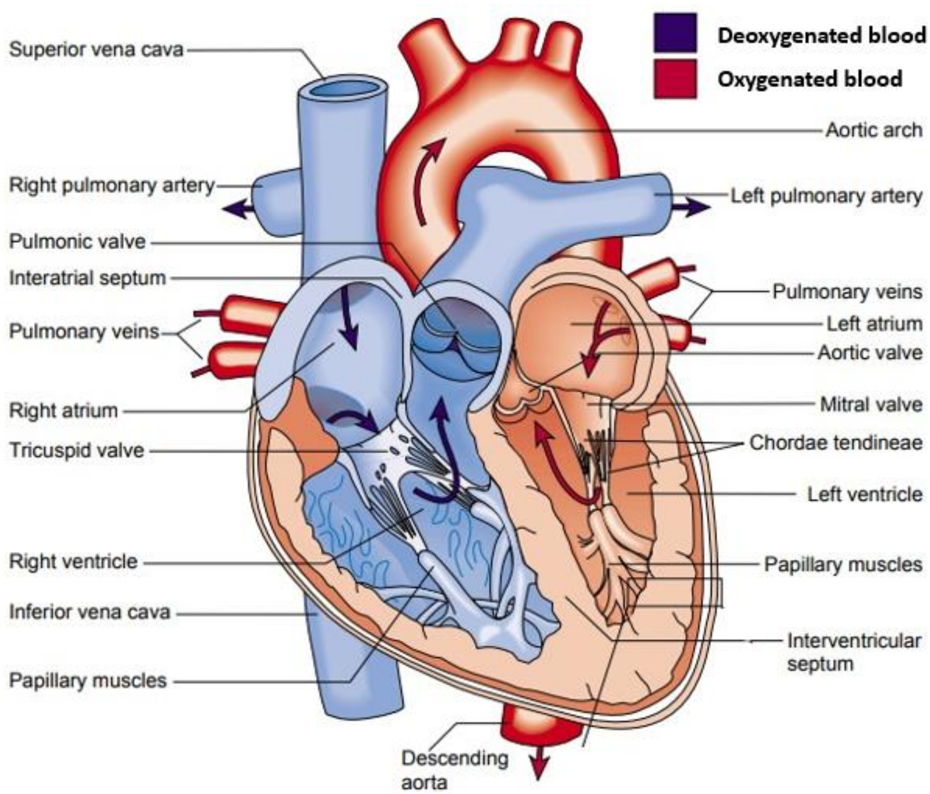
Anatomy Lecture Notes Section 5: The Cardiovascular System

The cardiovascular system consists of the **heart** (cardio) and **blood vessels** (vascular). This system is a **closed system**, meaning that the blood flowing through the heart and the vasculature always remains within those structures as it circulates around the entire body. Stable blood pressure is maintained by having a consistent total volume of blood (usually about 5L) within this system at all times. As we will see, exchange between the cardiovascular system of the body (the systemic circuit) and the lungs (the pulmonary circuit) occurs at the capillary level of the vasculature. Blood circulated throughout the body is a fluid connective tissue, the details regarding the components of blood are also included in this section.

The Heart

The heart is the central orchestrator of blood flow in the body. As an organ (seen image below), the heart is composed of **four chambers**: It has two upper chambers called the right and left **atria** (singular = atrium); and two lower larger chambers called the right and left **ventricles**.

The word **atrium** means 'entrance hall', because it is very much like a receiving room. It is useful to know that it is the atria that always *receives* the blood that is returning to the heart, whether from the body or the lungs. The **right atrium** receives deoxygenated blood returning from the body, and the **left atrium** receives oxygenated blood returning from the lungs. The right atrium is connected to the **right ventricle** below it, and the left atrium is connected to the **left ventricle** below that. In between them are the **atrioventricular** (AV) **valves** that ensure unidirectional (one-way) flow of blood in the heart.



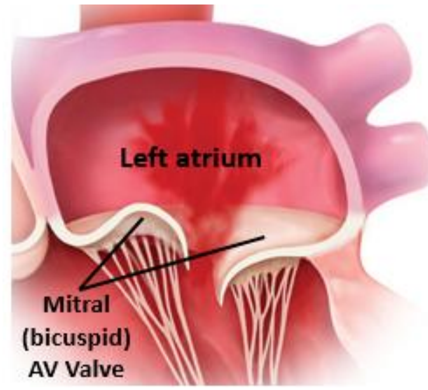
Circulation of Blood in the Heart

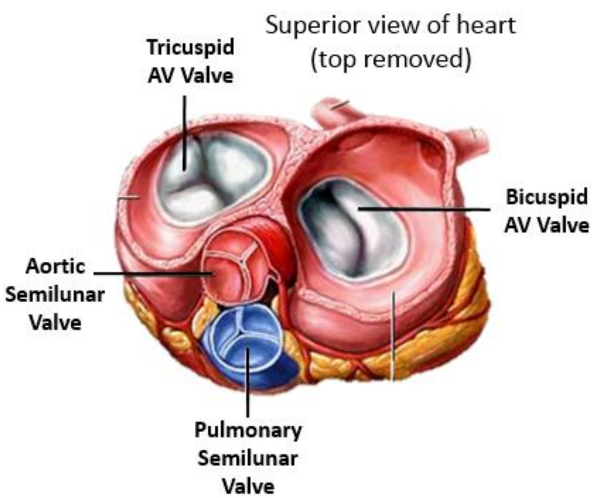
The figure above shows four internal chambers in the heart, 2 superior atria, and 2 large inferior ventricles. When looking at most artistic renderings of the heart, it is color coded to account for the differences in the oxygen levels of the blood in specific regions of the heart and body.

Chambers and vessels carrying **deoxygenated blood** are usually displayed in **blue**, while those carrying **oxygenated blood** are displayed as **red**. As will be discussed in the blood section, the molecule **hemoglobin** (**Hb**) which is found inside red blood cells, is a pigmented protein molecule that changes color. It is bright red when oxygen (O_2) is bound and a deeper sort of purple (blue/red) when is it lacking O_2.

Heart Valves

There are 4 heart valves, and their role is to prevent retrograde (back) flow of blood in the heart, ensuring that the flow is always in one direction - called **unidirectional** flow. There are 2 atrioventricular (AV) valves that are situated in between the atria and the ventricles. The valve between the right atrium and right ventricle is the **right tricuspid AV valve**, because it has 3 cusps. The valve between the left atrium and left ventricle is the **left bicuspid AV valve**, because it has 2 cusps. This bicuspid AV valve is also commonly referred to as the *mitral valve*, due to its resemblance to a mitre, a hat worn by bishops.





The other two heart valves are called the **semilunar valves**, as they resemble half-moon shapes. The **pulmonary semilunar valve** sits in between the right ventricle and the pulmonary trunk (which is a large artery). The **aortic semilunar valve** sits in between the left ventricle and the aorta (which is the largest artery in the body). These valves open when the blood is being ejected from the ventricles, and close to prevent backflow from the arteries into the ventricles.

The Circuits of the Body

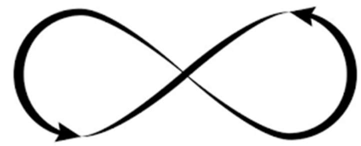
There are actually three circulations or circuits in the body, the two major circulations - the **Pulmonary** and **Systemic** circuits - plus the **Coronary** circulation, which is the circulation of the heart itself. The term circuit comes from the Latin circuitus, from circuire meaning 'go round', like a circle. All three of these circuits go away and come back to the heart.

The Pulmonary Circuit

The flow of blood from the heart to the lungs, and then back to the heart is called the **pulmonary circuit**. Succinctly, blood in this circuit goes from the right ventricle to the left atrium (RV to LA). This circuit starts in the **right ventricle**, where the deoxygenated blood leaves the right ventricle of the heart and travels through the pulmonary trunk (a large artery), and then branches into the L and R pulmonary arteries (seen as blue vessels in images) to deliver the deoxygenated blood to the L and R lungs respectively. In the lungs, the blood gathers oxygen (O_2) wherein the blood now becomes oxygenated. It also drops off carbon dioxide (CO_2) at the lungs. This blood then returns from both of the lungs to the **left atrium** of the heart by way of the L and R pulmonary veins (seen as red vessels in images). That is the end of the pulmonary circuit and where the systemic circuit them picks up and begins.

The Systemic Circuit

The other main circulation in the body is called the **systemic circuit**, where blood travels from the **left ventricle** of the heart and goes to the body and returns to the **right atrium**. Starting at the **left ventricle**, the fully oxygenated blood leaves the left ventricle through the aortic semilunar valve into the aorta (largest artery of body). Many arteries branch off the aorta as it travels around the entire body, delivering O_2 and nutrients. As the systemic vessels return from the body (via veins), the blood they carry is depleted of O_2 and has collected CO_2 from the tissues. This deoxygenated blood is returned to the **right atrium** of the heart by way of 3 different vessels to the right atrium: **1)** the superior vena cava (from above the heart); **2)** the inferior vena cava (from below the heart); and **3)** from the coronary sinus (from the heart's own circulation). The right atrium is the end of the systemic circuit. This blood then goes directly into the right ventricle below it, which is the start of the pulmonary circuit, and the cycle repeats. The pulmonary circuit always leads into the systemic circuit, which always leads into the pulmonary circuit… it is a continuous infinity figure 8 arrangement!



Important note about arteries and veins: They are named for where they are taking blood, not the level of O_2 in the blood.

- **Arteries** are blood vessels that <u>take blood away from the heart</u>.
- **Veins** are blood vessels that <u>return blood to the heart</u>.

It is true that most arteries carry oxygenated blood, and most veins carry deoxygenated blood, but there are a some important exceptions to that rule. A better understanding of blood vessels is that in the **systemic circuit**, arteries are carrying O_2 rich blood and veins are returning O_2 poor blood to the heart. While in the pulmonary circuit, it is the opposite, arteries still carry blood away from the heart, but have low O_2 levels, and the pulmonary veins that return blood to the heart have very high O_2 levels.

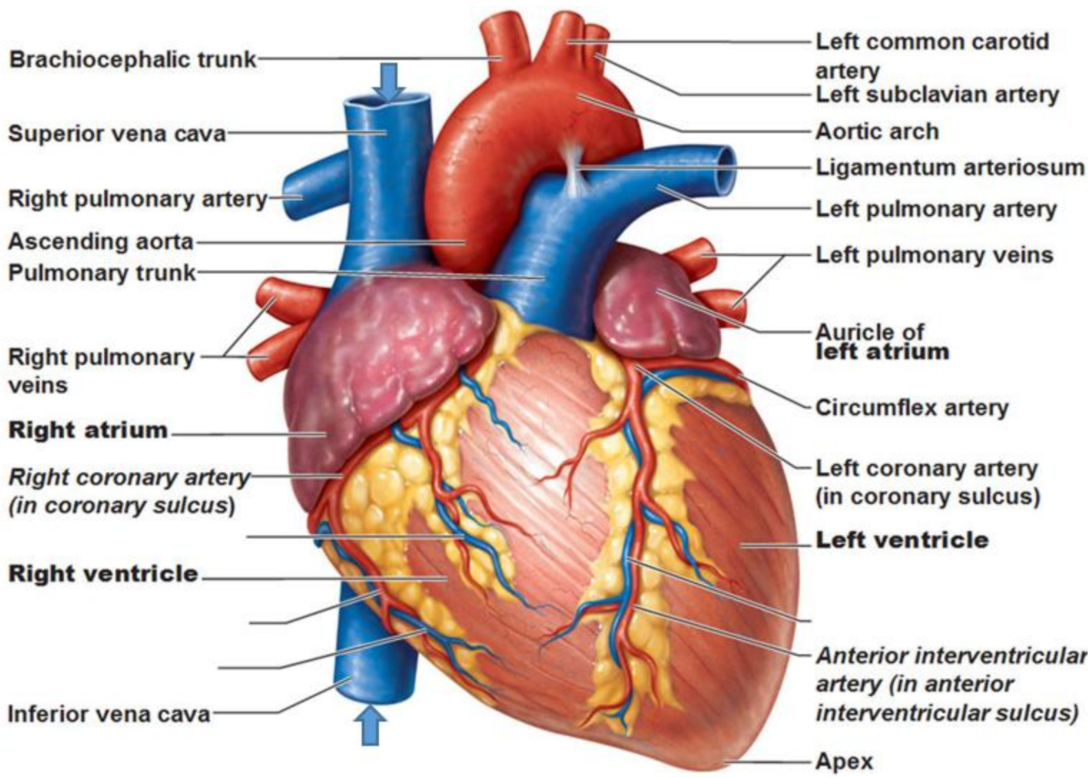
The General Sequence of Blood Vessels

In both the systemic and pulmonary circuits, the blood vessels leaving and returning to the heart make a type of 'loop'. Our emphasis is on the systemic circuit, and the loop usually follows this sequence:

Heart > **Artery** > **Arteriole** > **Capillary** > **Venule** > **Vein** > **Heart**.

