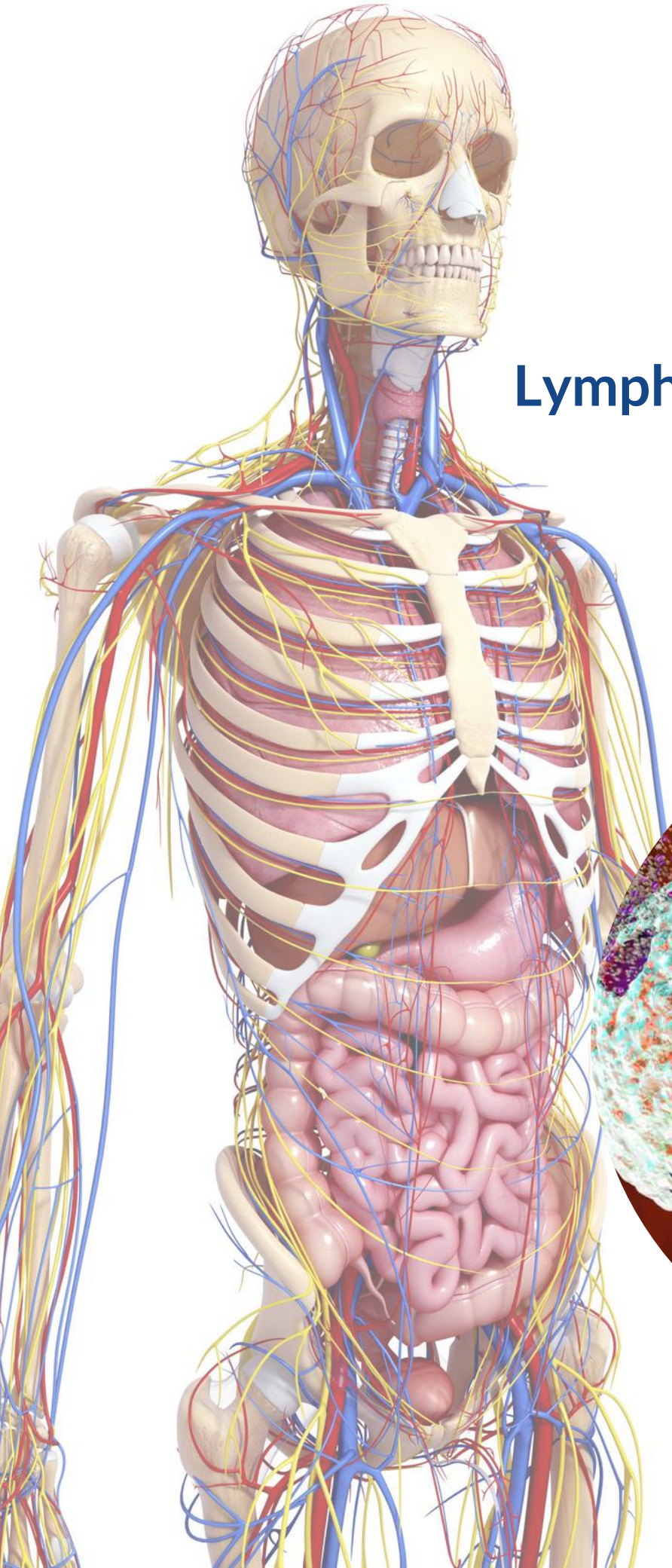
Lymphatic/Immune System Lesson Plan

Grade 12



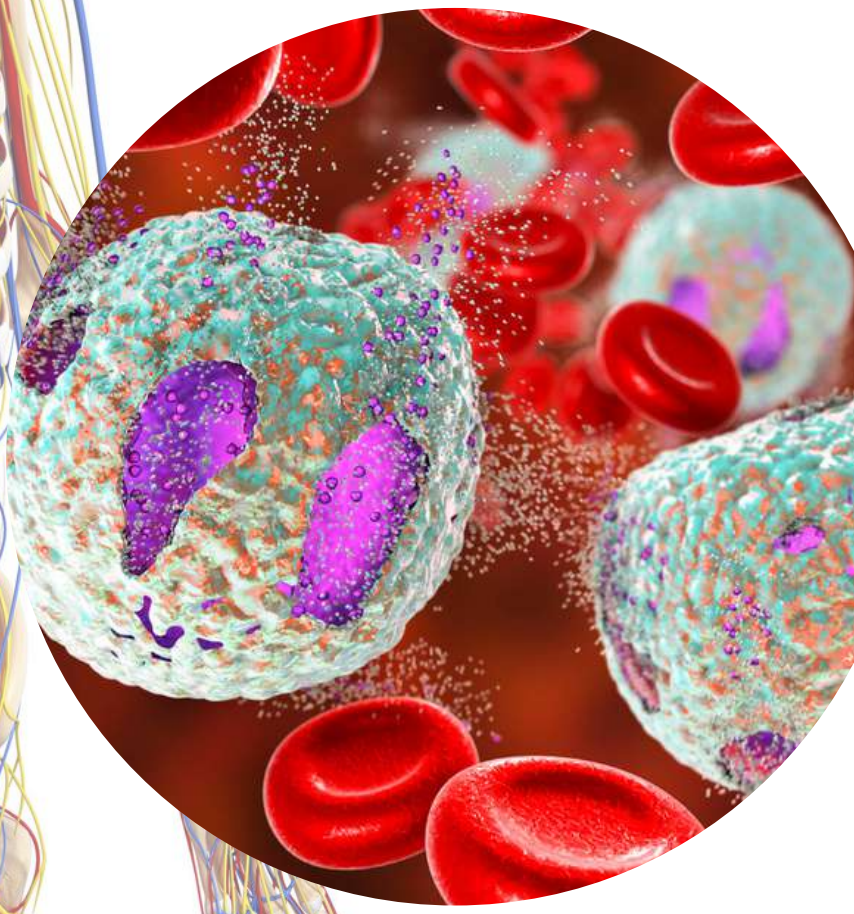


TABLE OF CONTENTS

The following unit plan was created in accordance with the Canadian Council on Animal Care's recommendations to replace any present procedures involving the use of animals in teaching, testing and research.

The Three Rs principle of Replacement states, if you can meet your scientific or educational goals without the use of animals, it is your ethical obligation to use non-animal methods. Grade 12 anatomy content is often taught using fetal pigs - here we offer an effective and humane alternative.

This is in alignment with the public's concern for animal welfare and a cultural respect for animals passed down from the Aboriginal perspectives of the First Peoples.

Elisabeth Ormandy created this unit plan and series of lesson plans for your use in teaching life science content to Grades 12 based on the BC Science Curriculum.

These Humane Science Education materials were developed to provide equivalent or greater standards in education for Canadian youth, without the use of animals.

Curriculum Alignment

This lesson plan can be used to create classes for Grades 12 based on the BC Science Curriculum. Specific **Big Ideas** covered in this lesson plan include:

Grade 12 - Organ systems have complex interrelationships to maintain homeostasis.

ORGAN SYSTEMS:

- Structure and function
- Structural and functional interdependence
- Maintenance of homeostasis

We have recommended specific virtual anatomy tools to use to get the most out of the unit plan. You'll find links to those on pages 5&6.

Lesson Plan Overview

Subject: Science

Unit Overview: Anatomy and Physiology

Unit Duration: ~90 minutes

Grade: 12

Big Idea: Organ systems have complex interrelationships to maintain homeostasis

Curricular Competencies

- *Analyze cause-and-effect relationships*
- *Construct, analyze, and interpret graphs, models, and/or diagrams*
- *Consider the changes in knowledge over time as tools and technologies have developed*

Content

- By the end of this lesson, students are expected to demonstrate understanding of the following:
  - *Lymphatic/immune system:*
    - *structure and function*
    - *structural and functional interdependence*
    - *maintenance of homeostasis*

Recommended Education Tools

Hardware & Workbooks:

This inventory is for a regular in-person class - use x1 iPad/tablet per student for responsible physical distancing. If teaching online, teachers can screen share their iPad/tablet or desktop.

- 6 (or more) iPads or other tablets
- 6 (or more) 3D Anatomica workbooks

Recommended Software:

- 3D Anatomica: https://3danatomica.com
- 3D4Medical Complete Anatomy: https://3d4medical.com

Lesson Plan Overview

Topic: Organ systems have complex interrelationships to maintain homeostasis. Homeostasis is maintained through physiological processes.

Content: The human lymphatic & immune system: organs, structure and function

Goals	Students will be able to: • Describe the function of the lymphatic system and its major components. • Describe the relationships between the different components of the lymphatic system. • Explain how the lymphatic system is interdependent with the nervous system. • Explain how the lymphatic system maintains homeostasis in the body.
Objectives	After this lesson students will state the structure and function of each tissue in the lymphatic system and explain how the musculoskeletal system is interdependent with other body systems.
Materials	• 3DAnatomica • 3D4Medical
Introduction	Using the 3DAnatomica and/or 3D4Medical app(s), the teacher will introduce the topic of the lymphatic system.
Development	Questions to support inquiry-based learning: • What is the advantage of having specialized tissues in the lymphatic system? • How does the lymphatic system help the body maintain internal balance during exercise? • What are the impacts of external stimulants (e.g. alcohol, caffeine) on the lymphatic system? • What lifestyle decisions would you make to improve your lymphatic health? • How does the lymphatic system respond to infection by a pathogen?
Practice	Students will work independently or in pairs to navigate 3DAnatomica and/or 3D4Medical to learn about the structure and function of the lymphatic system.

