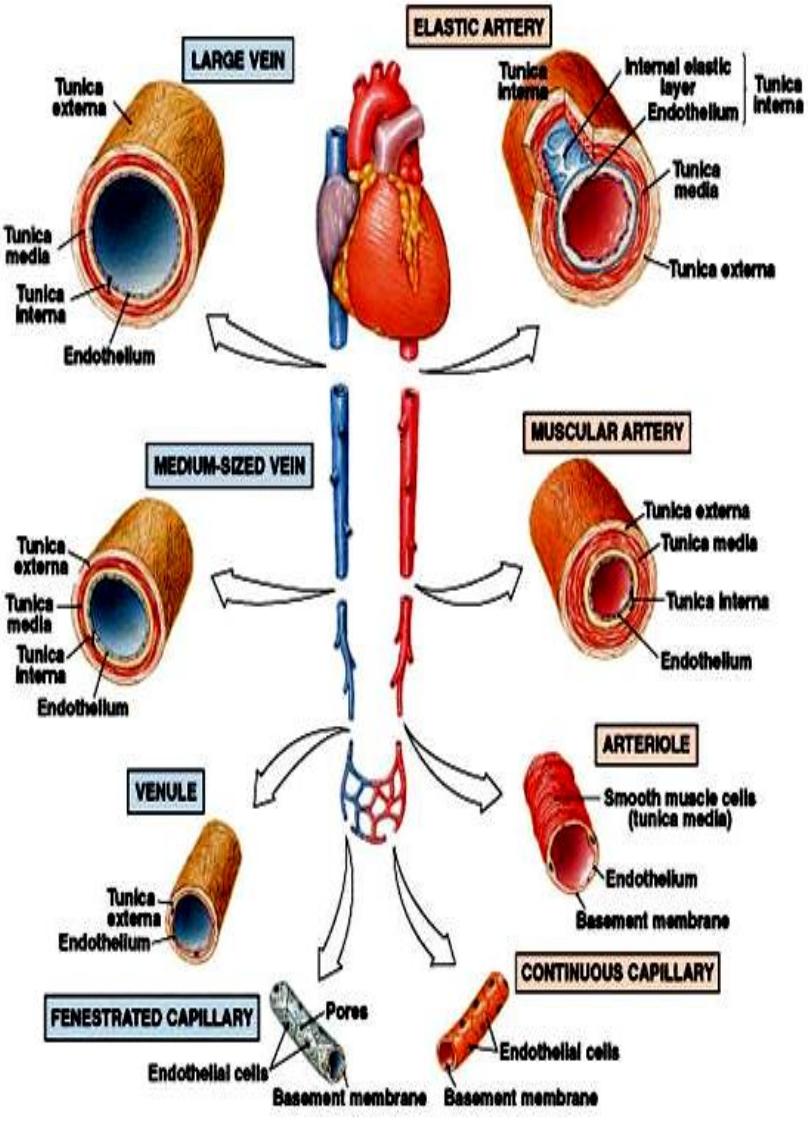
THE CARDIOVASCULAR SYSTEM

The cardiovascular system is concerned with the transport of blood and lymph through the body. It may be divided into four major components: the **heart, the macrocirculation, the microcirculation** and **the lymph vascular system.**

Essentially, the **macrocirculation** comprises all vessels, both arteries and veins that would be **visible to the eye**. The vessels of the macrocirculation supply and drain a network of fine vessels interposed between them, the capillaries. This network is also called the **capillary bed (microcirculation**). Water and other components of the blood plasma which exude from the blood vessels form the interstitial fluid, which is returned to the circulation by the **lymph vascular system**.



Source: M. Jouan, MSc. Thesis, **2005.**

THE HEART

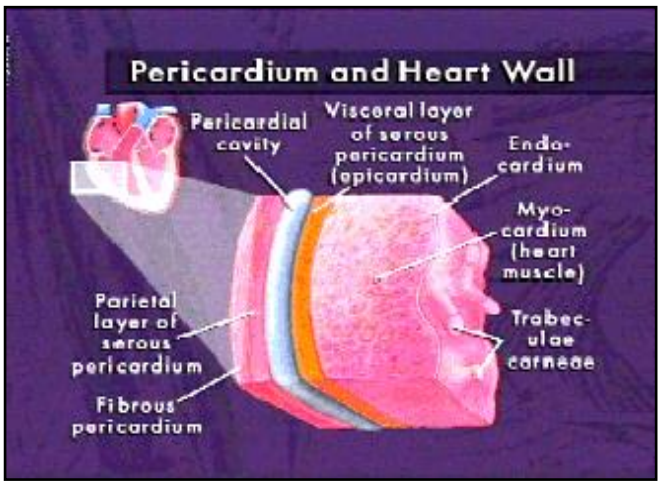
The outer coverings of the heart is **the Pericardium** - a **double** sac of serous membrane surrounding the heart

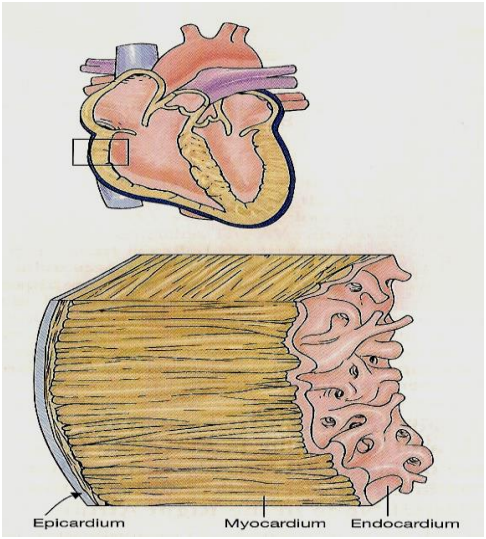
Parietal pericardium - a loose fitting **outer membrane** consisting of two layers:

1. The **fibrous layer** - composed of **tough, white fibrous** tissue covering the heart and anchoring it to the diaphragm, sternum and large blood vessels.
2. The **serous layer** - a thin inner membrane composed of **a thin fibrous layer** on top of a **mesothelium**. This layer folds back over and adheres to the heart forming the **visceral pericardium**. ***Mesothelium*** *is a simple squamous epithelial tissue, derived from mesoderm, which forms the surface lining, not only of the pericardial cavity but also peritoneal and pleural cavities (i.e., all major body cavities).*

Visceral pericardium - this layer is also called the **epicardium**. It is well integrated with the muscular wall of the heart. It is often infiltrated with fat. Its largest constituent is **connective tissue** and functions as a protective layer

Pericardial cavity - is **a fluid-filled cavity** located between the parietal and visceral membranes. The serous portions of the parietal and visceral membranes face the cavity and produce the **pericardial fluid**. This fluid **prevents the heart and lungs from rubbing against each other during their actions. Pericarditis** is an inflammation of the pericardium. It can produce painful adhesions between the membranes.



