

## CHAPTER-3 (B)

# Anatomy and physiology of the Cardiovascular and Lymphatic systems

### Introduction

The cardiovascular system consists of the heart, and blood vessels, and blood whilst the lymphatic system consists of lymphatic vessels, lymph nodes, spleen, and lymph. Essentially, however, the cardiovascular and lymphatic systems are one system, as ultimately, lymph is emptied into the subclavian veins to become part of the venous blood return to the heart.

Together they are commonly called the circulatory system, and they play an essential role in maintaining homeostasis.

### **Learning Outcomes:**

**The student should be able to:**

- Describe the surface landmarks of the heart.
- Describe the structure of the heart and the blood vessels.
- Describe the circulation of blood through the heart, the pulmonary circulation, the hepatic portal circulation.
- Describe the auto-regulatory conduction system of the heart.
- Explain the basic mechanics of venous return to the heart.
- Be able to identify the blood vessels as prescribed by the course notes.
- Be able to name the arteries of the major pulse points.
- Name the components of the lymphatic system
- Describe the structure and distribution of lymphatic vessels.
- Describe the direction of flow of lymph fluid.
- Major lymphatic trunks of the body; describe their areas of drainage.
- Identify the areas where lymphatic fluid enters the blood stream.
- Describe the structure and function of the organs and tissues of the lymphatic system.
- List the functions of the lymphatic system



### **Brief overview of circulation**

The circulatory circuit begins and ends in the muscular pump the heart. The heart is divided into the left and right sides, and each of these sides are separated into the superior atria, which receive the blood from the large veins, and inferior ventricles, which pump the blood out into the great arteries by valves.

Arteries conduct blood away from the heart, and veins, conduct the blood towards the heart. This has nothing to do with oxygenation, as you will see that the pulmonary vein, which is highly oxygenated, is in fact transporting the blood towards the heart. Generally, between an artery and a vein lies a capillary bed. We say generally, because there are some instances where this does not strictly occur.

### **Location of the heart:**

Roughly, the heart lies immediately superior to the diaphragm, and within the mediastinum, between the left and right lungs. It helps to imagine the heart as a cone lying upon its side, with an apex (the point) and a base

**The apex-** lies on the diaphragm and is located externally in the 5<sup>th</sup> intercostal space, approximately along the sagittal plane.

**The base** of the heart is the broad opposite end of the apex. It is located about 3cm to the right of the midline on the 3<sup>rd</sup> costal cartilage, and 3cm to the left of the midline on the 2<sup>nd</sup> costal cartilage.

**Note:** The left and right sides are referred to as if viewed from the patient's perspective. So your patient's right side of the heart, from your point of view is the left side.

### **The Structure of the Heart**

#### **The Pericardium**

The pericardium is the membrane that surrounds the heart. It functions to protect the heart, hold it within its position in the mediastinum, and prevent it overstretching.

It is made up of two layers:

1. **The Fibrous Pericardium-** the superficial layer, it is made up of elastic irregular connective tissue.
2. **The Serous Peritoneum-** the deep layer, it forms a double layer around the heart. The outer parietal layer is fused to the fibrous pericardium, whilst the inner visceral layer (epicardium) is fused to the heart wall. In the small spaces between the two layers of the serous peritoneum (termed the **pericardial cavity**) there is pericardial fluid. It reduces the friction from the rubbing of the two membranes when the heart contracts.

#### **The heart wall**

The heart wall is made up of three layers:

1. The outer **Epicardium-** a thin layer of connective tissue
2. The middle **Myocardium-** a thick layer of cardiac muscle, which forms the bulk of the heart.
3. The inner **Endocardium-** a thin layer of endothelium, which is continuous with that of the great vessels, attached to the heart.

#### **The chambers of the heart**

The heart is divided into the left (systemic) side, and the right (pulmonary) side. Each side is also divided by valves, into the **atria**, which receive the

blood into the heart, and the **ventricles**, which pump it out into the great vessels. Between the left and right atria and ventricles lies a dividing septum.

### **The right atrium**

The thin-walled atrium, receives deoxygenated blood from the **superior** and **inferior vena cava** veins, and the **coronary sinus**. Blood passes from the right atrium into the right ventricle through the **tricuspid** (atrioventricular) **valve**. The valve opens in one direction only, and is 'tethered' to the papillary muscles of the right ventricle by the **chordae tendinae**, which act like guy ropes allowing the blood to pass into the ventricle, but not back towards the atrium when the ventricular wall contracts.

### **The right ventricle**

The pulmonary ventricle is divided from the left ventricle by the **interventricular septum**. When the muscular wall of the ventricle contracts, the deoxygenated blood is forced through the **pulmonary** (semilunar) **valve** into the **pulmonary trunk**, which divides into the **left** and **right pulmonary arteries**.

### **The left atrium**

This thin-walled chamber receives oxygenated blood from the lungs via the four **pulmonary veins**. Blood passes from the left atrium into the left ventricle via the **mitral or bicuspid** (atrioventricular) **valve**, which like the tricuspid valve, is also limited in its movement by chordae tendinae.

### **The left ventricle**

This muscular chamber forms the apex of the heart, and is responsible for pumping the oxygenated blood through the body. As a result of its great workload, it has the thickest muscular layer of the four chambers. When this chamber contracts, blood passes through the **aortic** (semilunar) **valve** into the **ascending aorta**, which conveys the blood to the body, and the coronary arteries, which supply the actual heart muscle.

**Note:** the tricuspid and the mitral valves are also known as the atrioventricular valves, and the aortic and pulmonary valves are also called the semilunar valves. The mitral valve is also called the bicuspid valve.

### **Circulation from the heart:**

The heart is a system of two pumps. This encompasses the **systemic** and **pulmonary** circulatory routes.

#### **Pulmonary route**

This route encompasses the transport of blood from the right atrium through the pulmonary capillary bed, and back to the left atrium of the heart. The pulmonary trunk emerges from the pulmonary semilunar valve of the right atrium, and divides into the left and right pulmonary arteries, carrying deoxygenated blood to the lungs. The branches continue to divide, until the

capillaries surround the alveolar sacs of the lungs. Here the exchange of gasses takes place. The capillaries reunite to form the pulmonary veins, which carry oxygenated blood towards the heart, entering at four locations in the left atrium.

