BLOOD VASCULAR SYSTEM

The blood and lymphatic vascular systems are classified as specialized connective tissue.

The **main functions** of the blood are to transport oxygen, nutrients and hormones to the tissues and to collect the waste products (carbon dioxide and waste metabolites) for removal from the body via the excretory system.

The cardiovascular system consists of the:

- **Heart** (muscular pump)
- **Pulmonary circulation** (system of blood vessels to and from the lungs)
- **Systemic circulation** (system of blood vessels bringing blood to and from all the other organs of the body).

Arteries are classified into two main groups:

- **Conducting** (**Elastic Arteries)**.

  These are large arteries closest to the heart (aorta, renal artery) with very high blood pressure and flow (320mm/sec in the aorta).

- **Distributing** (**Muscular Arteries)**.

  These are smaller diameter arteries with a slower blood flow.

The arteries lead to smaller vessels, the **arterioles**, which lead to the **capillaries**. The capillaries are present in the form of microcirculation networks (**capillary beds**) in the organs and tissues. Exchange of metabolites and transport through the vessel wall is only possible in the capillaries, as only here the blood flow is sufficiently reduced (about 0.3mm/sec) and the vessel wall sufficiently thin.

On the return route to the heart the blood flows in **venules**, **small veins** and **large veins**.

Arterial blood in the Systemic Circulation is richly oxygenated, whereas the venous blood has little oxygen. In the Pulmonary Circulation the arterial blood is poorly oxygenated, whereas the venous blood, are highly oxygenated (having replenished its oxygen supplies in the lungs).

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 lumina of all the vessels of the blood vascular and lymphatic vascular systems. Endothelial cells lining the blood vessels are very flattened, elongated cells, with elongated nuclei that protrude into the lumina. The total number of endothelial cells in the body is enormous (estimated as $6x10^{23}$ cells) and cover a very large surface area ($700\text{-}1000m^2$) and in total weigh about 1.5kg.

Blood capillaries

Blood capillaries have a diameter of about 7-9µm, which is close to the dimensions of erythrocytes (about 7.2µm). The diameter of the capillaries varies according to the functional status of the tissue or organ. When functional demands rise the diameter of the capillaries enlarges, allowing increased exchange of oxygen and metabolites.

There are three different types of capillaries, however the differences are only visible at the ultrastructural level (by light microscopy these differences are not detectable) :

- **Continuous capillaries**
- **Fenestrated capillaries**
- **Sinusoids**

Continuous capillaries

These have **continuous endothelial cells** located on a **continuous basal lamina**. In cross sections they are seen to be composed of 2-3 endothelial cells, connected by **tight junctions**. In the region of the contact between the ends of two endothelial cells there is a **marginal fold**, a small area in which the edge of one of the cells protrudes into the lumen. Continuous capillaries are characterized by abundant small invaginations of the cell surfaces (**caveolae**) and numerous **micropinocytotic vesicles** in the cytoplasm. All the materials crossing the cell (**transcellular transport**), in both directions do so via these micropinocytotic vesicles.

Continuous capillaries are found in those organs that need strict control on access of the substances from the blood. These include all the organs with a "blood-barrier" such as the "blood-brain-barrier" of the Central Nervous System or the "blood-thymus barrier".

Fenestrated capillaries

These possess endothelial cells with groups of very small "**pores**" or "**fenestrae**", about 80-100nm diameter. These are seen in transmission electron micrographs and in particular after freeze-etching techniques. Fenestrated capillaries are common in most of the endocrine glands. One prominent site for fenestrated capillaries is in the renal glomeruli. The fenestrated capillaries lie on a continuous basal lamina.

Sinusoids

Sinusoids are irregular vessels with large diameters (30-40nm). In most cases the sinusoids are not cylindrical. Sinusoids are found in the liver, endocrine glands and in the hematopoietic organs (bone marrow, spleen). In many cases the sinusoids are also fenestrated. This is the case in those organs which need a very rich blood supply including most of the endocrine glands (hypophysis, suprarenal cortex, pancreas). Phagocytes are commonly associated with the walls of the sinusoids.

The exchange of materials through capillary walls can be:

transcellular via :

- micropinocytotic vesicles in the endothelium (as in continuous capillaries)
- fenestrations (as in fenestrated endothelium or sinusoids)

or **intercellular** via :

- gap junctions

- spaces between endothelial cells (as in sinusoids of spleen, liver).

