The Cardiovascular System

The cardiovascular system consists of the heart and blood vessels. The blood vessels that take blood from the heart to various tissues are called arteries. The smallest arteries are called arterioles. Arterioles open into a network of capillaries that pervade the tissues. Exchanges of various substances between the blood and the tissues take place through the walls of capillaries.In some situations, capillaries are replaced by slightly different vessels called sinusoids. Blood from capillaries (or from sinusoids) is collected by small venules that join to form veins. The veins return blood to the heart.

Blood vessels deliver nutrients, oxygen and hormones to the cells of the body and remove metabolic base products and carbon dioxide from them.

Endothelium

The inner surfaces of the heart, and of all blood vessels are lined by flattened ***endothelial cells*** (also called ***endotheliocytes***). On surface view the cells are polygonal, and elongated along the length of the vessel. Cytoplasm is sparse. The cytoplasm contains endoplasmic reticulum and mitochondria. Microfilaments and intermediate filaments are also present, and these provide mechanical support to the cell. Many endothelial cells show invaginations of cell membrane (on both internal and external surfaces). Sometimes the inner and outer invaginations meet to form channels passing right across the cell (seen typically in small arterioles). These features are seen in situations where vessels are highly permeable.

Adjoining endothelial cells are linked by tight junctions, and also by gap junctions. Externally, they are supported by a basal lamina.

Functions of endothelium

Apart from providing a smooth internal lining to blood vessels and to the heart, endothelial cells perform a number of other functions as follows:

1. Endothelial cells are sensitive to alterations in blood pressure, blood flow, and in oxygen tension in blood.
2. They secrete various substances that can produce vasodilation by influencing the tone of muscle in the vessel wall.
3. They produce factors that control coagulation of blood. Under normal conditions clotting is inhibited. When required, coagulation can be facilitated.
4. Under the influence of adverse stimuli (e.g.,by cytokines) endothelial cells undergo changes that facilitate passage of lymphocytes through the vessel wall. In acute inflammation, endothelium allows neutrophils to pass from blood into surrounding tissues.

5. Under the influence of histamine (produced in allergic states) endothelium becomes highly permeable, allowing proteins and fluid to diffuse from blood into tissues. The resultant accumulation of fluid in tissues is called Oedema.

Arteries

Basic structure of Arteries

The histological structure of an artery varies considerably with its diameter. However, all arteries have some features in common which are as follows (Fig. 13.1):

1. The wall of an artery is made up of three layers
2. The innermost layer is called the tunica intima (tunica = coat). It consists of:

- An endothelial lining
- A thin layer of glycoprotein which lines the external aspect of the endothelium and is called the basal lamina
- A delicate layer of subendothelial connective tissue
- A membrane formed by elastic fibres called the internal elastic lamina.

3. Outside the tunica intima there is the tunica media or middle layer. The media may consist predominantly of elastic tissue or of smooth muscle. Some connective tissue is usually present. On the outside the media is limited by a membrane formed by elastic fibres, this is the external elastic lamina.
4. The outermost layer is called the tunica adventitia. This coat consists of connective tissue in which collagen fibres are prominent. This layer prevents undue stretching or distension of the artery.

Note: The fibrous elements in the intima and the adventitia (mainly collagen) run longitudinally (i.e., along the length of the vessel), whereas those in the media (elastic tissue or muscle) run circularly. Elastic fibres, including those of the internal and external elastic laminae are often in the form of fenestrated sheets (fenestrated = having holes in it).