### **Systemic route**

From the left atrium, the blood descends to the left ventricle, which contracts powerfully to drive the oxygenated blood through the aortic semilunar valve towards the aorta, which distributes it to the rest of the body. Oxygenated blood flows through the **arteries**, into smaller arteries, into **arterioles**, and then into the **capillary bed** as they enter the tissue, where an exchange of nutrients, gasses and waste occurs. The capillaries unite to form the **venules**, which merge to form the **veins** of the venous circulation, and are returned to the heart via the vena cava vessels. The pump action of the heart affects only the arterial blood flow. Venous return to the heart is governed by skeletal muscular action, changing pressure in the abdominal and thoracic cavities as a result of diaphragmatic breathing, and a system of valves within the veins.

**Remember!** Arteries are vessels, which convey the blood away from the heart, whilst veins, convey blood towards the heart. The terms have nothing to do with the oxygenation status of the blood.

### **The conduction system of the heart**

The contraction of the heart muscle occurs without stimulation from the nervous system, it is however, **regulated** by the autonomic nervous system, and the endocrine system. Think how your heart races in response to the adrenaline produced by fear (the fight or flight systemic nervous system response).

Specialised self-excitabile **autorhythmic cells** in the heart wall, particularly found at the **sinoatrial (SA) node**, are able to conduct **electrochemical impulses** independently of the rest of the body. The SA node is called the 'pacemaker' of the heart, and sets the pace for the contractions of the ventricles. Impulses from the SA node, travels along the **internodal tracts** through the atrial wall to the **atrioventricular (AV) node** in the **interatrial septum**. The impulse pauses slightly at the AV node and descends directly through the **bundle of His** (atrioventricular bundle), before spreading upwards across the ventricles through the Purkinje fibres. This pathway allows the atria to contract and empty into the ventricles, and then for the ventricles to push the blood into the arteries from the bottom up, emptying fully. Thus the contractions of the heart are initiated 'internally' by the heart, and follow a coordinated pathway.

### **The cardiac cycle**

Each beat of the heart represents a cardiac cycle during which the chambers fill and empty. The beating of both the left and right sides of the heart are

synchronised. The cardiac cycle is continuous, and consists of three main stages: atrial systole, ventricle systole and diastole.

### **Atrial systole**

Some of the blood that enters the atria from the veins flows directly into the ventricles; the rest is pumped into them when the atria contract. The atrial walls are thin, and do not produce much pressure when they contract, but it is enough to open the AV valves and force the blood into the ventricles.

### **Ventricular systole**

Follows atrial systole. The thicker muscular walls of the ventricles contract, squeezing the blood and raising its pressure. Once the pressure of the blood in the ventricles exceeds that in the atria the AV valves are pushed shut (heard through stethoscope as a lub). The pressure then exceeds that of the blood in the arteries, resulting in the semilunar valves opening and the blood flowing into the arteries.

### **Diastole**

After systole, the atrial and ventricular walls relax. As the ventricles relax, the pressure drops and falls below that of the arteries causing the semilunar valves to shut (heard through stethoscope as a dub) preventing the backflow of blood from the arteries. As the atria relax blood once again passes into them from the veins.

Diastole is then followed by atrial systole, and the cardiac cycle begins again.

## **Blood vessels**

Heart-arteries-arterioles-capillaries-venules-veins-heart

### **Arteries**

Made up of 3 coats:

#### **1. The inner Tunica interna** (tunic refers to coat).

This layer is composed of several layers itself:

- An inner most lining of endothelium, which is composed of simple squamous epithelium.
- A basement membrane upon which the endothelium rests.
- An internal elastic lamina.

#### **2. The Tunica media**

Made up of **elastic fibres** and **smooth muscle** arranged in a circular fashion. This elasticity allows for a great increase of stretch caused by a volume of blood being pumped through the artery, with each heartbeat. Constriction and relaxation of these smooth muscle cells contributes significantly to the blood pressure of an individual.

Muscular arteries have an **external elastic lamina** between the tunica media and tunica externa.

### **3. The outer Tunica externa**

Made up mainly of elastic and collagen fibres.

#### **Types of Arteries**

##### **Elastic arteries**

These are the larger arteries, which have a large lumen diameter, thinner walls, and a high proportion of elastic fibres within their walls. They function to continue the propulsion of the blood from the heart towards the capillary bed through their pressure reservoir.

E.g. aorta, brachiocephalic, and common carotid.

##### **Muscular arteries**

The medium sized arteries contain more smooth muscle fibres within their tunica media, and are hence, much thicker walled. As a result of their muscle, they play the important role of vasodilation and vasoconstriction.

E.g. the brachial and radial arteries.

##### **Arterioles**

These tiny vessels vary from having some characteristics of arteries and some of the capillaries. All have a tunica interna of endothelium, but the larger arterioles also have some smooth muscle and elastic fibres within their tunica media. These vessels function to regulate the blood flow into the capillaries.

The arteries are innervated by the Sympathetic Nervous System.

##### **Capillaries**

These are microscopic vessels, which, in most cases connect the arterioles to the venules. This is referred to as the microcirculation. Capillaries function to allow for the exchange of nutrients and waste products between the blood and the tissue cells through the interstitial fluid.

But for a few exceptions, capillaries are found near to almost every cell in the body. Their distribution, however, is not equal throughout the body. Tissues, which have high metabolic requirements such as the kidneys, muscles and liver, have a denser capillary bed than other tissues with fewer metabolic requirements, such as the tendons. Some tissues have no access to the circulatory system i.e. the cornea and lens of the eye, and cartilage.

Although capillaries have such a wide distribution, most of the time only 25% of the capillary bed has blood flowing through it. From a therapeutic point of view, this means that metabolic toxic waste products may remain within the tissues, contributing to disorders such as arthritis. Exercise encourages blood to flow through the entire capillary bed, and allows the flushing out of the toxic waste products to take place. This effect can also be achieved through the use of circulatory stimulants.

Capillaries are made up of a single layer of epithelium, the **endothelium**, and a **basement membrane**. This means that the exchange of substances is relatively easy through the single layer of cells.

Substances can move in and out of the capillaries through four means:

1. Through intercellular clefts
2. Through fenestrations
3. Within pinocytotic vesicles
4. Through the plasma membrane of the endothelial cells.

Another structural type of capillary is the **sinusoid**. These vessels are wider than capillaries, and their endothelial cells have large fenestrations and no basement membrane. They also have very large intercellular spaces to allow for large proteins to pass from the tissues into the bloodstream. Sinusoids are adapted to function within particular organs such as the liver, red bone marrow, spleen.

### **Venule**

Venules, also called capillary veins have the same three layers or coats as veins, but are smaller vessels that join to veins, in a similar manner to how arterioles are derived from arteries.