Lesson Plan Approach

If teaching regular in-person classes:

- Split students into **6 groups**.
- Give each group a **3D Anatomica workbook** to refer to, and one (or more) iPad(s) or tablet(s) with the **3D Anatomica app**, and **3D4Medical Complete Anatomy app** loaded and ready to use.
- Your **introduction** should include discussion of the function of the lymphatic/immune system, identifying the major components, and the vocabulary you would like students to learn (~ 15 mins). **Define homeostasis**. Have the students follow along using the 3D4Medical Complete Anatomy app.
- **Discuss sequence** of organs and structures that lymph moves through within the lymphatic system. Have students use the 3D Anatomica and 3D4Medical Complete Anatomy app to explore the flow of blood in their groups, filling their 3D Anatomica workbook and/or handouts provided. This can be student or teacher led. (40-45 mins)
- Explore the "**Components in Detail**" pages using the 3D4 Medical App. The students can cut away at the structures in the app to locate structures that need to be labeled.
- Ask students to brainstorm **ways the lymphatic/immune system interacts with other systems,** and go over the specific examples provided
- Discuss different ways the lymphatic/immune system helps maintain homeostasis using examples provided, then ask students to provide their own examples using what they've learned.
- **Close the class with a 20-minute recap** of what the students have learned, discuss how the parts of the lymphatic/immune system work together, and check for understanding. Begin a **conversation on ethics** of animals in science using the questions provided

If teaching a physically-distanced class:

- Use x1 iPad for each student and proceed as per the directions above.

If teaching online:

- Lead the students through the lymphatic/immune system by screen sharing your own iPad/tablet or desktop with the 3D4Medical Complete Anatomy app installed, filling out the tables, and labeling the models as you go
- Proceed as per the directions above

Detailed Lesson Content & Teaching Notes

Introduction to the Lesson

Include a First Nations land acknowledgement and ask students to reflect on what respect for animals means to them. Provide an introduction to the apps and models that will be used in class.

Introduction to the Topic

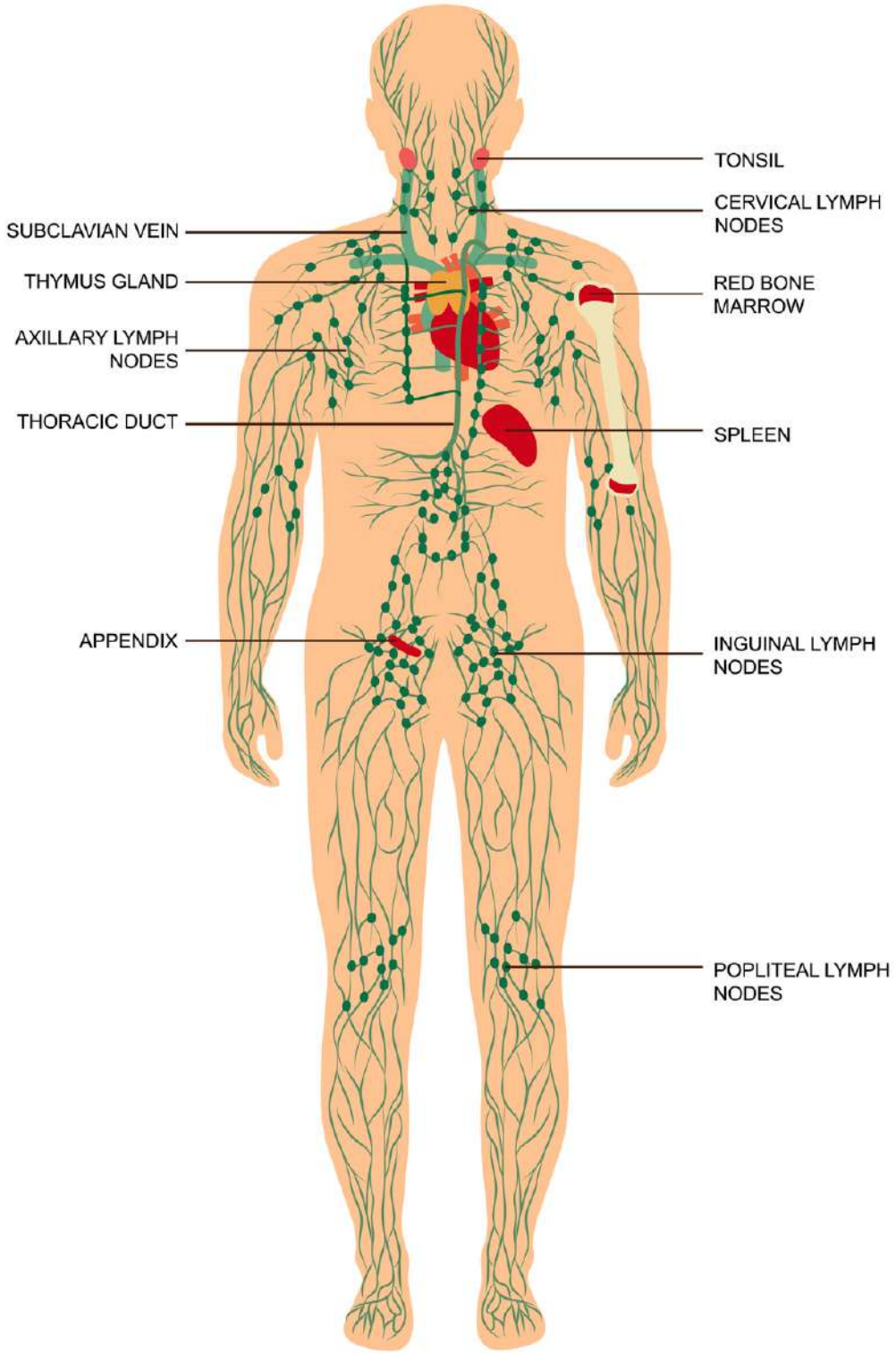
Students will use **3DAnatomica** and **3D4Medical Complete Anatomy** app to explore the musculoskeletal system at large. We recommend covering the function of the circulatory system, identifying the major components of the system, and discussing the vocabulary you would like the students to learn (such as the names of major lymph organs, vessels and cells) early in the lesson.

THE LYMPHATIC/IMMUNE SYSTEM AT-A-GLANCE

Function	The **immune system** is the complex collection of cells and organs that destroys or neutralizes pathogens that would otherwise cause disease or death. The **lymphatic system**, for most people, is associated with the immune system to such a degree that the two systems are virtually indistinguishable. The lymphatic system is the system of vessels, cells, and organs that carries excess fluids to the bloodstream and filters pathogens from the blood.
Components	tonsils, thymus gland, spleen, lymph nodes, lymphatic vessels
Important vocabulary	bone marrow, tonsils, thymus, spleen, lymph nodes, lymphatic vessels, lymphocytes, B cells, T cells, natural killer cells, pathogens, interstitial space, immune response,

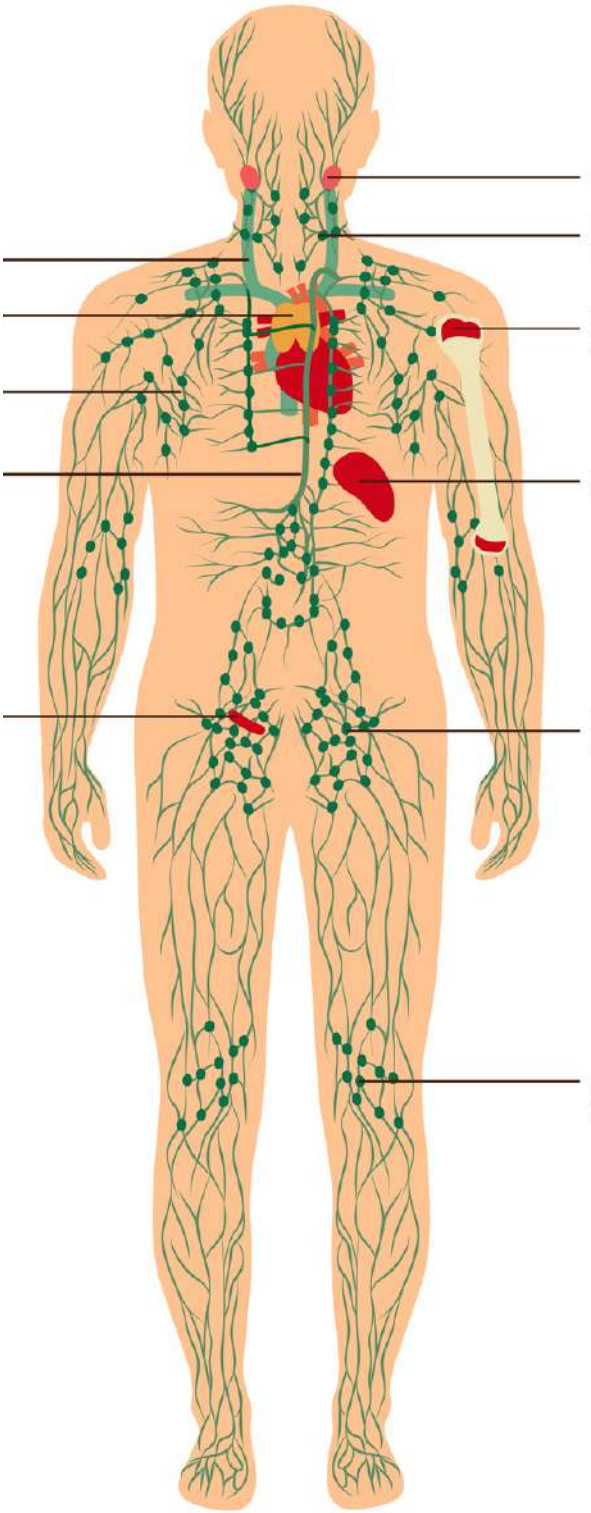
Components in Detail:

Structure of Lymphatic System (teacher copy)



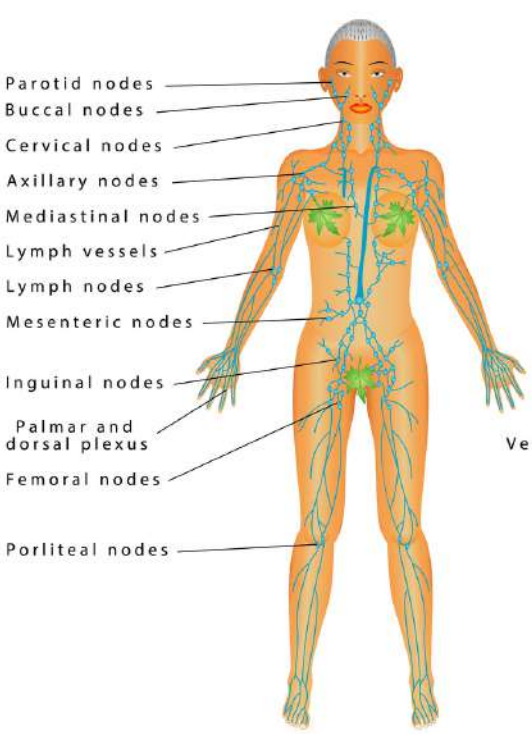
Components in Detail:

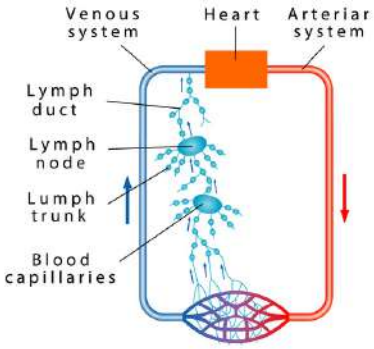
Structure of Lymphatic System (student copy)



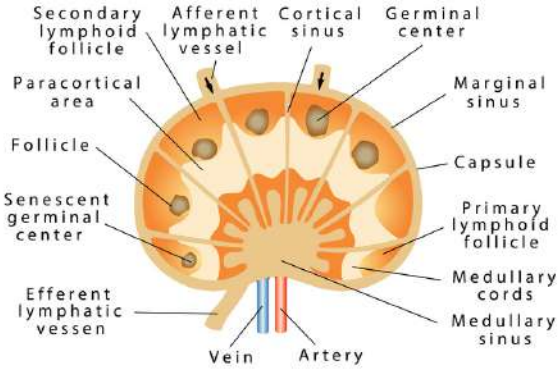
Components in Detail:

Structure of Lymphatic System - Detailed

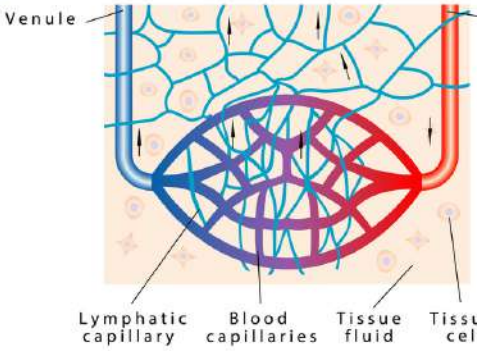


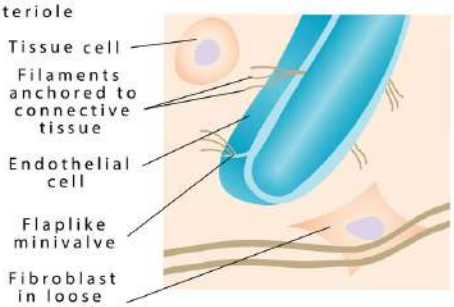


LYMPHATIC SYSTEM



LYMPH NODE





Lymphatic capillaries are interlaced with the **arterioles** and **venules** of the cardiovascular system. **Collagen fibres** anchor a lymphatic capillary in the tissue. **Interstitial flui**d slips through spaces between the overlapping endothelial cells that compose the lymphatic capillary.

The lymphatic vessels begin as open-ended **capillaries**, which feed into larger and larger lymphatic vessels, and eventually empty into the bloodstream by a series of ducts. Along the way, the lymph travels through the **lymph nodes**, which are commonly found near the groin, armpits, neck, chest, and abdomen. Humans have about **500–600** lymph nodes throughout the body

A major distinction between the lymphatic and cardiovascular systems in humans is that **lymph is not actively pumped by the heart**, but is forced through the vessels by the movements of the body, the contraction of skeletal muscles during body movements, and breathing. One-way valves (**semi-lunar valves**) in lymphatic vessels keep the lymph moving toward the heart. Lymph flows from the lymphatic capillaries, through lymphatic vessels, and then is dumped into the circulatory system via the **lymphatic ducts** located at the junction of the jugular and subclavian veins in the neck.

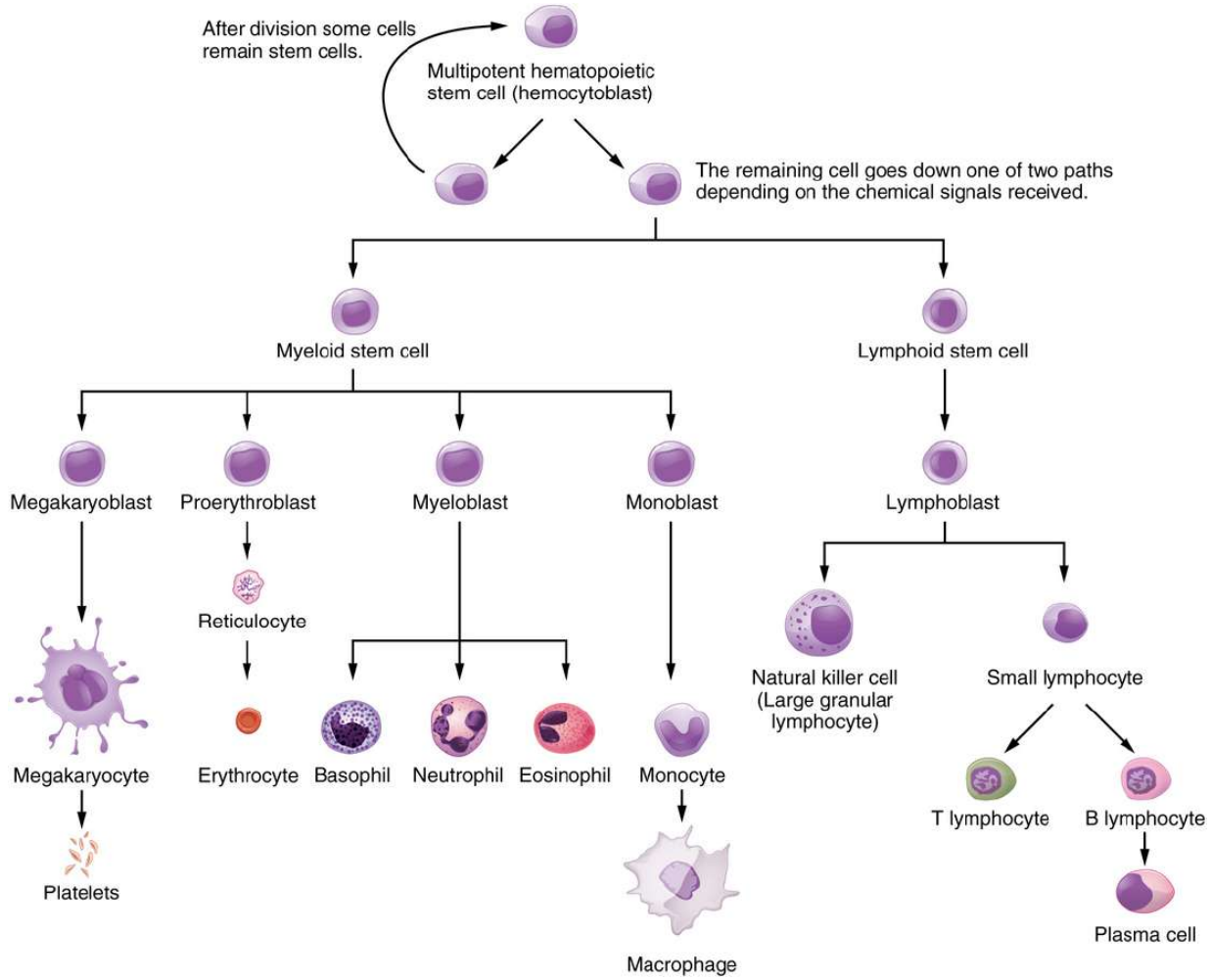
Components in Detail:

Function of the Lymphatic System

A major function of the lymphatic system is to **drain body 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 litres 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 litres is reabsorbed directly by the blood vessels. But what happens to the remaining three litres? 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 being blocked by cancer cells or destroyed by injury, protein-rich interstitial fluid accumulates (sometimes "backs up" from the lymph vessels) in the tissue spaces. This inappropriate accumulation of fluid referred to as **lymphedema** may lead to serious medical consequences.