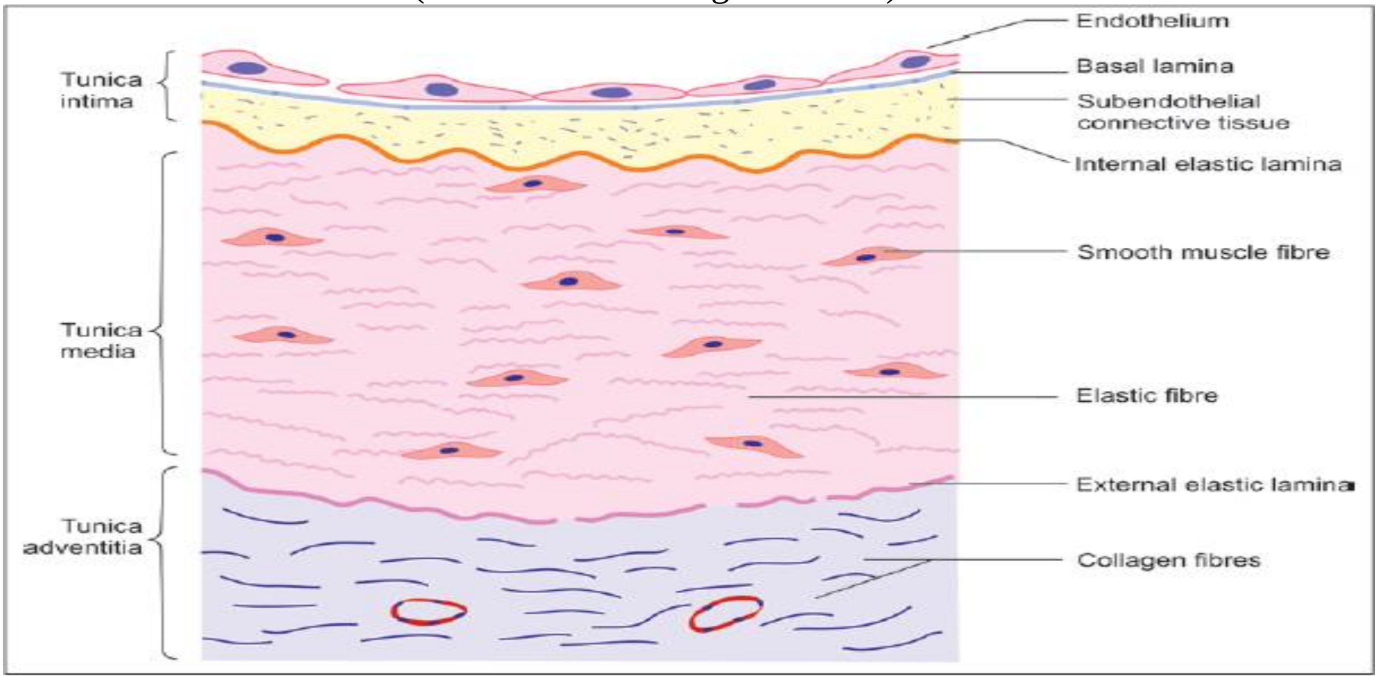

Fig. 13.1: Layers in the wall of a typical artery (Schematic representation)

Elastic and Muscular Arteries

On the basis of the kind of tissue that predominates in the tunica media, arteries are often divided into:
- Elastic arteries (large or conducting arteries)
- Muscular arteries (medium arteries)

Elastic arteries include the aorta and the large arteries supplying the head and neck (carotids) and limbs (subclavian, axillary, iliac). The remaining arteries are muscular (Table 13.1). Although all arteries carry blood to peripheral tissues, elastic and muscular arteries play differing additional roles.

Elastic Arteries

When the left ventricle of the heart contracts, and blood enters the large elastic arteries with considerable force, these arteries distend significantly. They are able to do so because of much elastic tissue in their walls. During diastole (i.e., relaxation of the left ventricle) the walls of the arteries come back to their original size because of the elastic recoil of their walls. This recoil acts as an additional force that pushes the blood into smaller arteries. It is because of this fact that blood flows continuously through arteries (but with fluctuation of pressure during systole and diastole). The elastic arteries are also called as ***conducting vessels*** as their main function is to conduct the blood from heart to muscular arteries.

Structure of Elastic Arteries

a. Tunica intima: It is made up of endothelium، sub-endothelial connective tissue and internal elastic lamina. The sub-endothelial connective tissue contains more elastic fibres in the elastic arteries. The internal elastic lamina is not distinct from the media as it has the same structure as the elastic membranes of the media.
b. Tunica media: The media is made up mainly of elastic tissue. The elastic tissue is in the form of a series of concentric membranes that are frequently fenestrated (Plate 13.1). In the aorta (which is the largest elastic artery) there may be as many as fifty layers of elastic membranes. Between the elastic membranes there is some loose connective tissue. Some smooth muscle cells may be present.
c. Tunica adventitia: It is relatively thin in large arteries, in which a greater proportion of elastic fibres are present. These fibres merge with the external elastic lamina.

