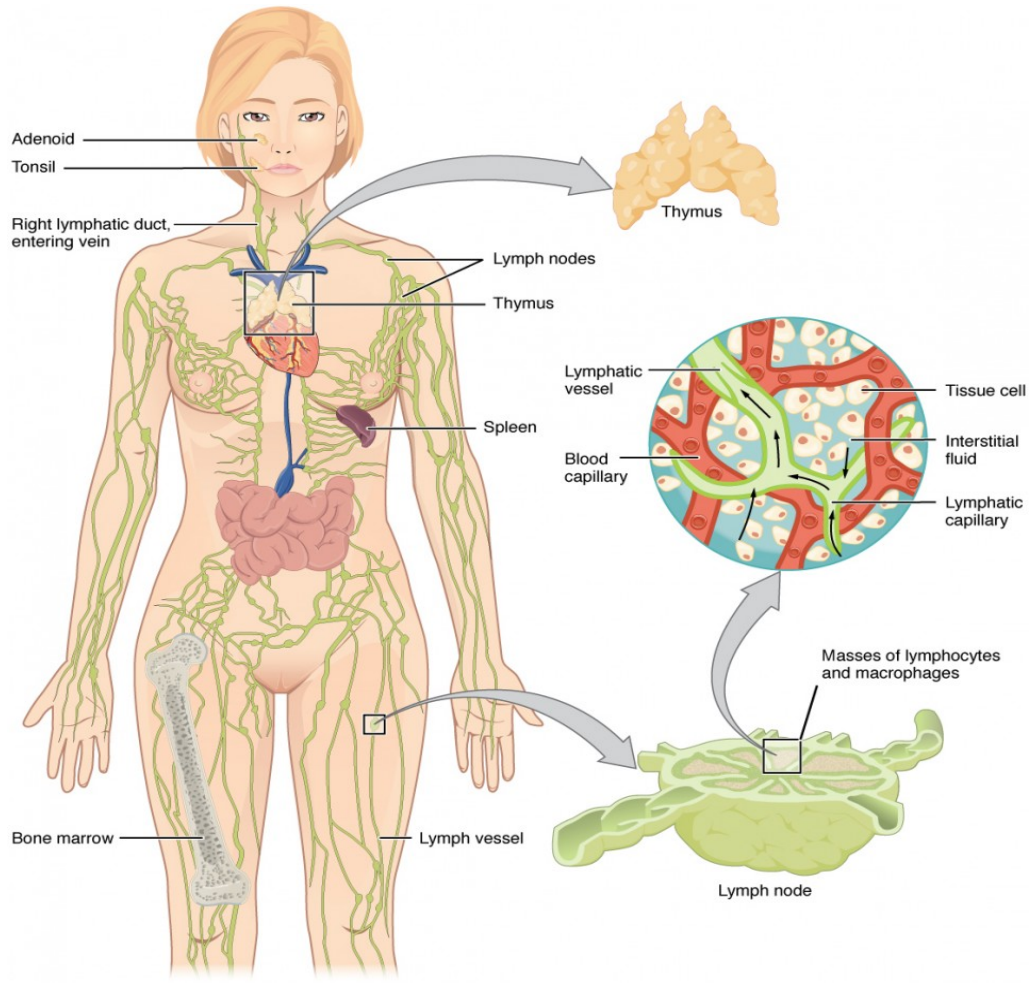


Figure 7.2. Lymphatic vessels in the arms and legs convey lymph to the larger lymphatic vessels in the torso.https://www.oercommons.org/courses/anatomy-and-physiology-ii?__hub_id=27

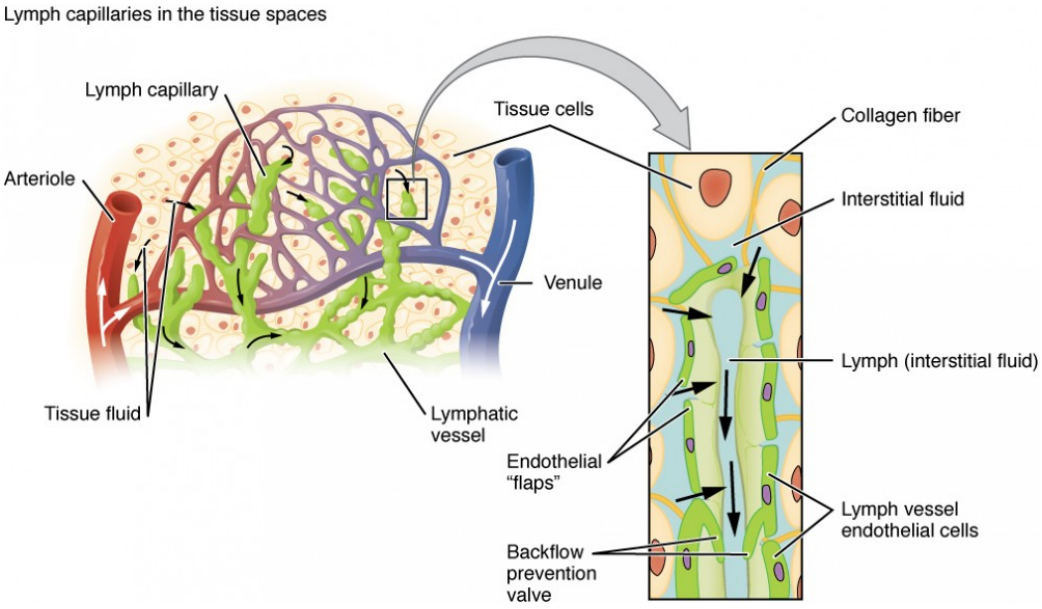


Figure 7.3. Lymphatic capillaries are interlaced with the arterioles and venules of the cardiovascular system. Interstitial fluid slips through spaces between the overlapping endothelial cells that compose the lymphatic capillary.
https://www.oercommons.org/courses/anatomy-and-physiology-ii?__hub_id=27

Larger Lymphatic Vessels, Trunks, and Ducts

The lymphatic capillaries empty into larger lymphatic vessels, which are like veins in terms of their three-layer structure and the presence of valves. These one-way valves are located close to one another, and each one causes a bulge in the lymphatic vessel, giving the vessels a beaded appearance.

The superficial and deep lymphatics eventually merge to form larger lymphatic vessels known as **lymphatic trunks**. On the right side of the body, the right side of the head, right side of the thorax, and right upper limb drain lymph fluid into the right subclavian vein via the right lymphatic duct. On the left side of the body, the remaining portions of the body drain into the larger thoracic duct, which drains into the left subclavian vein. The thoracic duct itself begins just beneath the diaphragm in the **cisterna chyli**, a sac-like chamber that receives lymph from the lower abdomen, pelvis, and lower limbs by way of the left and right lumbar trunks and the intestinal trunk (Figure 6.4).