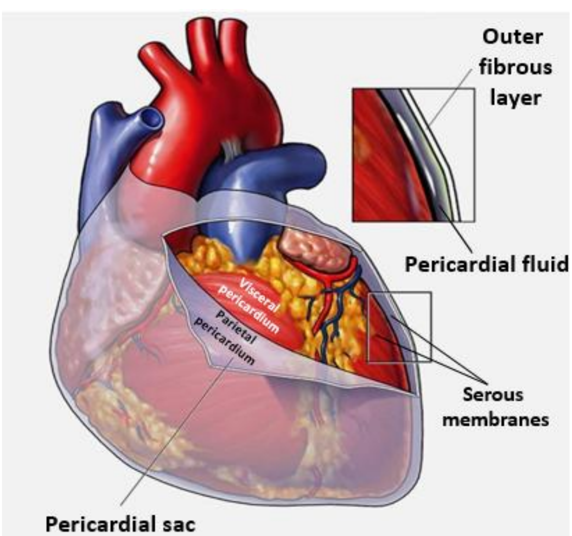
There are important exceptions to this sequence, but they arise in special regions and will be covered separately. We can use this sequence of blood vessels shown above as we describe the 2 circuits. Again, our main focus will be the **systemic circuit**, and the first blood vessel that leaves the heart is the largest artery in the human body, the **aorta**, it is the foundational vessel of the entire systemic arterial system. The aorta branches into many arteries as is travels away from the heart to deliver O_2 rich blood throughout the body. As they branch, the vessels become smaller and smaller, until they become **arterioles**, which is the next main category of blood vessels. The arterioles are the structures that control blood pressure and blood flow in the body. As these continue to get smaller, they become **capillaries**. The capillaries are the site of nutrient, waste and gas exchange with the cells of the body.

The blood in the capillaries is often described as sort of purple color, not bright red and not really blue. This is because the capillaries are the interchange between the O_2 rich arteries (bright red) and the O_2 poor veins (blue-ish) of the systemic circuit. After the capillaries, the blood vessels chuck a U-ie, that is, they make a U-turn and begin to head back to the heart – and now they are called veins. As the capillaries end, they merge and enlarge to become **venules**, which are like small veins (as the name implies). The venules merge and become larger and become **veins**. Veins are the largest type of blood vessel in terms of their diameter, and for this reason blood flow is high in these vessels. This blood returning from the body is delivered to the receiving room of the systemic circuit, which is the right atrium.



Recall that blood inferior to the heart returns to the heart by the ***inferior*** vena cava. The blood superior to the heart returns to the heart by the ***superior*** vena cava. And finally, the blood from the heart returns to the heart by the ***coronary*** sinus (a large vein).

The Pericardial Sac



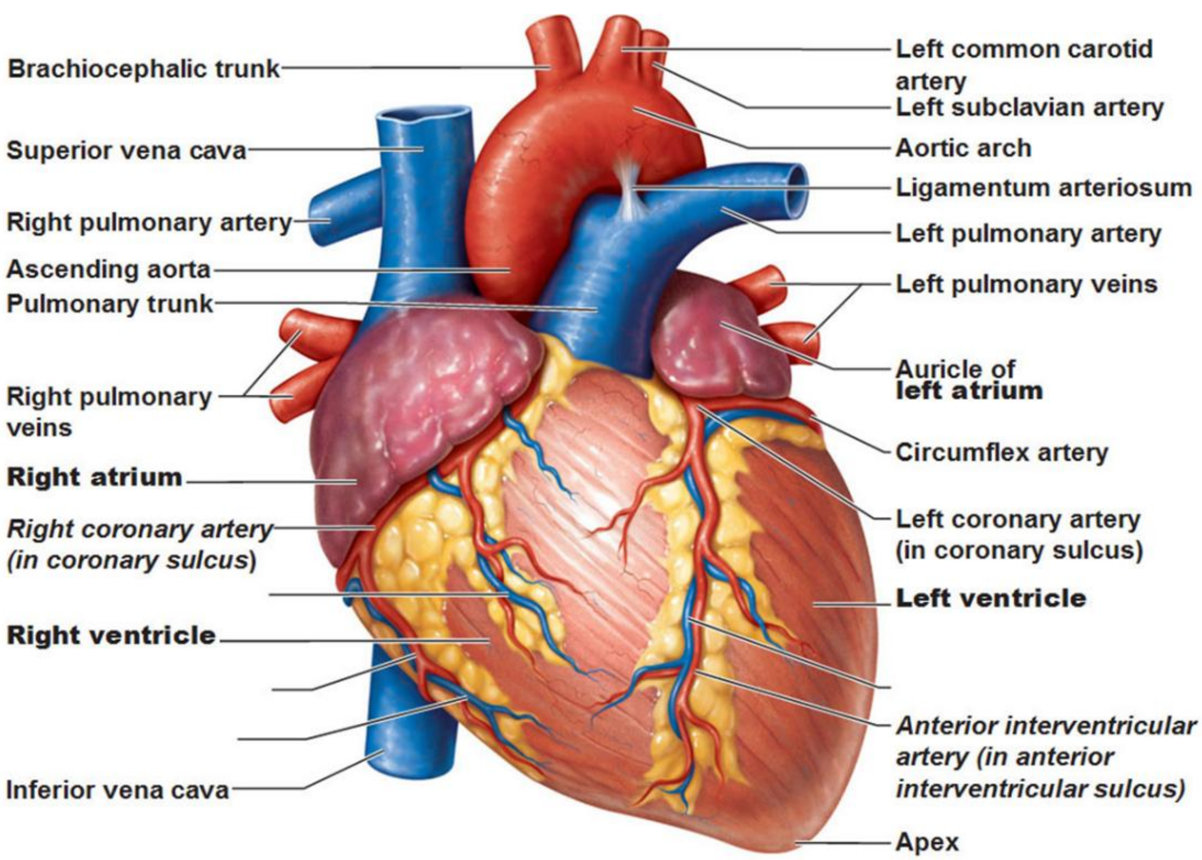
The heart is located in a tough, fibrous bag known as the **pericardial sac**, which has an outer fibrous layer and an inner serous layer. In the image to the left, the sac is open and the pericardial cavity can be seen, which contains pericardial fluid to reduce friction between surfaces that move across each other. The outer surface of the heart is a serous membrane, it is called the **visceral pericardium** because it is 'of the organ'. This outermost layer of the heart is also called the **epicardium**. The inner lining of the pericardia sac is also a serous membrane, called the **parietal pericardium**. Thus, the two serous membranes face each other with a thin layer of serous fluid in between them to reduce friction of the constantly moving heart.

Brief Overview of Coronary Circuit

The apex of the heart is the inferior tip, and the base of the heart is the broad superior border. The **right coronary artery** branches directly from the ascending aorta and leads further down to the **right marginal artery**. The **left coronary artery** also branches directly from the ascending aorta and takes blood around the heart sheltered within the coronary sulcus, also known as the atrioventricular (AV) sulcus. The left coronary artery continues on to become the **anterior interventricular artery** and the **circumflex artery**. The large cardiac veins can also be seen on the anterior and posterior sides of the heart. The **great cardiac vein** is embedded within the anterior interventricular sulcus and the **middle cardiac vein** runs within the posterior interventricular sulcus. The large dilated **coronary sinus** sits in the posterior portion of the coronary sulcus. *The term *sinus* in the cardiovascular system means a large vessel, usually a vein. Using your lab manual as a guide, label all of the major vessels on the heart, as well as the vessels entering and exiting the heart.

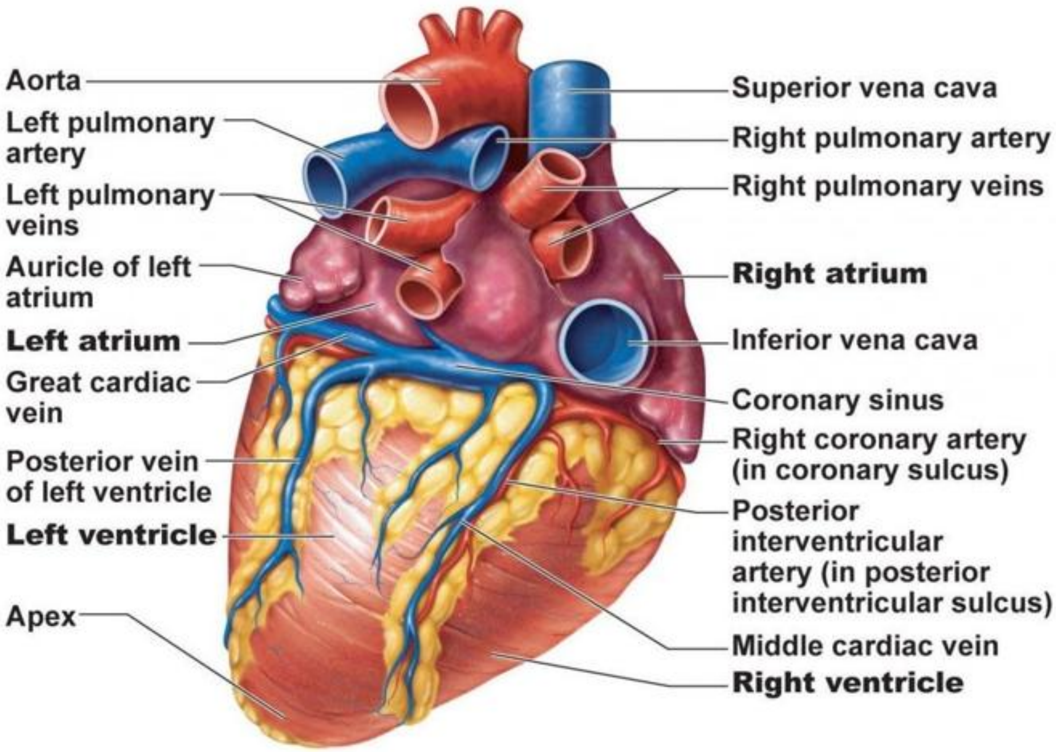
Anterior Surface View of Heart

Many of the external surface features of the heart are easily seen, and they also provide landmarks for the chambers of the heart. The two atria have an external feature called **auricles** (meaning ears). They allow for an expansion of atrial blood volume in times of greater cardiac output (during enhanced filling). Another notable set of external structures are the sulci (singular sulcus). These are shallow grooves on the external surface of the heart that are filled with fat and hold coronary blood vessels. As seen in the images below, the major coronary blood vessels are situated within these sulci. The **anterior interventricular sulcus** is seen on the anterior surface of the heart, and the **posterior interventricular sulcus** is seen on the posterior surface of the heart. The **coronary sulcus** is a shallow groove that encircles the heart, located snugly between the atria and ventricles. This sulcus is also filled with adipose tissue and blood vessels.

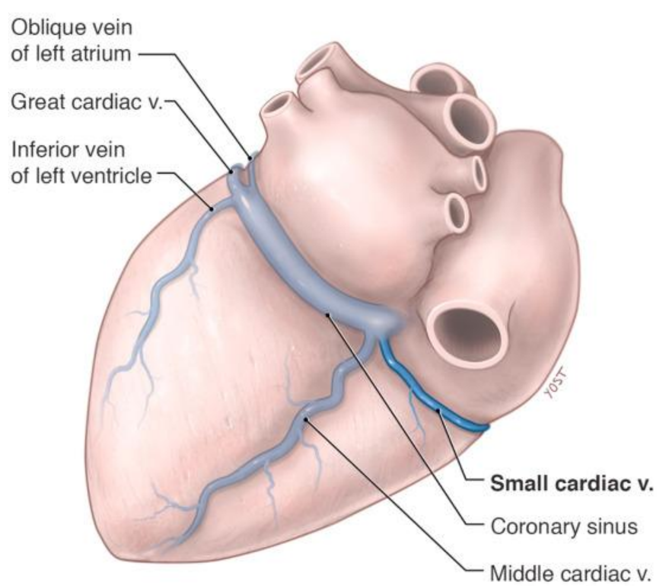


Posterior Surface of Heart

As mentioned, the posterior side of the heart has arteries and veins that sit in the various sulci. The **posterior interventricular artery** sits in between the ventricles on the posterior surface of the heart, held in place by adipose tissue within the posterior interventricular sulcus. This vessel receives blood from the right coronary artery. The **middle cardiac vein** carries blood in the opposite direction, as it is taking blood into the coronary sinus, to be returned to the right atrium. The **small cardiac vein** is also found on the posterior surface of the heart and enters the coronary sinus from the opposite direction.