Pericytes (Perivascular cells)

Many capillaries have inconspicuous, elongated cells, similar in appearance to embryonic mesenchymal cells, associated with them. These cells, known as **pericytes**, or **perivascular cells**, are quite difficult to see in most histological preparations. These pericytes appear to have important roles in repair of blood vessels and connective tissue after injury. They have the potential to develop into fibroblasts, smooth musccells and may even be phagocytic.

Endothelial cells are known to produce a variety of local factors that are important in the functioning of the cardiovasystem. These include nitric oxide.

Morphology of muscular (distributing) arteries

These vessels bring blood from the heart to the tissues in a high-pressure, fast-flow, system and consequently the arterial wall needs to be able to withstand the biomechanical stresses.

The arterial wall is composed of three main layers or tunics.

- ***Tunica intima*** (internal tunic) consisting of :

  - **endothelium** (single lining layer of endothelial cells)
  - **sub-endothelial layer**
  - **inner elastic limiting membrane** (elastic lamina, which after fixation appears undulating).

- ***Tunica media*** (middle tunic) consisting of :

  - **circular smooth muscle** (or spiral)
  - **concentric elastic lamina** (formed by the smooth muscle cells).

- ***Adventitia*** (outer layer) composed of :

  - **connective tissue** surrounding the vessel
  - **outer elastic limiting membrane** (on the border between the *Tunica media* and the *Adventitia*
  - ***Vasa vasorum***. These are small blood vessels supplying oxygen and nutrients to the wall of the artery. The blood flow in the arterial lumen is too great for exchange of oxygen or nutrients.

Morphology of Elastic Arteries

These are arteries closest to the heart and need to withstand stresses of extremely high blood flow. Their structure is best seen in the aorta. They are called elastic arteries as their Tunica media possesses 50-75 **well-developed elastic lamina** in between the thick smooth muscle bands. These have a similar appearance to the inner elastic limiting membrane. The elastic lamina prevent the excessive expansion of the vessel diameter and when they spring back they push the blood onwards i.e. they provide a shock-absorber effect permitting a more continuous blood flow despite the intermittent action of the heart. The elastic lamina absorb the intermittent impact of the cardiac pulse. During diastole (inactive heart), the large elastic arteries return to normal size impelling the blood forward. This contributes to a more constant arterial pressure and blood flow. The function of the elastic arteries can be considered as an auxiliary pump, when no forward pressure is exerted by the heart.

Smooth muscle in arteries

The smooth muscle in arteries is important in maintaining the vessel diameter during blood flow and also plays a role in blood pressure levels. The vascular smooth muscle is in a state of **tonus** (partial contraction). The degree of tonus of the smooth muscle cells in the wall of arteries and arterioles is controlled by the autonomic nervous system and also by endocrine secretions. In **hypertension** (high blood pressure), often associated with stress or aging, the peripheral arterial vessels show increased tonus.

Arterioles

Arterioles are small vessels with a diameter of 0.5mm or less.
They consist of three basic layers:

- ***Tunica intima*** with endothelium alone (no subendothelial layer) and a very thin inner elastic limiting membrane
- ***Tunica media*** with only 4-5 layers of smooth muscle
- ***Adventitia*** that is fairly thin

Metarterioles

These are small vessels that are on the border between arterioles and the capillary bed. They can act as sphincters and cut off the flow of blood into the capillary bed.

Arteriovenous anastomoses

These represent direct connections between arterioles and venules. When there is no need for blood flow in the capillary bed these permit direct blood passage (arterial-venous-shunt). Arteriovenous anastomoses are very common in the dermis of the skin.

Anatomical and Functional End Arteries

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.

Arterial pathology has major clinical importance in medicine. Common arterial disorders include: atherosclerosis (fatty deposits and occlusion), arteriosclerosis (hardening of the arteries), hypertension, aneurysms (ballooning of the vessel). Cardiac infarct and cerebral infarct resulting from occlusion of the lumen of arteries are major causes of morbidity.

Veins

The veins constitute a **low-pressure system** of vessels. The return of blood to the heart from the capillary beds of the tissues follows a route of **small venules**, **small veins** and **large veins**. As the venous vessels near the heart they become large and with thicker walls. The route of the veins is in parallel to that of the arteries.

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 or distensible than arteries. (As a result in histological preparations the lumen often appears collapsed or irregular)
- 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 are classified as large, medium or small veins.

Veins have three layers (***Tunica intima***, ***Tunica media*** and ***Adventitia***), however the borders between these layers are much less distinct than in arteries.

In veins the smooth muscles of the *T. media* are all **circular muscles**, grouped in bundles, whereas muscles present in the adventitia are **longitudinal**.