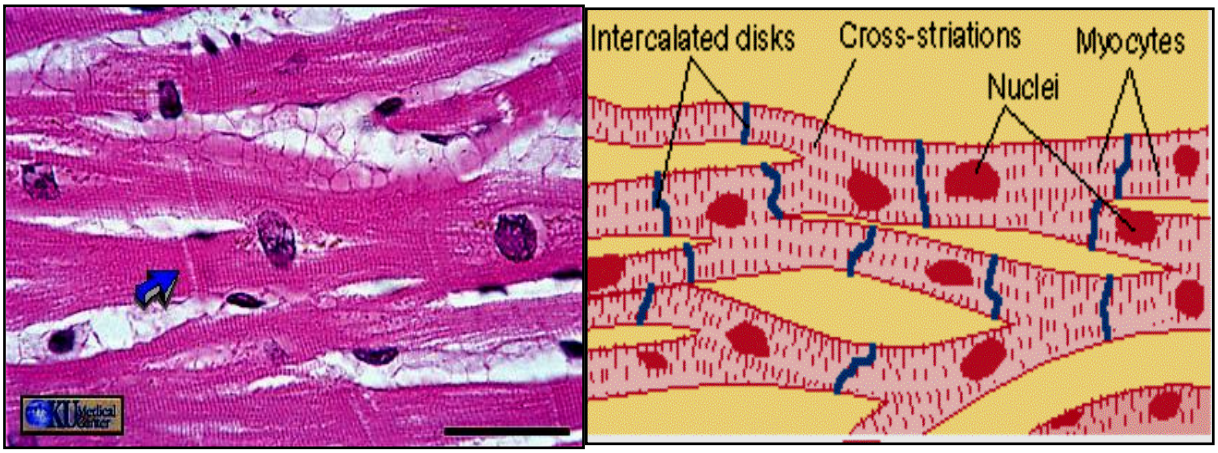


The Heart Wall - three layers:

A. The Epicardium (described above)

B. The Myocardium - the **muscular wall** of the heart composed of **cardiac muscle** and a reinforcing internal network of **fibrous connective tissue** called the "**skeleton of the heart**". This connective tissue serves two primary functions:

1. It provides **anchorage** for the cardiac muscle and the atrioventricular valves. The portion of the skeleton anchoring the A-V valves is called the **coronary trigone.**
2. The **elastic** component of the skeleton provides the **recoil** that assists in filling the chambers following systole.



Cardiac muscle

- Striated.
- Cylindrical in shape
- Shorter than skeletal muscle
- Rich in mitochondria (up to 40% of cell volume)
- Branched.
- Has one nucleus in the center of the cell.
- No nerves are involved in the spread of contraction through the muscle.
- Adjacent cells are interconnected end–to- end by **intercalated discs**.

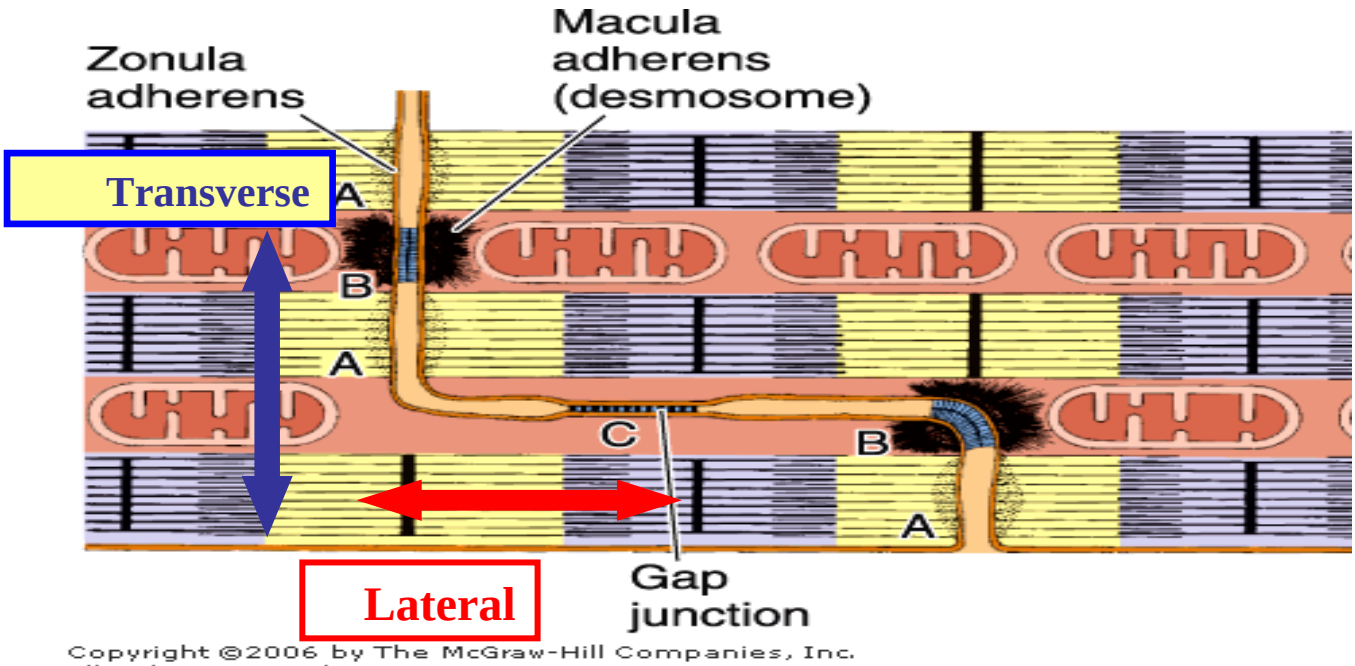
Intercalated discs where fibres interdigitate, Containing three types of specialized junctions that permit the cardiac muscles to function as a **syncytium** (unit), which obeys 'all or none law'.

Transverse Part:

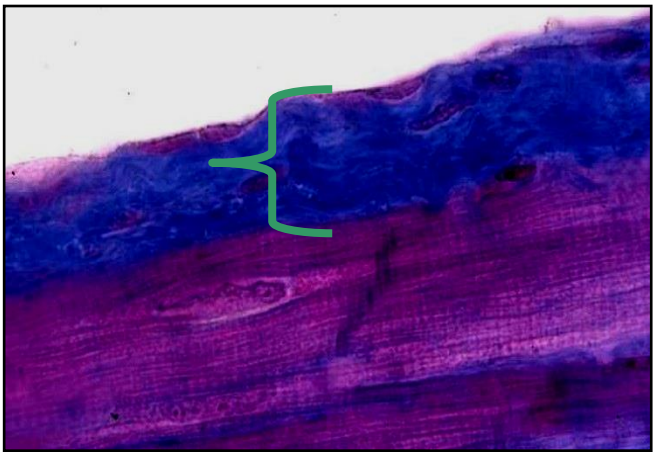
- **A. zonula (fasciae) adherents**; hold cardiac muscle cells together and the site where the thin filaments in the terminal sarcomere anchor onto plasma membrane
- **B. desmosomes (macula adherentes)** act as **rivets** to **prevent the cells from pulling apart** under the strain of contraction

Lateral Part:

- **C. Gap junctions (nexus)** - for **impulse transfer** providing ionic continuity between adjacent myocytes (**electrical communication** between cardiac muscle cells)