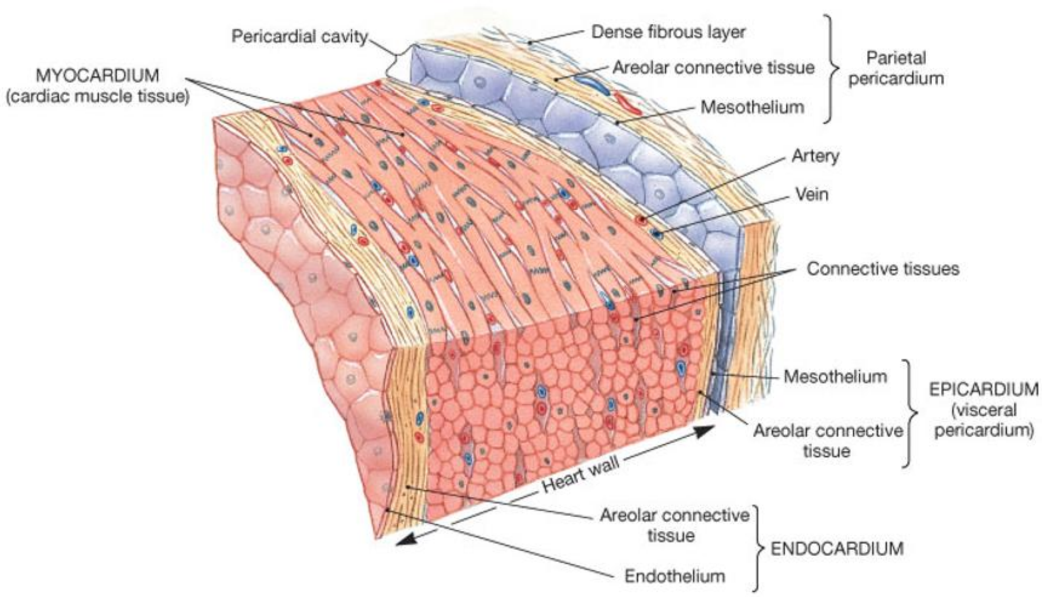


In the drawing to the right that shows only the venous return on the posterior aspect of the heart, it can be more clearly seen how the **great and small cardiac veins** approach the coronary sinus from opposite directions. The **oblique vein** drains blood from the left atrium into the large dilated coronary sinus. Also shown are the veins returning from the left ventricle, the **inferior vein of left ventricle**, and the **middle cardiac vein** that sits right in between the two ventricles nestled within the posterior interventricular sulcus.

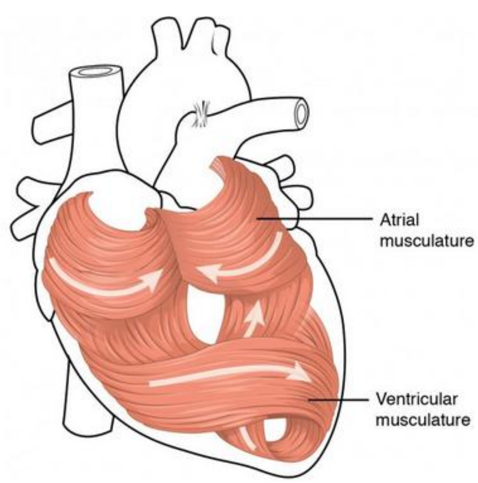


The Heart Tissue

The heart is composed of three layers of tissues. The innermost layer is called the **endocardium** - this is the surface that blood flows along. It is composed of the inner endothelium (simple squamous epithelium) as the surface that blood flows across and areolar connective tissue that supports it. The middle layer is called the **myocardium** – this is by far the thickest layer of the heart and composed of cardiac muscle tissue (see image below). Finally, the outermost layer is the **epicardium**, which is a serous membrane made of areolar connective tissue, and simple squamous epithelium as the outermost surface. Recall that this layer can also be called the **visceral pericardium**, as it is the serous membrane of this organ.



As mentioned, the myocardium is the thickest layer of the heart. The cardiac muscle pattern is actually extremely complex and elegantly arranged in complimentary spiral patterns incorporated into all 4 chambers of the heart (see image directly below and left). The spiral arrangement forms a figure 8 pattern around the atria. The deeper ventricular cardiac muscles also form a figure 8 around the two ventricles and spiral toward the apex, but also up toward the base of the heart.

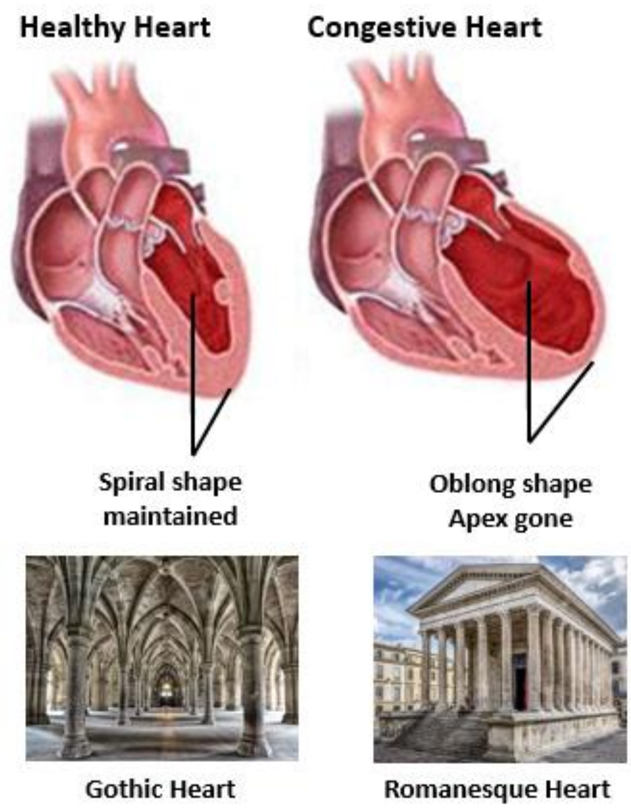


As early as **1749** it was suggested that the left ventricle of the heart had a ***helical configuration***, but much more recent findings published in the scientific literature in **1980** show that the muscle fibers of the entire heart are arranged in what is termed a **helical ventricular myocardial band** (see image left). The heart is literally one continuous strip of muscle that is folded in and coiled upon itself. Somewhat like an intertwined **double helix**, only more complex.

The left and right ventricles pump the same amount of blood per contraction, but the muscle of the left ventricular wall is about 3 times thicker than the right ventricle, and indeed pumps about 3 times greater pressure than the right side. The right ventricle does not need to generate as much pressure, since the pulmonary circuit is very close by, and thus requires much less force due to the lower resistance.

Healthy hearts need this complex structural arrangement in order to effectively conduct blood flow in the heart. If they lose this anatomical structure (or architecture), they can no longer effectively conduct blood flow and become dysfunctional, leading to various ailments.

In a 2001 study published in a peer reviewed journal for cardiac surgeons it was stated that in a **healthy heart** the left ventricle has a **Gothic architecture** wherein the heart's remarkable efficiency results from the arrangement of myocardial fibers supported by the collagen matrix scaffold. In contrast, the dramatic changes that occur to the structure of the heart in the serious and prevalent condition of **congestive heart failure** is associated with a transformation of the heart to a **Romanesque architecture**, leading to the diseased heart, particularly the left ventricle (see images below).



Their conclusions came from the analysis of gothic and roman buildings and three-dimensional images obtained by MRI with mathematic methods for measurements of the curvature and thickness of the heart's ventricular walls.

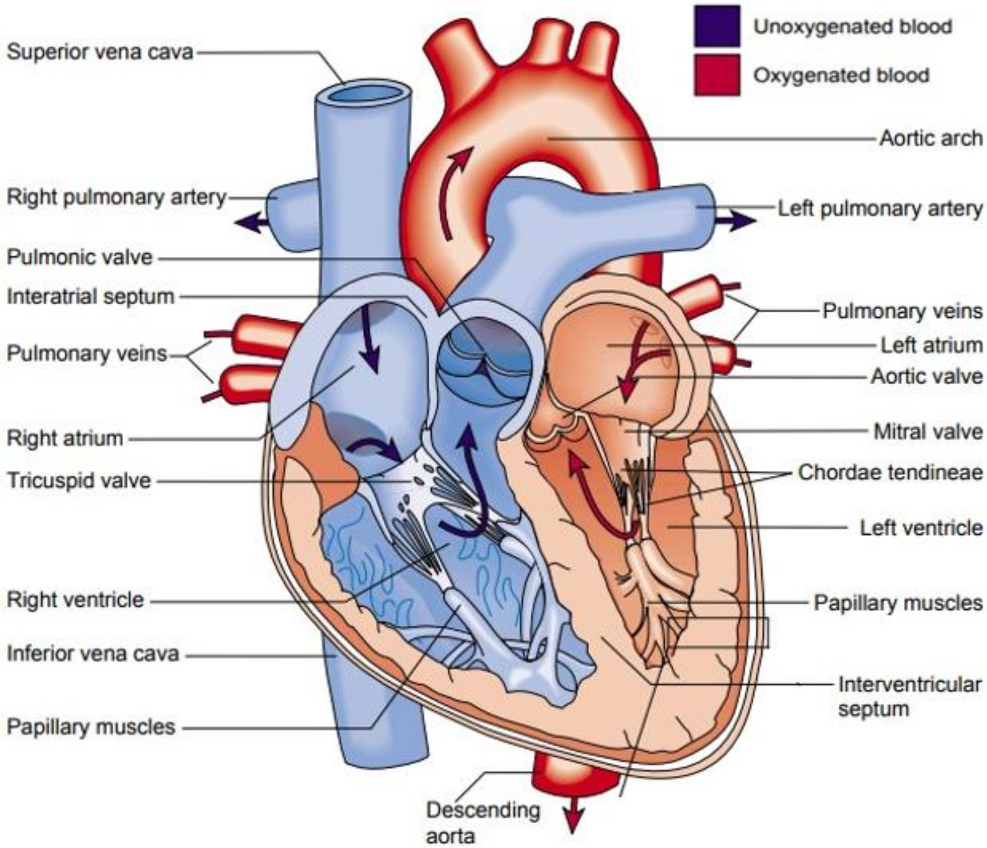
The changed **architecture** of the heart can be clearly seen in the two representations of the heart above to the right, as the spiral gothic shape is retained in the healthy heart compared to the loss of that form in the blown-out shape of the congestive heart.

The article declared that this understanding of the <u>architecture of the healthy heart</u> was certain to bring about dramatic changes in the design of surgical strategies to improve ventricular function by restoring the heart to its healthy architecture. It has now been over 20 years since this revelatory study and have you ever heard anything about the perfect Gothic architecture of a healthy heart? Me neither. Never heard a single thing about it until I started seeking information that made more sense than the usual drivel. Studies like these underscore that so much more is known about the heart and the impact of architecture on our health, but very little of it seems to be openly disclosed and shared with all. If interested in a more detailed look at the Heart of the Matter, there is an in depth paper on the matter.

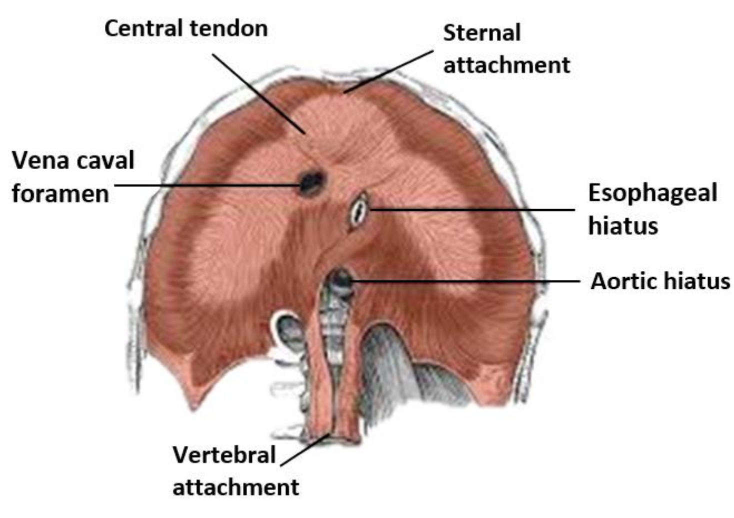
Arteries and Veins

As we have already discussed, an arterial system of blood vessels takes blood away from the heart, and a venous system of blood vessels takes blood back to the heart. We will also discuss how there is one set of systemic arteries, but there are 2 sets of systemic veins. The 2 sets of veins are: **1) deep veins** – these run parallel to their arterial companion and almost always have the same names. For example, the brachial artery has the companion brachial vein, the femoral artery has the companion femoral vein. **2) superficial veins** – these are a unique set of veins that have no arterial companion and have unique names. This second set of superficial veins are found close to the external surface of the skin in the upper and lower limbs. The basilic and the cephalic veins of the arm are a good example, as well as the great and small saphenous veins of the thigh and leg.

