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HISTOLOGICAL STRUCTURE OF THE CIRCULATORY SYSTEM

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Annotation: 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.

Key words: Cardiovascular, blood, arteriolas, plasma.

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 may also be termed the capillary bed. 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.

You have already seen blood vessels of various sizes and types in preparations available in other lab sessions, and you should be aware that the histological appearances of vessels of different sizes (arterioles vs. arteries) and different types (arteries vs. veins) are different from each other. These differences are the result of quantitative variations of a common structural pattern that can be seen in all blood vessels with the exception of capillaries, i.e. the division of the walls of the blood vessels into three layers or tunics.

The tunica intima delimits the vessel wall towards the lumen of the vessel and comprises its endothelial lining (typically simple, squamous) and associated connective tissue.

Beneath the connective tissue, we find the internal elastic lamina, which delimits the tunica intima from the tunica media.

The tunica media is 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 the tunica adventitia,

which consist mainly of connective tissue fibers. The tunica adventitia blends with the connective tissue surrounding the vessel. The definition of the outer limit of the tunica adventitia is therefore somewhat arbitrary.

Arteries

All arterial vessels originate with either the pulmonary trunk (from the right ventricle) or the aorta (from the left ventricle). Specialisations of the walls of arteries relate mainly to two factors: the pressure pulses generated during contractions of the heart (systole) and the regulation of blood supply to the target tissues of the arteries. The tunica media is the main site of histological specialisations in the walls of arteries.

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Vessels close to the heart (aorta, pulmonary trunk and the larger arteries that originate from them) are

Elastic arteries

The tunica intima of elastic arteries is thicker than in other arteries. A layer of loose connective tissue beneath the endothelium (subendothelial connective tissue) allows the tunica intima to move independently from other layers as the elastic arteries distend with the increase in systolic blood pressure. Distension of the walls is facilitated by concentric fenestrated lamellae of elastic fibres in a thick tunica media. In adult humans, about 50 elastic lamellae are found in the tunica media of the aorta. The energy stored in the elastic fibres of the tunica media allows elastic arteries to function as a "pressure reservoir" which forwards blood during ventricular relaxation (diastole). Smooth muscle cells and collagen fibres are present between the layers of elastic fibres. Both fibre types are produced by the smooth muscle cells. Each elastic lamella forms together with interlamellar fibres and cells a lamellar unit. The external elastic lamina is difficult to discern from other layers of elastic fibres in the tunica media. The tunica adventitia appears thinner than the tunica media and contains collagen fibres and the cells typically present in connective tissue.

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 vesssels 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. The vessels are called vasa vasorum. In macroscopic preparations vasa vasorum are visible as fine dark lines on the surface of the larger arteries.

Aorta, human - H&E , elastin & van Gieson
The thin endothelial lining of the aorta corresponds to that of other vessels. The flattened cells are easily damaged during preparation and it may be difficult to identify the endothelium. The subendothelial layer of connective tissue is characterised by a lower density of cells, i.e. fewer nuclei, a fibrous appearance of the tissue and the absence of well-defined elastic layers. Because the lamellae of elastic fibers diffract light differently from the remaining tissues they should also be visible in H&E stained sections. Elastic lamellae become visible in the tunica media. The majority of cells in the tunica media are smooth muscle cells. Smooth muscle cells and collagen fibres are found between the layers of elastic fibres. If you scan the periphery of the aorta you may find small blood vessels, the vasa vasorum, in the tunica adventitia and penetrating into the outer part of the tunica media. Draw the aorta at low magnification and label the three tunics. Draw part of the tunica media at high magnification and identify collagen fibres, layers of elastic fibres and smooth muscle cell nuclei in your drawing.

The diameter of individual arteries decreases as we follow them further into the periphery. However, their total diameter increases, which leads to a fall in blood pressure. Also, the properties of the elastic arteries have to some extent evened out differences in diastolic and systolic blood pressure. The amount of elastic fibres in the tunica media decreases with these physiological changes. We now find a type of arteries which are termed

Muscular arteries

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The tunica intima is thinner than in elastic arteries. Subendothelial connective tissue other than the internal elastic lamina is often difficult to discern. The internal elastic lamina forms a well defined layer. The tunica media is dominated by numerous concentric layers of smooth muscle cells. Fine elastic fibres and and a few collagen fibres are also present. 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.

The basic structure of the walls of arteries does not change much as we come to the next type of arterial vessels. Size is used to differentiate them from muscular arteries.

Arterioles are arterial vessels with a diameter below 0.1 - 0.5 mm (different values in different textbooks). The endothelium appears to rest on a still well-defined internal elastic lamina. The tunica media consists of 1-5 concentric layers of smooth muscle cells. It may be difficult to identify the external elastic lamina or to distinguish the tunica adventia from the connective tissue surrounding the vessel.
The smooth muscle of arterioles (to some extent also that of muscular arteries) regulate the blood flow to their target tissues and receive both sympathetic and parasympathetic innervation. Arterioles finally branch to give rise to the capillary network (microcirculation).