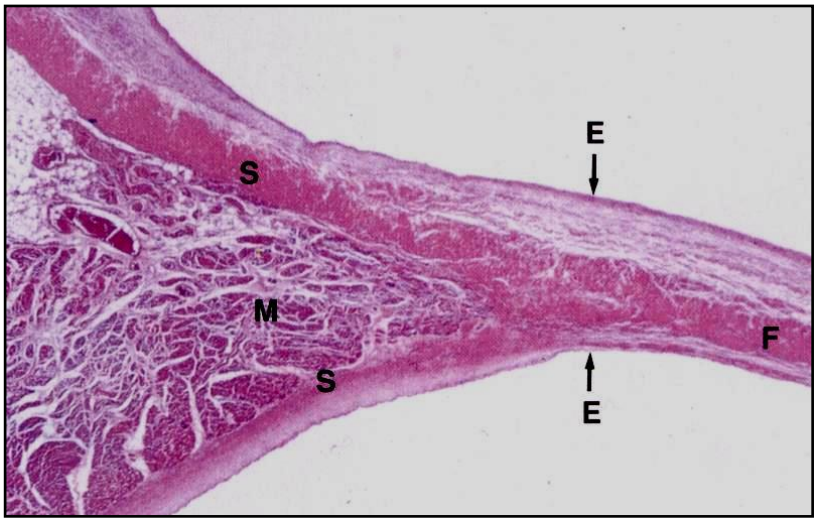


C. The Endocardium - lines the chambers of the heart. In the chambers it consists of a **simple squamous endothelium** overlying a delicate layer of **loose connective tissue**. It lines the dense connective tissue of the cusps of the A-V valves. It is **continuous** with the endothelium of the blood vessels. Inflammation of this layer is called **endocarditis.**

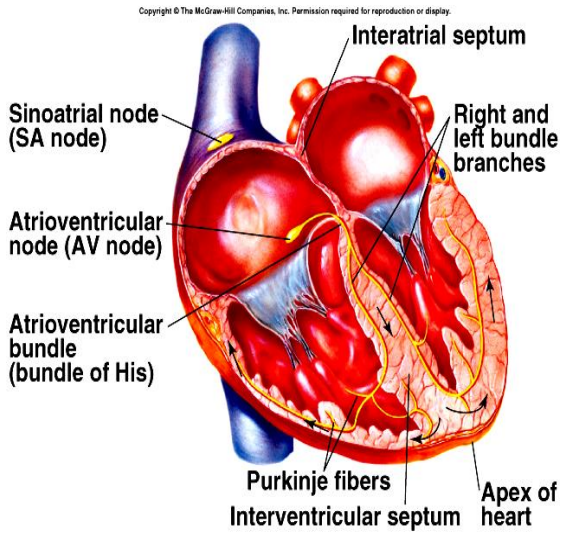


Cardiac Valves

- All insert into fibrous **trigone**
- Connective tissue (**lamina fibrosa**, a tough central **collagen** fibers sheet rich with **elastic** fibers) surrounded by **endothelium**

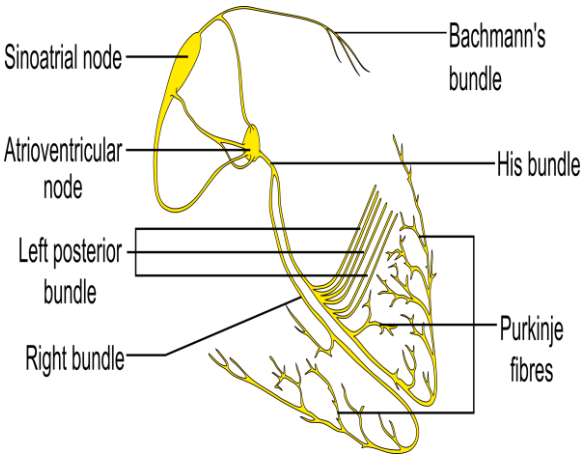


♥ Conduction pathway:



Contraction of the heart is synchronized by **specialized muscle fibres** that are capable of contraction in a rhythmic manner **without** any direct stimulus from the nervous system, consisting of

- **Sinoatrial (SA) node** located near the junction of the superior vena cava and the right atrium which **initiates** the beating action (called the **pacemaker**). SA node initiates an impulse that spread along the cardiac muscle fibres of the atria and along internodal pathways
- **Internodal pathways (tracts)** form the communication between SA and AV nodes.
- **Atrioventricular (AV) node** it electrically connects atrial and ventricular chambers, once the impulse reaches the AV node it is conducted across the fibrous skeleton to the ventricles by the
- **Bundle of His (AV bundle)** which then divided into smaller
- **Rt & Lt bundle branches** descending into interventricular septum.
- **Purkinje fibers** stimulation of Purkinje fibers cause both ventricles to contract simultaneously. Specialized cardiac muscle cells, which conduct electrical signals to coordinate heart contractions.



BLOOD VESSELS

Blood vessels constrict (**vasoconstriction**) and dilate (**vasodilatation**) to

- Regulate arterial blood pressure
- Adjust blood flow within organs
- Regulate capillary blood pressure
- Distribute blood volume within the body

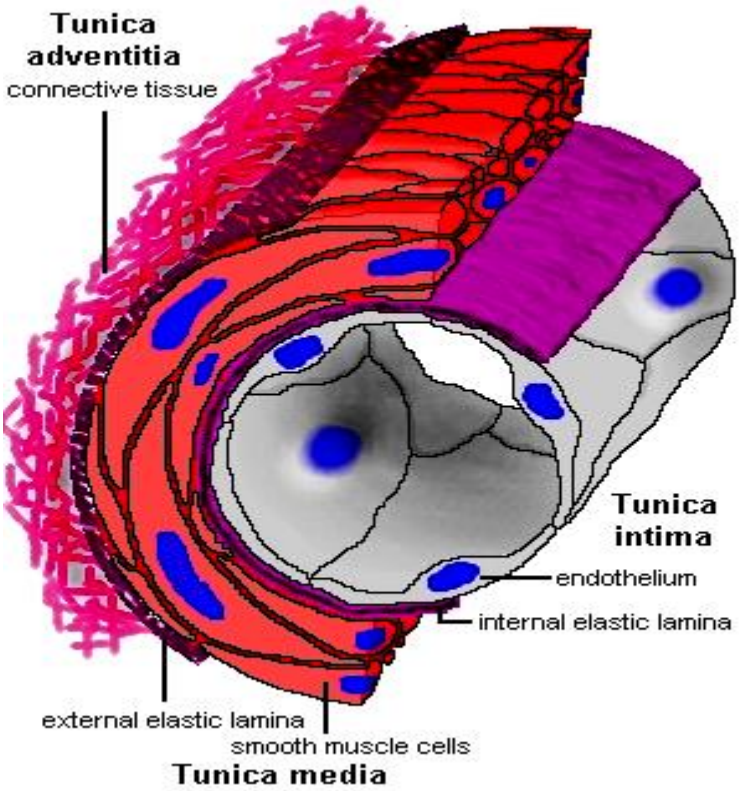
Changes in the diameter of blood vessels (arterioles) is brought about by activation of smooth muscles in their walls by autonomic nerves, metabolic and biochemical factors as well as vasoactive substances released from endothelium of blood vessels

There are five main types of blood vessels; **arteries, arterioles, capillaries, venules** and **veins.**

Laid end to end, all the blood vessels in an average human body would encircle the earth twice, a distance of approximately 100,000 kilometers.