### **Veins**

Made up of 3 coats:

**Tunica interna** – endothelium and basement membrane, but thinner than the arteries.

**Tunica media** – very little smooth muscle and few elastic fibres.

**Tunica externa** - Collagen and elastic fibres.

- Veins lack the internal and external elastic laminae of the arteries.
- The lumen of a vein is larger than that of the comparable artery.
- Veins have valves, which help to prevent the back flow of blood.

Imagine the long vein of a leg. The blood pressure created by the pumping action of the heart and elastic arteries has diminished within the capillary bed, and the blood has to return to the heart, against the flow of gravity. Blood return is greatly aided by the squeezing action of contracting skeletal muscles (such as the calf muscles in the leg), and the blood which is pumped in this manner is held in the valves, whilst it awaits the next skeletal pump action.

Another structural type of vein is called a **venous sinus**. These vessels have a thin endothelial wall, with no smooth muscle. It also lacks the tunics media and externa, but is supported by the surrounding connective tissue. Sinuses are found in the brain- the sagittal sinus, and in the heart- the coronary sinus.

### **Venous return**

Venous return is influenced by:

- **The heart:** Blood flows from the higher pressure in the veins, towards the lower pressure in the right atrium.
- **The skeletal muscle pump:** The blood is squeezed through the proximal valve, whilst the distal valve closes to prevent back flow of blood.
- **The respiratory pump:** With inhalation, the diaphragm results in an increase of pressure in the abdominal cavity, and a compression of the veins. The blood moves from the compressed veins to the decompressed veins in the thoracic cavity, and then into the right atrium.

Thus with a condition such as varicose veins, exercises such as walking and deep breathing significantly aid the venous return, and help to prevent further deterioration of the condition.

### Thoroughfare channels

Thoroughfare channels are vessels, which bypass the capillary bed, connecting arteries or arterioles to veins or venules. They help coordinate the flow of blood around the body enabling more oxygenated blood to go to areas of high metabolic requirements, and less to those of lower requirements. Muscles control the opening and closing of these channels.

### Portal systems:

A portal system carries blood between **two** capillary beds, without first passing through the heart. There are two such systems in the human body – the hepatic portal system, and the hypothalamic/anterior pituitary portal system.

#### **The Hepatic Portal System:**

The liver receives blood from two sources:

1. The **hepatic artery**- bringing oxygenated blood from the heart to the liver.
2. The **hepatic portal vein**- brings deoxygenated blood and nutrients, from the capillary bed of the gastrointestinal tract.

The hepatic portal vein divides into two branches and carries this blood to the liver **sinusoids**, where oxygen, most nutrients, and toxins are taken up by the hepatocytes (cells of the liver).

The hepatocytes secrete nutrients and metabolites back into the blood, which drains into the hepatic vein.

Thus, the liver receives blood from two sources- the hepatic portal vein and the hepatic artery, but all the blood is returned to the hepatic veins. Blood from the heart travel through two capillary beds before returning to the heart. The gastrointestinal capillary bed, and the hepatic capillary bed, before draining into the hepatic vein, and then into the vena cava.

**Task:** There are 8 major pulse points. Please make a note of their location, and attempt to palpate them on yourself.

**The circulatory routes:**

Note of the names of the large blood vessels associated with the heart. You need to know their names, as the names of the blood vessels emerging from them.

Be able to identify the following blood vessels.

(pp) – refers to ‘pulse point’.

**Note** that the muscle of the heart wall is supplied with its own arteries, known as the coronary arteries. It is not necessary to learn the names of these arteries.

**You are required to learn the names and course of the following:**

(pp) indicates the location of pulse points

**The great arteries of the heart:**

Pulmonary artery  
Ascending aorta, aortic arch,  
thoracic aorta  
Left subclavian  
Left common carotid (pp)  
Brachiocephalic

**Arteries of the head and neck:**

Brachiocephalic  
Right subclavian  
Vertebral  
Right common carotid (pp)  
Internal carotid  
External carotid  
Ophthalmic  
Facial (pp)  
Superficial temporal (pp)

**Arteries of the brain:**

Internal carotid  
Anterior cerebral  
Anterior communicating  
Posterior communicating  
Vertebral  
Basilar  
Posterior cerebral

**Task:**

Name the arteries, which make up the Circle of Willis.

**Arteries of the upper limb:**

Brachiocephalic  
Subclavian  
Axillary  
Brachial  
Radial  
Ulnar  
Superior palmer arch  
Deep palmer arch

**Arteries of the lower limb:**

Abdominal aorta  
Right (or left) common iliac  
Internal iliac  
External iliac  
Femoral (pp)  
Profunda femoris  
Perforating branches  
Genicular  
Popliteal (pp)  
Anterior tibial  
Posterior tibial (pp)  
Dorsalis pedis (pp)  
Arcuate  
Dorsal metatarsal  
Dorsal digital  
Peroneal  
Medial plantar  
Lateral plantar  
Plantar arch



**Aorta and branches:**

Aortic arch  
Coronary  
Brachiocephalic  
Common carotid  
Subclavian  
Internal thoracic  
Costocervical trunk

Thoracic aorta  
Bronchial  
Oesophageal

Abdominal aorta  
Celiac trunk  
Left gastric  
Common hepatic  
Superior mesenteric  
Renal arteries  
Testicular/ovarian  
Inferior mesenteric  
Common iliac

**Arteries of the gastrointestinal tract:**

Aorta  
Celiac trunk  
Common hepatic  
Splenic  
Left gastric

Superior mesenteric  
Inferior mesenteric

As we move onto the veins, do bear in mind that they flow from distal to proximal.

**Veins of the head and neck:**

Internal jugular  
External jugular  
Vertebral  
Right subclavian  
Right brachiocephalic

**Sinuses of the dura mater:**

Superior sagittal sinus  
Straight sinus  
Inferior sagittal sinus  
Cavernous sinus

**Caval and azygos systems:**Superior vena cava system:

Internal jugular  
Right and left brachiocephalic  
Superior vena cava

Inferior vena cava system:

Common iliac  
Testicular/ovarian  
Renal  
Hepatic  
Inferior vena cava

**Azygos system:**

Azygos  
Posterior intercostal

**Veins of the upper limb:**

Dorsal digital network  
Basilic  
Medial  
Cephalic  
Median cubital  
Brachial  
Axillary  
Subclavian  
Brachiocephalic

**Veins of the lower limb:**

Posterior tibial  
Anterior tibial  
Popliteal  
Femoral  
External iliac  
Internal iliac  
Right or left common iliac  
Inferior vena cava  
Great saphenous  
Small saphenous – these are the two veins which are prone to becoming varicosed.