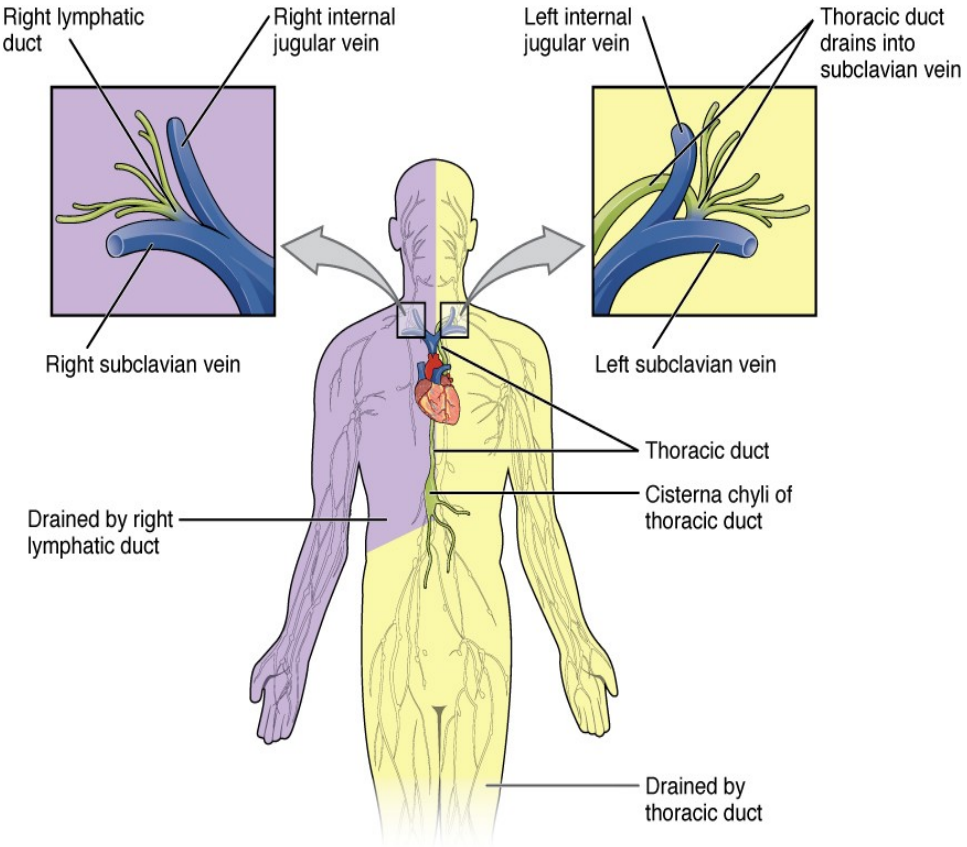


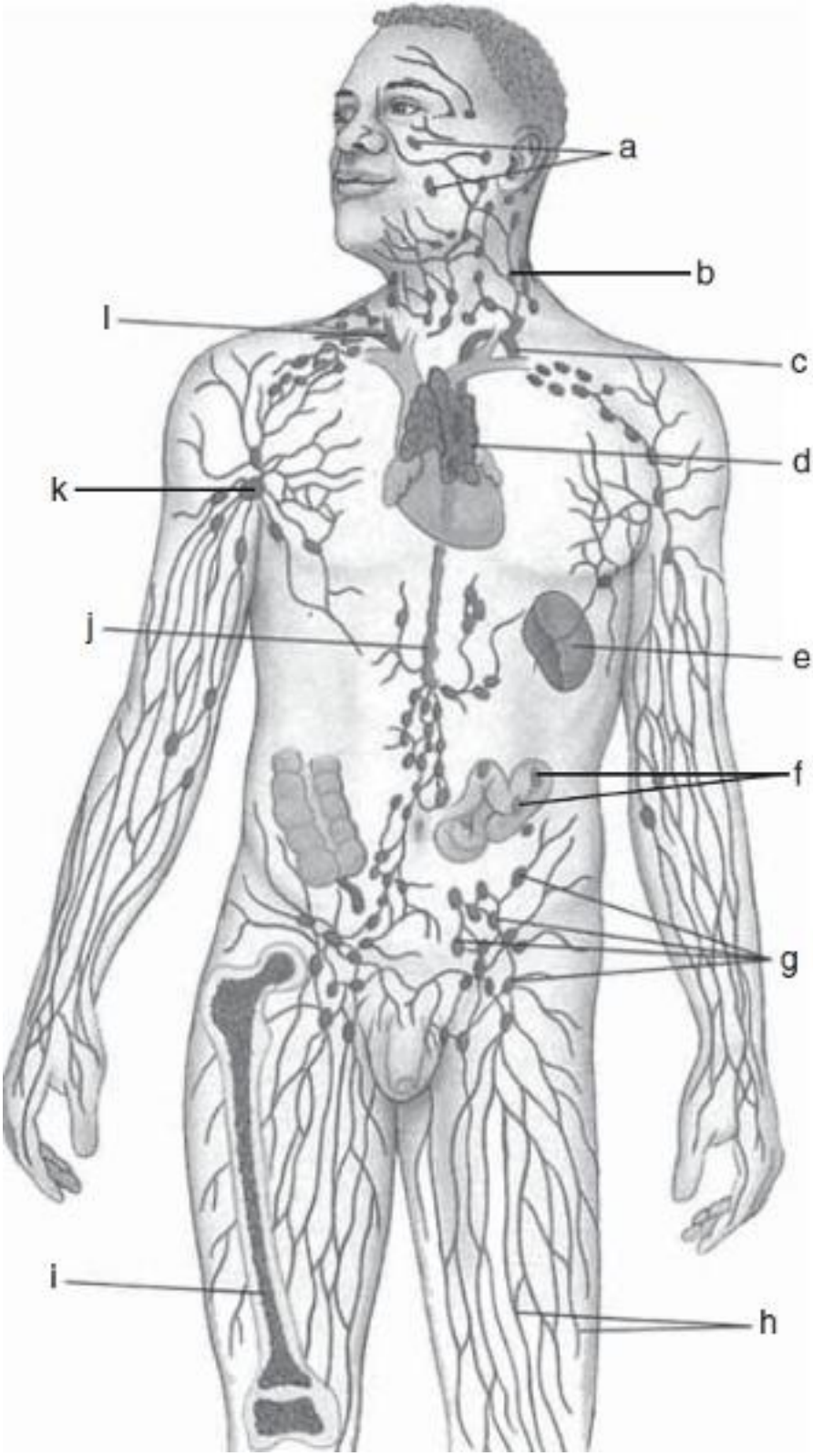
Figure 7.4. The thoracic duct drains a much larger portion of the body than does the right lymphatic duct. https://www.oercommons.org/courses/anatomy-and-physiology-ii?__hub_id=27

The overall drainage system of the body is asymmetrical. The right lymphatic duct receives lymph from only the upper right side of the body. The lymph from the rest of the body enters the bloodstream through the thoracic duct via all the remaining lymphatic trunks. In general, lymphatic vessels of the superficial lymphatics of the skin, follow the same routes as veins, whereas the deep lymphatic vessels of the viscera generally follow the paths of arteries.