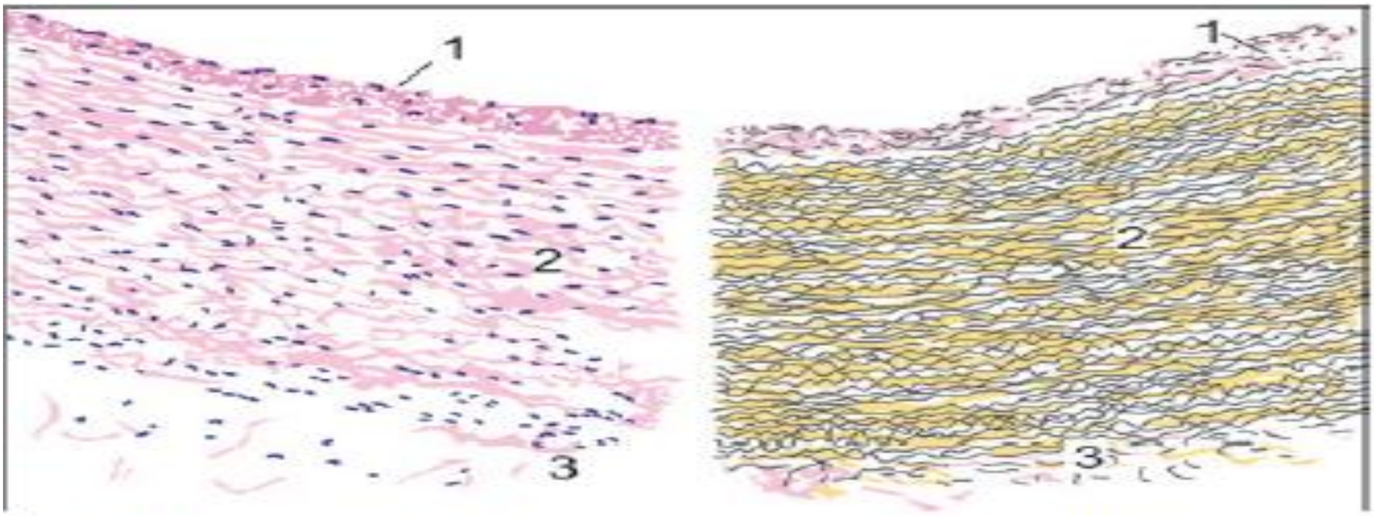

Fig. 13.2: Elastic artery (Schematic representation). The left half of the figure shows the appearance in a section stained with haematoxylin and eosin. The right half shows the appearance in a section stained by a special method that makes elastic fibres evident. (With this method the elastic fibres are stained black, muscle fibres are yellow, and collagen is pink). 1—tunica intima; 2—tunica media containing abundant elastic tissue arranged in the form of a number of membranes; 3— tunica adventitia

Muscular Arteries

A muscular artery has the ability to alter the size of its lumen by contraction or relaxation of smooth muscle in its wall. Muscular arteries can, therefore, regulate the amount of blood flowing into the regions supplied by them, hence they are also called as distributing arteries.

Structure of Muscular Arteries

The muscular arteries differ from elastic arteries in having more smooth muscle fibres than elastic fibres. The transition from elastic to muscular arteries is not abrupt. In proceeding distally along the artery there is a gradual reduction in elastic fibres and increase in smooth muscle content in the media.

a. Tunica intima: The internal elastic lamina in the muscular arteries stands out distinctly from the muscular media of smaller arteries.
b. Tunica media: It is made up mainly of smooth muscles (Plate 13.2). This muscle is arranged circularly. Between groups of muscle fibres some connective tissue is present, which may contain some elastic fibres. Longitudinally arranged muscle is present in the media of arteries that undergo repeated stretching or bending. Examples of such arteries are the coronary, carotid, axillary and palmar arteries.
c. Tunica adventitia contains primarily collagen and few elastic fibers.