As the vertebrate immune system evolved, the network of lymphatic vessels became convenient avenues for transporting the cells of the immune system. Additionally, the transport of dietary lipids and fat-soluble vitamins absorbed in the gut uses this system. Cells of the immune system not only use lymphatic vessels to make their way from interstitial spaces back into the circulation, but they also use **lymph nodes** as major staging areas for the development of critical **immune responses**. A lymph node is one of the small, bean-shaped organs located throughout the lymphatic system.

Components in Detail:
Organization of Immune Function



The **immune system** is a collection of barriers, cells, and soluble proteins that interact and communicate with each other in extraordinarily complex ways. The modern model of immune function is organized into three phases based on the timing of their effects. The three temporal phases consist of the following:

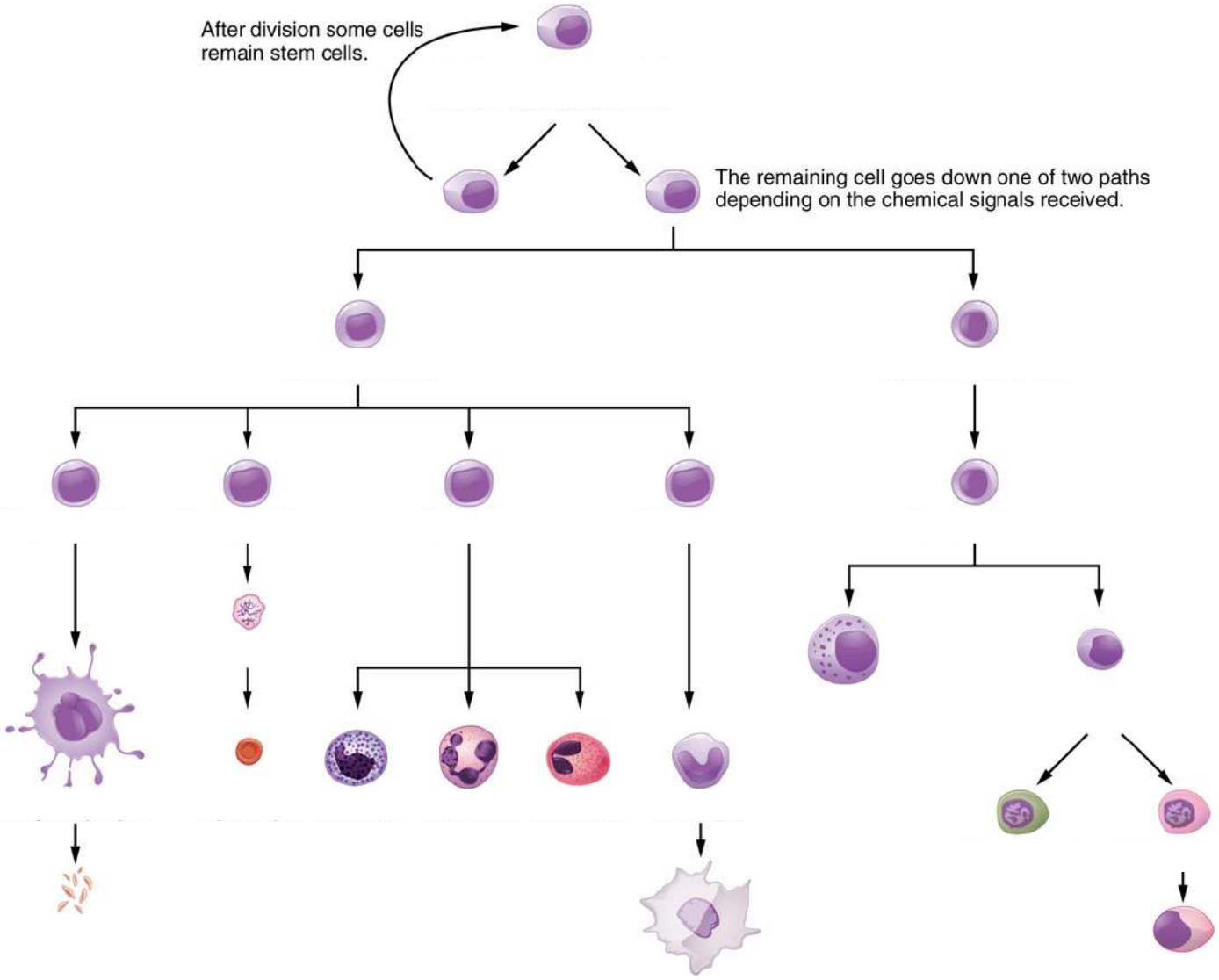
- **Barrier defenses** such as the skin and mucous membranes, which act instantaneously to prevent pathogenic invasion into the body tissues
- The rapid but nonspecific **innate immune response**, which consists of a variety of specialized cells and soluble factors
- The slower but more specific and effective **adaptive immune response**, which involves many cell types and soluble factors, but is primarily controlled by white blood cells (leukocytes) known as lymphocytes, which help control immune responses

The cells of the blood, including all those involved in the immune response, arise in the **bone marrow** via various differentiation pathways 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 function. 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
- **Cells containing cytoplasmic granules**, which help mediate immune responses against parasites and intracellular pathogens such as viruses

Components in Detail:

Organization of Immune Function (student copy)



Components in Detail:

Lymphocytes - B cells, T cells and Natural Killer Cells

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. 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** and **T cells mature in the thymus**, they both initially develop from bone marrow. T cells migrate from bone marrow to the thymus gland where they further mature. 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. The human body contains approximately 1012 lymphocytes.

B CELLS

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**.

T CELLS

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

PLASMA CELLS

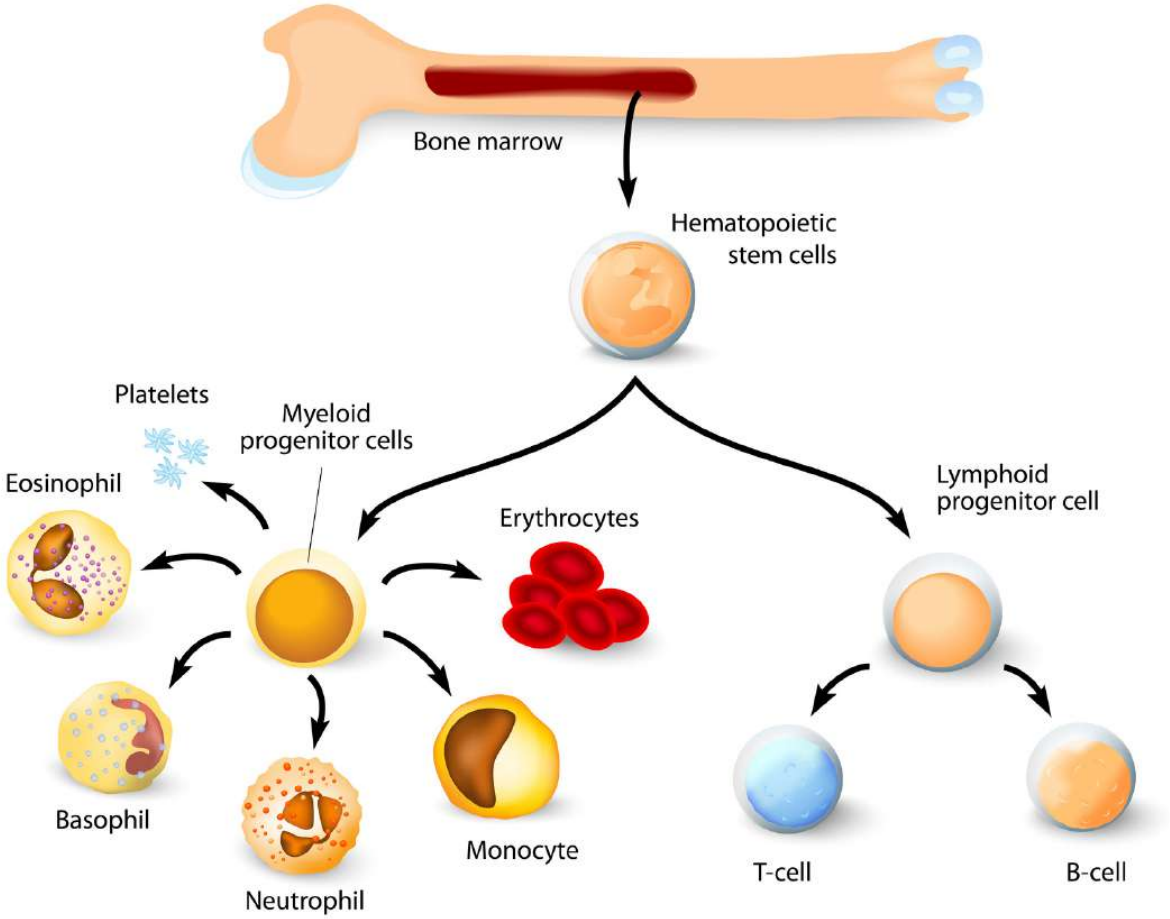
Another type of lymphocyte of importance is the **plasma cell**. A plasma cell is a B cell that has differentiated in response to antigen binding, and has thereby gained the ability to secrete soluble antibodies. These cells differ in morphology from standard B and T cells in that they contain a large amount of **cytoplasm** packed with the protein-synthesizing machinery known as **rough endoplasmic reticulum**.