Lab Exercise 7: Lymphatic System Anatomy

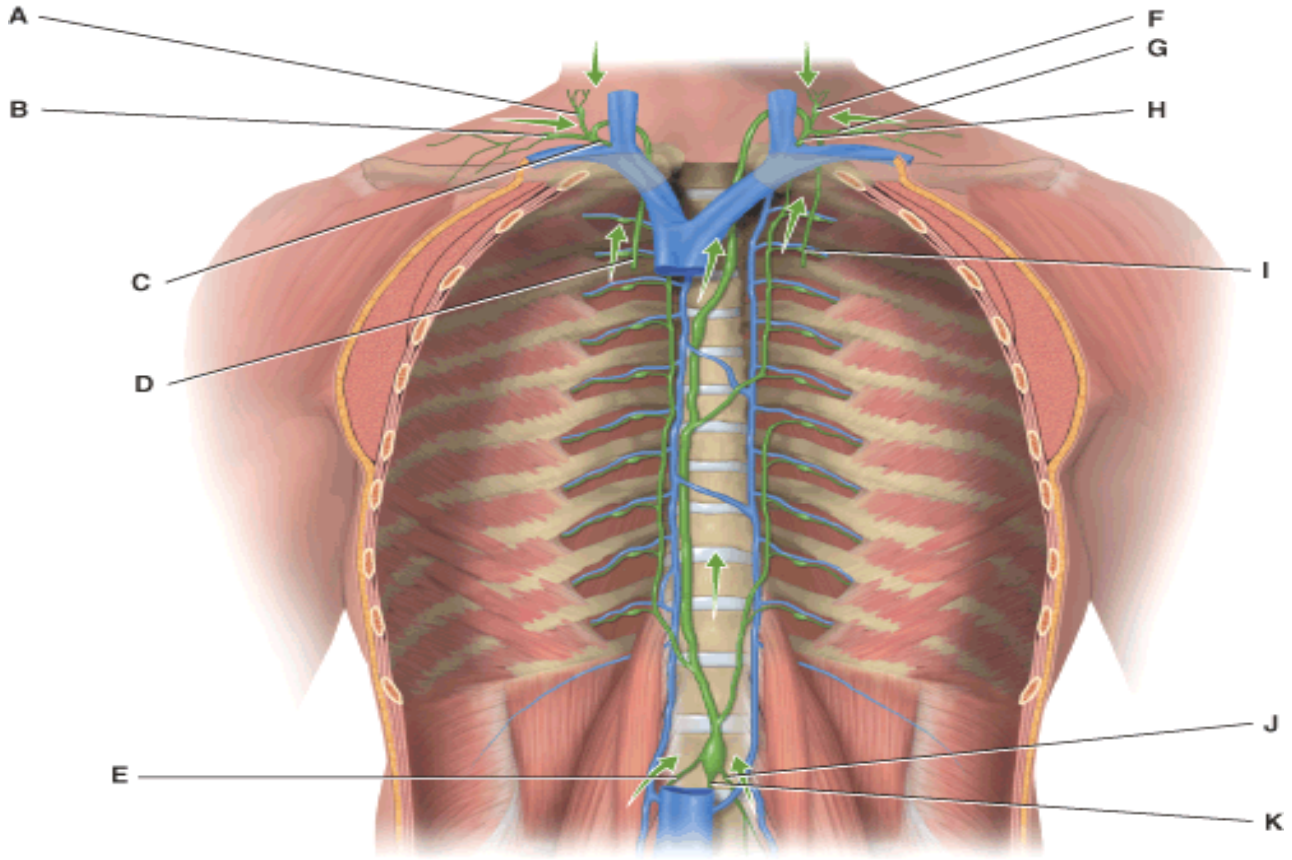
Activity 7.1: Identify Lymphatic Vessels and Organs

Use your textbook and other resources to label the structures in the diagram below.



Activity 7.2: Lymphatic Vessels

Use your textbook and other resources to label the major lymphatic trucks, ducts and blood vessels in the diagram below.



Tortora and Derrickson: Principles of Anatomy and Physiology, 2017. Lymphatic system and immunity, chapter 22. Ed 15, John Wiley and son, pp 812

A.

B.

C.

D.

E.

F.

G.

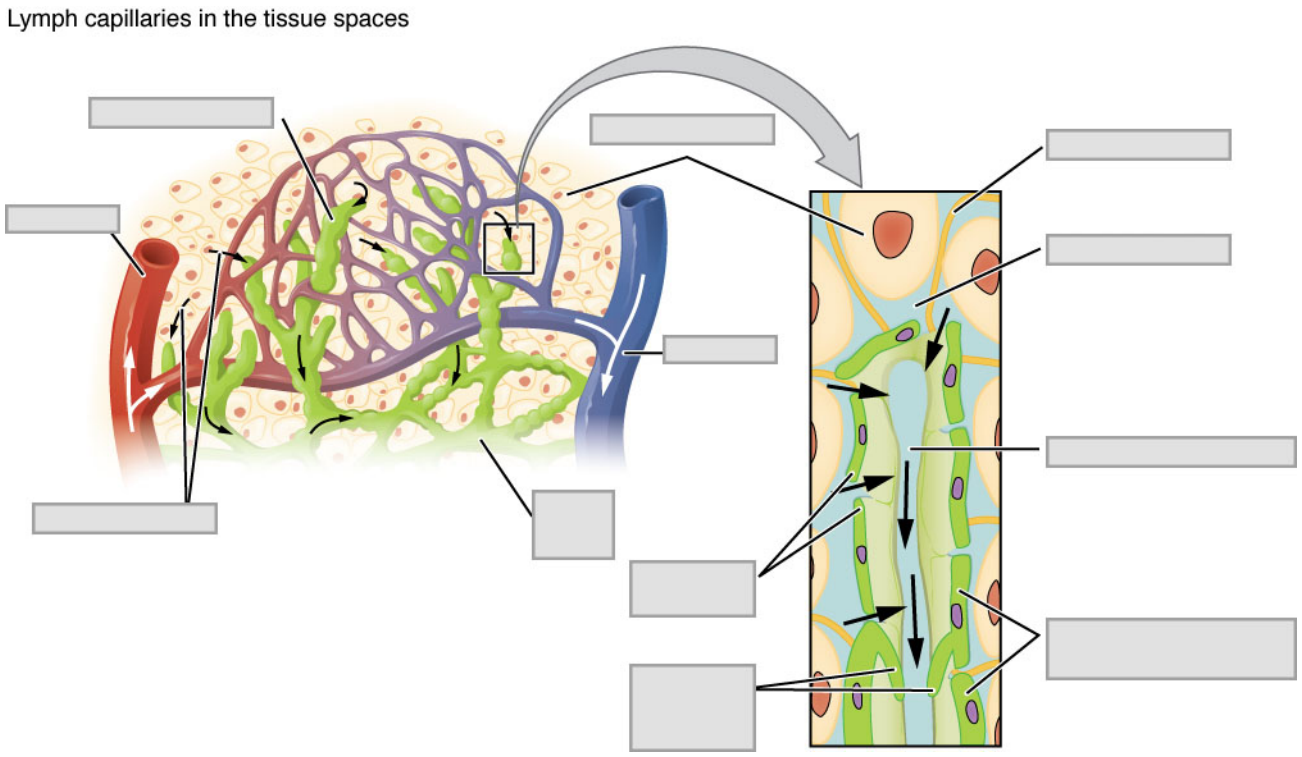
H.