General Structure of Blood Vessels

The arteries and veins have the same basic structure. **Like the heart**, the walls of the blood vessels the wall of the blood vessels consists of **three major layers** or tunics, while the capillaries have only one thick cell layer



From inside to outside, the wall of the blood vessels consist of

Tunica intima (the thinnest layer): corresponds to and continuous with the **endocardium** of the heart

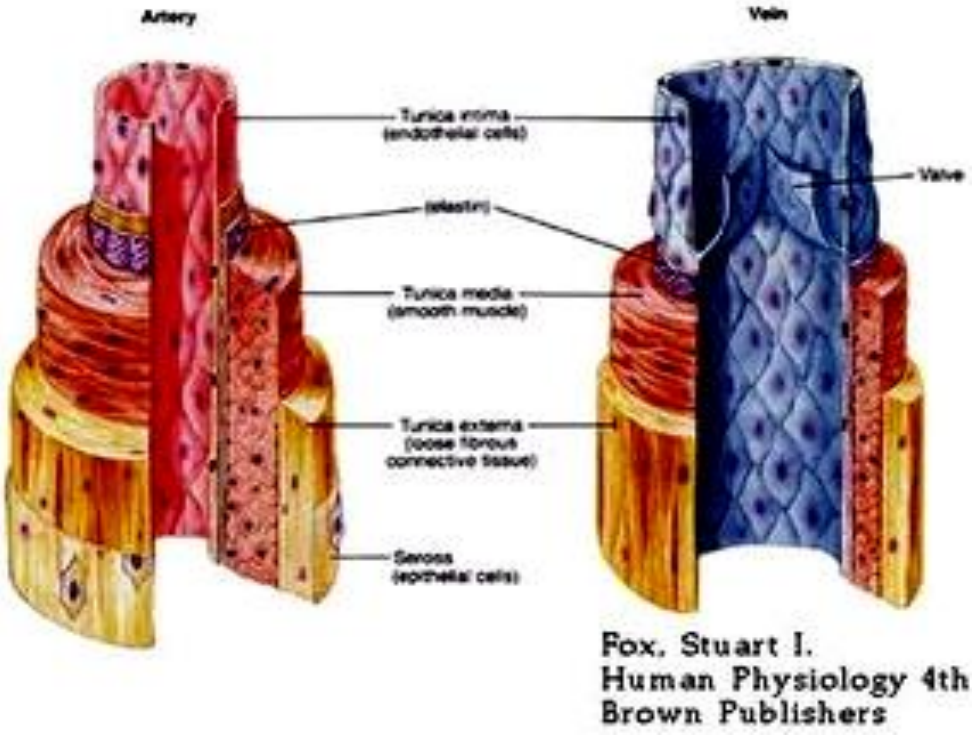
- a single layer of **simple squamous endothelial** cells (the endothelial cells are derived from embryonic **mesenchyme** and should **not** be regarded as epithelial, but as connective tissue cells. Endothelial cells line the lumen of all the vessels of the blood vascular and lymphatic vascular systems).
- subendothelial **connective tissue**
- elastic bands called the **internal elastic lamina** which delimits the intima**.**

Tunica media (the thickest layer): the **most variable** layer both in **size** and **structure** depending on the function of the vessel**.** It is represented in the heart by the **myocardium**

- Formed by a layer of **circumferential smooth muscle** and variable amounts of connective tissue.
- A second layer of elastic fibers, **the external elastic lamina**, is located beneath the smooth muscle. It delimits the tunica media from outer layer

Tunica adventitia, also variable in thickness in different vessels, corresponding to the **epicardium** of the heart

- entirely made of **connective tissue**.
- It also contains **nerves** that supply the muscular layer,
- nutrient capillaries (**vasa vasorum**)in the larger blood vessels



Fox, Stuart I.
Human Physiology 4th
Brown Publishers

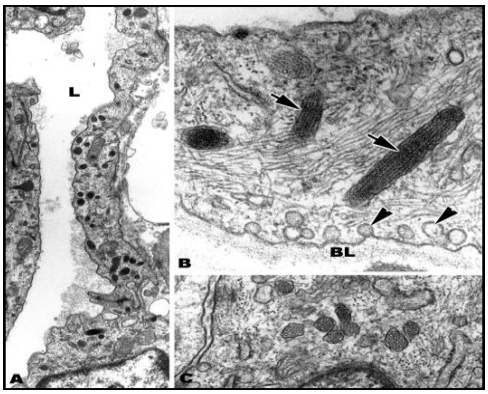
ARTERIES

Blood vessels that conduct blood away from the heart to organs and tissues, they branch along their course forming arteries progressively smaller diameter.

Arteries are classified into:

I. Conducting or Elastic Arteries (large arteries) >1cm

- These are large arteries closest to the heart with very high blood pressure **e.g.** aorta, pulmonary, branches of the aorta, such as the carotid artery, the subclavian artery, the celiac trunk, the mesenteric arteries, the renal artery and the iliac artery
- The **tunica intima** of elastic arteries is **thicker** than in other arteries



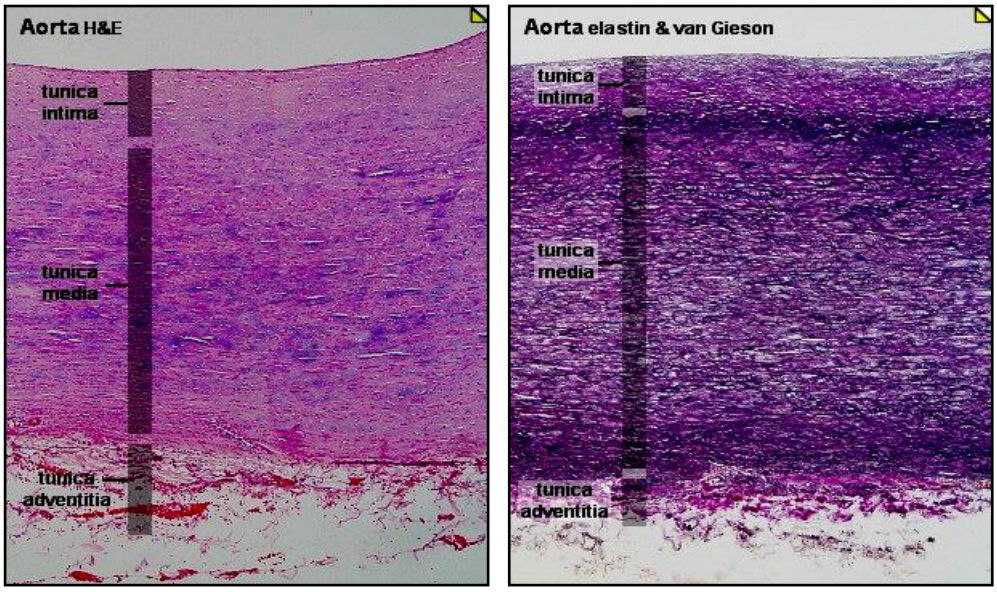
  - **Endothelium** with **Weibel-Palade** bodies i.e. a membrane bounded **rod-like** inclusions, 0.1µm in diameter and 3µm in length, that have a dense elements containing the glycoprotein **von Willebrand factor** (facilitate platelets **coagulation, (carry factor VIII**), stored **only** in arteries and manufactured by most **endothelial** cells
  - **Internal elastic** lamina is **less prominent**

