The lymphatic system includes: lymph, lymphatic vessels, lymphatic tissue, lymphatic nodules, lymph nodes, tonsils, the spleen, and the thymus.

The major functions of the lymphatic system include fluid balance, fat absorption, and defense.

Recall that as blood flows thru systemic capillaries, a small net amount of fluid is exuded into the interstitial space. While this fluid loss from the capillaries is necessary to maintain the presence and composition of tissue fluid (and thus intracellular fluid as well), too much fluid loss is not a good thing. Luckily, we have **lymphatic vessels**, whose main function is to return this fluid to the vascular system. Additionally, they play a huge role in detecting pathogens and activating the appropriate immune response.

Lymphatic vessels return approximately 3L of fluid to the vascular system per day. This ensures that blood volume is sufficient. They also return any leaked plasma proteins back to the bloodstream. Fluid within lymphatic vessels is known as **lymph**. Lymph is similar to plasma except it contains fewer proteins. It contains water, nutrients, ions, gases, wastes, and hormones.

Lymphatic vessels are a 1-way system flowing toward the heart. There are several types of lymphatic vessels including: **lymphatic capillaries**, **lymphatic collecting vessels**, **lymphatic trunks**, and **lymphatic ducts**.

Lymphatic capillaries are blind capillaries found almost everywhere blood capillaries are found, i.e., everywhere tissue fluid is formed. Areas w/o lymphatic capillaries include bones, teeth, and CNS. Little ISF is found w/i bones and teeth. CNS ISF drains into the cerebrospinal fluid. The simple squamous epithelial cells of the capillary wall overlap and are loosely attached to another. This makes the lymphatic capillaries quite permeable (much more so than blood capillaries) and ensures that fluid is able to enter but not leave. Fluid enters easily, as do proteins, WBCs, pathogens, and cancer cells. Specialized lymphatic capillaries, known as **lacteals**, are present in the intestinal mucosa where they assist in absorption of dietary fat.

Lymphatic collecting vessels receive lymph from lymphatic capillaries. They're similar to veins (tunics with similar proportions) but contain more valves. There exist both superficial and deep lymphatic collecting vessels. They pass thru **lymph nodes**, where lymph is monitored and "cleaned" of pathogens and cancer cells.

The union of the largest lymphatic vessels form **lymphatic trunks**. The **jugular trunks** drain the head and neck; the **subclavian trunks** drain the upper limbs, superficial thoracic wall, and mammary glands; the **bronchomediastinal trunks** drain thoracic organs and the deep thoracic wall; the **intestinal trunks** drain the intestines, stomach, pancreas, spleen, and liver; and the **lumbar trunks** drain the lower limbs, pelvic and abdominal walls, pelvic organs, gonads, kidneys, and adrenal glands.

The union of lymphatic trunks forms **lymphatic ducts**. There are 2 lymphatic ducts: the **right lymphatic duct** and the **thoracic duct**. The right lymphatic duct drains lymph from the right arm and the right side of the head and thorax. It receives lymph from the right jugular, right subclavian, and right bronchomediastinal trunks. It then empties into the right internal jugular vein. The thoracic duct drains lymph from the rest of the body. It receives lymph from the left jugular, left subclavian, left bronchomediastinal, intestinal, and lumbar trunks. It empties into the left internal jugular vein. Note that there is a large degree of variability in the formation and emptying of the lymphatic ducts.

There are 3 main factors responsible for lymph flow: the skeletal muscle pump, the respiratory pump, and the contraction of smooth muscle in the lymphatic vessel walls.

An inability to move lymph (perhaps due to blockage of a lymphatic vessel) can result in an excess of ISF accumulation, i.e., **edema**.

In addition to the network of lymphatic vessels, the lymphatic system also contains lymphoid organs. Lymphoid organs are made up of lymphoid tissues, which are composed of lymphoid cells.

The main lymphoid cells are the: **lymphocytes**, **macrophages**, **dendritic cells**, and **reticular cells**.

Lymphocytes are produced in red bone marrow and within lymphoid organs. There are 2 main types: **T lymphocytes** and **B lymphocytes**. T lymphocytes attack virus-infected and cancerous cells, and, more importantly, coordinate and control the immune response. B lymphocytes differentiate into **plasma cells**, which secrete **antibodies** – immune proteins.

Macrophages are, of course, phagocytes. They swallow and destroy foreign particles. They also help activate the immune response.

Dendritic cells assist in activating the immune response.

Reticular cells are fibroblast-like cells that produce the **reticular fibers** that form the framework upon which lymphoid organs and tissues are constructed.

Lymphoid tissue is formed from aggregations of lymphoid cells. It provides a storage and proliferation site for lymphocytes. It also provides a site for lymphocytes and macrophages to be on the lookout for pathogens or cancer cells. There are 2 main types of lymphoid tissue: **diffuse lymphatic tissue** and **lymphoid follicles**.