**The hepatic portal system:**

Hepatic vein  
Portal vein  
Splenic vein  
Inferior mesenteric  
Superior mesenteric  
Right and left gastric veins

# Embryonic Development of the cardiovascular and lymphatic Organs

## The Heart

In the early stages of heart development, the **oxygenated** blood is provided by the **placenta** via the **umbilical vein** which then divides into two, and passes through the **yolk sac**. These 2 vessels then fuse to form the **sinus venosus**. This enlarged vessel then leads to the single **primitive atrium** and then on to the single **primitive ventricle** of the developing heart. Both the atrium and ventricle have begun to beat. Once the blood has passed through the ventricle, it continues on into the **truncus arteriosus** from which the paired **aortic arches** will eventually develop. Then the blood can move on to the vessels throughout the developing embryo before returning to the umbilical arteries and then back to the placenta.

The heart itself develops between days 24 and 28 of gestation. The areas where the primitive atrium and ventricle are found, fold so that they are in intimate contact with each other. The **truncus arteriosus** will give rise to the major arteries, the **pulmonary artery**, and the **dorsal aorta**. Before these arteries can develop, the ventricles must separate internally by a **membranous structure** into the **left and right ventricles**. The **atrium** divides into 2 again by the formation of a membrane.

## Lymphatic System

**The lymphatic system is made up of:**

- Lymph flowing through lymphatic vessels
- Structures and organs which contain lymphatic tissue
- Red bone marrow, which contains the stems cells that develop into lymphocytes

As well as being part of the circulatory system, it is an integral part of the immune system.

**The primary organs** of this system are the red bone marrow, which houses the stem cells, which develop into B lymphocytes, and pre-T lymphocytes. The pre-T lymphocytes migrate to the thymus gland, where they develop and mature.

**The secondary lymphatic organs and tissue** are the sites where most immune responses occur- the lymph nodes, spleen and lymphatic nodules.

## **Components of the Lymphatic System:**

Lymphatic vessels, trunks and ducts

Lymph nodes

Primary lymphatic organs –

- Red bone marrow
- Thymus gland
- Secondary lymphatic organs and tissues -
- Lymph nodes
- The spleen
- Lymphatic nodules

Some of the blood fluid and lymphocytes, leaves the blood vessels, and enters the interstitial spaces. Lymph vessels form capillary networks, which recover this fluid as well as other components and return these to the venous system- thus, the lymphatic circulation takes some of the pressure off the venous circulation.

## **Functions of the Lymphatic System**

- Drains interstitial fluid
- Transports dietary lipids and fat-soluble vitamins (A, D, E & K) absorbed by the gastrointestinal tract into the blood.
- Facilitates the immune response, primarily through lymphocytes, in one of two basic ways known as cellular immunity and humoral immunity.
  - **T Lymphocytes** destroy invaders through releasing cytotoxic substances and causing the invader to rupture. (Cellular immunity)
  - **B Lymphocytes** secrete anti-bodies, which combines with and destroy specific foreign invaders. (Humoral Immunity)

**Note:** The lymphatic vessels, lymph nodes, and the spleen contain macrophages which destroy some foreign substances by phagocytosis, whilst lymphocytes deal with others through the above mechanisms. However pathogens and cancer cells can spread through the body via the lymphatic system if unrecognised.

## **Lymphatic Vessels and Circulation**

Lymphatic capillaries are found throughout the body except in avascular tissue, the CNS, portions of the spleen and red bone marrow.

Lymphatic capillaries are close-ended tubules located between the cells, which begin blindly and unite to form lymphatic vessels. They are made up of simple endothelial tubes, which are not surrounded by a basement membrane and therefore can absorb macromolecules more easily. The structure of the lymphatic vessel allows lymphatic fluid to enter, but not leave via openings in the vessel walls.

Lymphatic capillaries contain anchoring filaments at right angles to the vessel, which attach the vessels to surrounding cells. When the interstitial fluid accumulates, these filaments are pulled, and this opens the vessels allowing fluid to enter into the lymphatic capillary.

Lymphatic vessels are similar to veins, but have thinner walls, more valves, and very large lumen. Lymphatic vessels have very little smooth muscle, as compared to veins, and no elastic tissue, as compared to arteries.

The lymph flows within the vessels and through lymphatic nodes. In the skin, lymphatic vessels lie sub-cutaneously and tend to follow the veins, whilst in the viscera the vessels generally follow the arteries, and form plexuses around them.

Specialised lymphatic vessels called lacteals are found in the small intestine. Lacteals function to transport lipids from the gastric lumen into the lymphatic vessels, and from there, into the blood stream. The lipids make the normally clear lymph fluid a milky white, and it is referred to as chyle.

### **Trunks and Ducts**

Lymph passes from lymphatic capillaries into lymphatic vessels and through lymph nodes. Lymph vessels pass through lymph nodes either to another node of the same group, or to a node of another group. The exiting vessels unite to form lymph trunks.

These principal trunks pass into two main channels:

#### **The thoracic duct**

This duct is about 40cm long and begins as a dilation, the cisterna chyli, anterior to the second lumbar vertebra, and drains into the blood stream via the left subclavian vein. This is the major collecting duct of the lymphatic system.

The thoracic duct drains:

- The left side of the head, neck & chest, the left-arm, the entire body, inferior to the ribs.
- The right and left lumbar trunks
- The intestinal trunk
- The left bronchomediastinal trunk
- The left jugular trunk
- The left subclavian trunk

#### **The right lymphatic duct.**

This duct is about 1.25cm long and drains lymph from the upper right side of the body, into the blood stream, via the right sub-clavian vein.

The right lymphatic duct drains:

- The right jugular trunk

- The right subclavian trunk
- The right bronchomediastinal trunk

### **Lymph Flow**

The flow of lymphatic fluid is slow and it is maintained by the contraction of skeletal muscles and the pressure changes within the thorax. As in veins, unidirectional flow is maintained by the presence of valves.

Lymphatic fluid is responsible for returning plasma protein to the blood stream. Very little protein can escape due to its large size, however, those that do escape cannot return due to the concentration gradient of proteins within the blood.

#### **Sequence of fluid flow:**

Blood capillaries (blood) > interstitial spaces (interstitial fluid) > lymphatic capillaries (lymph) > lymphatic vessels (lymph) > lymphatic ducts (lymph) > Subclavian vein (blood).

Lymph is returned to the blood vessels via two pumps.

#### **Skeletal muscle pump action:**

Muscle contraction, compress lymphatic vessels and forces the lymph towards the Subclavian veins. The lymphatic valves prevent back-flow of the lymph.