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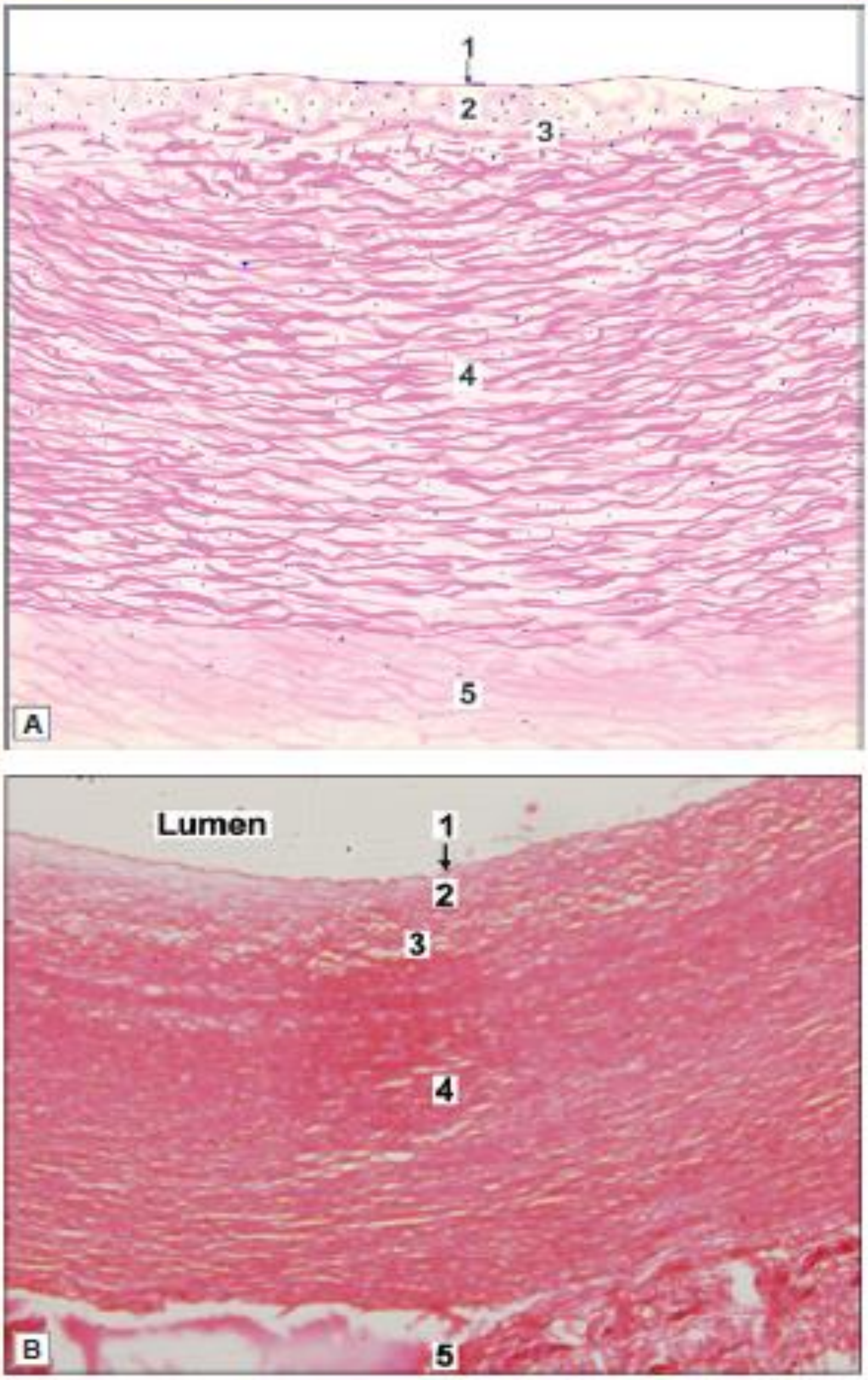
PLATE 13.1: Elastic Artery



Elastic artery. A. As seen in drawing; B. Photomicrograph

Elastic artery is characterised by presence of:

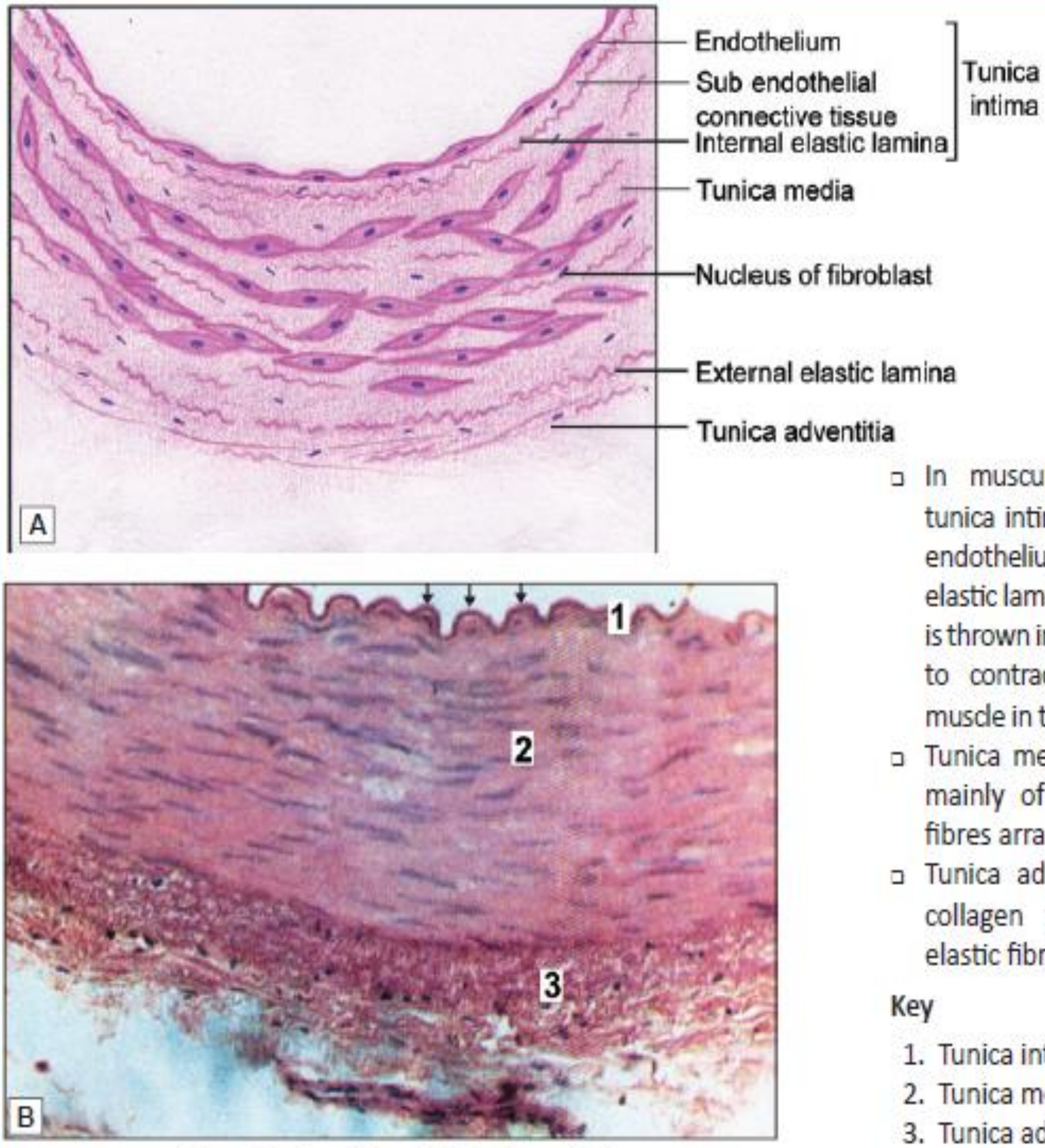
- Tunica intima consisting of endothelium, subendothelial connective tissue and internal elastic lamina
- The first layer of elastic fibres is called the internal elastic lamina. The internal elastic lamina is not distinct from the elastic fibres of media
- Well developed subendothelial layer in tunica intima
- Thick tunica media with many elastic fibres and some smooth muscle fibres
- Tunica adventitia containing collagen fibres with several elastic fibres
- Vasa vasorum in the tunica adventitia (Not seen in this slide).

Key

1. Endothelium
2. Subendothelial connective tissue
3. Internal elastic lamina
4. Tunica media
5. Tunica adventitia

(1–3: Tunica intima)

PLATE 13.2: Muscular (Medium Size) Artery



Muscular (medium size) artery. A. As seen in drawing; B. Photomicrograph

- In muscular arteries, the tunica intima is made up of endothelium and internal elastic lamina (arrow), which is thrown into wavy folds due to contraction of smooth muscle in the media
- Tunica media is composed mainly of smooth muscle fibres arranged circularly
- Tunica adventitia contains collagen fibres and few elastic fibres.

Key

1. Tunica intima
2. Tunica media
3. Tunica adventitia

Clinical Correlation

Atheroma

The most common disease of arteries is atheroma, in which the intima becomes infiltrated with fat and collagen. The thickenings formed are atheromatous plaques. Atheroma leads to narrowing of the arterial lumen, and consequently to reduced blood flow. Damage to endothelium can induce coagulation of blood forming a thrombus which can completely obstruct the artery. This leads to death of the tissue supplied. When this happens in an artery supplying the myocardium (coronary thrombosis) it leads to myocardial infarction (manifesting as a heart attack). In the brain (cerebral thrombosis) it leads to a stroke and paralysis. An artery weakened by atheroma may undergo dilation (aneurysm), or may even rupture.

Arterioles

When traced distally, muscular arteries progressively decrease in caliber till they have a diameter of about 100 µm. They then become continuous with arterioles. The larger or muscular arterioles are 100 to 50 µm in diameter (Fig. 13.3).

Arterioles less than 50 µm in diameter are called terminal arterioles. All the three layers, i.e. tunica adventitia, tunica media and tunica intima are thin as compared to arteries. In arterioles, the adventitia is made up of a thin network of collagen fibres.

Arterioles are the main regulators of peripheral vascular resistance. Contraction and relaxation of the smooth muscles present in the walls of the arterioles can alter the peripheral vascular resistance (or blood pressure) and the blood flow.