I.

J.

Activity 7.3: Lymphatic Capillary Vessel

Use your textbook and other resources to label the structures of the lymphatic capillary



Lymphoid Organs

The lymphatic system is commonly divided into the primary lymphoid organs, which are the sites of B and T cell maturation, and the secondary lymphoid organs, in which further differentiation of lymphocytes occurs. Primary lymphoid organs include the **thymus**, **bone marrow**, and **fetal liver**. In humans the thymus and bone marrow are the key players in immune function. All lymphocytes are derived from stem cells in the bone marrow. Stem cells destined to become B lymphocytes remain in the bone marrow as they mature, while prospective T cells migrate to the thymus to undergo further growth (Figure 7.5). Mature B and T lymphocytes exit the primary lymphoid organs and are transported via the bloodstream to the secondary lymphoid organs, where they become activated by contact with foreign materials that function as antigens.

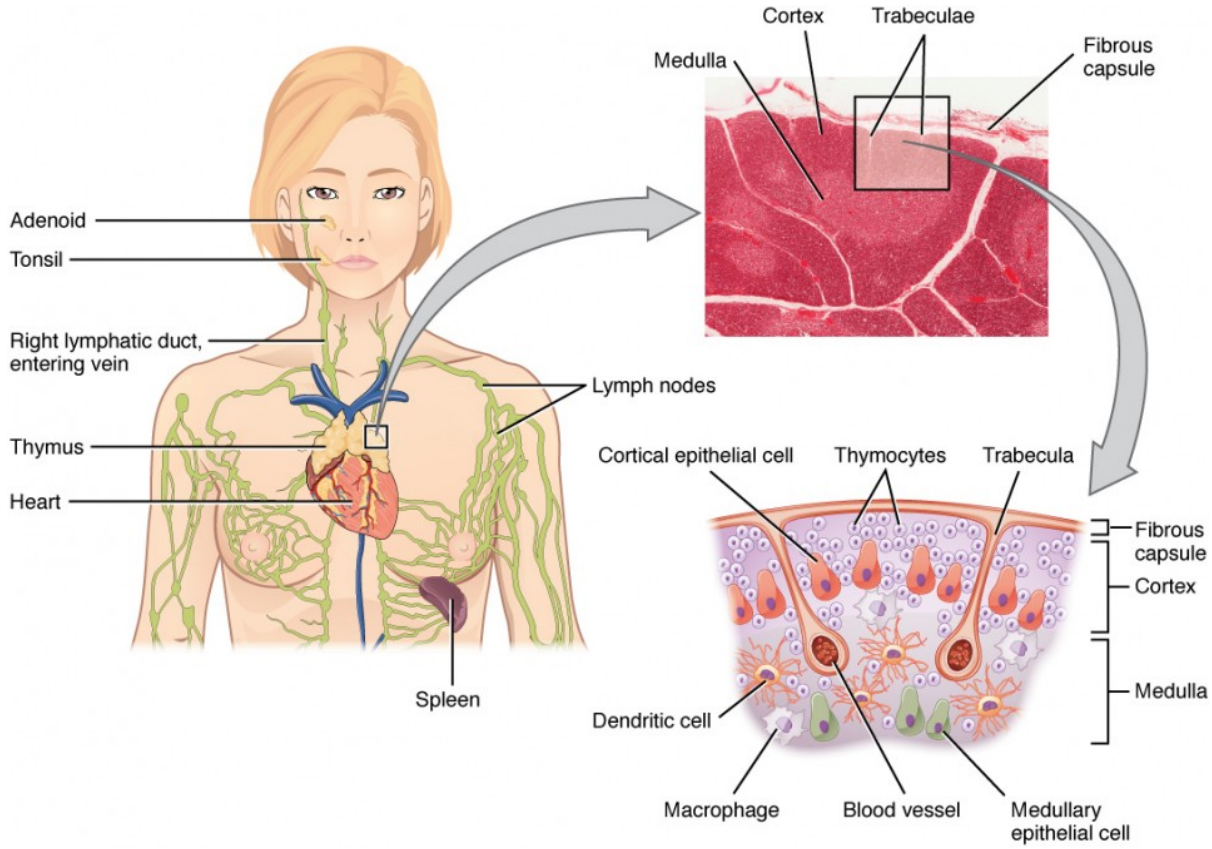


Figure 7.5. The thymus lies above the heart. The trabeculae and lobules, including the darkly staining cortex and the lighter staining medulla of each lobule, are clearly visible in the light micrograph of the thymus of a newborn. LM × 100. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

Secondary Lymphoid Organs and their Roles in Active Immune Responses

Lymphocytes develop and mature in the primary lymphoid organs, but they mount immune responses from the secondary lymphoid organs. A naïve lymphocyte is one that has left the primary organ and entered a secondary lymphoid organ. Naïve lymphocytes are fully functional immunologically but have yet to encounter an antigen to respond to. In addition to circulating in the blood and lymph, lymphocytes concentrate in secondary lymphoid organs, which include the lymph nodes, spleen, and lymphoid nodules.

Lymph nodes function to remove debris and pathogens from the lymph and are thus sometimes referred to as the "filters of the lymph" (Figure 7.6). Any bacteria that infect the interstitial fluid are taken up by the lymphatic capillaries and transported to a regional lymph node. Dendritic cells and macrophages within this organ internalize and kill many of the pathogens that pass through, thereby removing them from the body.

Spleen

In addition to the lymph nodes, the **spleen** is a major secondary lymphoid organ. It is about 12 cm (5 in) long and is attached to the lateral border of the stomach via the gastrosplenic ligament (Figure 6.7). The spleen is a fragile organ without a strong capsule and is dark red due to its extensive vascularization. The spleen also functions as the location of immune responses to blood-borne pathogens.

