

10 Circulatory System

Competency

AN69.1: Identify elastic and muscular blood vessels and capillaries under the microscope.

AN69.2: Describe the various types of blood vessels and their structure–function correlation.

AN69.3: Describe the ultrastructure of blood vessels.

Specific Learning Objectives

- a. Classify blood vessels based on their structure and functions with suitable examples.
- b. Identify and draw the microstructure of cross-sections of a large artery, medium-sized artery, medium-sized vein, and a large vein and capillaries.
- c. Correlate the structure and function of the different types of blood vessels.
- d. Demonstrate and describe the following structures: tunica intima–endothelium and subendothelium; tunica media–elastic fibers, smooth muscle nuclei; and tunica adventitia–vasa vasorum in the slide of a large artery/elastic artery.
- e. Demonstrate and describe the following structures: tunica intima–endothelium and subendothelium; tunica media–smooth muscle nuclei and connective tissue; tunica adventitia–longitudinal sections of smooth muscle fibers and vasa vasorum in the slide of a large vein.
- f. Demonstrate and describe the following structures: tunica intima–endothelium and subendothelium, and internal elastic lamina; tunica media–external elastic lamina; tunica adventitia–vasa vasorum in a medium-sized artery.
- g. Describe and demonstrate the following structures: tunica intima–endothelium and subendothelium; tunica media–smooth muscle nuclei and collagen fibers; tunica adventitia–vasa vasorum in the slide of a medium-sized vein.
- h. Compare and contrast the microscopic features of the different types of blood vessels.
- i. Describe the ultrastructure of the different types of blood vessels.

Introduction

- The circulatory system mainly consists of the heart and blood vessels.
- Blood vessels are a closed system of tubes, namely, arteries, capillaries, and veins.

Arteries (Artery = Air Tube)

- Arteries are thick-walled blood vessels that carry the oxygenated blood from the heart to capillaries (except the pulmonary artery and umbilical artery, which carry deoxygenated blood).

Veins

- Veins carry deoxygenated blood toward the heart (except the pulmonary vein and umbilical vein, which carry oxygenated blood).

Capillaries

- Capillaries are small-diameter blood vessels arranged in a network within the tissues.

General Structure of Blood Vessels

- The vessel wall (artery and vein) is made up of three layers (*tunics*): tunica intima, tunica media, and tunica adventitia.

Tunica Intima

- It is the innermost layer consisting of the following:
 - *Endothelium*: Made up of a simple squamous epithelium (endotheliocytes) resting on the basal lamina linked by tight junctions and gap junctions.
 - *Subendothelial connective tissue*: Made up of a thin layer of delicate connective tissue. In capillaries, it is replaced by pericytes
 - *Internal elastic lamina*: It is a thin, fenestrated membrane formed by wavy elastic fibers.

Tunica Media

- It is the middle layer made up of an elastic tissue or smooth muscles and collagen fibers.
- The tunica media is limited by a thin, fenestrated membrane of elastic fiber called the *external elastic lamina*.

Tunica Adventitia

- It is the outermost layer and is made up of connective tissues with predominant collagen fibers.

Classification of Arteries

Based on the size and dominant components of the tunica media, arteries are classified into the following:

- Large artery (elastic artery/conducting artery).
- Medium artery (muscular artery/distributing artery).
- Arterioles.

Large Artery (Elastic Artery/ Conducting Arteries)

- They conduct blood from the heart to medium-sized arteries.
- The diameter of a large artery is around 30 mm.
- Examples: Aorta and its branches (brachiocephalic trunk, common carotid artery, and subclavian artery) and pulmonary trunk.

Microscopic Structure of a Large Artery

The microscopic structure of a large artery is depicted in **Figs. 10.1** and **10.2**.

- Tunica intima:
 - *Endothelium*: Made of simple squamous epithelium resting on the basal lamina.
 - *Subendothelial connective tissue*: Made up of elastic and type I collagen fibers, fibroblasts, and smooth muscle cells.
 - *Internal elastic lamina*: It is *not conspicuous* as it has the same structure as the elastic membrane of the tunica media.