Diffuse lymphatic tissue refers to a collection of scattered reticular tissue elements and associated lymphocytes. It has no clear boundary and blends w/ other tissues. It's found w/i lymph nodes and the spleen and is especially prominent in the mucous membranes lining the urinary, reproductive, respiratory, and digestive tracts. These are prime

locations for pathogen entry and that makes this lymphatic tissue quite necessary. This type of diffuse lymphatic tissue is referred to as **mucosa associated lymphatic tissue** (or **MALT**). The 2 major subdivisions of MALT are: **GALT** (**gut associated lymphatic tissue** in the digestive tract) and **BALT** (**bronchus associated lymphatic tissue** in the respiratory tract).

Lymphoid follicles (a.k.a. **lymphoid nodules**) are solid, spherical bodies consisting of tightly packed reticular elements and cells. They're numerous in the loose connective tissue of the digestive, respiratory, urinary, and reproductive tracts. They often form parts of larger lymphoid organs and are also found isolated in the distal small intestine and appendix – sites where large concentrations of bacteria necessitate large quantities of lymphatic tissue. The **Peyer's patches** are aggregates of lymphoid follicles found in the distal ileum (last portion of the small intestine). There are similar lymphoid aggregates common within the **appendix**. These sites are ideal to destroy bacteria attempting to invade the small intestine from the colon and anal canal. They're also a good location for pathogen exposure and the subsequent generation of "memory cells."

Lymphoid organs are characterized by large collections of lymphoid tissue surrounded by a **connective tissue capsule**. The principal lymphoid organs are the **lymph nodes**. Other lymphoid organs include: **tonsils**, **thymus**, and **spleen**.

Lymph nodes are clustered along lymphatic vessels and filter the lymph flowing through them. There are hundreds of lymph nodes w/i the body. Most are deep, but large, superficial clusters appear in the **inguinal**, **cervical**, and **axillary** regions.

A **dense connective tissue capsule** surrounds each node. Extending inward from the CT capsule are strands of CT known as **trabeculae**. They divide the node into compartments. Reticular fibers within the node support its population of lymphocytes and macrophages. Each lymph node has 2 distinct regions: a **cortex** and a **medulla**. The lymph node cortex consists of a **subcapsular sinus** (beneath the capsule) and **cortical sinuses**, which are separated by diffuse lymphatic tissue, trabeculae, and lymphatic nodules. The inner medulla consists of diffuse lymphatic tissue (the **medullary cords**) separated by **medullary sinuses**.

Afferent lymphatic vessels bring "unfiltered" lymph to the lymph nodes. The lymph empties into the subcapsular sinus and then flows thru the cortical and medullary sinuses. As it does so, it's scrutinized by the resident macrophages (which will ingest foreign particles and pathogens) and lymphocytes (which can proliferate and mount a serious immune response). The medullary sinuses drain into the **efferent lymph vessels**, which then take "filtered" lymph away. Efferent vessels leave at an indentation in the node known as the **hilum**. A lymph node typically has more afferent vessels than efferent vessels. This creates a bottleneck that forces lymph to flow slowly thru the node, giving lymphocytes and macrophages ample time to perform surveillance. Also note that the efferent vessels of one node can become the afferent vessels of another.

The spleen is the largest lymphoid organ. It sits just below the diaphragm slightly behind the stomach and above the kidney. The spleen is surrounded by a CT capsule and divided by inward extending trabeculae. Its primary function is **blood cleansing** – removal of aged/malformed RBCs, pathogens, and other undesirables. The spleen also provides a site of lymphocyte proliferation and immune surveillance and response. As arterioles terminate w/i the spleen they are surrounded by a sheath of lymphocytes – this arrangement is referred to as the **white pulp of the spleen**. The lymphocytes there will scrutinize the blood for pathogens. Splenic arterioles empty into splenic capillaries, which are quite large, twisty, incomplete sinusoids. They run btwn cords of splenic tissue, which includes macrophages, lymphocytes, plasma cells, granulocytes, and platelets. This is the **red pulp of the spleen**. Aged RBCs, pathogens, and foreign matter are removed from the blood by macrophages. The connective tissue framework of the spleen is made up of **reticular fibers** and **reticular cells**.

The thymus is found in the superior mediastinum. It contains a thin connective tissue capsule and has trabeculae that partition it into **lobules**. The thymus functions primarily in fetus and infancy where it plays a major role in T lymphocyte maturation. The lymphocytes that survive the maturation process are able to respond to foreign substances but do not attack the body's healthy cells. The thymus stops growing during adolescence. It then becomes more and more fibrotic and fatty during adulthood. It is the only lymphoid organ that does not directly fight antigens.

The tonsils form a ring of lymphatic tissue at the entrance to the **pharynx**. There are 3 main tonsils: **palatine**, **pharyngeal**, and **lingual**. The palatine tonsils are paired and located on either side of the posterior end of the oral cavity. They are the largest and most often infected. The lingual tonsil is a collection of lymphoid follicles lying at the base of the tongue. The pharyngeal tonsil is found in the posterior wall of the nasopharynx. It's referred to as the **adenoids** if enlarged. Tonsils are unique among lymphoid organs in that they are not fully encapsulated. Their surface is overlain by epithelium. They contain deep invaginations known as **crypts**. Their strategy is to basically "invite" bacteria into the crypts and then destroy them. It's a risky approach that can occasionally backfire, but wide exposure to bacteria/viruses results in the creation of a lot of "**memory immune cells**" that can swiftly deal with invaders later in life.