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.

Components in Detail:

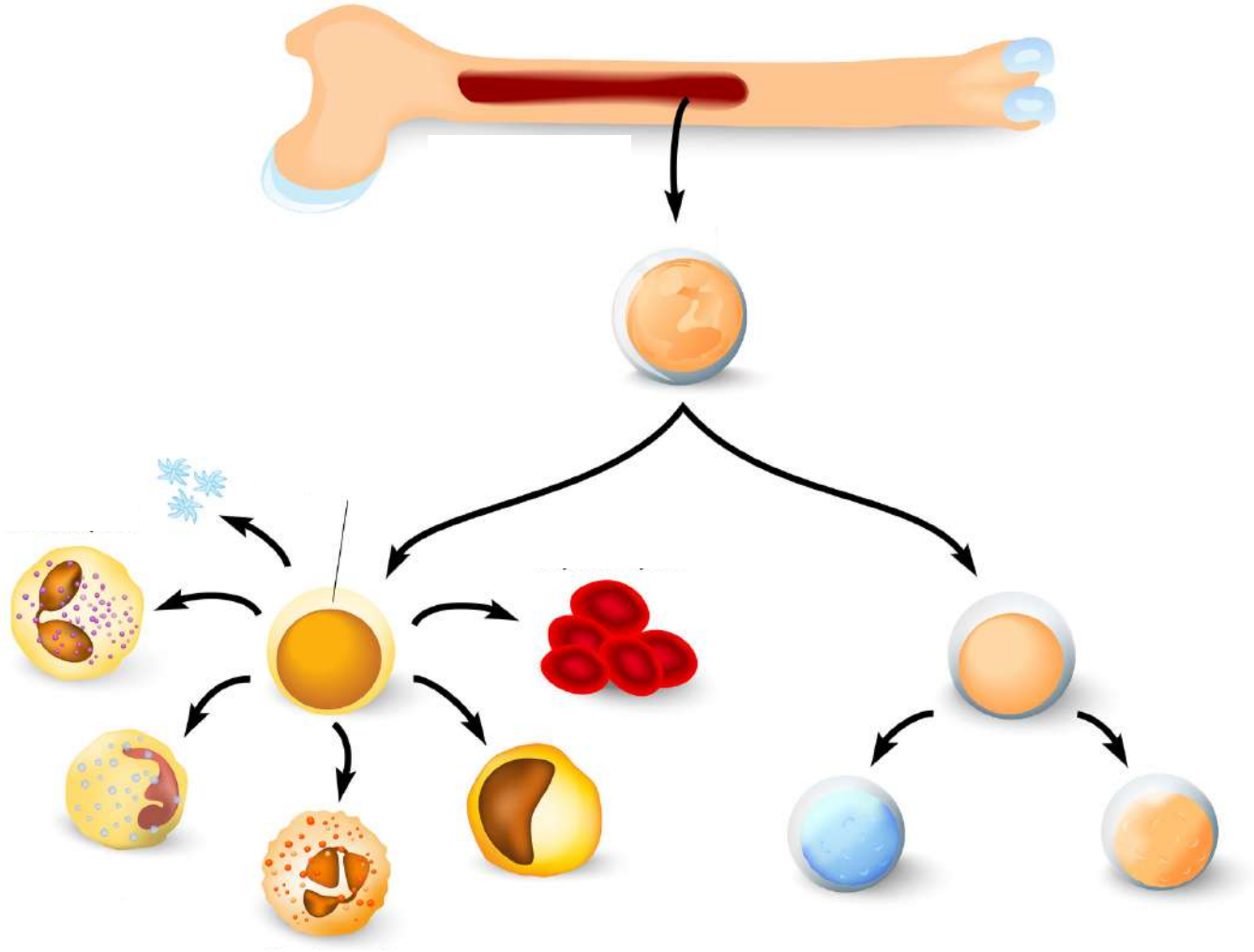
Primary Lymphoid Organs - Bone Marrow



In the embryo, blood cells are made in the **yolk sac**. As development proceeds, this function is taken over by the **spleen, lymph nodes, and liver**. Later, the bone marrow takes over most hematopoietic functions, although the final stages of the differentiation of some cells may take place in other organs. The red bone marrow is a loose collection of cells where **hematopoiesis** occurs, and the yellow bone marrow is a site of energy storage, which consists largely of fat cells. The **B cell** undergoes nearly all of its development in the **red bone marrow**, whereas the immature **T cell**, called a **thymocyte**, leaves the bone marrow and matures largely in the **thymus gland**.

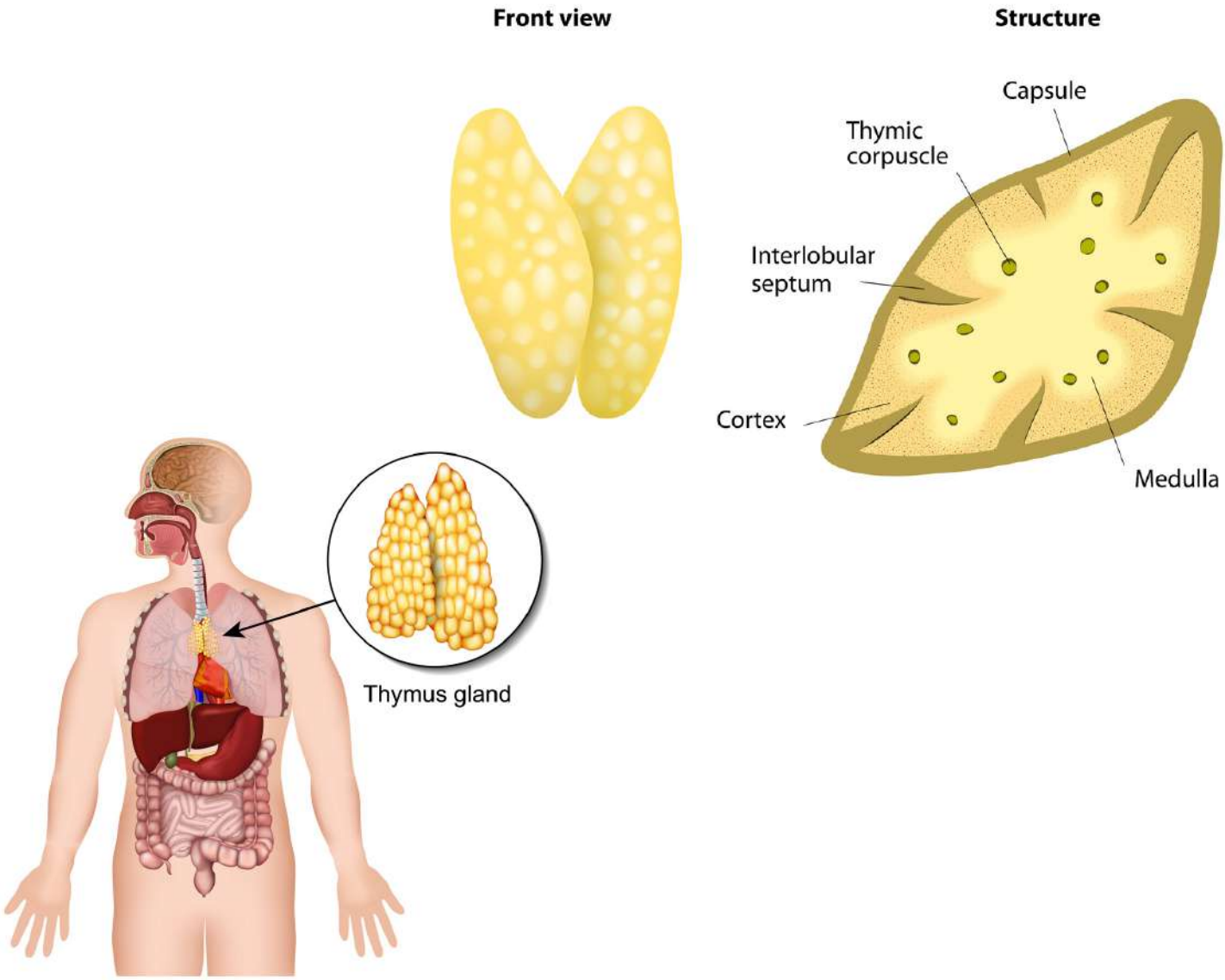
Components in Detail:

Primary Lymphoid Organs - Bone Marrow (student copy)



Components in Detail:

Primary Lymphoid Organs - Thymus

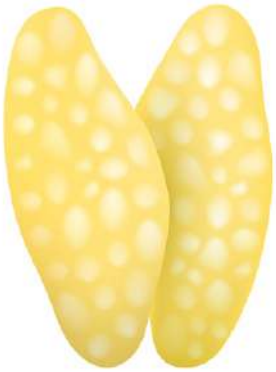


The **thymus gland** is a bilobed organ found in the space between the **sternum** and the **aorta** of the heart. Connective tissue holds the lobes closely together but also separates them and forms a **capsule**. The connective tissue capsule further divides the thymus into lobules via extensions called **trabeculae**. The outer region of the organ is known as the **cortex** and contains large numbers of **T cells (thymocytes)** with some epithelial cells, macrophages, and dendritic cells (two types of phagocytic cells that are derived from monocytes). The cortex is densely packed so it stains more intensely than the rest of the thymus. The **medulla**, where thymocytes migrate before leaving the thymus, contains a less dense collection of thymocytes, epithelial cells, and dendritic cells.

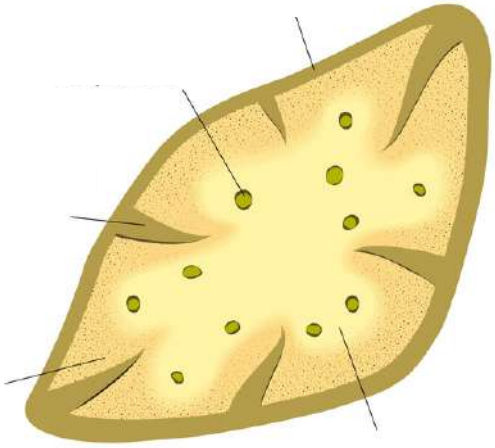
Components in Detail:

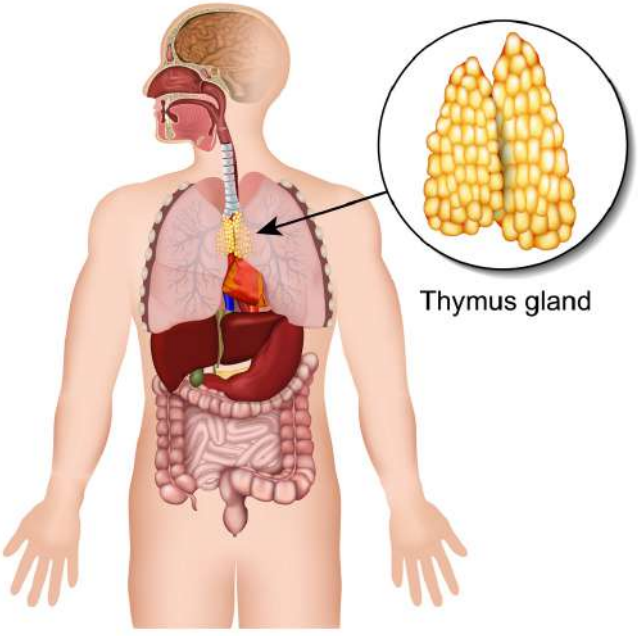
Primary Lymphoid Organs - Thymus (student copy)

Front view



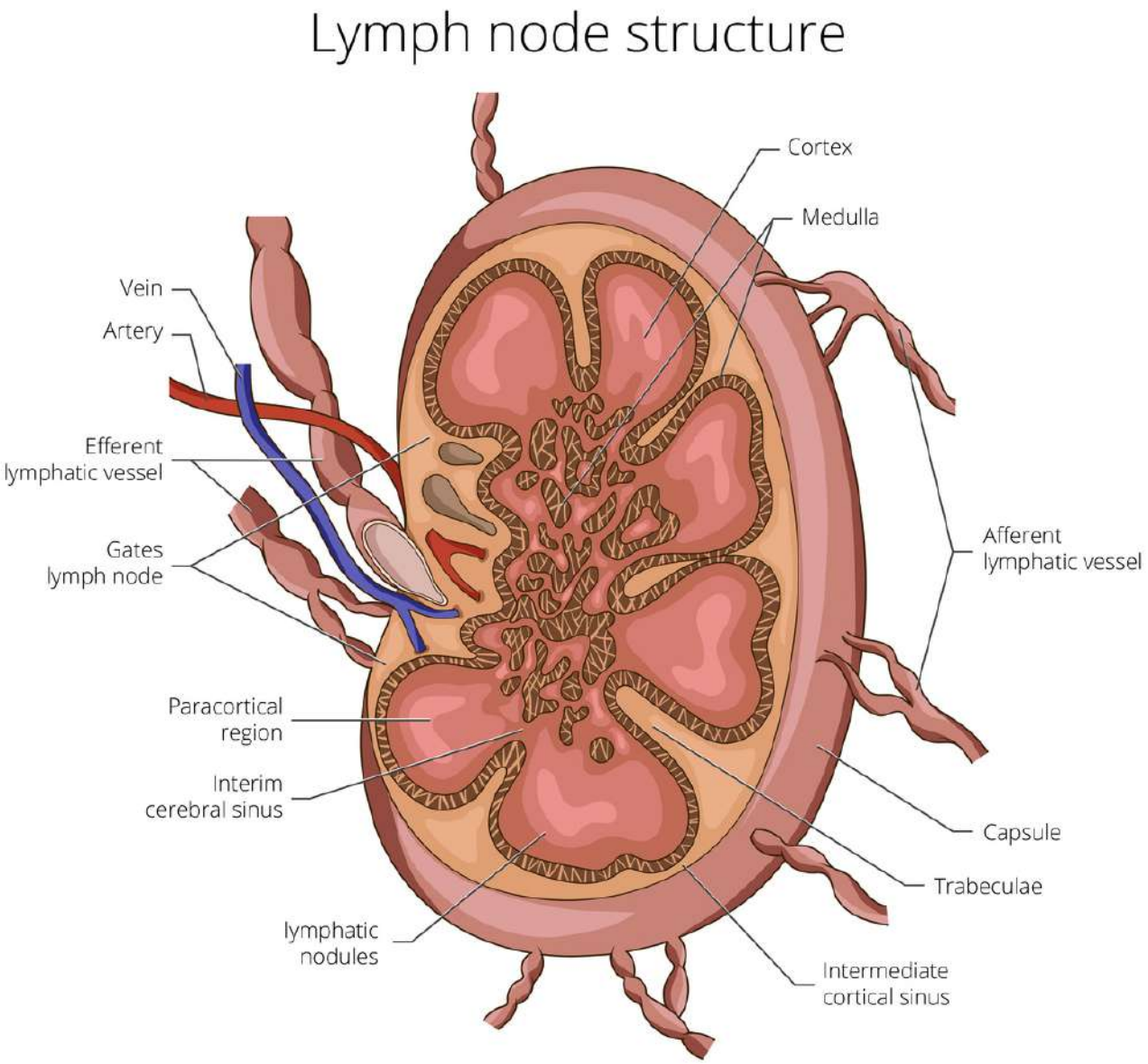
Structure





Components in Detail:

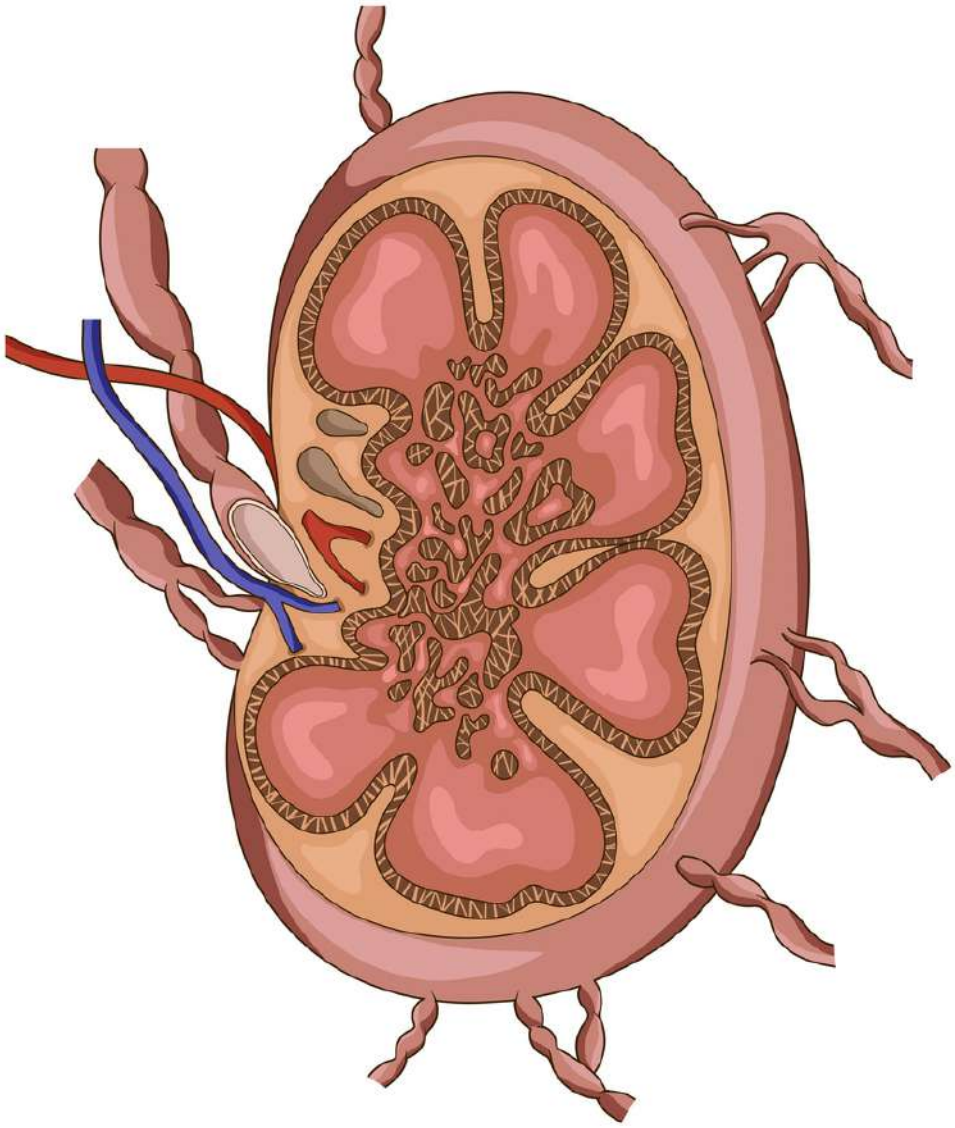
Secondary Lymphoid Organs - Lymph Nodes



Lymph nodes function to remove debris and pathogens from the lymph, and are thus sometimes referred to as the "filters of the lymph". 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. The lymph node is also the site of **adaptive immune responses** mediated by **T cells**, **B cells**, and **accessory cells** of the adaptive immune system. Like the thymus, the bean-shaped lymph nodes are surrounded by a tough capsule of connective tissue and are separated into compartments by **trabeculae**, the extensions of the capsule. In addition to the structure provided by the capsule and trabeculae, the structural support of the lymph node is provided by a series of **reticular fibres** laid down by **fibroblasts**.

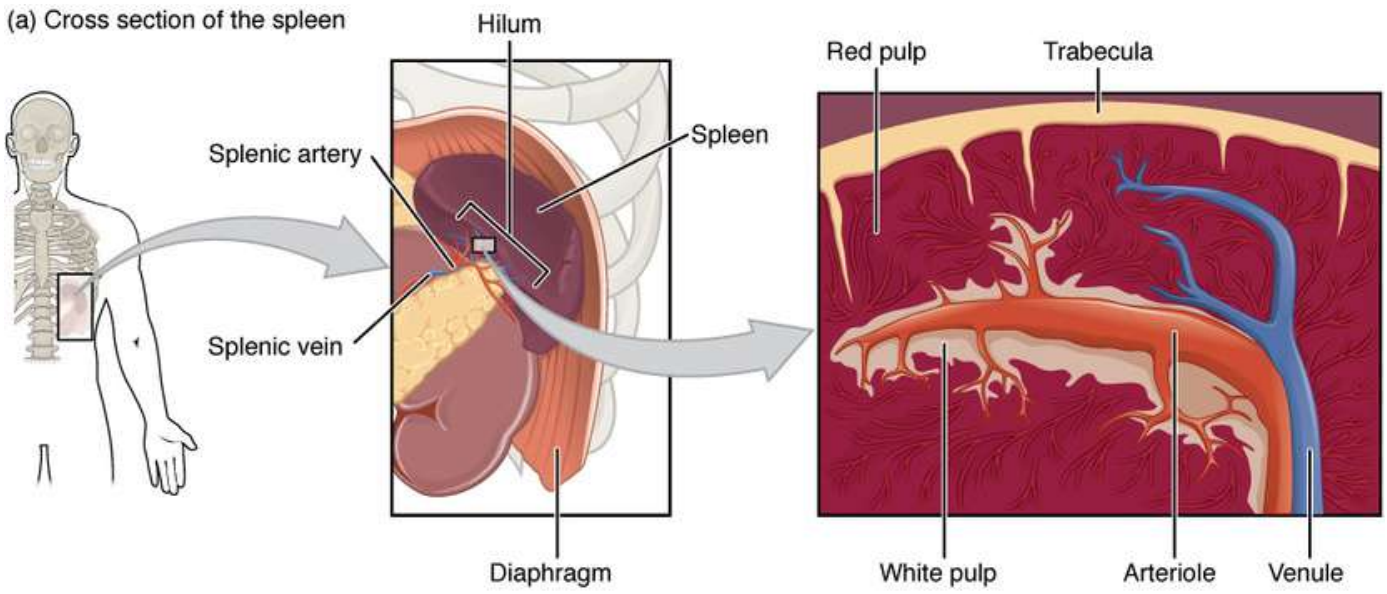
Components in Detail:

Secondary Lymphoid Organs - Lymph Nodes



Components in Detail:

Secondary Lymphoid Organs - Spleen

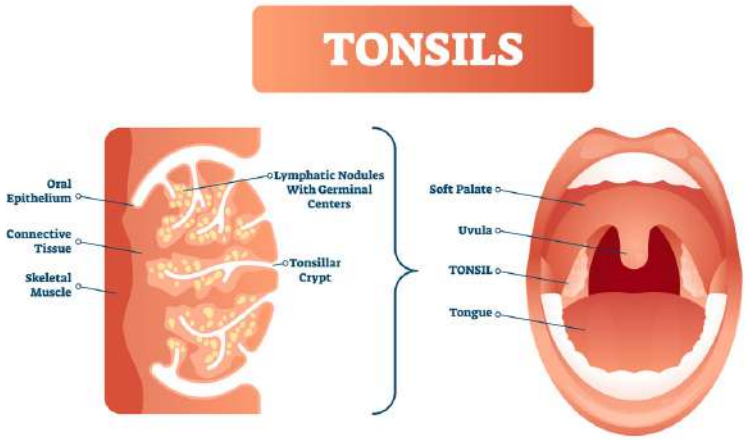


In addition to the lymph nodes, the **spleen** is a major secondary **lymphoid organ**. It is about 12 cm (5 in) long and is attached to the lateral border of the stomach via the gastrosplenic ligament. The spleen is a fragile organ without a strong **capsule**, and is dark red due to its extensive vascularization. The spleen is sometimes called the "filter of the blood" because of its extensive vascularization and the presence of **macrophages** and **dendritic cells** that remove microbes and other materials from the blood, including dying red blood cells. The spleen also functions as the location of immune responses to blood-borne pathogens.

The spleen is also divided by **trabeculae** of connective tissue, and within each splenic nodule is an area of **red pulp**, consisting of mostly red blood cells, and **white pulp**, which resembles the lymphoid follicles of the lymph nodes. Upon entering the spleen, the **splenic artery** splits into several **arterioles** (surrounded by white pulp) and eventually into **sinusoids**. Blood from the capillaries subsequently collects in the **venous sinuses** and leaves via the **splenic vein**. The red pulp consists of **reticular fibers** with fixed macrophages attached, free macrophages, and all of the other cells typical of the blood, including some lymphocytes. The white pulp surrounds a central arteriole and consists of **germinal centers** of dividing **B cells** surrounded by **T cells** and accessory cells, including macrophages and dendritic cells. Thus, the red pulp primarily functions as a filtration system of the blood, using cells of the relatively nonspecific immune response, and white pulp is where adaptive T and B cell responses are mounted.

Components in Detail:

Secondary Lymphoid Organs - 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 located 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 tonsil located at the back of the throat, the **pharyngeal tonsil**, 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. This seems to be the major function of tonsils—to help children's bodies recognize, destroy, and develop immunity to common environmental pathogens so that they will be protected in their later lives. Tonsils are often removed in those children who have recurring throat infections, especially those involving the **palatine tonsils** on either side of the throat, whose swelling may interfere with their breathing and/or swallowing.

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 underlying 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 (Figure 10). 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.

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.

How Does the Lymphatic System Work Together With Other Organ Systems?

Musculoskeletal System: Lymphocytes and macrophages arise from bone marrow cells; skeleton protects thymus and spleen. Skeletal muscle pump moves lymph through lymphatic vessels.