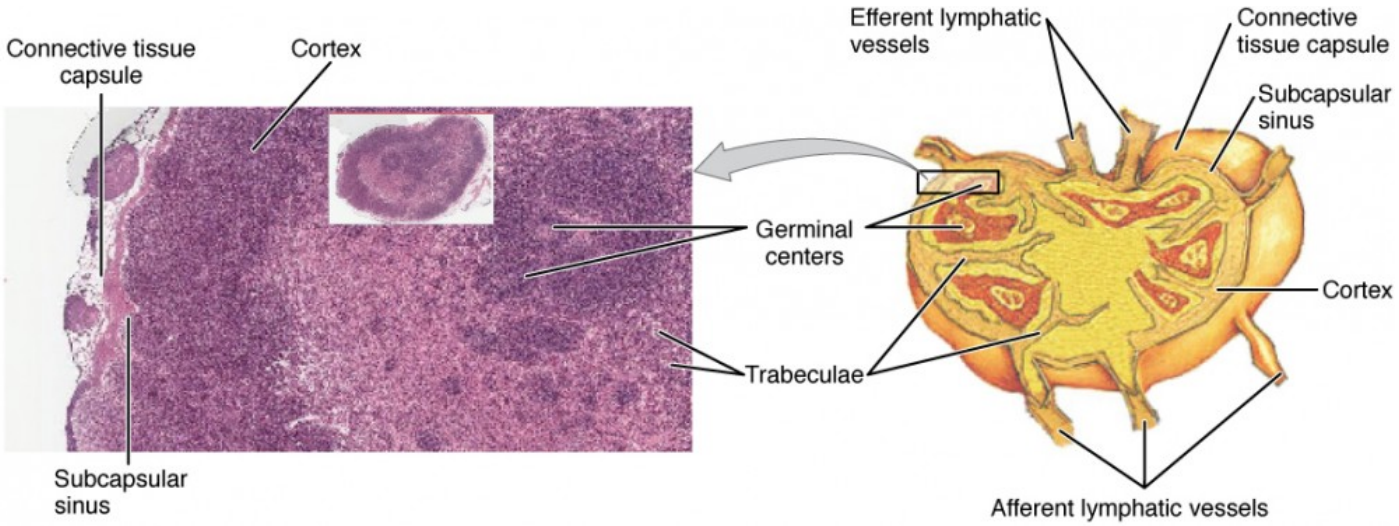


Figure 7.6. Lymph nodes are masses of lymphatic tissue located along the larger lymph vessels. The micrograph of the lymph nodes shows a germinal center, which consists of rapidly dividing B cells surrounded by a layer of T cells and other accessory cells. LM × 128. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

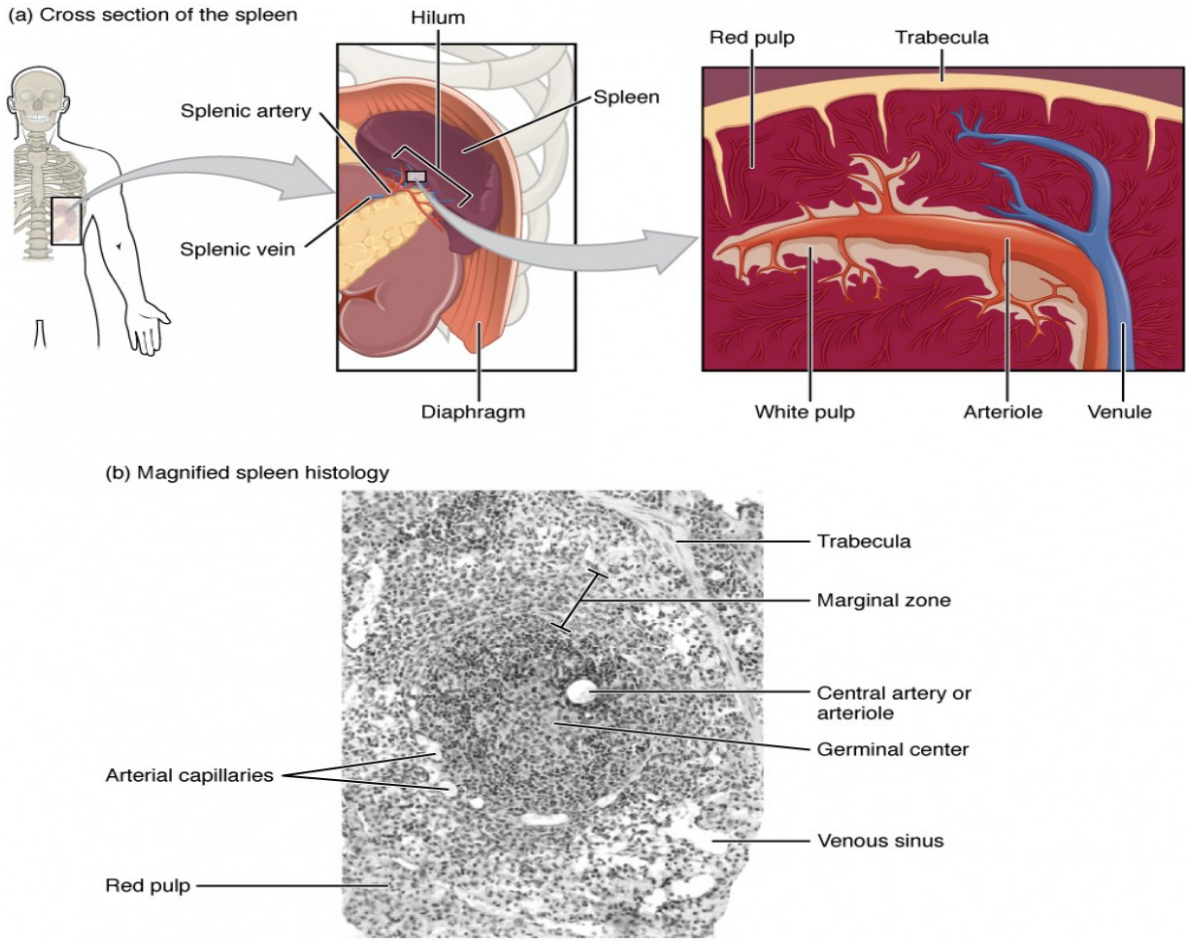
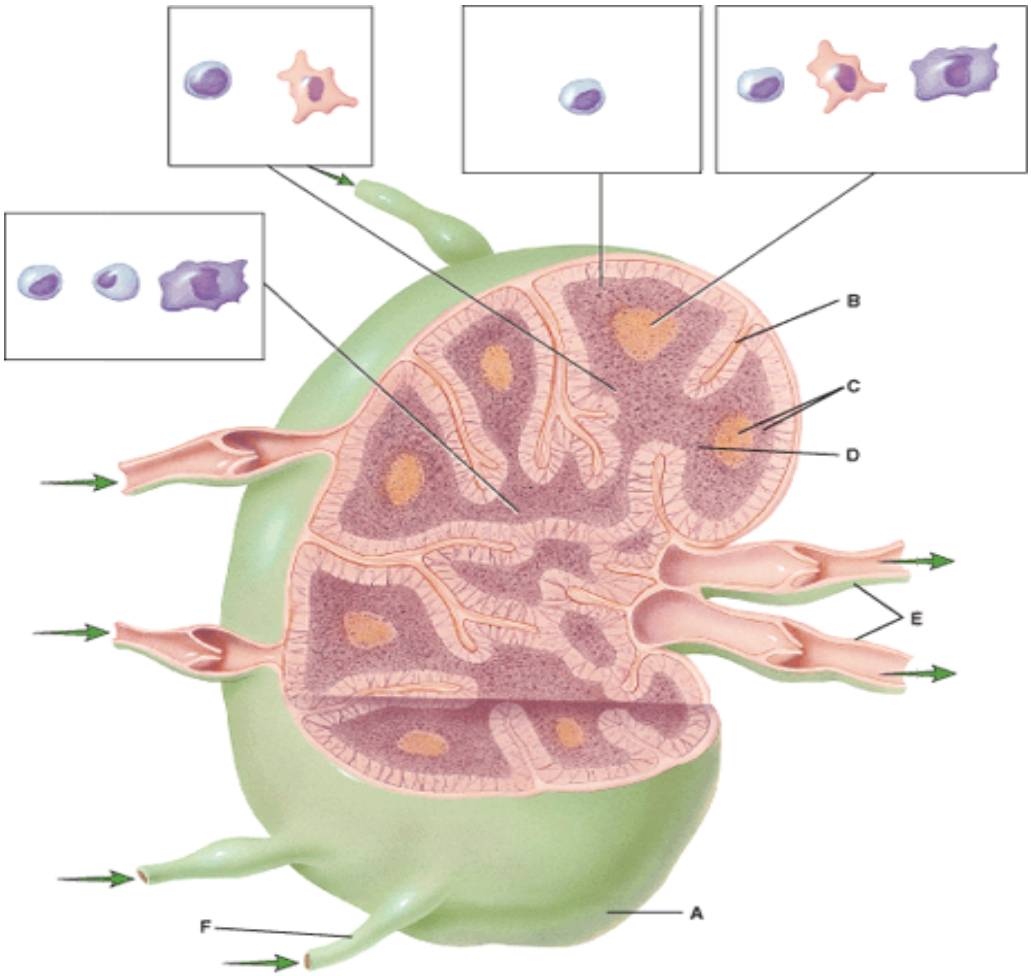