#### **Respiratory pump action:**

- **Inhalation** – the thoracic region has a lower pressure, which ‘pulls’ the lymph fluid from the higher abdominal pressure.
- **Exhalation** – the abdominal pressure falls, this promotes the flow of lymph from the more distal vessels into the abdomen.

### **Lymphatic organs and tissues**

The organs and tissues of the lymphatic system are classified into two functional groups:

**Primary lymphatic organs** – provide the environment for stem cells to divide and mature into B and T cells.

This occurs in the red bone marrow and the thymus gland. The red bone marrow releases mature B cells, and pre-T cells, which migrate to the Thymus gland to mature.

**The secondary lymphatic organs and tissues** - are sites where most of the immune responses occur. Lymph nodes, the spleen and lymphatic nodules.

#### **The Thymus gland:**

The gland is located in the mediastinum, and is composed of two lobes divided into lobules by trabeculae. The lobules are made up of an outer cortex, and an inner medulla composed of lymphocytes and reticular epithelial cells. The reticular epithelial cells produce the thymic hormones, which contribute to the development of T cells. (T cells are named because of their association with the Thymus gland). The pre-T cells migrate from the red bone marrow to the Thymus

gland, where they mature, and then enter the systemic circulation via the venules supplying the gland, as matured T lymphocytes.

## **Lymphatic Nodes:**

These bean-shaped organs are clustered along the lymphatic vessels. Palpable nodes are found in the neck (cervical chain), axillae and inguinal area.

The nodes are covered by a dense connective tissue capsule, which extends into the node as trabeculae. The trabeculae divide the node into compartments, and support the blood vessels into the node.

### **The node is divided into:**

The **stroma** – capsule, trabeculae, reticular fibres, and fibroblasts.

The **parenchyma** – is further divided into two areas:

- The **outer cortex** contains lymphatic nodules of B lymphocytes, called germinal centres, which contain macrophages, and are the centres of B cell proliferation into anti-body secreting plasma cells. Dendritic cells serve as antigen-presenting cells.
- The **inner cortex** contains T lymphocytes.

The **medulla** contains B cells and plasma cells in strands known as the medullary cords.

### **Flow through the node:**

Lymph flows through the nodes and vessels in one direction only.

Enters the node through many afferent vessels > subcapsular sinus > trabeculae sinuses > medullary sinuses > exits through one or two efferent lymphatic vessels at the hilus – the site where blood vessels also enter and leave the node. As lymph enters the node, the reticular fibres within the sinuses trap foreign debris. Macrophages destroy some of the aliens by phagocytosis, or present them to the T lymphocytes for destruction. B cells transform into plasma cells, which secrete antibody, facilitating the destruction of these foreign bodies. .

### **Task:**

Write a list of the six major chains of lymph nodes throughout the body.

## **The spleen**

The spleen is not green, as is usually depicted, but a deep purple due to the rich supply of red blood cells. Located in the left hypochondriac region posterior to the 9<sup>th</sup>, 10<sup>th</sup> and 11<sup>th</sup> ribs. Like the lymph nodes, the spleen has a hilus, which gives entry to the splenic artery, and exit to the splenic vein, efferent lymphatic vessels. The spleen differs from the lymph nodes, however, in that it filters the blood rather than the lymph, of foreign particles and debris.

### **The stroma is made up of:**

The capsule- dense connective tissue, and a serous visceral peritoneum membrane.

Trabeculae extend inwards from the capsule  
Reticular fibres and fibroblasts.

**The parenchyma:**

**White pulp** –lymphocytes and macrophages arranged around the central arteries.

**Red pulp** – venous sinuses filled with blood and splenic cords.

The splenic cords are made up of RBC's, phagocytes and lymphocytes.

**The flow of blood through the spleen:**

Blood flows with the splenic artery, through the hilus, into central arteries of the white pulp. Here, T & B cells carry out immune functions while macrophages phagocytose foreign particles.

In the red pulp, the spleen phagocytoses old or damaged blood cells and platelets, antigens are destroyed by antibodies.

**Functions of the spleen:**

- Removes dysfunctional erythrocytes, bacteria and other debris
- Manufactures lymphocytes and monocytes, and is involved in haemopoiesis during foetal life.
- Stores platelets, which are discharged as required.
- Stores blood, and by contracting, it adds blood to the general circulation

**Lymphatic nodules**

These are concentrations of lymphatic tissue not surrounded by a capsule, and are thus referred to as tissues not organs. They are commonly referred to as mucosa associated lymphoid tissue (MALT).

Some nodules may be small and solitary, but many are large aggregations. E.g. The five tonsils of the pharynx (1 pharyngeal tonsil, 2 palatine tonsils, 2 lingual tonsils)

Peyer's patches.

The appendix

# Haematology

## Learning Outcomes

### The student should be able to:

Describe the functions of the blood and its components



## Blood

The cardiovascular system primarily functions in the transport of blood, and in order to conceptualise the significance of this system, it is important to understand the characteristics and functions of blood.

Blood is transported from the heart, to the lungs via the pulmonary circulation, in order to absorb oxygen, and release carbon dioxide. It then returns to the heart, to be redirected to the rest of the body, where it releases the oxygen into the interstitial fluid, and collects metabolic waste products for excretion via the liver, kidneys and lungs.

## Functions of the blood

### Transportation

- Transports oxygen to the cells and carbon dioxide from the cells to the lungs.
- Transports nutrients from the gastrointestinal tract to the cells, and heat and waste products away.
- Transports hormones from the endocrine glands to other receptor cells within the body.

### Regulation

- Helps to regulate pH through buffers.
- Adjusts the body temperature.
- Influences blood osmotic pressure.

### Protection

- Homeostasis
- Through clotting, prevents excessive blood loss after injury
- White blood cells protect against pathological microbial invasion.

### Blood storage:

60% - held in the systemic veins and venules when the body is at rest.

15% - held in the arteries and arterioles

12% - held in the pulmonary vessels

8% - held in the heart

5% - held in the systemic capillaries.

Large volumes of blood are also held in the abdominal organs such as the liver and spleen.

### **Components of blood**

Whole blood is made up of two components, **blood plasma** and **formed elements**.

#### **Blood plasma**

- A watery fluid, which contains dissolved substances.
- This straw-coloured liquid is made up of about 91% water, and about 7% plasma proteins. The remaining 2% are solutes.
- The liver cells manufacture most of the plasma proteins, which include albumin, globulin, fibrinogen, immunoglobulins.
- Plasma makes up 55% of blood as a whole.