- Thick **tunica media** which constitutes most of the wall.
  - Distension (with the increase in **systolic blood** pressure) of the walls is facilitated by **concentric fenestrated lamellae of elastic fibers** in a thick tunica media (about 50 elastic lamellae).
  - **Smooth muscle** cells and **collagen fibres** (collagen **type III**) are present between the layers of elastic fibres.
  - **Indistinct external elastic lamina**

- **Thin tunica adventitia** composed of elastic and collagen fibres and is provided with **vasa vasorum** and lymphatics

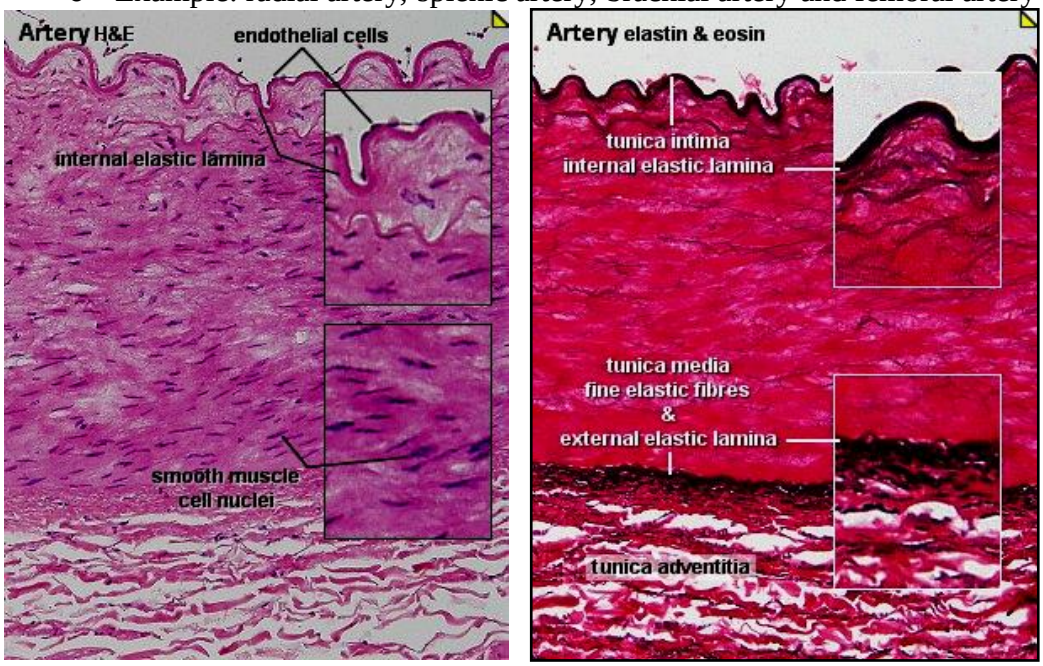
*Elastic arteries are those nearest to the heart and because of the large content of elastic tissue they are **EXPANSIBLE.** As blood is pumped from the heart during contraction the walls of the elastic arteries expand; when the heart relaxes the **elastic recoil** of these vessels force the blood onward at the time when no pumping force is exerted by the heart.

* The walls of these large arteries are so thick that their peripheral parts cannot derive enough oxygen and nutrients from the blood of the vessel that they form. Larger vessels are therefore accompanied by smaller blood vessels which supply the tunica adventitia and, in the largest vessels, the outer part of the tunica media of the vessel wall. These blood vessels are called **vasa vasorum**.



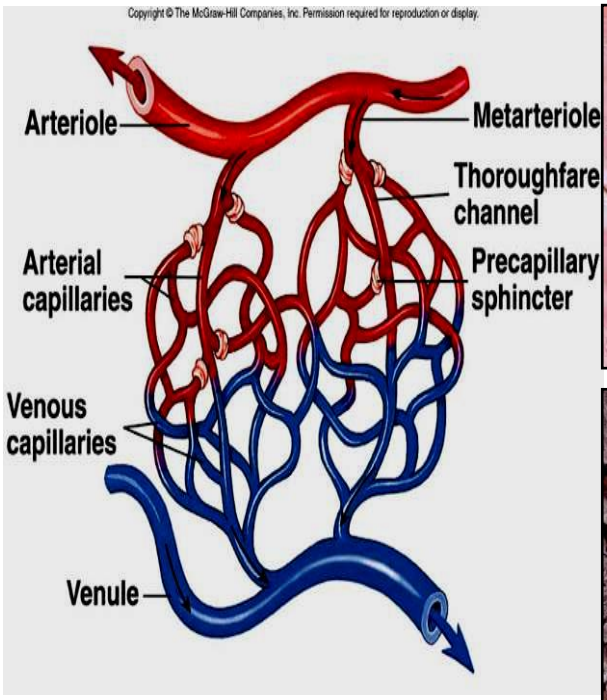
II. Distributing or Muscular Arteries (medium arteries) 0.1-10mm

- These are smaller diameter arteries with a slower blood flow.
- The **tunica intima** is **thinner** than in elastic arteries **with endothelium** and **Weibel-Palade** bodies
- The **internal elastic lamina** forms a **well defined layer** appears as a refractile wavy pink line
- The **tunica media** is dominated by **numerous concentric layers** of smooth muscle cells. **Fine** elastic fibres and a **few** collagen fibres
- The **external elastic** lamina can be **clearly distinguished** although it may be **incomplete** in places
- The thickness and appearance of the **tunica adventitia** is **variable**.
- Example: radial artery, splenic artery, brachial artery and femoral artery

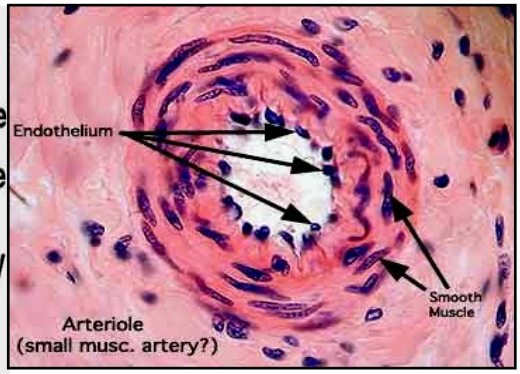


III. Arterioles (small arteries) <0.1mm

- **Tunica intima** is smaller with **endothelium** and internal elastic lamina which may be **incomplete** and which is not always well-defined (absent in small and terminal arteriole but present in large arterioles)
- **Tunica media** is made up of **circular smooth muscles** i.e. single smooth muscle layer in small arterioles; 2-4 layers in large arterioles
- **Tunica adventitia** posses **autonomic** nerve fibres to control the size of the lumen which is responsible **peripheral resistance** necessary to control arterial **blood pressure**
- Arterioles are the **major resistance vessels.** Since the artery, while reaching its target tissue, branches into several arterioles with diameters small enough to offer considerable resistance to flow
- **Microvascular bed** composed of arterioles, capillaries and venules in the following arrangement:
  - **Metarterioles** are small vessels provide direct communication between arterioles and venules and are important in bypassing the blood flow through the capillaries (form the proximal part of thoroughfare channel). True capillaries branch mainly from metarterioles and provide exchange between cells and the circulation. **Precapillary sphincters** are rings of smooth muscles at the origin of true capillaries that regulate blood flow into true capillaries and thus control blood flow through a tissue
  - The **thoroughfare channel** a structure so named because it is **without** precapillary sphincter. These channels drain the capillary bed and empty blood into small venules