In the image below, the aorta represents the beginning of the **systemic arterial vessels**. It leaves the heart as the **ascending aorta**, curves arching over to the left side of the body in the **aortic arch**, and then travels down the left side of the body as the **descending thoracic aorta**. It travels through our large dome-shaped, diaphragm (made of skeletal muscle), traveling through a hole in that muscle called the **aortic hiatus**.



The diaphragm is an important landmark in the body, tightly dividing the upper thoracic cavity from the lower abdominal cavity. The image at the right shows an inferior view of the diaphragm and the **3 holes** that allow for the passage of vital structures through it. The **aortic hiatus** (aorta), the **vena caval foramen** (inferior vena cava) and the **esophageal hiatus** (esophagus). Once it passes through the diaphragm it enters the abdominal cavity and is then called the descending abdominal aorta.



Diaphragm (Inferior View)

There are many branches off the aorta in the abdomen, there are 3 unpaired branches and 5 paired branches as it continues downward. At the end of the aorta, it does 'the splits' and becomes the L and R common iliac arteries, with the single median sacral artery springing out from the split in the middle. The common iliac arteries become the internal and external iliac arteries before they cross the inguinal ligament into the thigh region and become the femoral arteries. The arteries continue down to the toes, and then turn around for the return voyage.

BLOOD

Blood is a fluid connective tissue that has everything in it that the body could possibly need! When whole blood (shown in test tube at the right) is spun at high speed, it separates into its 2 main components. The 2 components are **1) plasma** – which is called the fluid portion of blood, and **2)** the **formed elements** – which are the cells of the blood. The plasma is the fluid portion of the blood and consists of water, proteins, and dissolved materials such as oxygen, carbon dioxide, electrolytes (ionic particles), glucose, aminos acids, lipids and other materials. Plasma makes up about **55%** of the blood volume. The formed elements are also called the **cellular** elements of blood. This makes up about **45%** of the blood volume and consists of **erythrocytes** (red blood cells), **leukocytes** (white blood cells) and **thrombocytes** (platelets).

By far, the most abundant type of cell in blood is the **red blood cells** (RBC), also called erythrocytes, they represent over **99%** of all cells in the blood. They are the smallest blood cell, measuring about 7 to 8 µm, and have a biconcave disc shape, meaning they are indented on both sides in order to maximize surface area for gas exchange. The special features of the RBC that are specific to their function will be discussed in more detail in the next section. Briefly, there are about 5 million erythrocytes per cubic millimeter of blood. The erythrocytes do not have a nucleus and they appear like a with a thin spot instead of the donut hole. About a third of the weight of a red blood cell is due to the **hemoglobin** contained within each cell, which makes the cells red.

The white blood cells are called **leukocytes**. In total, there are 5 types of leukocytes, and each fall into one of are two main types leukocytes; **granular leukocytes** and **agranular leukocytes**. There are about 7 thousand leukocytes per cubic millimeter of blood.

Granular leukocytes - include **neutrophils**, **eosinophils**, and **basophils**. The granular leukocytes have cytoplasmic granules that contain powerful degrative enzymes that either stain pink, dark purple or do not stain much at all. The granular leukocytes that do not stain much at all are called neutrophils because the granules are neutral to the stains. They are the most numerous of the leukocytes making up 60-70% of the leukocytes. **Neutrophils** have a three to five lobed nucleus. The **eosinophils** are granular leukocytes that have pink or orange staining granules. The nucleus is generally two-lobed. Eosinophils make up about 3 percent of the white blood cells. **Basophils** are a rare granular leukocyte in that they make up less than one percent of the white blood cells. The nucleus is S shaped, but it is frequently difficult to see because it is obscured by the dark staining cytoplasmic granules.

Agranular leukocytes – there are two kinds of agranular leukocytes are the **lymphocytes** and the **monocytes**. The lymphocytes can be large or small and they make up 20-30% of the leukocytes. The cytoplasm is light blue, and the nucleus is purple. The nucleus of the lymphocyte is dented or flattened. Lymphocytes come in two kinds: B cells release antibodies to protect the body, and T cells are involved in cell-mediated protection. The monocytes are large cells (about 3 times the size of a red blood cell) and they have very large nucleus. Some people say this looks like a kidney bean or a horseshoe. They represent only about 5% of the leukocytes.

Finally, there are also **thrombocytes**, they are also called **platelet cells**, though they are not really cells, but are fragments of the very large cells called **megakaryocytes**. There are about 200,000-450,000 thrombocytes per cubic millimeter of blood. They assist the body in clotting to prevent blood from flowing out of small ruptures in blood vessels. Thrombocytes are very small, ranging from 2 to 4 µm.

The Specific Internal Structures of the Heart

Deoxygenated blood enters the right atrium of the heart by three vessels: the superior vena cava, the inferior vena cava and the coronary sinus. The walls of the right atrium are thin-walled as they only have to pump blood to the right ventricle. The blood in the right atrium is in contact with the **fossa ovalis** which is a thin spot in the interatrial septum. This thin spot is a remnant of a hole in the fetal heart known as the **foramen ovale**. Blood in the right atrium flows through the cusps of the tricuspid or right atrioventricular valve into the right ventricle.

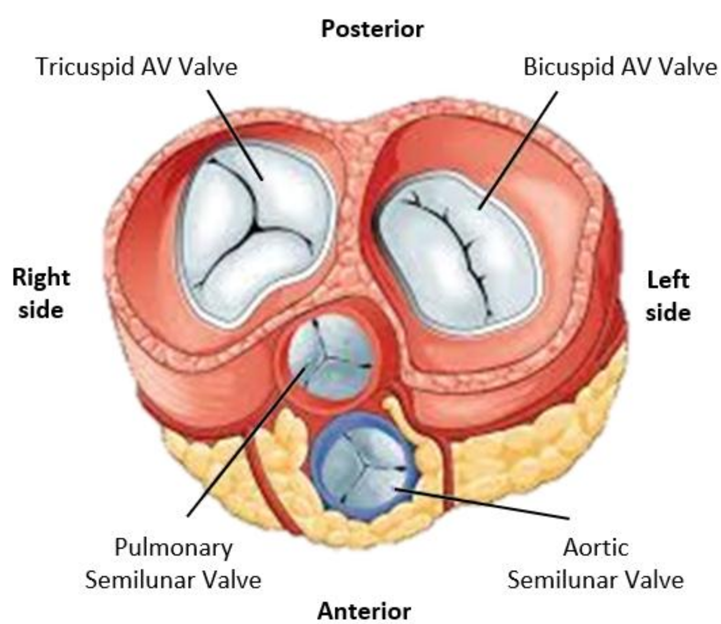
The tricuspid valve is made of the three cusps, the **chordae tendineae** and the **papillary muscles** that hold the chordae tendineae to the ventricle wall. The ventricle wall is lined with **trabeculae carneae** that act as struts along the edge of the wall. The wall between the ventricles is known as the **interventricular septum**.

From the right ventricle, blood passes through the pulmonary semilunar valve into the pulmonary trunk where the blood goes to the lungs to collect O_2 (and drop off CO_2) to become oxygenated. From the lungs the blood returns to the left atrium of the heart. Blood in the left atrium moves to the left ventricle through the left atrioventricular (AV) valve or bicuspid AV valve. This valve has two cusps, chordae tendineae and papillary muscles. When the left ventricle contracts, the blood moves through the aortic semilunar valve and into the ascending aorta.

Internal Superior Aspect of the Heart

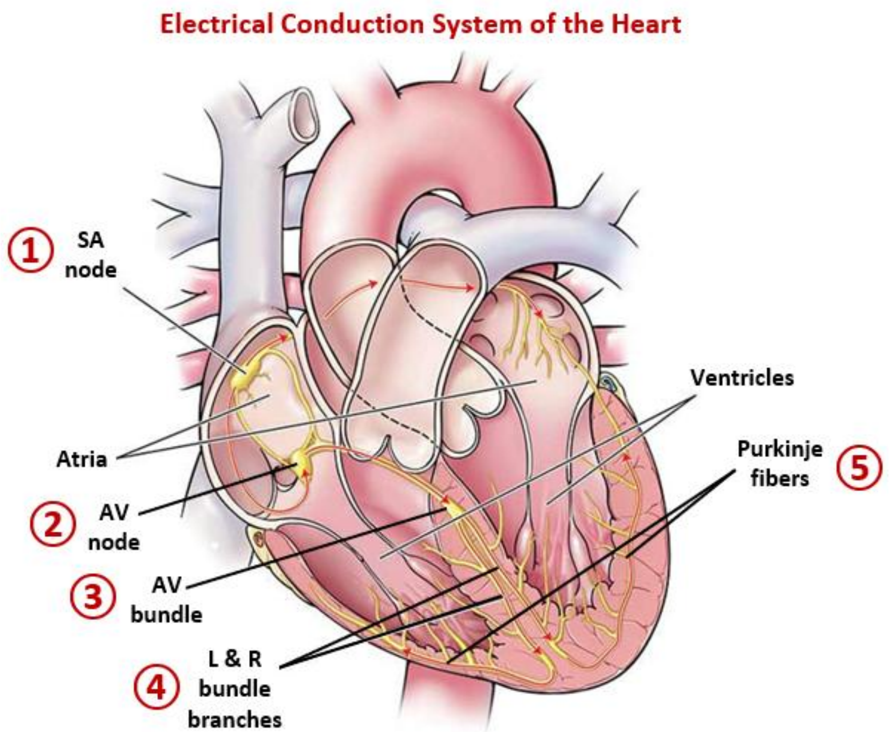
The view of the heart directly below is seen as if the atria and the major vessels have been removed. This allows for a very clear view of the 4 heart valves. From this perspective, the most anterior valve is the **pulmonary semilunar valve** that is sits right in between the right ventricle and the pulmonary trunk. Posterior to this (as seen in the drawing below) is the **aortic semilunar valve**. This valve sits in between the left ventricle and the aorta. Both of these valves prevent blood from returning to the into the ventricle from which they are leaving.

The 2 atrioventricular (AV) valves are located posteriorly and sit in between the atria and the ventricles. Each AV valve is named by the number of cusps it has - look at the image to the right and notice that the right AV valve has 3 cusps and is therefore called the **tricuspid AV valve**, and the left AV valve has 2 cusps and is therefore called the **bicuspid AV valve** (“tri before you bi”). The bicuspid AV valve is also known as the **mitral valve**. The function of any valve is to prevent retrograde or back flow of blood, ensuring the unidirectional flow of blood (in one direction).



The Electrical Conduction System

The heart has specialized autorhythmic cells that initiate an elegantly coordinated series of electrical impulses that radiates throughout the heart. This is the electrical conduction system of the heart, and consists of five major sites within the cardiac tissue. The cells are clustered in specific locations and follow a particular order, starting from the **sinoatrial (SA) node** in the superior portion of the right atrium (see image below). The SA node creates the sinus rhythm which sets the pace of the heartbeat, and is therefore called the '**pacemaker'** of the heart.



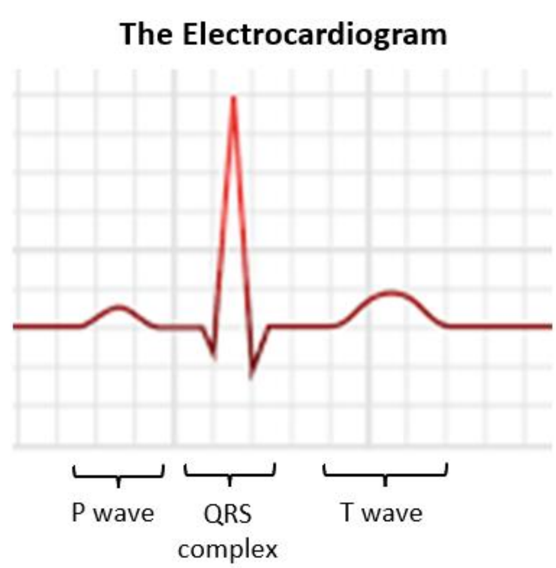
The cells at the SA node produce a **depolarization** that travels across the atria, depolarizing them - which is the signal for them to contract. Note: Depolarization is an electrical event, while contraction is a mechanical event.