Nervous System: Neuropeptides and emotional states affect immune function; blood-brain barrier prevents antibodies and immune cells from entering brain tissue.

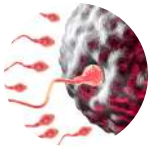
Endocrine System: Lymph transports some hormones. Hormones from thymus stimulate development of lymphatic organs and T cells; stress hormones depress immunity and increase susceptibility to infection and cancer.

Cardiovascular system: Circulatory would soon fail without return of fluid and protein by lymphatic system; spleen disposes of expired erythrocytes and recycles iron; lymphatic organs prevent accumulation of debris and pathogens in blood. Lymphatic vessels develop from embryonic veins; arterial pulsation aids flow of lymph in neighbouring lymphatic vessels; leukocytes serve in nonspecific and specific defense; blood transports immune cells, antibodies, complement, interferon, and other immune chemicals; capillary endothelial cells signal areas of tissue injury and stimulate margination and diapedesis of leukocytes; blood clotting restricts spread of pathogens.

Respiratory System: Alveolar macrophages remove debris from lungs. Provides immune system with O2; disposes of CO2; thoracic pump aids lymph flow; pharynx houses tonsils.

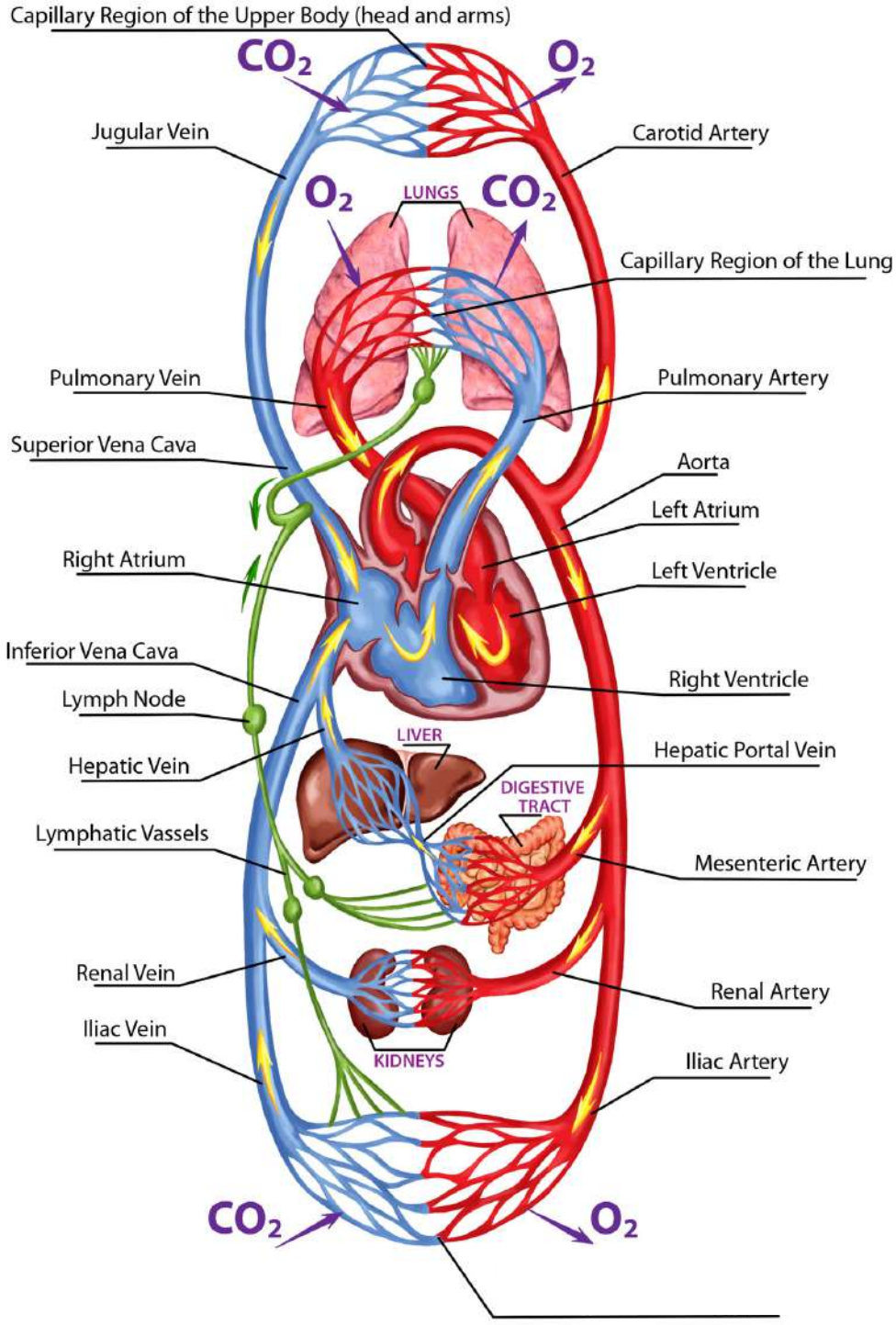
Urinary System: Absorbs fluid and proteins in kidneys, which is essential to enabling kidneys to concentrate the urine and conserve water. Eliminates waste and maintains fluid and electrolyte balance important to lymphatic and immune function; urine flushes some pathogens from body; acidic pH of urine protects against urinary tract infection.

Digestive System: Lymph absorbs and transports digested lipids. Nourishes lymphatic system and affects lymph composition; stomach acid destroys ingested pathogens



Reproductive System: Immune system requires that the testes have a blood-testis barrier to prevent autoimmune destruction of sperm. Vaginal acidity inhibits growth of pathogens.

How Does the Lymphatic System Help Maintain Homeostasis?



The lymphatic system helps **maintain fluid balance** in the body by collecting excess fluid and particulate matter from tissues and depositing them in the bloodstream.

Closing Check-In and Discussion

During the check closing in:

Recap with the students the lymphatic/immune system and the structure and function of the major organs, tissues and vessels. Go over ways the lymphatic system interacts with other body systems, as well as how it helps maintain homeostasis. Ask the following questions:

- **How might virtual dissections and models compare with using real specimens?**
- **Were you able to successfully learn the structure and function of individual parts of the lymphatic system?**

Closing - Discussion on Ethics

The knowledge to create these accurate virtual models of the lymphatic system had to initially come from real humans and or animals. However, now that we have such a plentiful resources for accurate models of these structures, as well as the ability to perform dissections virtually, do you think we need to continue using animals? Why or Why not?

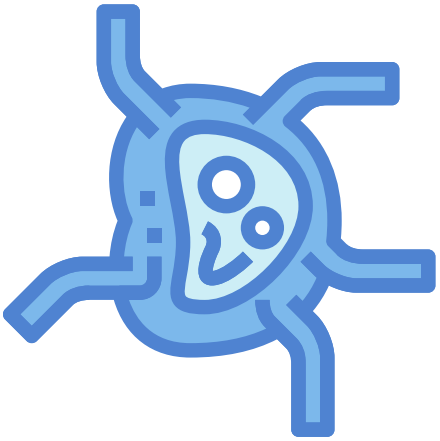
Think

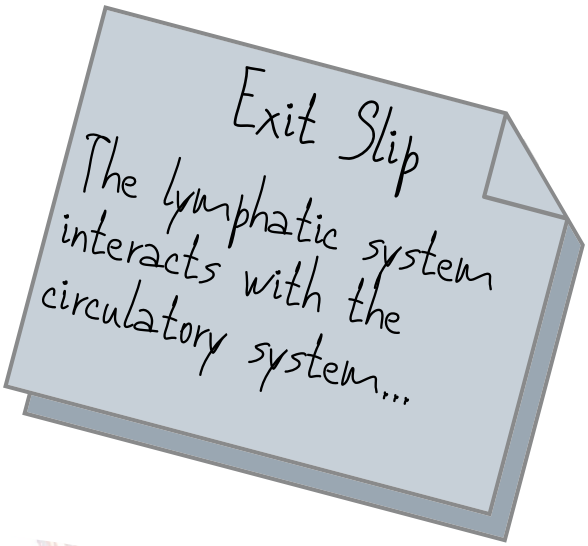
Ask the students to think about where they stand on the subject of animal dissections and the use of animals in science. They don't need to answer right away, rather, this is to get them to start forming their own ethical opinions.

Formative Assessment

The formative assessment can be in the form of an exit slip. This involves asking each student at the end of the class to answer 2-3 questions on a sheet of paper and hand it in, with their names on it, to ensure understanding of the main concepts covered. Examples of questions to include:

- **How does the lymphatic system help to maintain homeostasis within the body?**
- **What is one way the lymphatic system interacts with other body systems?**
- **Name three major white blood cells and two major lymphoid organs in the lymphatic system.**





Thank you for choosing these materials to support your class adventures!

These Humane Science Education materials were developed by Elisabeth Ormandy for the Canadian Society for Humane Science (2015-2022) working to achieve better science without animals. By choosing these unit plans, you have joined a growing family of Humane Science Educators!

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We gratefully acknowledge the support of the following funders of this Humane Science Education Program:

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