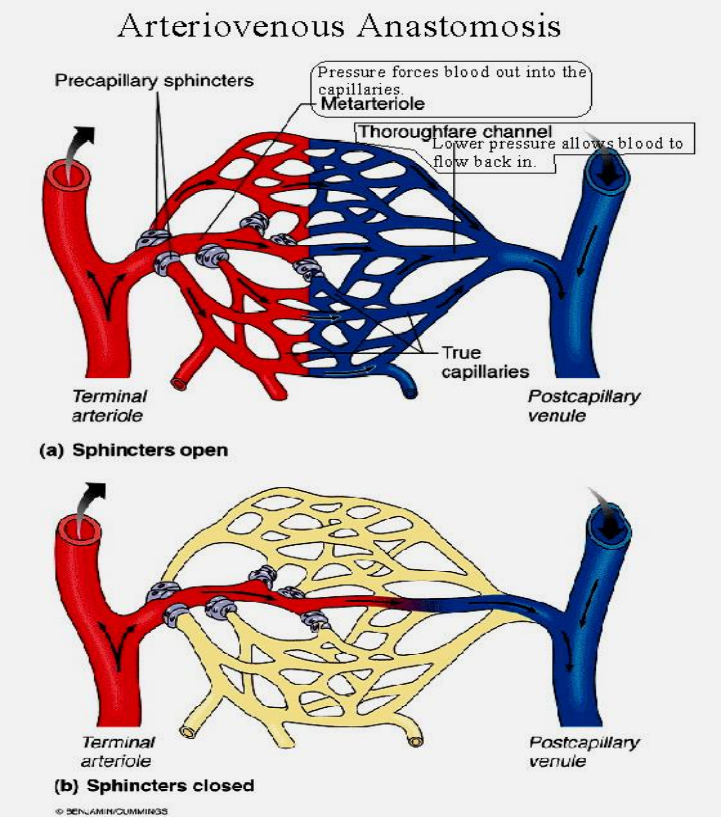


Microvascular bed



Arteriovenous anastomosis (arterial-venous-shunt)

- These represent **direct connections** between arterioles and venules allow blood to bypass the capillary bed very common in the dermis of the **skin, lips, nose** and **GIT**
- **Functions** as **backup routes** for blood to flow if one link is blocked**, control blood flow** and **assist in temperature regulation**

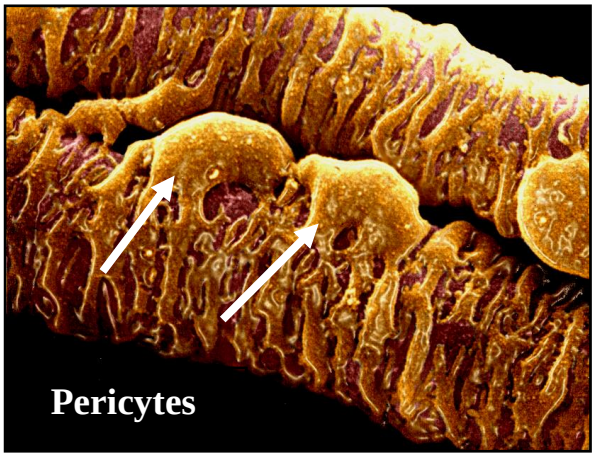


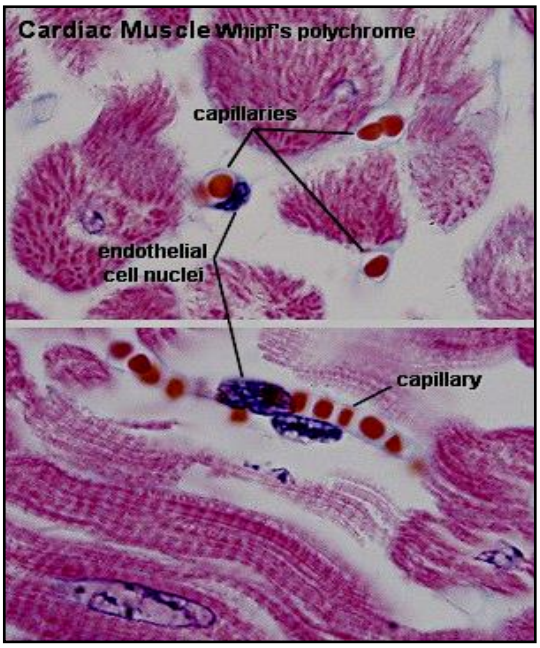
CAPILLARIES

- Blood capillaries have a diameter of about **7-9µm**, which is close to the dimensions of **erythrocytes** (about 7.2µm).
- **Only** the **tunica intima** is present, which typically only consists of the **endothelium**, its **basal lamina** and an **incomplete** layer of cells surrounding the capillary, the **(perivascular cells** or **pericytes)**. Pericytes have **contractile** properties and can regulate **blood flow** in capillaries, have a role in **repairing** blood vessels and may even be **phagocytic**.
- Numerous **pinocytotic vesicles** are present within the endothelium involving in **transporting** materials across endothelium in both directions

- The sum of the diameters of all capillaries is significantly larger than that of the aorta (by about three orders of magnitude), which results in decreases in blood pressure and flow rate.
- There are **three** different types of capillaries; however the differences are only visible at the **ultrastructural** level (by **electron microscopy**)

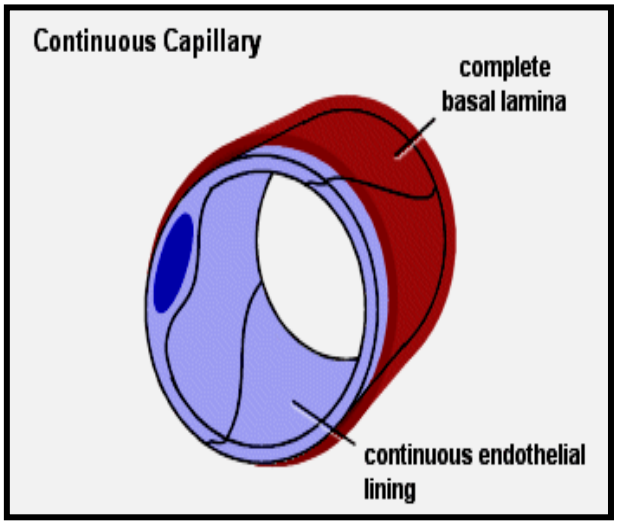
  - **Continuous capillaries**
  - **Fenestrated capillaries**
  - **Sinusoids (discontinuous capillaries)**