Locations of the Electrical Conduction System

The specific locations of the five components of the electrical conduction system in order are:

① **Sinoatrial (SA) node** *(in the superior posterior right atrium).*
② **Atrioventricular (AV) node** *(in the inferior medial right atrium).*
③ **AV Bundle (of His)** *(in the superior interventricular septum).*
④ **Right and Left bundle branches** *(run down along the interventricular septum).*
⑤ **Purkinje fibers** *(go up from apex of the ventricles toward the base of the heart).*

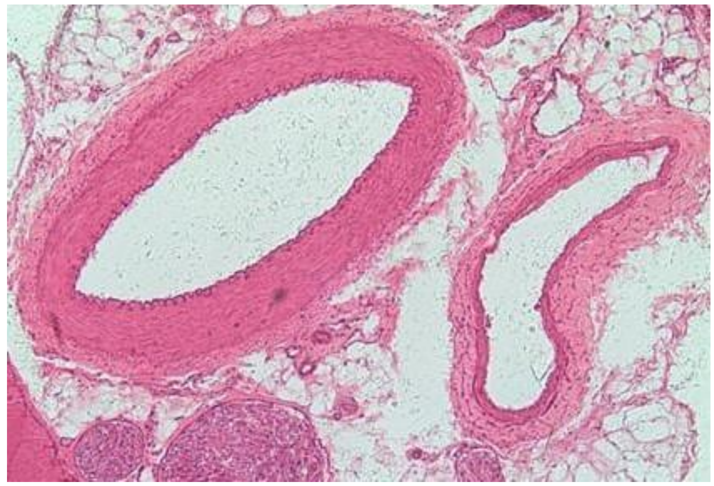
Once the impulse reaches the AV node there is a slight slowing of the electrical signal as it travels through it, this is known as the "AV nodal delay". This delay allows for the ventricles to be completely full before ventricular contraction begin. The signal (or impulse) then continues on to the atrioventricular bundle. This bundle then divides into the left and right bundle branches as it makes its way down the interventricular (I.V.) septum toward the apex (bottom) of the heart. Finally, the electrical impulse radiates into the large muscular ventricles via the Purkinje fibers, stimulating both the left and right ventricles to contract at essentially the same time. This completes one heartbeat. The electrocardiogram (ECG, see right) is a recording of the electrical activity of the heart and shows the wave patterns of one heartbeat. This cycle of the electrical conduction system repeats for every heartbeat.



Overview of Blood Vessels: The Vessel Wall

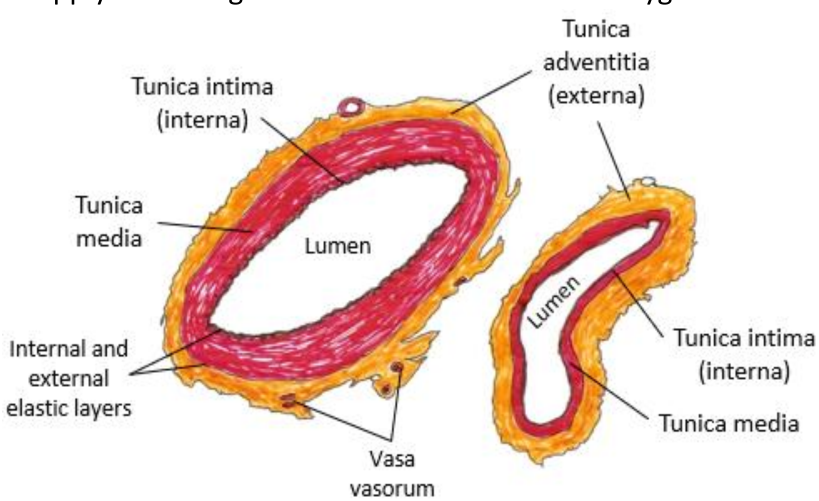
The anatomical structure of blood vessels differ because they have different roles and experience a different set of circumstances in the body. A good place to start is with a quick comparison of arteries and veins. Firstly, it may surprise some to know that the definition for an artery or a vein has nothing to do with the levels of oxygenation of the blood within them. It has to with the direction that blood is being carried. **Arteries** carry blood away from the heart, whereas **veins** carry blood back toward the heart. That is it. Blood vessels also have different roles depending on whether they are in the pulmonary or systemic circuits. Our focus will be on the higher pressure systemic circuit.

Ateries vs Veins



Both arteries and veins have **3 layers** or **tunics** to their vessel walls. As seen in the histological preparation in the photo to the right, the artery (on the left) and the vein (on the right) are large vessels, and it is easy to notice that **arteries** have much thicker walls than the neighboring vein. This is due to the higher pressure within the arteries of the systemic circuit. Just as high pressure hoses have thick walls, so do arteries. **Veins** have thinner walls than arteries and they do not have the same elastic fibers. This is because they are holding low pressure blood.

In the drawing of the histological image shown below, it is a little easier to see the 3 tunics of each vessel. The outer layer of both the artery and the vein is the **tunica externa** (tunica adventitia). The middle layer is the **tunica media**, made of smooth muscle (and elastic fibers in arteries only). The innermost layer **the tunica intima** (tunica interna). The area in the artery where the blood flows is called the lumen. Very large blood vessels in the body (both arteries and vein) have blood vessels of their own, which are called vasa vasorum (which means 'vessels of the vessels'). These are located in the outer tunica adventitia or externa, and they function to supply these large vessels with nutrients and oxygen.



Most often, veins have a larger lumen than arteries, so they are diametrically larger vessels than arteries. Veins tend to collapse in histological preparations due to the thinner vessel wall. Due to this. they can often look like a frowny clown face.  The veins have **venous valve**, which fold into the tunica interna and prevent back flow, ensuring the one-way flow of blood through veins.

The Blood Vessels of the Systemic Circuit

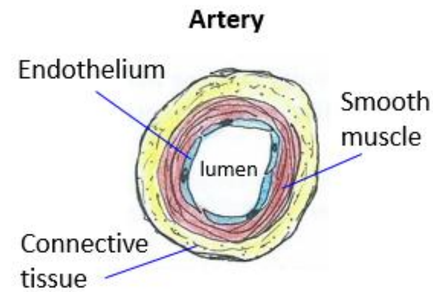
The different types of blood vessels vary in their structures, but they all share some similar general features. Each blood vessel has the same innermost layer called the **endothelium**, made of simple squamous epithelium. All vessels have a **lumen**, this is the central area through which blood flows. In general, blood vessels transport blood from the heart in this vessel order: **Arteries**, **arterioles**, **capillaries**, **venules** and **veins**. This leads back to the heart. There are some important exceptions to this sequence (e.g., portal systems) but most commonly this is the order of blood vessels in the body.

Arteries - These vessel wall has 3 layers called **tunics**:

1) Tunica interna: Endothelium (innermost) across which the blood flows.

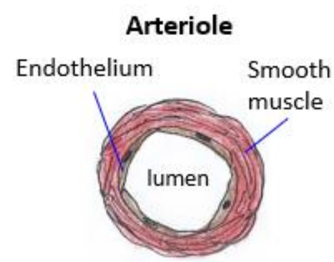
2) Tunica media: Vascular smooth muscle (VSM). *Note: Has elastic fibers on each side if this tunic!

3) Tunica externa: Connective Tissue (tunica adventitia).



Arteries function to withstand the high pressure blood from the heart (the arteries are closest to the heart), and they also to exhibit 'elastic recoil' during times of lower pressure, this helps to maintain stable arterial blood pressure. They have the thickest walls and ***2 layers elastic fibers*** on either side of the vascular smooth muscle or the tunica media. Although **arteries** have very thick walls, they have **smaller lumens than veins**, a characteristic that helps to maintain the pressure of blood moving through the system. Together, their thicker walls and smaller diameters give arterial lumens a more rounded appearance in cross section than the lumens of veins.

Arterioles



After arteries, blood flows into **arterioles**. Like the name implies, arterioles are 'tiny' arteries that deliver blood to capillaries. This vessel wall has 2 layers:

1) Endothelium (innermost) across which the blood flows.

2) Vascular smooth muscle (VSM).

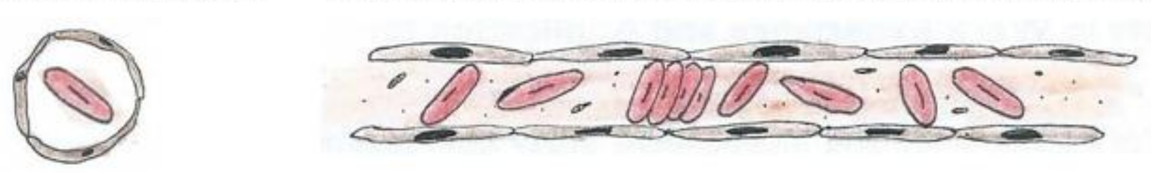
These vessels can **exhibit large changes in diameter** (or **radius**, r) and are therefore called '**Resistance**' vessels. The importance of arterioles is that they act as key regulators of **blood pressure** and **blood flow**!

Capillaries

A **capillary** is the **smallest**, **thinnest** blood vessel in the body. Its primary function is for **exchange** with the tissues throughout the entire body. This vessel wall has 1 layer, and it is only 1 cell layer thick.

1) Endothelium. Can also have <u>basement membrane</u> (connective tissue) around it.

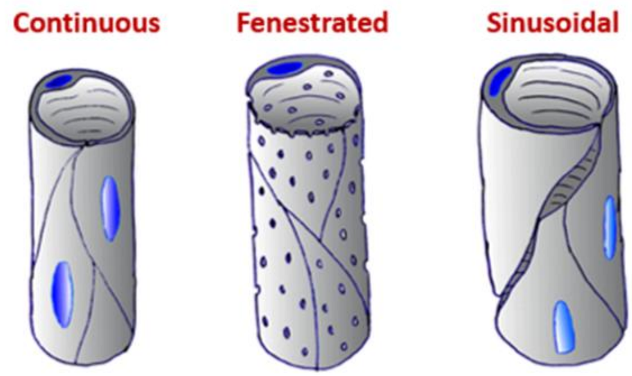
a) Cross section of a capillary **b)** Longitudinal section of capillary (with red blood cells inside)



Capillaries exchange **gases**, **nutrients** and **waste** between the blood, the interstitial fluid and the surrounding cells. The diameter of a capillary ranges from 5–10 µm. This size is a snug fit for the passage of RBCs that range from 7-9 µm in size. The term **microcirculation** describes blood flow through capillaries.

For capillaries to function, their walls must be 'leaky', meaning they need to allow substances to pass through them. There are **3 major types of capillary beds**, which differ in their degree of "leakiness". The 3 types of capillary beds are: **1)** continuous, **2)** fenestrated, and **3)** sinusoidal capillaries.

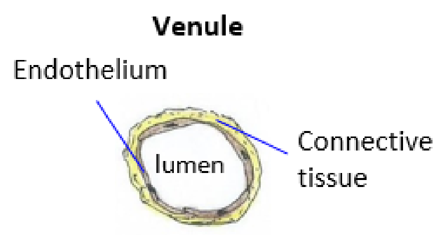
Capillaries are different from both arteries and veins in that they are composed of only simple squamous epithelium (called endothelium). The thin nature of capillaries allows them to exchange nutrients, water, carbon dioxide and oxygen with the cells.



Venules

Venules are "small veins", their function is to drain and collect the blood from the capillary beds and return it to the large veins. These are low pressure vessels. Vessel wall has 2 layers:

1) Endothelium (innermost) across which the blood flows.
2) Connective Tissue (see image at right).



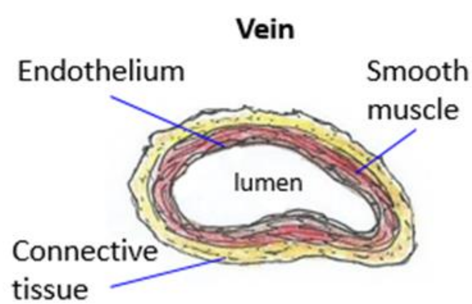
Venules (from 8–100 µm) collects blood from multiple capillaries exiting a capillary bed and join to form veins. It is the capillaries that are the primary sites of **diapedesis**, which is the passage of blood cells through the intact walls of the capillaries during times of healing and inflammation. This can also occur in venules, so there is still some degree of exchange that occurs in venules with the local tissues.

Veins

A vein is a blood vessel that carries blood back toward the heart. Veins are *diametrically* the **largest** type of vessel (have the largest lumen). This vessel wall has 3 layers, which are as with arteries, called tunics:

1) Tunica interna: Endothelium (innermost) across which the blood flows.
2) Tunica media: Vascular smooth muscle (VSM).
3) Tunica externa: Connective Tissue.

As previously mentioned, veins, like arteries, are composed of 3 layers, however veins have much **thinner walls** compared to arteries but have **larger lumens**. Often the lumen of veins are described as 'irregular', but this is typically because when sectioned vessels are viewed it is when the vessels are empty, and the thinner walled veins tend to collapse when they are empty.



Artery Pathways Overview

One of the ways to study arteries is to draw them as if you were making a street map. Begin with the heart and draw the blood vessels that travel out and deliver blood to the head, upper limbs, abdomen, internal organs, lower limbs etc. Arteries in the systemic circuit when viewed on models or in textbooks are typically colored red, as they are richly oxygenated. Use the list of arteries in your lab manual as your guide and notice how one vessel becomes another vessel as the branching pattern continues. The standard abbreviation for artery is a., and for arteries it is a.a. Similarly for vein it is v., and for veins it is v.v.