#### **Formed elements**

Cells and cell fragments which all originate from red bone marrow, including erythrocytes, thrombocytes and leukocytes.

Include:

#### **Erythrocytes** (red blood cells)

- Circular biconcave non-nucleated discs which contain large amounts of the oxygen carrying protein haemoglobin (which is very similar to chlorophyll in plants, but contains iron instead of magnesium).
- They have no nucleus and very few cell organelles.
- Formed in the red bone marrow
- Have a plasma membrane, which is strong and flexible, allowing these cells to squeeze through blood capillaries without tearing.
- A life-span of approximately 120 days eventually comes to an end, due to the membrane becoming too fragile. The RBC's are removed from the circulation by macrophages to be broken down into iron plus biliverdin – which is reduced to bilirubin, and finally the liver converts bilirubin to the fat soluble excretory product, bile.

Erythrocyte formation in the bone marrow is stimulated by the hormone erythropoietin released by the kidneys.

#### **Haemoglobin**

- Haemoglobin is a conjugated protein made up from four globin subunits. Each globin subunit consists of polypeptide chain joined to a haem prosthetic group. At the centre of the haem group is an iron ion which combines with oxygen.
- As each oxygen molecule combines, the molecule alters shape to allow easier loading of the next oxygen molecule.

- Haemoglobin is fully saturated in the lungs due to the high partial pressure of oxygen
- Haemoglobin releases oxygen at lower partial pressures of oxygen
- Carbon dioxide lowers haemoglobins affinity for oxygen, therefore more oxygen is released in respiring tissues, where oxygen is needed most.
- Oxygen pressure in the tissues is always lower than in arteries or arterioles therefore oxygen moves from blood to the tissues, whilst carbon dioxide moves the other way.

Factors which increase the release of oxygen from haemoglobin are- **low oxygen pressure, higher temperatures** (active tissues), **lower pH** (lactic acid from active tissues and higher levels of carbon dioxide lower pH), **2, 3 Diphosphoglycerate (DPG)** (formed when erythrocytes metabolise glucose via anaerobic glycolysis), and **hormones** (thyroxin and testosterone increase the formation of DPG).

### **Platelets/Thrombocytes**

- These are small, disc shaped, non-nucleated cells
- They have an essential role in coagulation (haemostasis/clotting).
- Have a life span of about 10 days.

Haemostasis takes place by 4 processes:

1. Vasoconstriction (serotonin release)
2. Platelet plug formation (become sticky)
3. Coagulation (fibrin)
4. Fibrinolysis (breakdown of the clot)

**Task:** the above explanation of haemostasis is very brief. Read and understand the major steps involved, especially in the initial **cascade reaction**, and remember the main **cofactors** at each stage.

### **Leukocytes** (white blood cells)

- Large blood cells which function to defend the body against invading pathogens and other foreign substances.
- These cells are nucleated and may, or may not contain granules.
- They are divided according to whether they have granules or not:

### **Granulocytes** (granules present)

- Neutrophils
- Eosinophils
- Basophils

### **Agranulocytes** (no granules)

- Lymphocytes- T cells (cytotoxic) and B cells (humoral)
- Natural Killer cells
- Monocytes

# Immunity

The immune system protects us from bacteria, viruses, fungi, parasites and protozoa in our food and environment. To do this it needs to distinguish between the body's cells (self) and those of pathogens (non-self).

There are two aspects of the immune system called the innate (non-specific) and adaptive (specific) immune systems.

## **Innate (non-specific) immune system**

- Present from birth
- Not antigen specific
- Not enhanced by secondary exposure
- Has no 'memory'
- Uses cellular and antibody mediated components
- Poorly effective without the adaptive (specific) immune system

## **Aspects of the non-specific immune system**

- **Barriers**- skin (keratin), cilia, mucus
- **Biochemical**- enzymes (e.g. in saliva and tears), acid (in stomach)
- **Blood**- phagocytes
- **Histamine** (mast cells)- initiates inflammation- attracts leukocytes, raises temperature, increases blood flow, capillaries become more leaky
- **Platelets**- haemostasis (cascade reaction)

## **Inflammation**

Inflammation is a rapid non specific immune response to tissue damage that is triggered by damaged cells. It has a role in many pathologies, and can become a problem itself if it becomes chronic and does not resolve. You will need to know and understand the process of inflammation.

The clinical signs of inflammation are:

- Redness (*rubor*)
- Heat (*calor*)
- Swelling (*tumor*)
- Pain (*dolor*)
- Loss of function

## **Specific (adaptive) immune system**

- Learns from experience (has memory)
- Antigen specific
- Enhanced by secondary exposure
- Uses cellular and antibody mediated components
- Poorly effective without the non specific immunity

Specific immune response consists of two different systems which cooperate closely; the humoral (antibody mediated) response, and the cell mediated response.

### **Humoral response**

- Macrophage ingest pathogen, digests it and then displays antigen on surface- antigen presentation
- In lymph node, macrophage joins with T-helper cells and B cells with complimentary antigen receptors- clonal selection. T-helper cells are activated and produce cytokines which activate elected B-cells to divide rapidly and produce clones.
- Clonal expansion- produces large number of B lymphocyte to combat rapidly dividing bacteria. B cells differentiate primarily into Plasma cells, and some into B memory cells. B memory cells are stored in lymphatic tissue (to produce a rapid response if reinfected with same pathogen), whilst Plasma cells produce antibodies at a rapid rate.
- Antibodies circulate in the blood and lymph and are secreted on the surface of mucus membranes. They bind to the antigen of the pathogen, and work in one of four ways:
  1. Agglutination- binds pathogens together
  2. Antitoxin- neutralises toxins produced by pathogens
  3. Lysis- digests bacterial membrane, killing bacteria
  4. Opsonisation- identifies pathogens for macrophages to attack
- Plasma cells are short lived; whilst antibodies remain longer, then decrease.

### **Cell mediated response**

- Activated by antigen (but must have co-stimulation e.g. cytokine). T cells cloned- differentiate into T helper (CD4) cells, T killer (CD8) cells and T-memory cells. If antigen on antigen presenting cell (MHCII) then T helper cells clone, if antigen is on the surface of nucleated 'self' cell (MHCI) the T-killer cells clone. T cells can only recognise antigen if presented/mixed with chemical marker (MHCI or MHCII)
- Once attached to antigen they become sensitised and clone rapidly. T killer cells need cytokines produced by T helper cells, therefore both MHCI and MHCII is needed for best defence.
- T killer cells recognise the MHCI marker on infected cells and destroy the by secreting perforins which make holes in the cells membrane rupturing the cells and secreting lymphotoxin which activates the target cells enzymes which fragment the cells DNA.
- T suppressor cells dampen down the immune response once infection is dealt with

MHC stands for major histocompatibility complex, which is a 'self' antigen  
MHCII is a foreign antigen mixed with MHC and presented by antigen presenting cells.