Muscular arterioles can be distinguished from true arteries:

1. By their small diameter
2. They do not have an internal elastic lamina. They have a few layers of smooth muscle in their media.

Terminal arterioles can be distinguished from muscular arterioles as follows:

1. They have a diameter less than 50 µm, the smallest terminal arterioles having a diameter as small as 12 µm.
2. They have only a thin layer of muscle in their walls.
3. They give off lateral branches (called Meta arterioles) to the capillary bed.

The initial segment of each lateral branch is surrounded by a few smooth muscle cells. These muscle cells constitute the precapillary sphincter. This sphincter regulate the flow of blood to the capillaries.

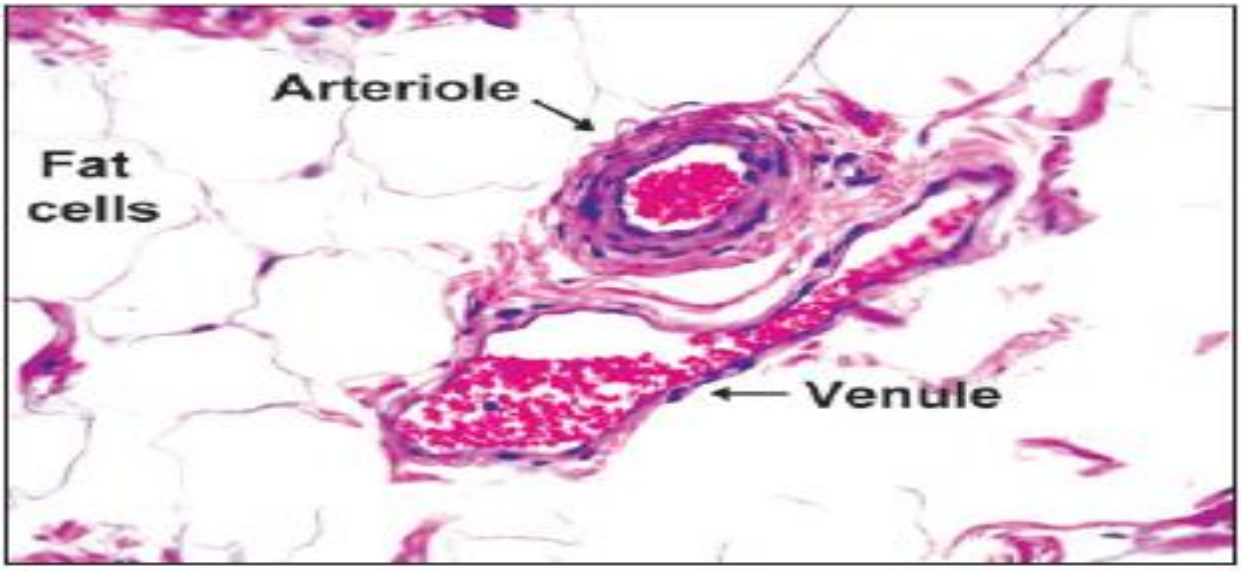


Fig. 13.3: Photomicrograph showing an arteriole and a venule

Capillaries

Terminal arterioles are continued into a capillary plexus that pervades the tissue supplied. Capillaries are the smallest blood vessels. The average diameter of a capillary is 8 µm. Exchanges (of oxygen, carbon dioxide, fluids and various molecules) between blood and tissue take place through the walls of the capillary plexus (and through post capillary venules). The arrangement of the capillary plexus and its density varies from tissue to tissue, the density being greatest in tissues having high metabolic activity.

Structure of Capillaries

The wall of a capillary is formed essentially by endothelial cells that are lined on the outside by a basal lamina (glycoprotein). Overlying the basal lamina there may be isolated branching perivascular cells (pericytes), and a delicate network of reticular fibres and cells. Pericyte or adventitial cells contain contractile filaments in the cytoplasm and can transform into other cells.

Types of Capillaries

There are two types of capillaries:

1. Continuous 2. Fenestrated

Continuous Capillaries

Typically, the edges of endothelial cells fuse completely with those of adjoining cells to form a continuous wall. Such capillaries are called continuous capillaries (Fig. 13.4).

In continuous capillaries exchanges of material between blood and tissue take place through the cytoplasm of endothelial cells. This is suggested by the presence of numerous pinocytotic vesicles in the cytoplasm; and by the presence of numerous depressions (caveolae) on the cell surfaces, which may represent pinocytotic vesicles in the process of formation. Apart from transport through the cytoplasm, substances may also pass through the intercellular material separating adjoining endothelial cells. Continuous capillaries are seen in the skin, connective tissue, muscle, lungs and brain.