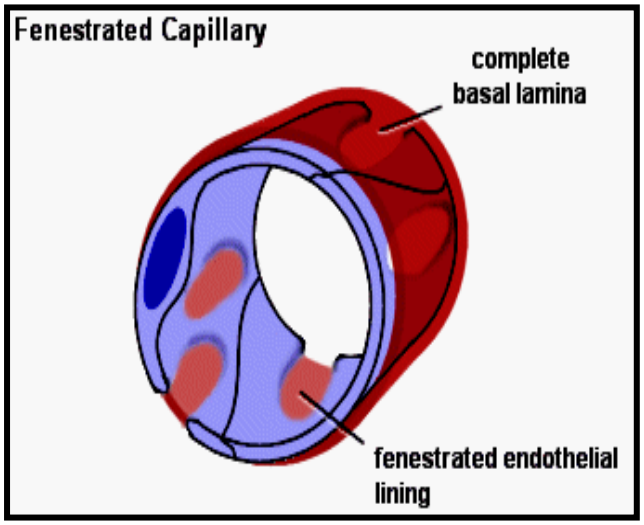




Continuous capillaries and fenestrated capillaries

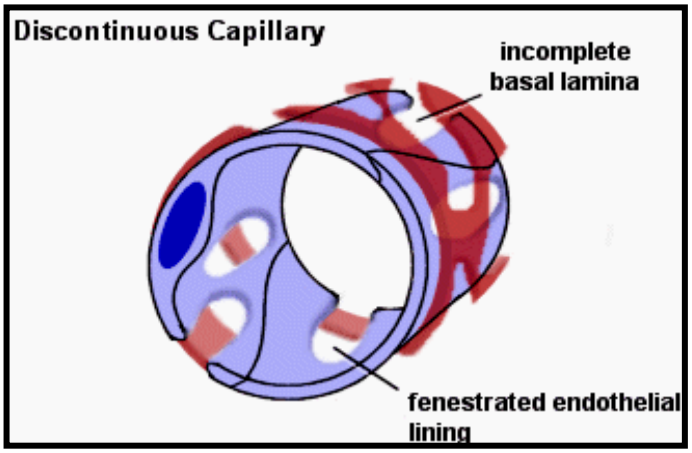
- Both types have a **continuous endothelium** lining, resting on a **continuous basal lamina** (**diaphragm**) but the **fenestrated** capillaries there are a **tiny pores (fenestrae)** <100 nm in diameter
- **Continuous capillaries** are found in those organs that need **strict control** on access of the substances from the blood e.g. **blood-brain-barrier**" of the Central Nervous System or the "**blood-thymus barrier**, **muscle** and **connective tissues**
- **Fenestrated capillaries** are common in most of the **endocrine glands**. One prominent site for fenestrated capillaries is in the **renal glomeruli** and also in the **intestinal villi**





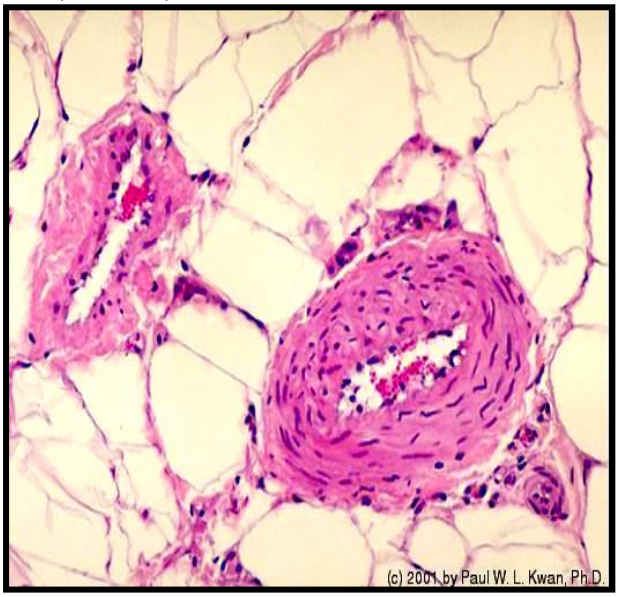
Discontinuous capillaries (Sinusoid)

- Sinusoids are **irregular vessels** with large diameters (30-40µm). The endothelium does **not** form a continuous lining and large **gaps** are present between adjacent cells. The basal lamina is also **discontinuous**.
- They are found where a very **free** exchange of substances or even cells between bloodstream and organ e.g. **liver**, **endocrine glands** and in the **hematopoietic** organs (**bone marrow, spleen)**



VEINS

- Veins are subjected to more **variation** than arteries
- Veins are classified as **large**, **medium** or **small veins** (**venules**)
- Characteristics of veins:



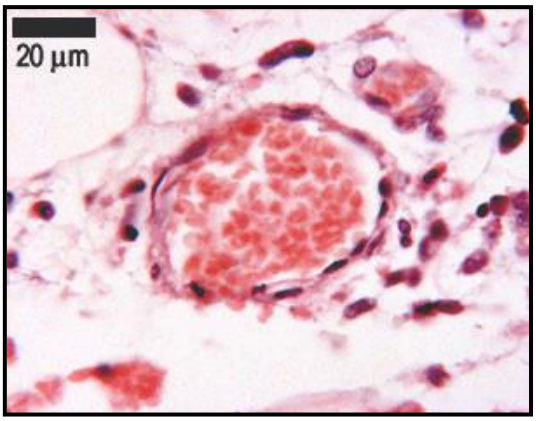
  - more **numerous** than arteries
  - diameter of vessels is **larger** than that of adjacent arteries
  - walls of veins are **thinner** and **less elastic** i.e. **little elastic recoil** (As a result in histological preparations the lumen often appears **collapsed** or **irregular**)
  - veins are highly **stretchabl**e i.e more **compliant** (**less resistance**)
  - the relative numbers of **vasa vasorum** are **greater** in the veins (necessary as the vessels have much **less oxygenated** blood)
  - **valves** are found in veins.
  - Veins have **less** smooth muscles than arteries

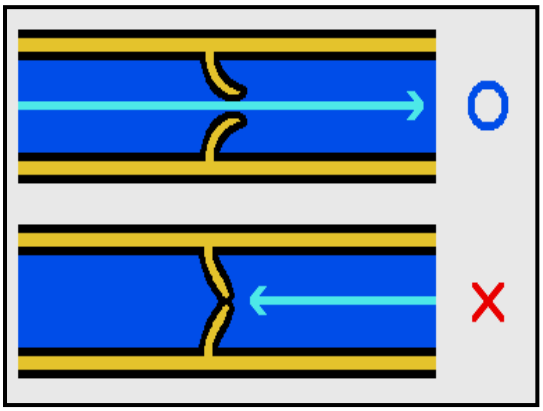
Venules: Postcapillary venules and muscular venules