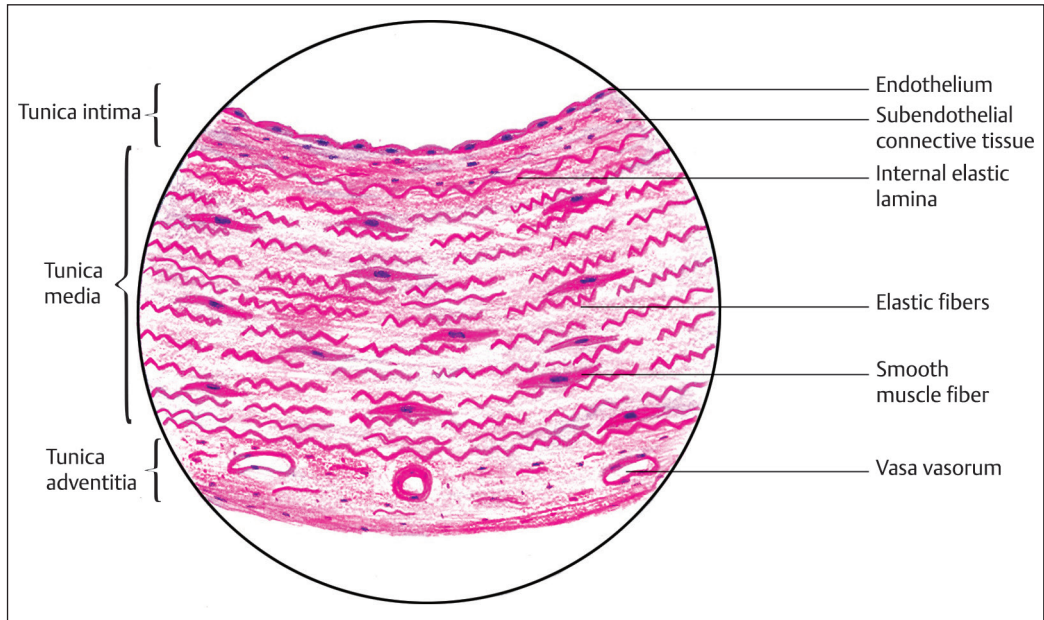


Fig. 10.1 Diagram of a large artery (H&E pencil). H&E, hematoxylin and eosin.

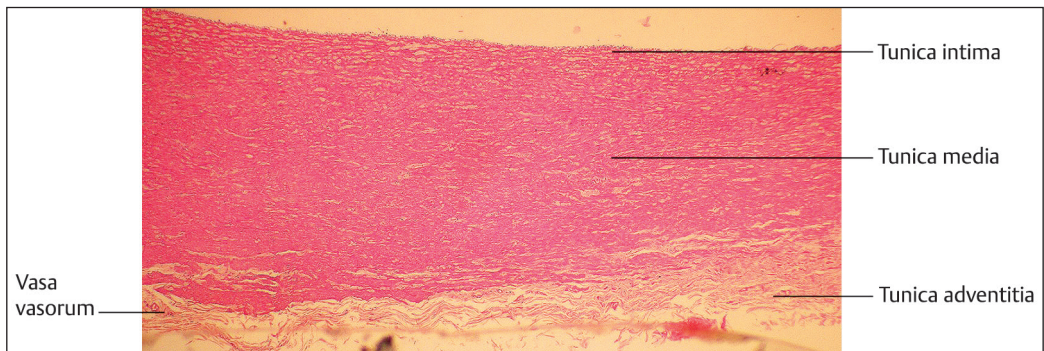


Fig. 10.2 Section of a large artery in low magnification (H&E stain). H&E, hematoxylin and eosin.

Identification Points (Fig. 10.2)

1. A large artery consists of three layers—tunica intima, tunica media, and tunica adventitia.
2. The tunica media is the thickest layer, and it consists of more elastic fibers in the form of fenestrated elastic membranes and a few smooth muscles.

- Tunica media:
 - It is the thickest of the three layers.
 - It is made up of elastic fibers arranged in the form of a series of fenestrated membranes and smooth muscle cells.
 - There are about 50 to 70 concentric elastic lamellae in a large-sized artery.
 - The elastic fibers facilitate the distension of the elastic artery during ventricular systole.

- Connective tissue is present between the elastic membranes.
- These smooth muscle cells synthesize collagen and other extracellular matrices. The external elastic lamina is not well demarcated.
- Tunica adventitia:
 - The tunica adventitia consists of collagen, elastic fibers, fibroblasts, macrophages, mast cells, lymphatics, and nerve cells.
 - It prevents the formation of an aneurysm by resisting the outward pressure of blood.
 - It also contains the *vasa vasorum* and *nervi vasorum*, which are networks of small vessels providing nourishment to the outer portion of the arterial wall and autonomic nerves regulating their diameter.
 - The inner part of the vessel wall is nourished by blood in the lumen.