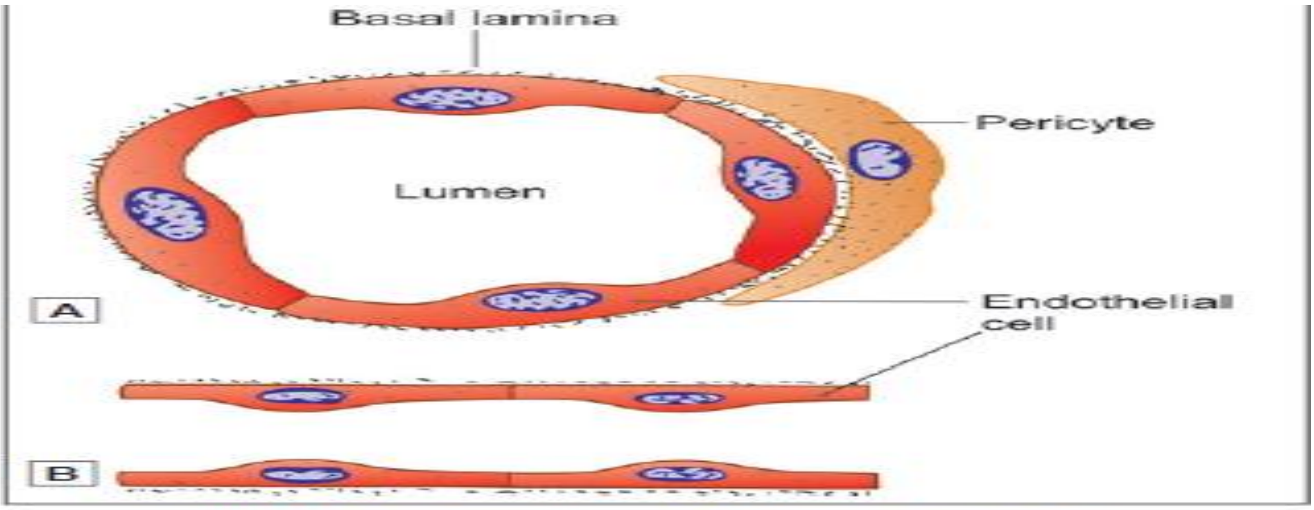


Fig. 13.4: Structure of continuous capillary.
A. Circular section; B. Longitudinal section
(Schematic representation)

Fenestrated Capillaries

In some organs the walls of capillaries appear to have apertures in their endothelial lining, these are, therefore, called fenestrated capillaries (Fig. 13.5).

In the case of fenestrated capillaries diffusion of substances takes place through the numerous fenestrae in the capillary wall. Fenestrated capillaries are seen in renal glomeruli, intestinal villi, endocrine glands and pancreas.