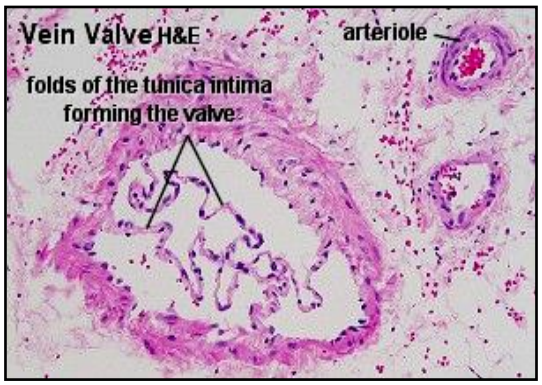
- Postcapillary venules receive blood from capillaries and possess an **endothelial lining** with its **basal lamina** and **Pericytes**. They are larger than capillaries
- Muscular venules are distinguished from postcapillary venules by the presence of a **tunica media** (which is **present in muscular venules**)

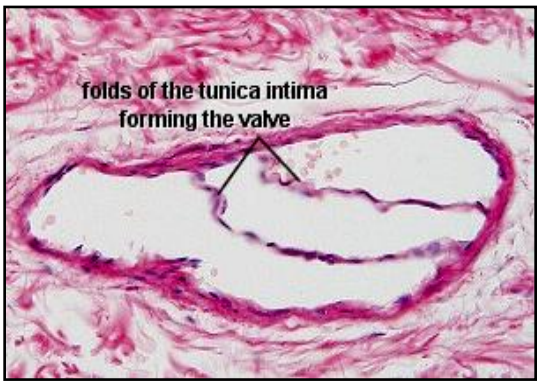
Medium veins <1cm

- The **three tunics** of the wall are most evident in medium sized vein
- **Tunica intima** consists of **endothelium** with its **basal lamina**
- **Tunica media** is much **thinner** than in medium-sized arteries with circularly arranged smooth muscles
- **Valves** formed by loose, pocket-shaped folds of the **tunica intima**, which extend into the lumen of the vein, formed by **endothelium** lining covering a core of **elastic fibres** from both sides. The valves **prevent the backflow** of blood. Weakness in the walls of veins can result in **varicose veins** and improper closure of the valve
- **Tunica adventitia** is usually **thicker** than the tunica media and have **longitudinal** bundles of smooth muscles, collagen and elastic fibres



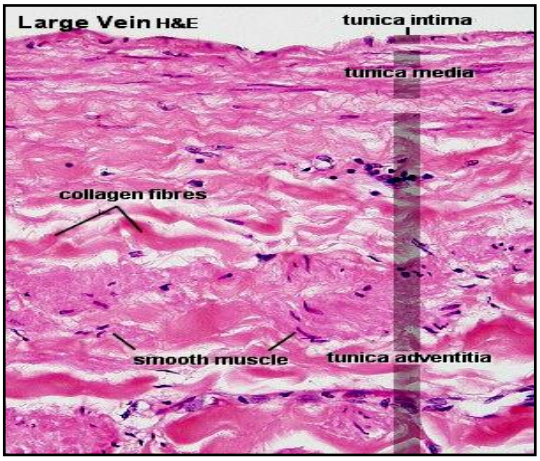






Large veins >1cm

- The tunica media is relatively **thin**, and the tunic adventitia is relatively **thick**
- **Tunica intima** consists of **endothelium** with its **basal lamina** and a small amount of **subendothelial** connective tissue. Often the boundaries with tunica media is **not** clear
- **Tunica media** is relatively thin and contains **smooth muscle** cells, collagen fibres and some fibroblasts.
- **Tunica adventitia** is the **thickest** layer it has bundles of **longitudinal** smooth muscle cells, collagen and elastic fibres.



Lymphatic Vessels

- Lymph vessels are dedicated to **unidirectional flow** of liquid, the lymph.
- **Three types** of lymph vessels can be distinguished based on their size and morphology
  - **Lymph capillaries**
  - **Lymph collecting vessels**
  - **Lymph ducts**

Lymph capillaries

- **larger** than blood capillaries and very **irregularly** shaped
- **basal lamina** is almost completely **absent**
- endothelial cells **do not** form tight junctions which facilitates the **entry of liquids** into the lymph capillary, and sometimes with **temporary openings** to entry of **larger particles** (lipid droplet) which are found in the villi of the ileum and jejunum
- lymph capillaries merge to form lymph collecting vessels

Lymph collecting vessels

- **larger** and form **valves** but otherwise appear **similar** to lymph capillaries
- Lymph vessels **empty** intermittently into **lymph nodes**
- The lymph is moved by the **compression** of the lymph vessels by **surrounding tissues**

Lymph ducts

- contain one or two layers of **smooth muscle** cells
- They also form **valves** which may give **a beaded appearance** to the lymph ducts

- **Peristaltic contractions** of the smooth muscle and the **compression** by surrounding tissues contribute to the movement of lymph towards the heart.
- A **lymph duct** is a great lymphatic vessel that empties lymph into one of the subclavian veins. There are two lymph ducts in the body—**the right lymphatic** duct and the **thoracic duct**. The right lymphatic duct drains lymph from the right upper limb, right side of thorax and right halves of head and neck.

Blood portal systems

In typical configurations, an artery or arteriole carrying oxygenated blood enters the capillary bed, where there is exchange of oxygen and metabolites, and the vessel exiting the capillary bed is a venule or vein with deoxygenated blood.

Portal systems describe situations where the blood vessel leaving the capillary bed is of the same category as the blood vessel entering the capillary bed. (vein - capillary bed - vein // artery - capillary bed - artery).

In a **venous portal system** (such as in the liver) a vein (hepatic portal vein) enters the capillary bed and a vein (hepatic vein) exits the capillary bed. A similar portal system is found in the hypothalmus-hypophysis.

An example of an **arterial portal system** is found in the renal cortex. Afferent arterioles break up into the capillary bed of the glomerular tufts of the renal corpuscle and the blood exits in efferent arterioles.

Anatomical and Functional End Arteries

An **end artery** is an artery that is the only supply of oxygenated blood to a portion of tissue. End arteries are also known as **terminal arteries**. Examples of an end artery include the splenic artery that supplies the spleen and the renal artery that supplies the kidneys

Anatomical end arteries are vessels whose terminal branches do not anastomose. In the event that these vessels become blocked (atherosclerosis, blood clot) the tissues will be deprived of oxygen and an "infarct" develops (e.g. coronary arteries, kidneys, brain).

Functional end arteries have anastomoses and in the event of blockage, alternative routes for blood and oxygen are available, but the capability of anastomosis is insufficient to keep tissue alive in case of occlusion.

Umbilical artery and vein

The **umbilical artery** is a paired artery that extend into the umbilical cord. They supply **deoxygenated** blood from the fetus to the placenta in the umbilical cord. The umbilical arteries are the only arteries in the human body, aside from the pulmonary arteries, that carry deoxygenated blood.

The **umbilical vein** is a vein present during fetal development that carries **oxygenated** blood from the placenta to the growing fetus. During embryologic development, there are two umbilical veins, left and right that drain blood from the placenta to the heart. The right umbilical vein **regresses** and under normal circumstances is completely obliterated during the second month of development.