Head and Aortic Arteries

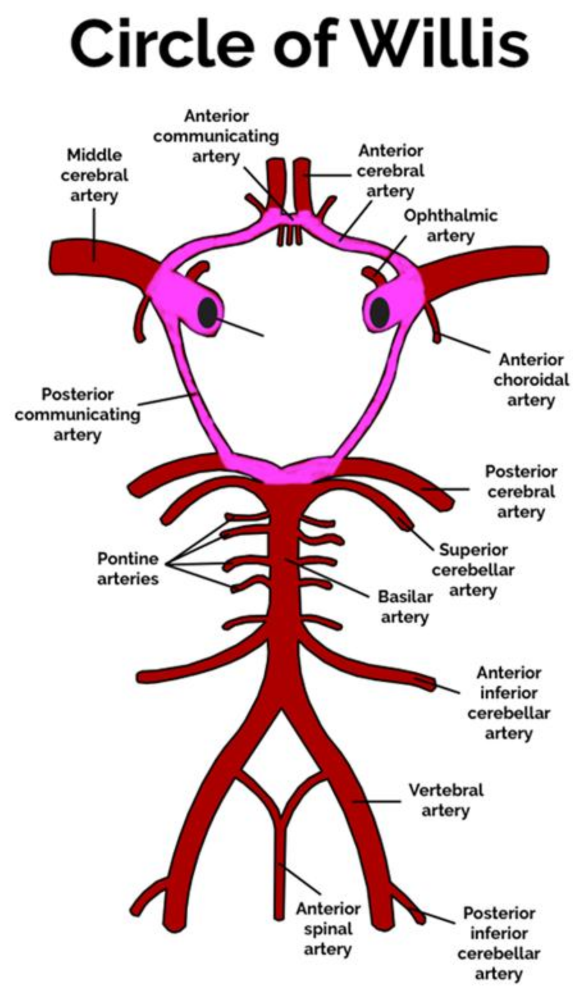
Blood from the heart exits the **brachiocephalic trunk** (which is an artery) and takes two main pathways to the right side of the head. One of these is the **right common carotid artery** which exits the brachiocephalic artery. Bot common carotid arteries split into the **external carotid artery** and the **internal carotid artery**. The external carotid artery has several branches, among them the facial artery, the superficial temporal artery, the maxillary artery, and the occipital artery. The internal carotid artery takes blood through the carotid canal of the skull and into the brain. The other main pathway of blood to the right side of the head is the **vertebral artery** which arises from the **subclavian artery**. The left side of the head has a similar pathway except that the left common carotid artery and the left subclavian artery arise from the aortic arch and not from the brachiocephalic artery.

Arteries of the Brain

The brain is nourished by two main arterial conduits. The first of these is from the **internal carotid arteries**. The other blood vessels that directly deliver blood to the brain are L and R vertebral arteries that travel through and are protected by the transverse foramen of the cervical vertebrae.

The L and R **common carotid arteries** branch off at the carotid sinus and become the **external carotid arteries** (which deliver blood to the face and head), and the **internal carotid arteries** that travel through the carotid canal within the petrous portion of the temporal bone as they deliver blood to the brain.

The blood from the internal carotid arteries comes from the neck and enters a circular pathway known as the **circle of Willis** (**arterial circle**). These arteries connect at a vessel called the **basilar artery** and it leads to the arterial circle. The arterial circle consists of the **anterior communicating arteries** and the **posterior communicating arteries**. From this circle blood then moves **into** one of many arteries that feed the brain. The cerebrum is fed by the anterior, middle and posterior cerebral arteries. The cerebellum is fed by the cerebellar arteries.



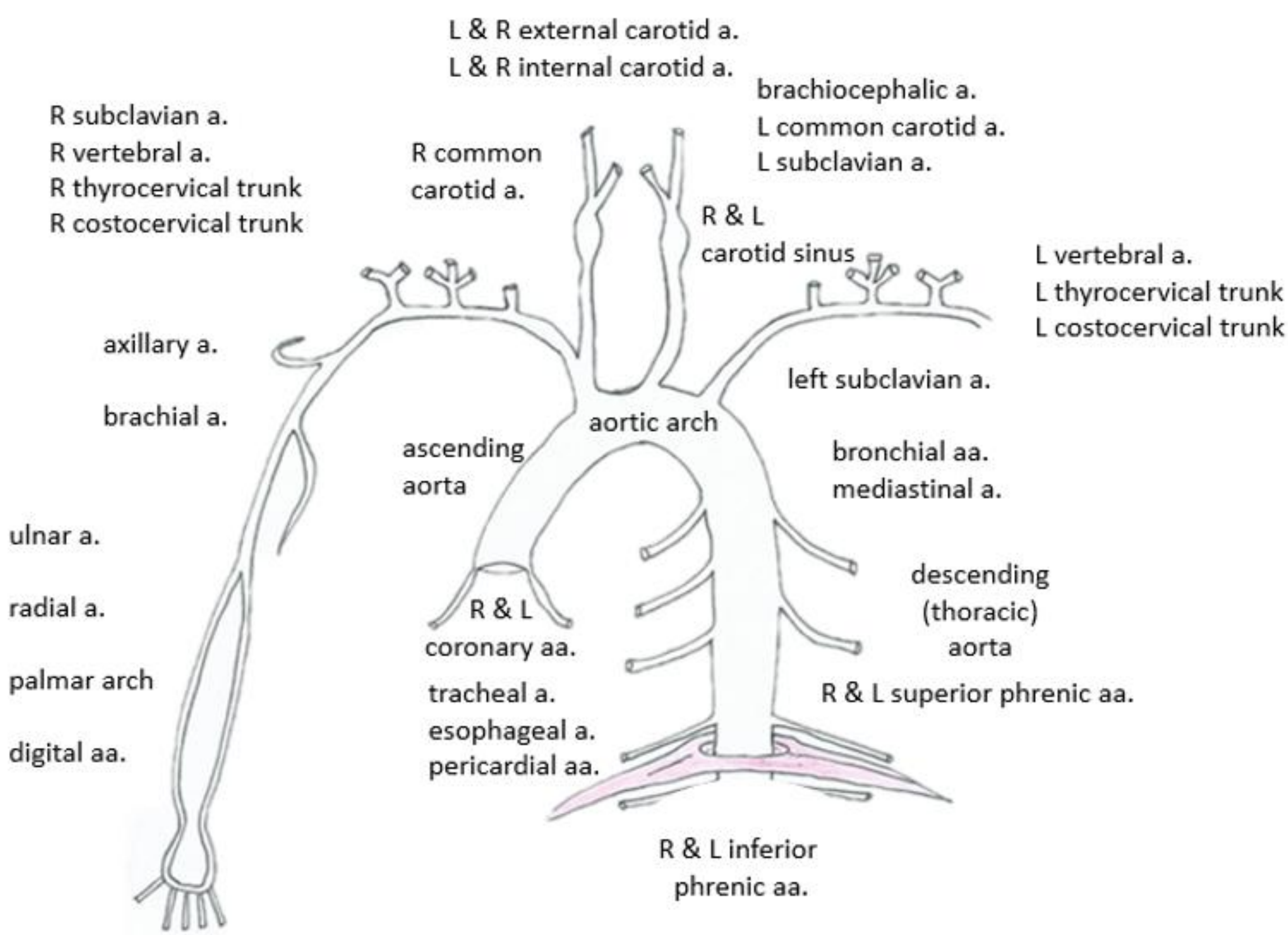
Anatomy of Systemic Arterial Branches

Work to Identify the vessels on this Blood Vessel Diagram from our Lab Manual
It is very important to put in the time and energy in that is required to understand the branching patterns from the aorta. The **Aorta** is the largest artery in the human body and it is *thee* vessel that becomes all of these other vessels as they branch away from it.

Your Objective is to know the Arterial Branches of the System Circuit (as listed here).
Your first task is to match the names to the badly drawn arterial branches shown below from your lab manual. Maybe a line connecting the name to correct vessel. Your next task is to go over the material - again and again and again and again – this is how confusing things become things we know for any topic. We are almost through the toughest parts and you will be amazed at how much you will recall after you focus on a section and then repeat it over and over a few times.

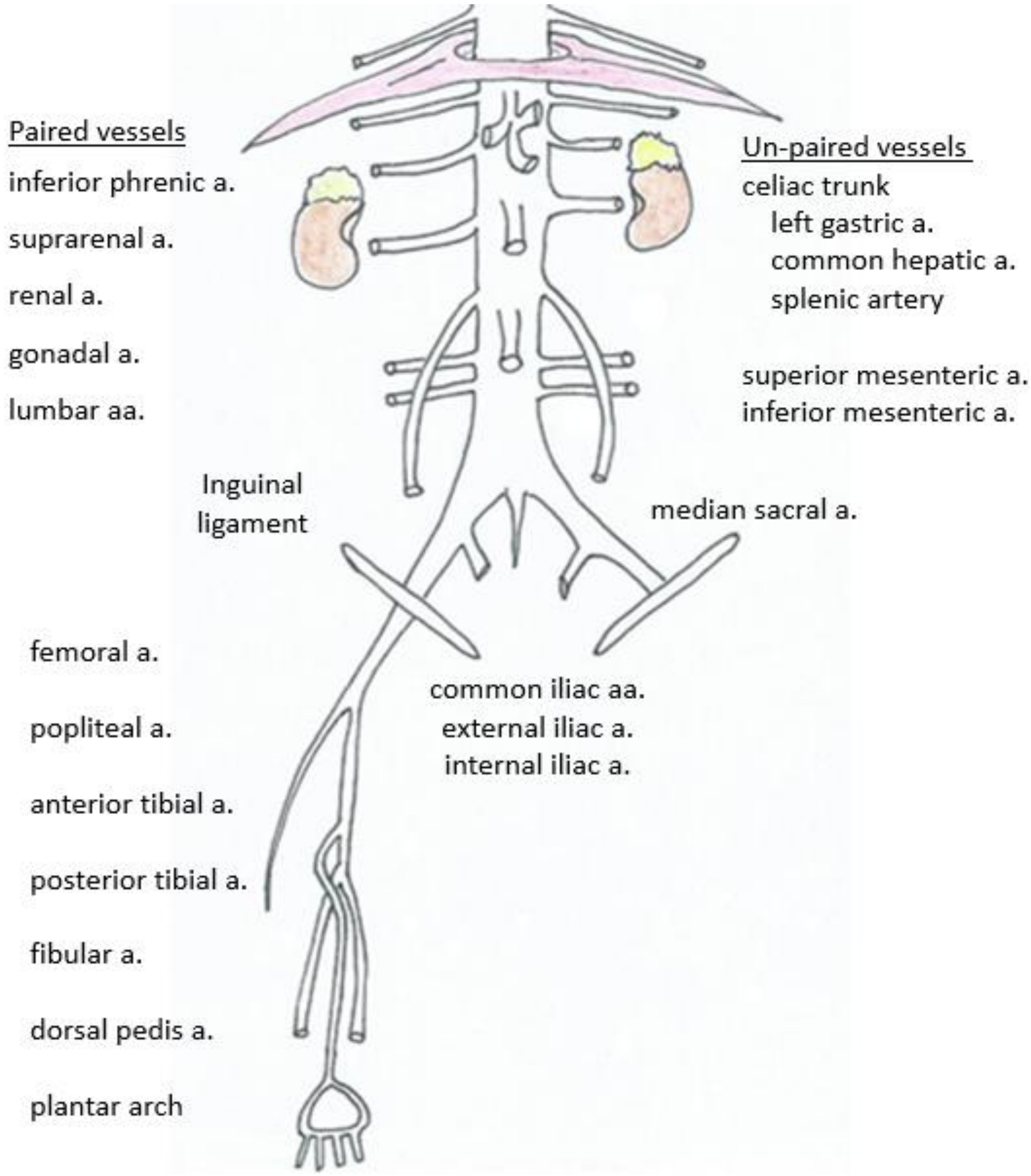
Branches off the Thoracic Aorta

Supplying blood to organs and structures in the thoracic cavity, neck, brain, head and arms.



Branches off the Abdominal Aorta

Supplying blood to organs and structures in the abdominopelvic cavity, and to the thigh and leg.



Arteries of Upper Limb

The arteries of the upper limb receive blood from the **subclavian artery** which takes blood to the **axillary artery**. Blood in the axillary artery travels to the anterior scapula by the subscapular artery to the external chest wall by the lateral thoracic artery, to the upper humeral region by the posterior circumflex humeral artery, and to the distal regions of the arm by the brachial artery. The **brachial artery** is the major artery of the arm and it divides distally to form the **radial artery** and the **ulnar artery**. The radial artery is frequently palpated at the wrist to determine the pulse rate. The radial and ulnar arteries rejoin (called collateral circulation) in the hand as the superficial and **deep palmar arch arteries**. These arteries take blood to the fingers as digital arteries.