MHCI is a foreign antigen from inside an infected cell mixed with MHC and displayed upon the surface membrane of an infected cell- signalling that it is infected.

### **Memory**

During an initial infection the clonal response an expansion is relatively slow.  
Once T and B memory cells have been produced, if there is reinfection then the response is rapid, as there are more cells to respond, and the response is longer lasting.

# The cardiovascular system

## SELF ASSESSMENT QUESTIONS



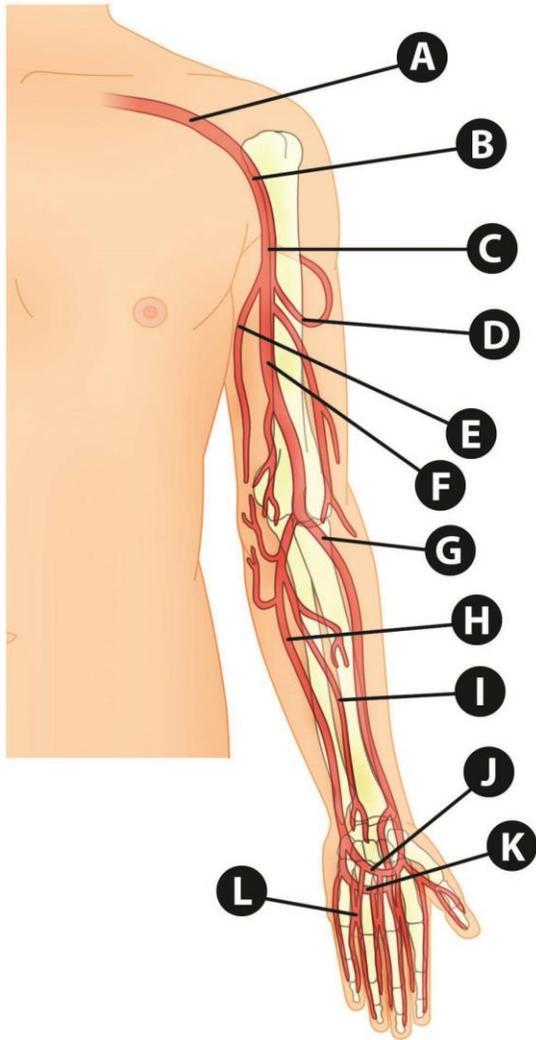
1. Compare and contrast the structure and function of the arterial and venous circulatory systems.
2. Write an account on the intrinsic and extrinsic control mechanisms of the heart.
3. Explain how blood pressure homeostasis is maintained. Illustrate your answers with two scenarios; when blood pressure falls to below normal level and conversely when it rises above normal limits.
4. Write a descriptive account of the circulation of lymphatic fluid.
5. Discuss the structure and function of the spleen and lymph nodes.
6. Discuss the role of the lymphatic system plays in immunity.
7. List specific and non-specific defence mechanisms
8. Discuss the function of T & B lymphocytes
9. Write an account of antibody-mediated immunity.

Please refer to your labelling supplement handbook and label any images associated with the above chapter.

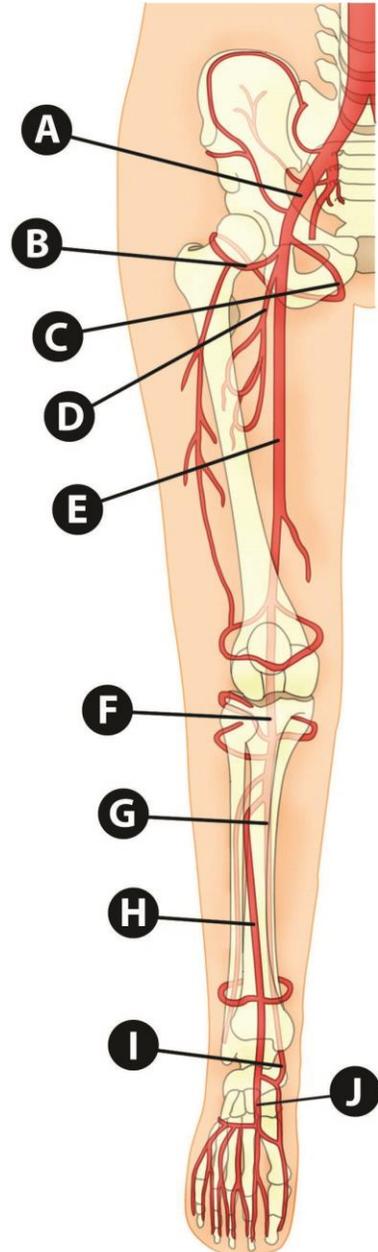


Label the following vessels

## Arm arteries

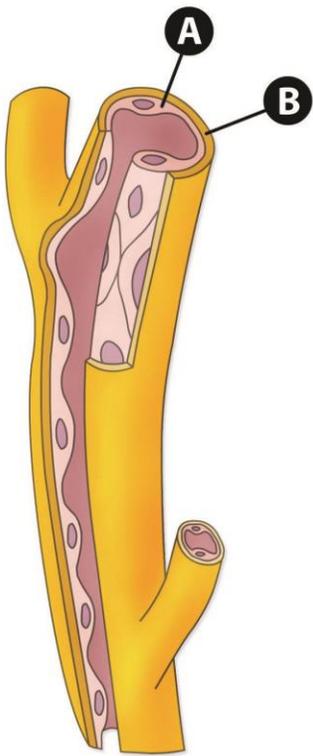


## Leg arteries

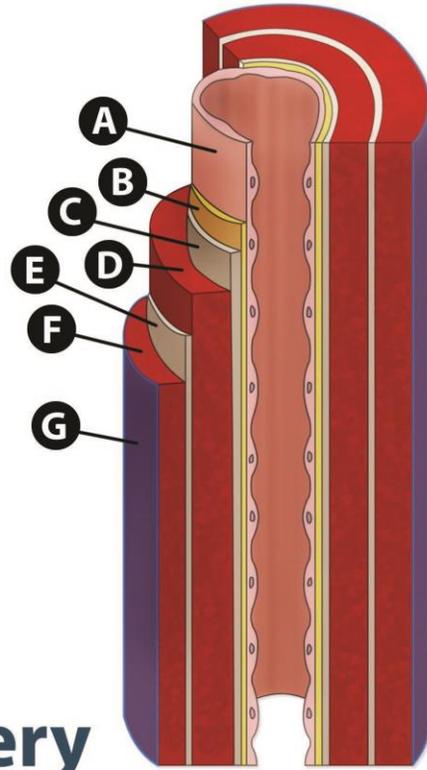


Label the following structures:

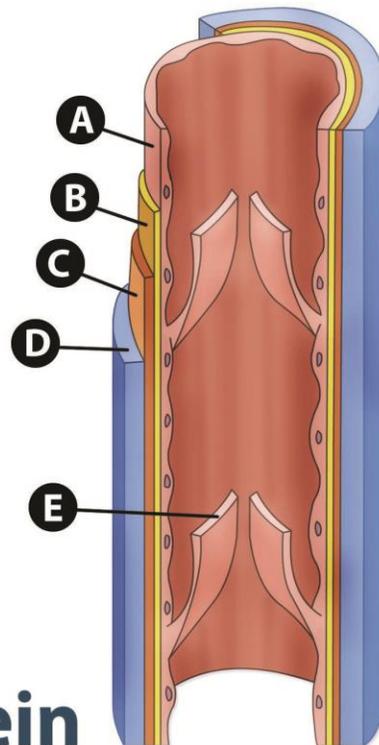
# Structure of blood vessels



**Capillary**

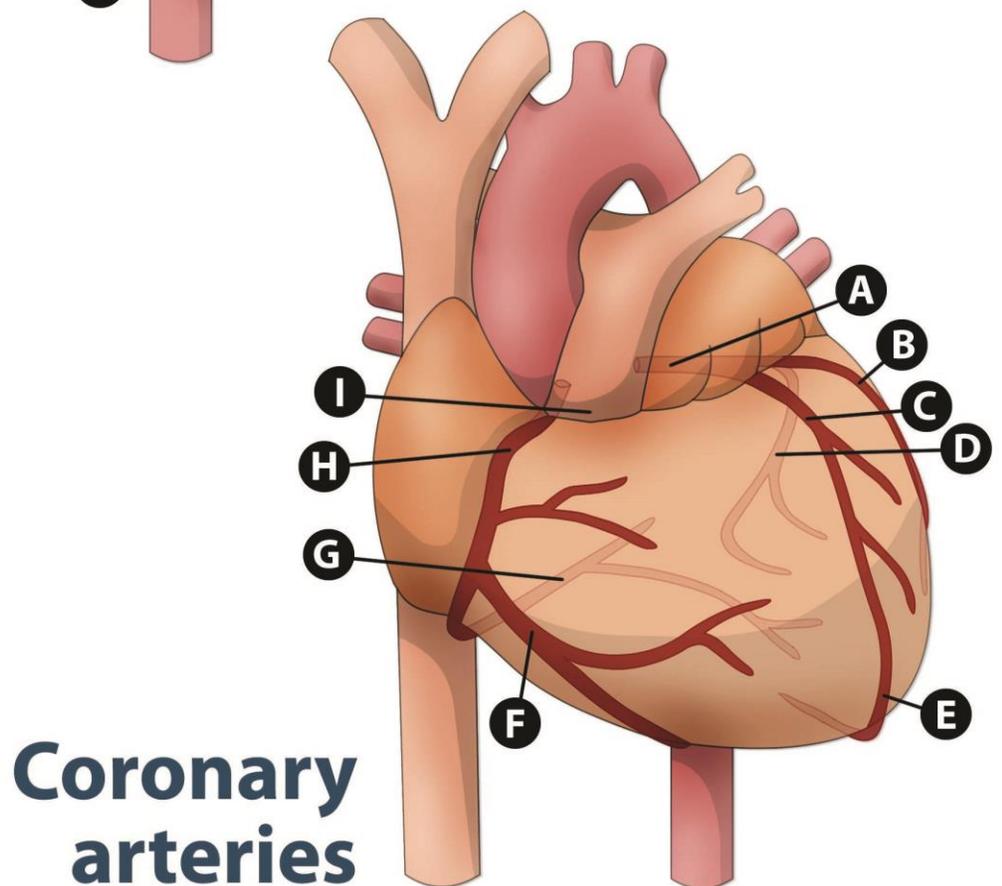
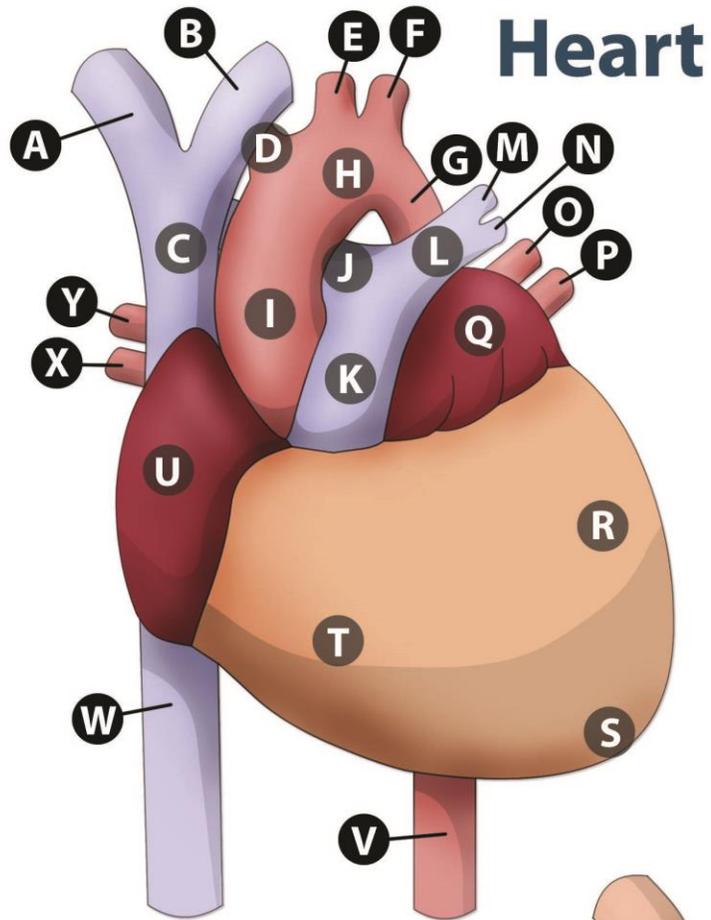


**Artery**



**Vein**

Label the following heart components:



Label the following components of the lymphatic system:

# Lymphatic drainage