Figure 7.7. (a) The spleen is attached to the stomach. (b) A micrograph of spleen tissue shows the germinal center. The marginal zone is the region between the red pulp and white pulp, which sequesters particulate antigens from the circulation and presents these antigens to lymphocytes in the white pulp. EM × 660. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

Activity 7.4: Lymph nodes

Use your textbook and other resources to label the lymph node below.



Tortora and Derrickson: Principles of Anatomy and Physiology, 2017. Lymphatic system and immunity, chapter 22. Ed 15, John Wiley and son, pp 816

A.

B.

C.

D.

E.

F.

Lymphoid Nodules

The other lymphoid tissues, the lymphoid nodules, have a simpler architecture than the spleen and lymph nodes in that they consist of a dense cluster of lymphocytes without a surrounding fibrous capsule. These nodules are in the respiratory and digestive tracts, areas routinely exposed to environmental pathogens.

Tonsils are lymphoid nodules located along the inner surface of the pharynx and are important in developing immunity to oral pathogens. The pharyngeal tonsil located at the back of the throat and, is sometimes

referred to as the adenoid when swollen. Such swelling is an indication of an active immune response to infection. Histologically, tonsils do not contain a complete capsule, and the epithelial layer invaginates deeply into the interior of the tonsil to form tonsillar crypts. These structures, which accumulate all sorts of materials taken into the body through eating and breathing, actually "encourage" pathogens to penetrate deep into the tonsillar tissues where they are acted upon by numerous lymphoid follicles and eliminated (Figure 7.8).

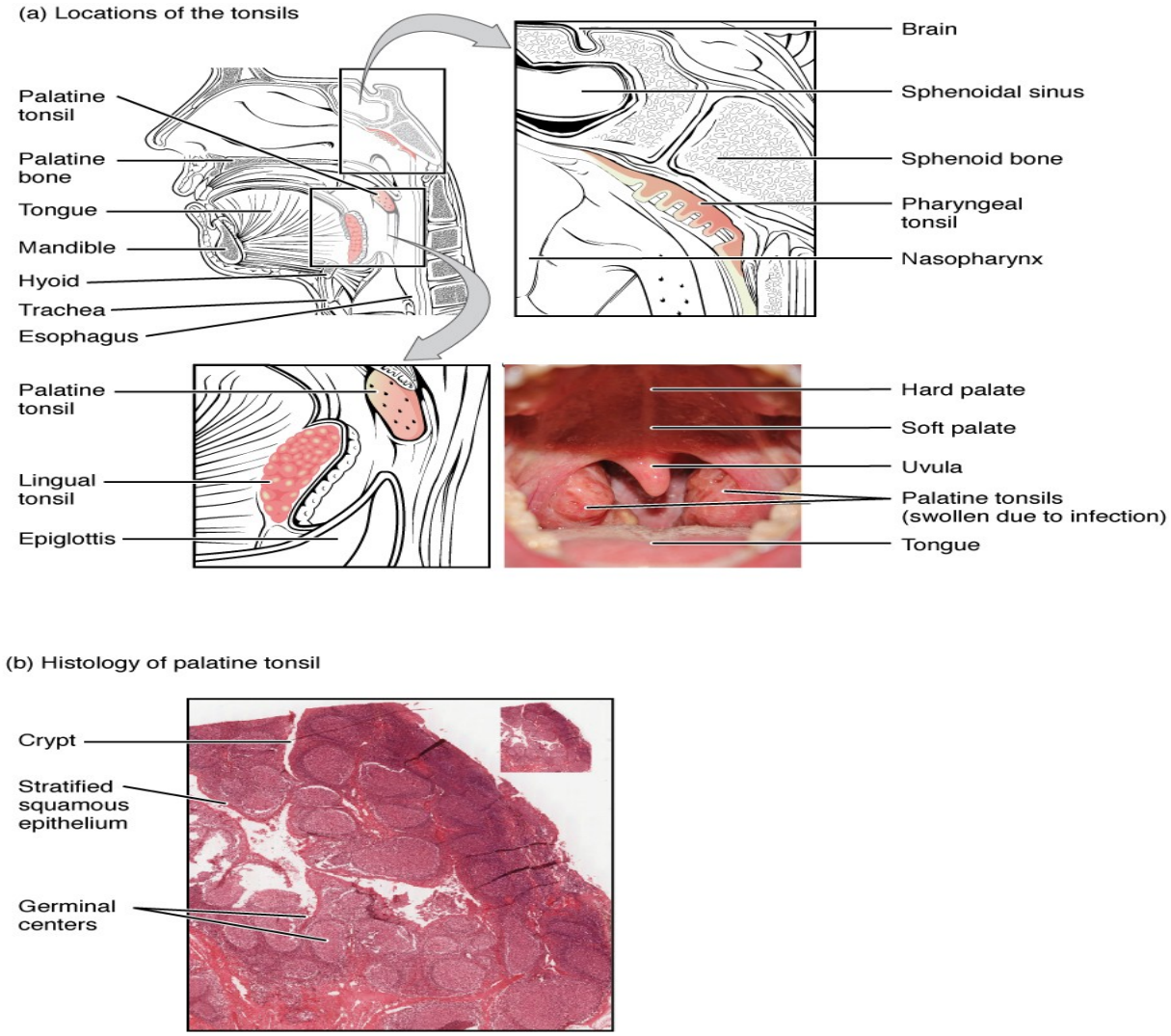


Figure 7.8. (a) The pharyngeal tonsil is located on the roof of the posterior superior wall of the nasopharynx. The palatine tonsils lay on each side of the pharynx. (b) A micrograph shows the palatine tonsil tissue. LM × 40. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