Muscular Artery (Medium-Sized Artery/Distributing Artery)

- Medium-sized arteries are smaller in diameter than the elastic arteries.
- Medium-sized arteries are also called distributing arteries as they regulate the amount of blood flowing into the organ or tissue supplied by them.

Microscopic Structure of Medium-Sized Artery

The microscopic structure of a medium-sized artery is depicted in **Figs. 10.3** and **10.4**.

- Tunica intima:
 - The endothelium and subendothelial connective tissues are the same as those of large arteries.
 - The internal elastic lamina is *prominent* and is wavy because of the contraction of the underlying smooth muscles of the tunica media.

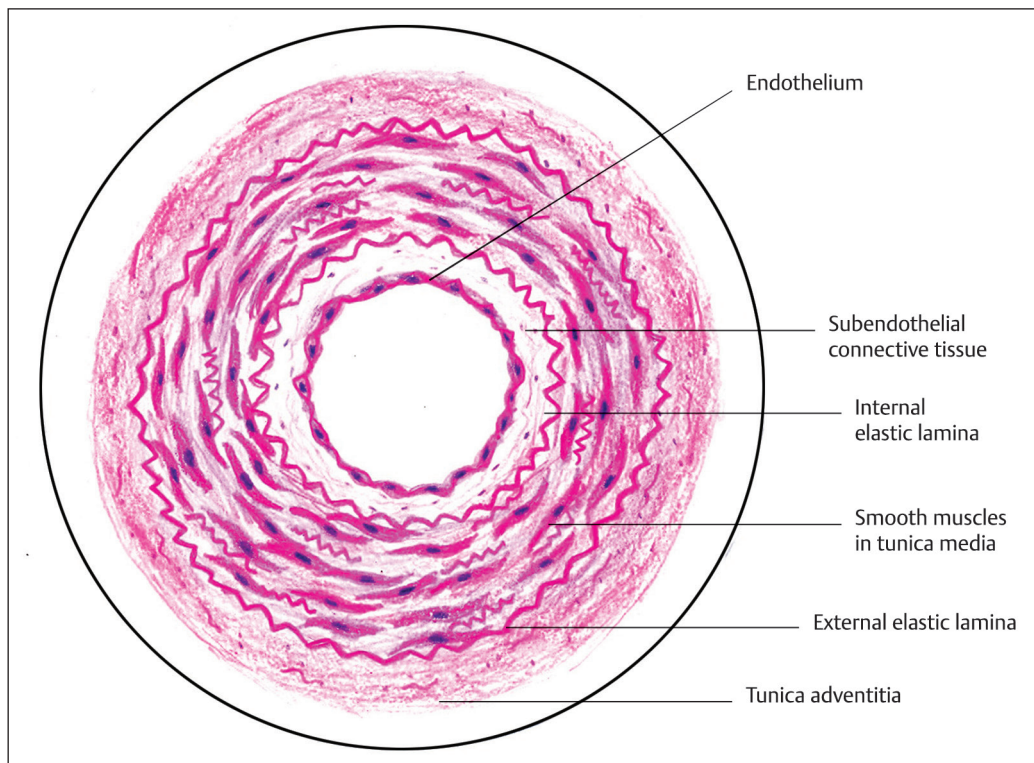


Fig. 10.3 Diagram of a medium-sized artery (H&E pencil). H&E, hematoxylin and eosin.