The movement of blood in veins is passive. The muscles play a role in tonus. Most of the muscles in veins are present in the adventitia and are longitudinal.

Valves are present in veins, especially in those that transport blood against the force of gravity, such as in the legs. The valves are composed of folds of the *Tunica intima* (endothelium and connective tissue). The valves prevent the backflow of blood. Weakness in the walls of veins can result in **varicose veins** and improper closure of the valves.

Venules

These have a very small diameter (20-50μm). In total preparations such as from the mesentery, the venule wall is so thin that the erythrocytes are visible, whereas they are not seen in the adjacent and parallel arterioles.

Post-capillary venules

In lymphatic organs, such as the lymph nodes, the post-capillary venules have high or cuboidal endothelium. These specialized venules permit the recirculation of lymphocytes (especially T-lymphocytes) from the blood to the lymph.

Umbilical blood vessels

The umbilical blood vessels are atypical. The single vein is unusual in that it is very muscular. The paired umbilical arteries are also unusual. The *T. intima* is composed only of endothelium. The *T. media* is composed of two muscle layers: an inner longitudinal layer and an outer circular layer. Elastic fibers are present throughout the media.

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 or 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.

LYMPH VASCULAR SYSTEM

Functions of the Lymph Vascular System

- The lymph vessels return to the blood extracellular fluid from connective tissue spaces. This system ensures the return of water, electrolytes and plasma proteins to the blood.
- The lymph vascular system plays a kerole in homeostasis of the volume of extracellular fluid.
- The lymph vascular system also returns lymphocytes from the lymph nodes to the blood.
- The system also transports immunoglobulins (antibodies) from the lymphnodes to the blood.

Lymph capillaries

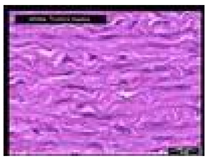
Lymph is a fairly clear, transparent fluid that flows (passively) in small lymph capillaries. These are found in most organs close to blood capillaries (an exception is the CNS). The lymph capillaries begin as small blind-ending tubes.

- Typical lymph capillaries have a diameter of 10-50μm only. Lymph vessels have very thin walls. The wall of the lymph capillary is composed of a single layer of endothelium (about 0.3μ m thick). Lymph vessels are hard to detect in histological preparations as the lumen tends to collapse.
- Lymph capillaries (unlike endothelial cells of blood vessels) lack a basal lamina.
- No pericytes or adventitial cells afound.
- They lack marginal folds (as seen in ultrastructure of blood capillaries).
- The lumen is usually free of cells (in comparison with blood capillaries where erythrocytes and other blood cells are common).

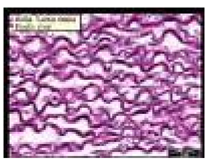
Movement of lymph in the lymph vessels is entirely passive. Valves, constructed from endothelial cells, prevent backflow of lymph. The lymph capillaries eventually drain into larger lymph vessels, with large lumina and thin walls and these ultimately drain into two large lymphatic ducts in the area at the base of the neck (**thoracic duct**, **right lymphatic duct**). These vessels return the lymph to the blood.

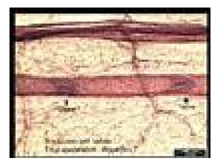
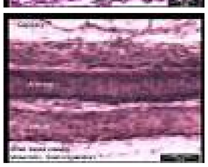
Lymph vessels drain into lymph nodes (each node has several afferent vessels, but only a single efferent vessel) and in passing through the node the lymph is filtered.



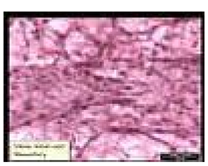
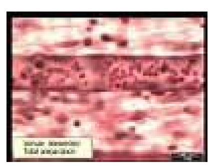
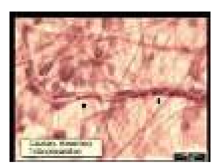
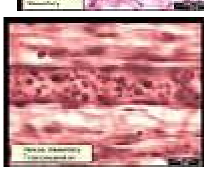



Small muscular artery Muscular artery (Elastin stain)
Aorta Aorta - Tunica Media

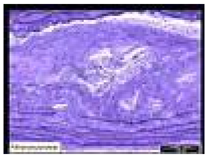


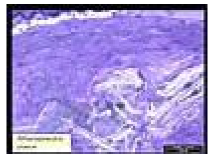



Aorta - Tunica Media Small Vein Small Vein with
Valves Small Blood Vessels

Valve - Small Vein Venule
Capillary Venule





Atherosclerosis

Atherosclerotic Plaque

Up

Back to lecture notes.