Mucosa-associated lymphoid tissue (MALT) consists of an aggregate of lymphoid follicles directly associated with the mucous membrane epithelia. MALT makes up dome-shaped structures found under the mucosa of the gastrointestinal tract, breast tissue, lungs, and eyes. Peyer's patches, a type of MALT in the small intestine, are especially important for immune responses against ingested substances. Peyer's patches contain specialized endothelial cells called M (or microfold) cells that sample material from the intestinal lumen and transport it to nearby follicles so that adaptive immune responses to potential pathogens can be mounted (Figure 7.9).

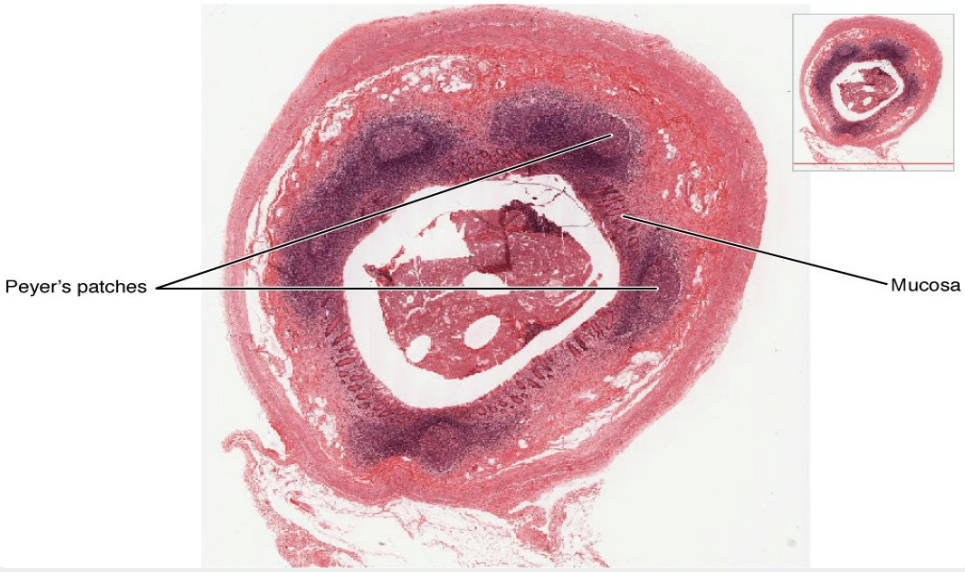


Figure 7.9. Mucosa-associated lymphoid tissue (MALT) of the digestive system- Peyer's patches. LM × 40. (Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

Bronchus-associated lymphoid tissue (BALT) consists of lymphoid follicular structures with an overlying epithelial layer found along the bifurcations of the bronchi, and between bronchi and arteries. They also have the typically less-organized structure of other lymphoid nodules. These tissues, in addition to the tonsils, are effective against inhaled pathogens.

Activity 7.5: Summary of Lymphatic cells, Tissues and Organs

Use your textbook or other resources to compete the table below.

Cell Type	Description/Location	Function
T helper		
T cytotoxic		
B cells		
Stromal cells		

Mucosa-Associated Lymphatic Tissue

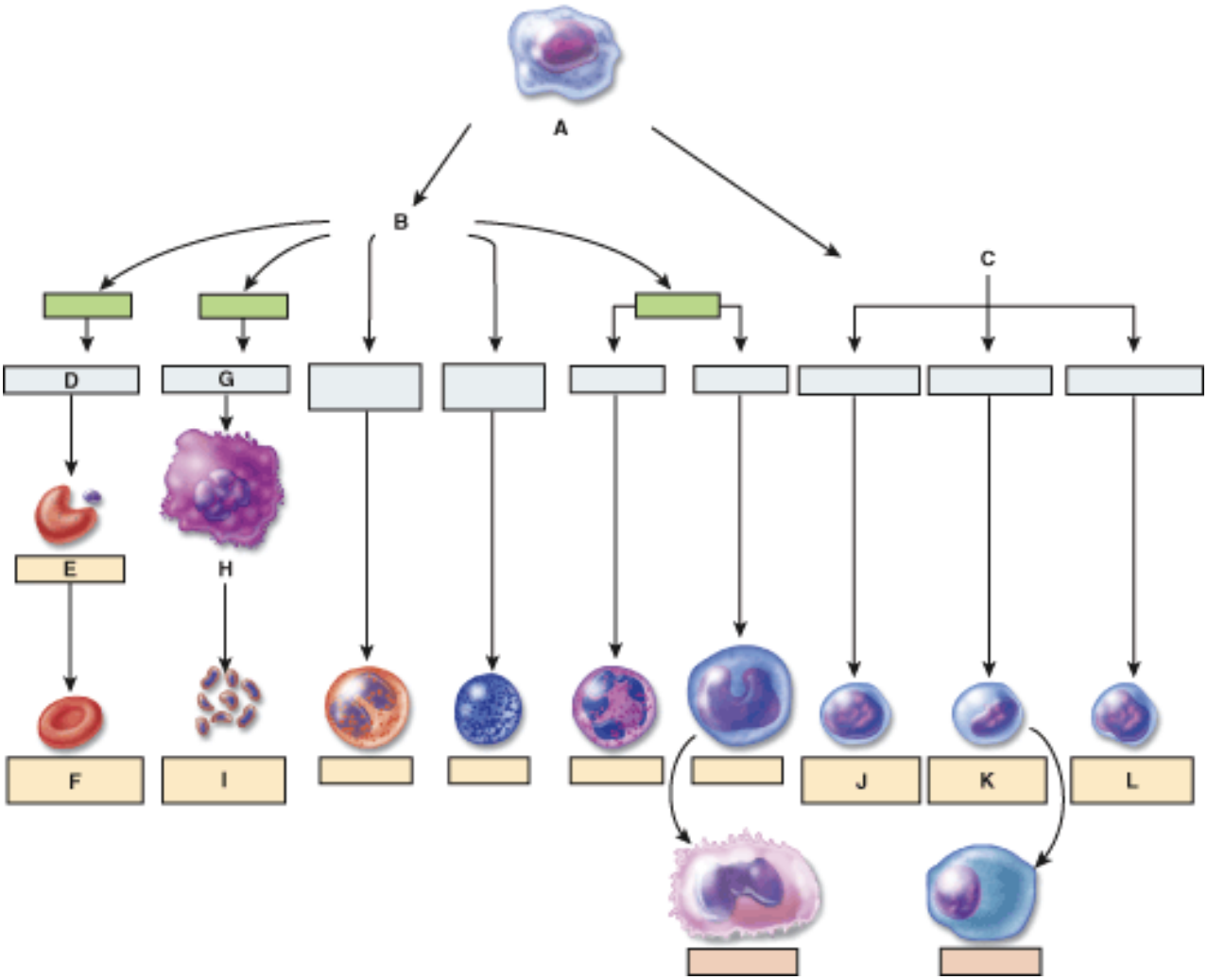
Payers patches		
Appendix		
Pharyngeal tonsil		
Primary follicle		
Secondary follicle		

Organs

Lymph nodes		
Bone marrow		
Spleen		
Thymus		

Activity 7.6: Cells of the Immune System

Use your textbook or other resources to label cells A-L in the diagram below.