Suitable Slides sections of arteries - H&E or elastin (in combination with other stains). Sections of small muscular arteries and arterioles are present in many sections, and the basic features of their structure are usually visible - even in smaller arteries. Large muscular arteries often have their "own section" in teaching collections.

Artery - H&E and elastin & eosin
Identifying muscular arteries in sections is rather straight forward. There are two easily recognizable features which distinguish these arteries from veins. If two vessels have a similarly sized lumen, the walls of arteries will be much thicker and more compact than the wall of veins. At high magnification, the internal elastic lamina forms a pink streak immediately below the endothelial cell lining in arteries and even arterioles, while it is difficult to identify in veins.
The layer of subendothelial connective tissue is very thin, and the endothelium seems to rest on the internal elastic lamina. Smooth muscle cell nuclei are frequent in the tunica media. The external elastic lamina stains similar to the internal elastic lamina, but it is thicker and appears fibrous instead of forming a continuous band. Collagen fibres and a few connective tissue cell nuclei are visible in the tunica adventitia.
If you close the iris diaphragm of the microscope, the elastic layers will stand out very clearly, but remember to open the diaphragm once you have seen them.

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. Also, capillaries are very small vessels. Their diameter ranges from 4-15 µm. The wall of a segment of capillary may be formed by a single endothelial cell. This results in a very large surface to volume ratio. The low rate of blood flow and large surface area facilitate the functions of capillaries in

- providing nutrients and oxygen to the surrounding tissue, in
- the absorption of nutrients, waste products and carbon dioxide, and in

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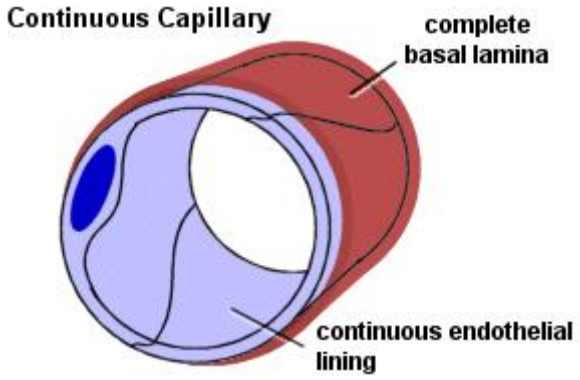
- the excretion of waste products from the body.

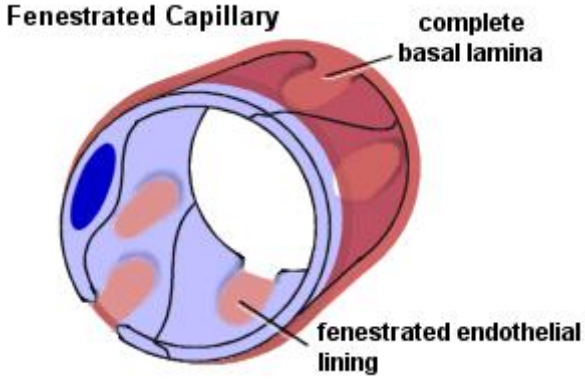
These functions are also facilitated by a very simple organisation of the wall of capillaries. Only the tunica intima is present, which typically only consists of the endothelium, its basal lamina and an incomplete layer of cells surrounding the capillary, the pericytes. Based on the features of the endothelium three types of capillaries can be distinguished:

Continuous capillaries are formed by "continuous" endothelial cells and basal lamina. The endothelial cell and the basal lamina do not form openings, which would allow substances to pass the capillary wall without passing through both the endothelial cell and the basal lamina. Endothelial cells and the basal lamina can act as selective filters in continuous capillaries.



Fenestrated capillaries

The endothelial cell body forms small openings called fenestrations, which allow components of the blood and interstitial fluid to bypass the endothelial cells on their way to or from the tissue surrounding the capillary. The fenestrations may represent or arise from pinocytotic vesicles which open onto both the luminal and basal surfaces of the cell. The extent of the fenestration may depend on the physiological state of the surrounding tissue i.e. fenestration may increase or decrease as a function of the need to absorb or secrete. The endothelial cells are surrounded by a continuous basal lamina, which can act as a selective filter.



Discontinuous capillaries are formed by fenestrated endothelial cells, which may not even form a complete layer of cells. The basal lamina is also incomplete. Discontinuous capillaries form large irregularly shaped vessels, sinusoids or sinusoid capillaries. They are found where a very free exchange of substances or even cells between bloodstream and organ is advantageous (e.g. in the liver, spleen, and red bone marrow).

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