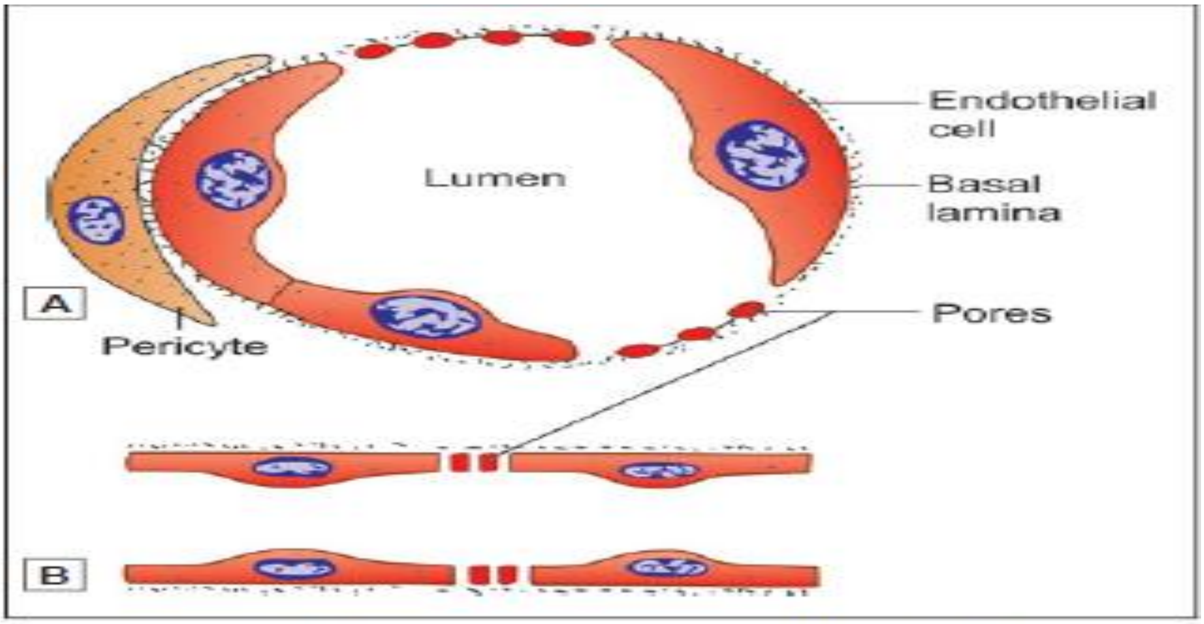


Fig. 13.5: Structure of fenestrated capillary. A. Circular section; B. Longitudinal section (Schematic representation)

Sinusoids

In some tissues the 'exchange' network is made up of vessels that are somewhat different from capillaries, and are called sinusoids (Fig. 13.6). Sinusoids are found typically in organs that are made up of cords or plates of cells. These include the liver, the adrenal cortex, the hypophysis cerebri, and the parathyroid glands. Sinusoids are also present in the spleen, in the bone marrow، and in the carotid body.

The wall of a sinusoid consists only of endothelium supported by a thin layer of connective tissue. The wall may be incomplete at places, so that blood may come into direct contact with tissue cells. Deficiency in the wall may be in the form of fenestrations (fenestrated sinusoids) or in the form of long slits (discontinuous sinusoids, as in the spleen.(At some places the wall of the sinusoid consists of phagocytic cells instead of endothelial cells. Sinusoids have a broader lumen (about 20 μm) than capillaries. The lumen may be irregular. Because of this fact blood flow through them is relatively sluggish.

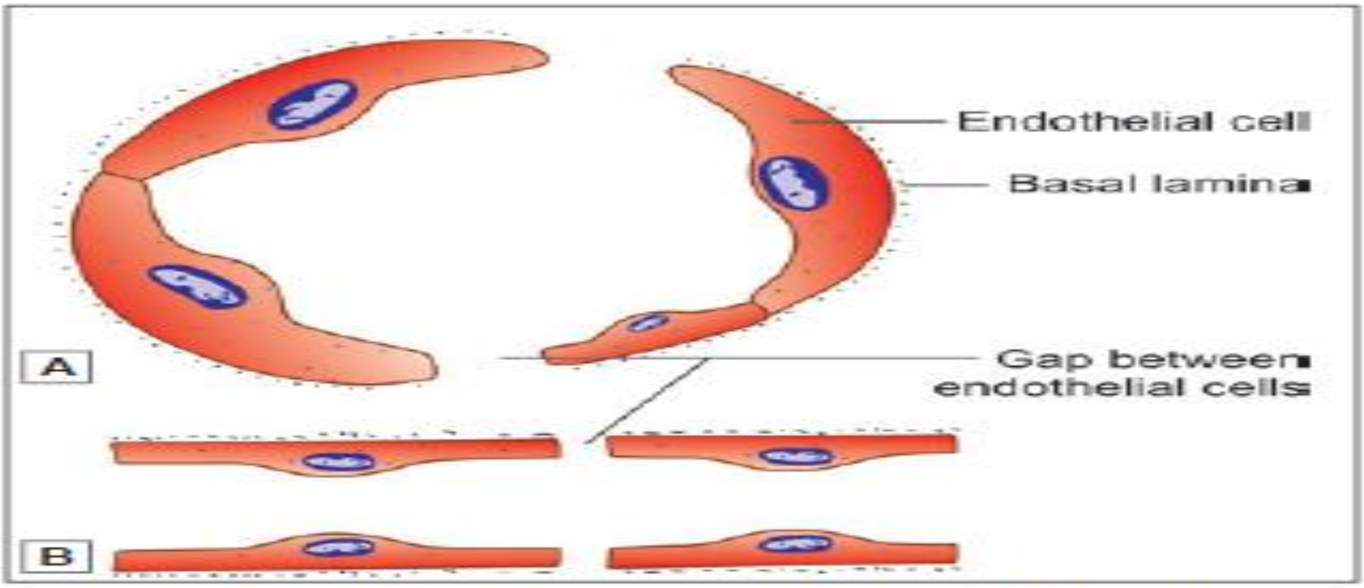


Fig. 13.6: Structure of sinusoid. A. Circular section; B. Longitudinal section (Schematic representation)