Tortora and Derrickson: Principles of Anatomy and Physiology, 2017. Cardiovascular system: Blood, chapter 19. Edition 15, John Wiley and son, pp 673

A.

B.

C.

D.

E.

F.

G.

H.

I.

J.

K.

L.

The Organization of Immune Function

The immune system is a collection of barriers, cells, and soluble proteins that interact and communicate with each other in complex ways. The modern model of immune function is organized into three lines of defense based on the timing of their effects. The three timelines consist of the following: the first two lines form the innate immune response while the third the adaptive immune response.

Innate Immune Response

- **First line of defense:** Barrier defenses such as the skin and mucous membranes, which act immediately to prevent pathogenic invasion into the body tissues
- **Second line of defense**: The rapid but nonspecific **innate immune response**, which consists of a variety of specialized cells

Adaptive immune response

- **Third line of defense**: The slower but more specific and effective **adaptive immune response**, which involves many cell types, but is primarily controlled by white blood cells (leukocytes) known as **lymphocytes**

The cells of the blood, including all those involved in the immune response, arise in the bone marrow from hematopoietic stem cells. In contrast with embryonic stem cells, hematopoietic stem cells are present throughout adulthood and allow for the continuous differentiation of blood cells to replace those lost to age or dysfunction. These cells can be divided into three classes based on function:

- **Phagocytic cells**-which ingest pathogens to destroy them
- **Lymphocytes**-which specifically coordinate the activities of adaptive immunity
- **Granulated cells**-which help mediate immune responses against parasites and intracellular pathogens such as viruses

Lymphocytes

As stated above, lymphocytes are the primary cells of adaptive immune responses. The two basic types of lymphocytes, B cells and T cells, are identical morphologically with a large central nucleus surrounded by a thin layer of cytoplasm and both originate from bone marrow. They are distinguished from each other by their surface protein markers as well as by the molecules they secrete. While B cells mature in red bone marrow, T cells mature in the thymus. Immature T cells migrate from bone marrow to the thymus gland. B cells and T cells are found in many parts of the body, circulating in the bloodstream and lymph, and residing in secondary lymphoid organs, including the spleen and lymph nodes.

B cells are immune cells that function primarily by producing antibodies. An **antibody** is any of the group of proteins that binds specifically to pathogen-associated molecules known as antigens. An **antigen** is a chemical structure on the surface of a pathogen that binds to T or B lymphocyte antigen receptors. Once activated by binding to antigen, B cells differentiate into cells that secrete a soluble form of their surface antibodies. These activated B cells are known as plasma cells.

Plasma Cells

Another type of lymphocyte of importance is the plasma cell. A **plasma cell** is a B cell that has differentiated in response to antigen binding and has thereby gained the ability to secrete soluble antibodies. These cells differ

in morphology from standard B and T cells in that they contain a large amount of cytoplasm packed with the protein-synthesizing machinery known as rough endoplasmic reticulum.

T Cells

The **T cell** does not secrete antibody; but, performs a variety of functions in the adaptive immune response. Different T cell types could either secrete soluble factors that communicate with other cells of the adaptive immune response or destroy cells infected with intracellular pathogens.

Natural Killer Cells

A fourth important lymphocyte is the natural killer cell, a participant in the innate immune response. A **natural killer cell (NK)** is a circulating blood cell that contains cytotoxic (cell-killing) granules in its extensive cytoplasm. It shares this mechanism with the cytotoxic T cells of the adaptive immune response. NK cells are among the body's first lines of defense against viruses and certain types of cancer.

Activity 7.7: Cells of the Immune System

Use your textbook or other resources to complete the table below.

Cell	Description/Function
Macrophage	
Neutrophil	
Eosinophil	
Basophil	
Dendritic	
Reticular	
T cell	
Natural killer	
Plasma cell	

Activity 7.8: Immune System

Use your textbook or other resources to fill in the space with the appropriate letter on the right, these describe the basic functions of the immune system

Terms	Answer	Function
Innate Immunity		a. redness, warmth, swelling, and pain as a result of infection
Adaptive Immunity		b. slow and possesses memory of previous antigen
Antigen		c. first and second lines of defense of the immune system
Cell Mediated Immunity		d. proteins produce by cells to coordinate an immune response
Antibody Mediated Immunity		e. foreign substance that induce immune response
Surface Barrier		f. over 30 protein secreted mainly by the liver that help to destroy antigen
Phagocytes		g. cells capable of engulfing antigen
Cytokines		h. destruction of antigen by B cell
Inflammation		i. Destruction of intracellular antigen
Complement System		j. skin and antimicrobial protein

Post Lab Review Questions

1. What is the function of the thymus?

2. What is the function of the spleen?

3. What are the differences between T cells and B cells?

4. Which of the following cells is phagocytic?

a. plasma cell b. macrophage
c. T cell d. NK cell

5. Which structure allows lymph from the lower right limb to enter the bloodstream?
   a. thoracic duct
   b. right lymphatic duct
   c. right lymphatic trunk
   d. left lymphatic trunk

6. Which of the following cells is important in the innate immune response?
   a. B cells
   b. T cells
   c. macrophages
   d. plasma cells

7. Which of the following cells would be most active in early, antiviral immune responses the first time one is exposed to pathogen?
   a. macrophage
   b. T cell
   c. neutrophil
   d. natural killer cell

8. Which of the lymph nodules are most likely to see food antigens first?
   a. tonsils
   b. Peyer's patches
   c. bronchus-associated lymphoid tissue
   d. mucosa-associated lymphoid tissue

9. Which of the following signs is *not* characteristic of inflammation?
   a. redness
   b. pain
   c. cold
   d. swelling

10. Which of the following is *not* important in the antiviral innate immune response?
   a. interferons
   b. natural killer cells
   c. complement
   d. microphages

11. Enhanced phagocytosis of a cell by the binding of a specific protein is called _____.
   a. endocytosis
   b. opsonization
   c. anaphylaxis
   d. complement activation

12. Which of the following leads to the redness or inflammation?
   a. increased vascular permeability b. anaphylactic shock
   c. increased blood flow d. complement activation