Arteries of Lower Limb

Blood in the lower limb comes from the branches of the iliac arteries. Blood in the **common iliac artery** flows into the **internal iliac artery** and into the **external iliac artery**. Once it passes by the inguinal ligament (a connective tissue band that stretches from the ilium to the pubis) the external iliac artery becomes the **femoral artery**. The femoral artery takes blood down the anterior thigh but there is a branch called the deep femoral artery that takes blood closer to the bone. The femoral artery moves posteriorly to become the **popliteal artery** and branches of the popliteal artery become the **anterior tibial artery**, the **posterior tibial artery** and the **peroneal (fibular) artery**. The tibial arteries take blood to the **dorsal arcuate artery**, the **dorsalis pedis artery**, and the dorsal metatarsal arteries which take blood to the digital arteries.

Abdominal and Thoracic Arteries

The aorta starts at the **ascending aorta** and curves via the **aortic arch**. The thoracic aorta is a portion of the descending aorta. It has several branches that take blood to most of the ribs and intercostal muscles. These are the posterior intercostal arteries. Below the diaphragm the descending aorta is known as the abdominal aorta and it has several branches. The first of these is the **celiac trunk** and it branches to take blood to the stomach, spleen and liver. The next branch is the **superior mesenteric artery**. Below this, are the **renal arteries** that take blood to the kidneys. The **gonadal arteries** are found inferior to the renal arteries and they take blood to the testes in males or the ovaries in females. A single **inferior mesenteric artery** is found below the gonadal arteries. The aorta terminates as it divides into the **common iliac arteries**.

Arteries of the Digestive System

The celiac trunk splits into three branches, the common **hepatic artery**, the **left gastric artery** and the **splenic artery**. There are other branches to the stomach which have collateral circulation (two or more arteries taking blood to one area). One of these is the right gastroepiploic artery and another is the left gastroepiploic artery. Below the celiac trunk is the **superior mesenteric artery** which takes blood to the small intestine and to several of the colic arteries that supply blood to the proximal portion of the large intestine. These are the middle colic artery, the intestinal branches, the right colic artery and the ileocolic artery. The **inferior mesenteric artery** takes blood to the distal portion of the large intestine via the left colic artery, sigmoid artery and the rectal artery.

Male and Female Pelvic Arteries

The **common iliac artery** takes blood to the **external iliac artery** and the **internal iliac artery** that takes blood to the pelvis. In females, branches of the internal iliac artery take blood to the inner pelvis. The vesical arteries take blood to the bladder, the uterine arteries take blood to the uterus, the vaginal arteries feed the vagina, the rectal arteries feed the rectum, and the sacral arteries go to the sacrum. The pudendal artery takes blood to the external regions where it supplies blood to the pelvic floor, the labia majora and minora and the clitoris. In males the internal iliac artery takes blood to the bladder, rectum, sacrum, the prostate, and seminal vesicles on the inside. The **pudendal artery** takes blood to the scrotum, penis and external pelvic floor. In both sexes the obturator artery takes blood from the internal iliac artery to the medial thigh while the gluteal arteries take blood to the muscles posterior to the pelvic cavity.

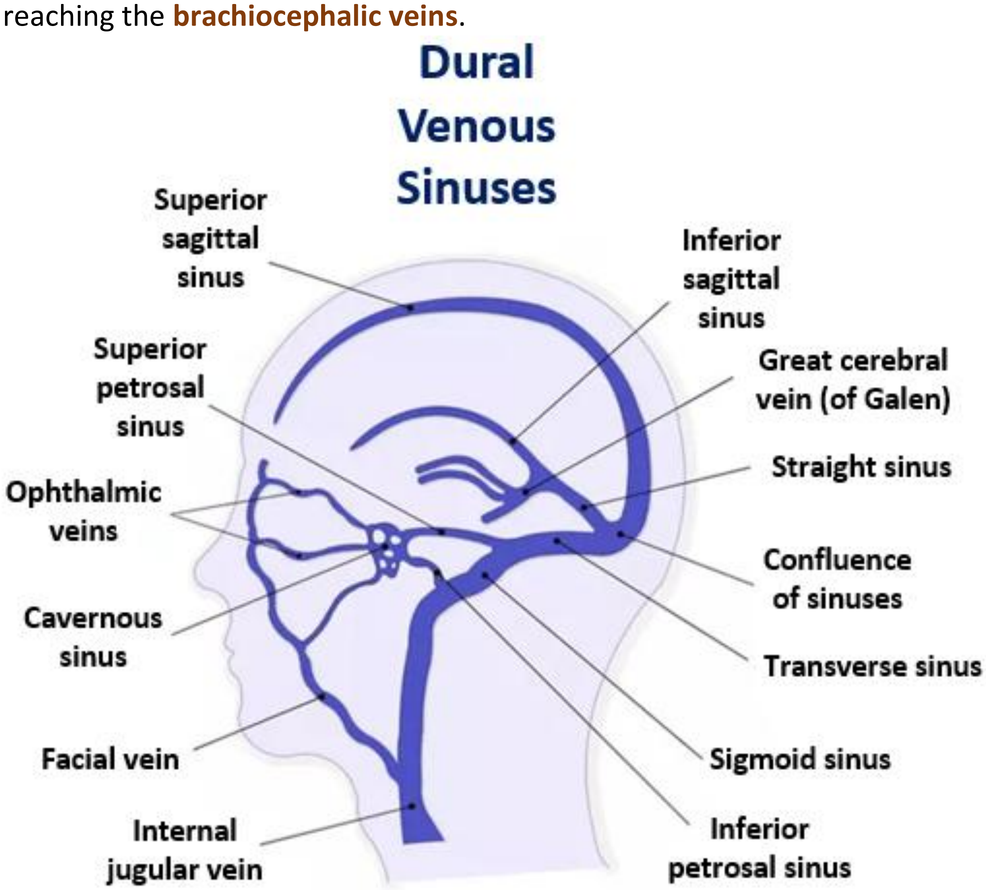
Veins

Veins are blood vessels that return blood to the heart. They are characteristically colored in blue on illustrations. The deep veins typically take the name of the artery next to them or the name of the organ that provides them with blood. Such that, the **femoral vein** runs next to the femoral artery and the **splenic vein** receives blood from the spleen. However, there is a second set of superficial veins (discussed below) which have no arterial companion vessel, and thus have unique names. Use the list of veins in your lab manual and begin to draw and label the major veins of the body.

Head and Neck Veins

The **dural venous sinuses** are the large veins that return blood from the brain to the heart. They are enclosed between the two dural layers of the cranial meninges, the inner meningeal and outer periosteal dural layers, hence they are called the dural venous sinuses (see image below).

The blood coming from the brain travels down the **superior sagittal** and **inferior sagittal sinuses** through the network of venous sinuses sitting on the surface of the brain, eventually draining into the large **internal jugular veins**. These veins take blood down both sides of the neck and enter the **brachiocephalic veins**. The external portion of the head is drained by several veins, including the facial and the maxillary veins, which also take blood to the internal jugular vein while the **superficial temporal vein** and the **posterior auricular vein** take blood to the **external jugular veins** which then flows into the **subclavian veins** before reaching the **brachiocephalic veins**.



The Two Sets of Veins

The veins of the upper and lower limbs are arranged in two sets, the deep set that are parallel to their arterial companions of the same name, and superficial veins, that are much closer to the surface of the body, do not have an arterial companion and have unique names.

Veins of the Upper Limb

The veins of the upper limb are somewhat variable and have many cross connections between them, but they can be divided into the deep veins and the superficial veins. The deep veins of the upper limb frequently form a meshwork around the arteries (venae comitantes) which allows for a great amount of heat transfer. Cool blood from the extremities is warmed by the arterial blood flowing in a counter current. Blood in the fingers returns to the forearm by the digital veins and then the superficial and deep palmar arch veins. The deep veins of the upper limb are the radial veins, the ulnar veins, and the brachial veins. The brachial veins lead to the axillary vein which takes blood to the subclavian vein.

As already mentioned, in the venous system of the systemic circuit there are two sets of veins: The deep set (discussed above) that are parallel to their arterial companions of the same name, and the **superficial veins**, that are unique. The superficial veins of the upper limb are the **basilic vein**, found on the medial aspect of the forearm and arm, the **median antebrachial vein**, on the anterior aspect of the forearm, and the **cephalic vein**, found on the lateral aspect of the forearm and arm and a small vein that connects the basilic vein with the cephalic vein called the median cubital vein. This median antebrachial vein is used frequently the vessel used to withdraw blood.

Veins of the Lower Limb

Blood in the toes returns by the digital veins. These veins take blood to the dorsal metatarsal veins and the dorsal venous arch veins. On the underside of the foot are the plantar veins. Blood moves up the leg by the posterior and anterior tibial veins and the great and small saphenous veins. The anterior and posterior tibial veins join together to form the popliteal vein posterior to the knee. The **small saphenous vein** joins the popliteal vein taking blood to the femoral vein. The **great saphenous vein** begins around the medial malleolus and runs the entire length of the medial lower limb when it enters into the femoral veins. Once the femoral vein crosses the inguinal ligament it becomes the external iliac vein.

Hepatic Portal Veins, Trunk Veins

Most of the blood of the body returns to the heart by capillaries flowing into venules and finally into veins before reaching the heart. In a **portal system** blood moves from one capillary system to another capillary system (in series) before reaching the heart. The hepatic portal system takes blood from the capillary beds of many of the abdominal organs and carries it to the liver where metabolic processing takes place. The hepatic portal vein receives blood from various veins including the splenic vein, the gastroepiploic vein, the left gastric vein and the colic veins which take blood to the superior mesenteric and inferior mesenteric veins. Once the blood is processed in the liver it enters the systemic circulation by the hepatic veins.

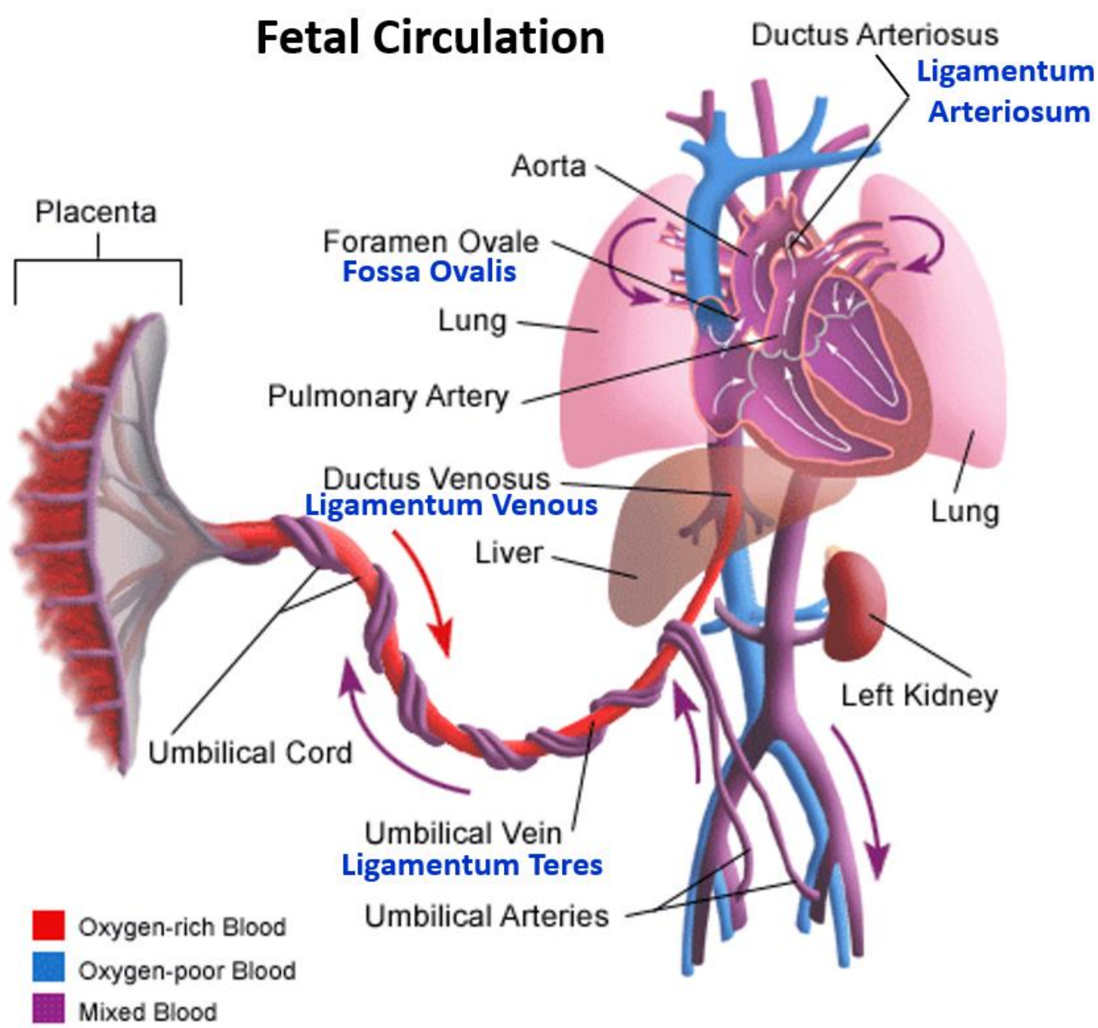
The return of blood from other parts of the pelvic and abdominal cavities does not go through the hepatic portal system but enters the inferior vena cava. The renal veins take blood from the kidneys to the inferior vena cava. The gonadal veins take blood from the testes or the ovaries. The left gonadal vein enters the left renal vein while the right gonadal vein enters the inferior vena cava. The intercostal veins take blood to the hemiazygos and the azygos veins.

The Fetal Circulation

The significant difference in the fetal circulation from the adult circulation lies in the fact that the lungs are non-functional in the fetus in terms of gas exchange. The source of oxygen for the fetus is the **placenta** where maternal blood carries oxygen and nutrients to the developing fetus. Therefore, an important component of the fetal circulation is to bypass the pulmonary circuit as much as possible, since that interface with the lungs for gas exchange is not required for the feus in-utero.

The blood supply from the **placenta** travels to the **fetus** by the one large **umbilical vein** (see the image of the fetal circulation below). This vessel is called a vein because it carries blood 'back' toward the fetal heart. It is very important to know that the blood flowing in the umbilical vein is **oxygenated** blood, which from our experience with the systemic circuit, is not what veins usually contain – however, we know that veins can carry oxygenated blood, for example, in the pulmonary circuit the pulmonary veins are richly oxygenated!

From the umbilical vein the blood passes through a small shunt vessel known as the **ductus venosus** and enters the **inferior vena cava** where it mixes with blood returning from the lower extremities. The ductus venosus actually bypasses the fetal liver, directing O_2-rich blood from the placenta directly into the O_2-poor blood of the inferior vena cava. Thus, the fetus receives a mixture of oxygenated and deoxygenated blood as in enters the fetal heart.



The mixed blood that reaches the fetal heart then begins the first of two bypass routes. Since the lungs do not oxygenate blood in the fetus, they do not require the entire blood volume to pass through them. The first bypass in the heart of the fetal circulation is the route blood take through the **foramen ovale**, an oval shaped hole between the right and left atria of the heart. This blood flows directly from the right atrium to the left atrium via the foramen within the interatrial septum. From **30%** to **50%** of fetal cardiac output is diverted through the foramen ovale.

Another bypass route occurs as the blood enters the pulmonary trunk of the fetal heart. Blood moves directly from the pulmonary trunk through the **ductus arteriosus** and into the descending aorta (see image on previous page). The ductus arteriosus diverts about **55%** to **60%** of the ventricular output from the fetal heart, again allowing the blood to bypass the lungs by going directly into the aorta. Only a small amount of blood, from **5%** to **10%** is required to meet the nutritional needs of the developing lungs.

The blood that travels out from the fetal heart is still a mixture of oxygenated and deoxygenated blood. As can be seen in the drawing above, this blood flows out via the aorta downward, splitting into the external and internal iliac arteries of the fetus. From the internal iliac arteries, blood flows into the **2 umbilical arteries** that merge and then spiral around the single incoming **umbilical vein** as the 2 umbilical arteries exit the fetus and head back toward the placenta. As shown in the image on previous page, the blood in the umbilical arteries is not fully deoxygenated but is 'mixed' blood.

Below is a summary of the significant changes in both the fetal heart and fetal circulation after birth.

Changes in Fetal Heart After Birth

Foramen Ovale → Fossa Ovalis Ductus
Ductus Arteriosus → Ligamentum Arteriosum

Changes in Fetal Vessels After Birth

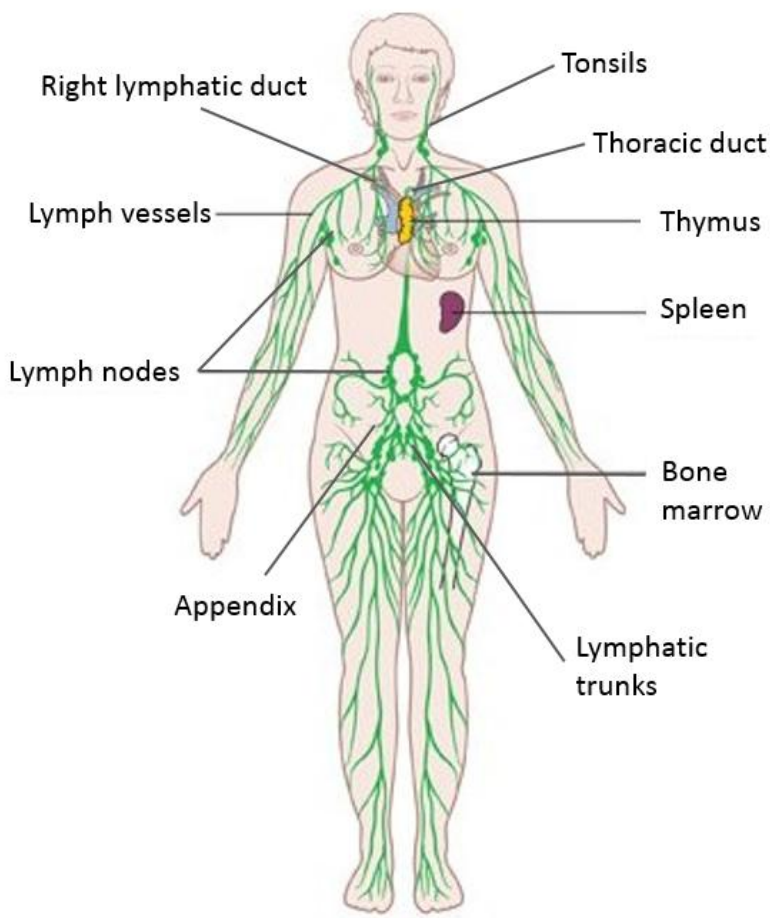
Ductus Venosus → Ligamentum Venosum
Umbilical Vein → Ligamentum Teres

Overview of the Lymphatic System

The lymph system is composed of lymphatics or lymph vessels and glands and is a system with many functions. Fluid that bathes the cells (interstitial fluid) is returned to the cardiovascular system, in part, by the lymph system. This fluid, called lymph, passes through lymph nodes where impurities and foreign microbes are removed. Other parts of the lymph system include lymph organs such as the spleen. These organs produce cells that protect the body from foreign compounds and have other immune functions such as cleansing the body of cellular debris and removing old blood cells from circulation.

The main exchange of fluid from the cardiovascular system occurs at the capillary level. Arterioles carry blood to the capillary bed and the venules return blood from the capillaries. About **90%** of the fluid that flows from the blood capillaries to the interstitial fluid around the cells is reabsorbed by the capillaries. The remaining 10% of the interstitial fluid enters the lymph system at the **initial lymphatics** (also called lymphatic capillaries). Once the tissue fluid is inside the lymphatic vessel it is called lymph. The initial lymphatics are highly permeable, thin-walled vessels that absorb tissue fluid in order to ultimately return this fluid to heart.

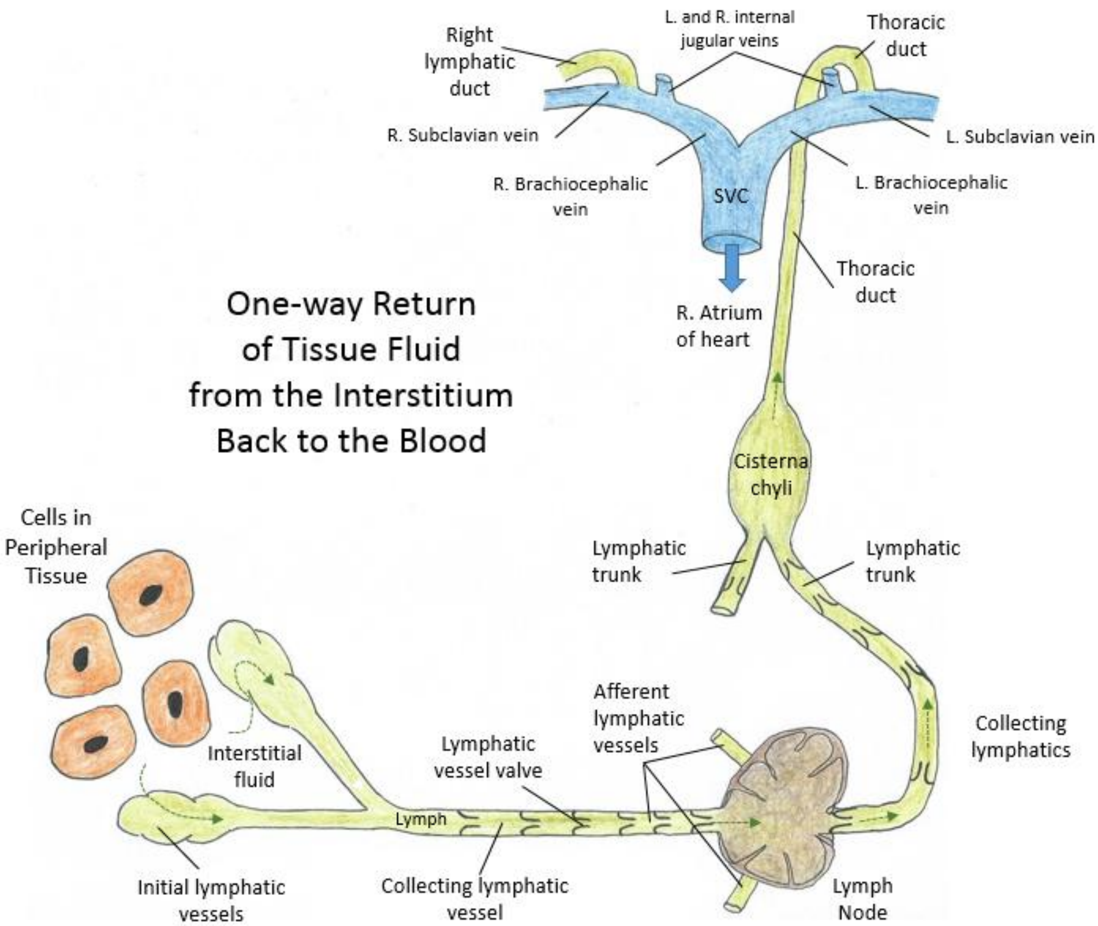
Lymphatic Vessels and Lymphoid Organs



As lymph travels through the lymphatic vessels, the vessels become larger in size, much like veins get larger as they get closer to the heart. The larger collective lymphatic vessels have one-way valves in them that prevent the fluid from falling back, ensuring the one-way flow of lymph from the tissues to the heart. The lymph continues to travel back to the heart into larger lymphatic trunks, which merge into a large lymphatic vessel at the base of the abdomen called the **cisterna chyli**. This vessel, in turn, takes lymph to the largest lymphatic vessel, called the **thoracic duct**, which returns the lymph to the left subclavian vein and therefore back to the cardiovascular system.

The One-way Return (Drainage) of Tissue Fluid

A primary function of the lymphatic system is to return tissue fluid that is out in the peripheral tissues to the cardiovascular system. The **right lymphatic duct** returns blood to the junction where the **right subclavian vein** and the right internal jugular vein reach the right brachiocephalic vein. The **thoracic duct** is the largest lymphatic vessel in the body, and it merges with the cardiovascular system at the point where the left internal jugular vein and the **left subclavian vein** enter the left brachiocephalic vein. The thoracic duct receives lymph from most of the body while the right lymphatic duct receives lymph from the right side of the head, the right pectoral region, and shoulder and right upper extremity.



The **lymph nodes** occur along the path of the body wide lymphatic vasculature and serve to cleanse the lymph of any unwanted materials.

The **thymus** is a lymphoid organ that occurs near these drainage areas.

The **spleen** is the largest lymphoid organ tucked away in the left quadrant of the abdomen. It has many important functions, which include:

- Filtration of Blood to cull old, damaged or abnormal red blood cells, platelets, and white blood cells, maintaining balance in the blood.
- Stores white blood cells (lymphocytes) that produce antibodies to defend the body. The spleen also stores iron, which is essential for red blood cell production.
- Stores of red blood cells, it can store about a **30%** reserve of red blood cells that can be released into the bloodstream in case of emergencies, such as bleeding or trauma.