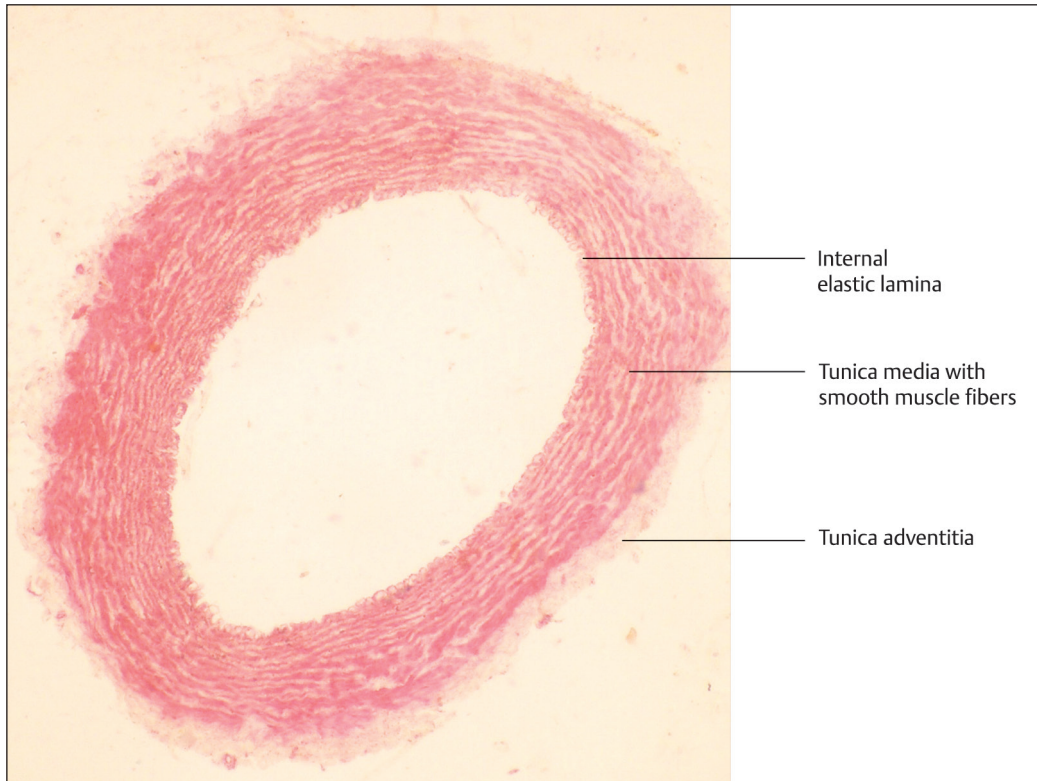


Fig. 10.4 Section of a medium-sized artery in low magnification (H&E Stain). H&E, hematoxylin and eosin.

Identification Points (Fig. 10.4)

1. A medium-sized artery consists of three layers: tunica intima, tunica media, and tunica adventitia.
2. The tunica media is the thickest one, consisting of more smooth muscle fibers than elastic fibers.
3. A prominent internal elastic lamina is present.

- Tunica media:
 - It is made up of circularly arranged smooth muscles, which have the capacity to alter the size of the lumen by contraction and relaxation.
 - This layer also contains collagen fibers and few elastic fibers between the smooth muscles.
- Tunica adventitia:
 - The tunica adventitia is similar in composition to a large artery.
 - It is relatively thicker than a large artery.

The differences between large- and medium-sized arteries are mentioned in **Table 10.1**.

Arterioles

- Muscular arteries with a diameter of $\leq 100 \mu\text{m}$ are called arterioles.
- They control the blood flow to the capillary network by contraction of smooth muscles.
- All three layers are very thin compared to the arteries, and the internal elastic lamina is either absent or fenestrated.

Table 10.1 Differences between the arteries and veins

Arteries	Veins
1. The wall of the artery is thicker.	1. The wall of the vein is thinner.
2. Three layers are well differentiated.	2. In small and medium-sized veins, three layers are not well differentiated.
3. The lumen of an artery is patent.	3. The lumen of a vein is collapsed.
4. The internal elastic lamina is prominent in a medium-sized artery.	4. The internal elastic lamina is thin.
5. The tunica media is the thickest layer, made up of smooth muscles and elastic fibers.	5. The adventitia is the thickest layer, made up of mainly elastic and muscular tissue (large vein).

- The arteriole divides into smaller branches called terminal and metarterioles.
- The terminal arteriole has a single layer of smooth muscle cells in the tunica media, which function as precapillary sphincters regulating the blood flow to the capillary bed.
- In metarterioles, the smooth muscles are replaced by pericytes.
- They regulate the peripheral vascular resistance and maintain systolic blood pressure.

Capillaries

- Capillaries are the smallest blood vessels with a diameter of 4 to 8 μm .
- They help in the exchange of gases and metabolites between the blood and tissues.
- The capillary wall has endothelium with the basal lamina and isolated pericytes.
- Pericytes are elongated contractile cells present at the outer surface of capillaries and postcapillary venules.
- They provide vascular support and stability to capillaries.
- Pericytes also act as stem cells and help in the repair process by helping in the formation of either fibroblasts or smooth muscles.
- Flow of blood through the capillaries is called *microcirculation*.

- Capillaries are absent in the basement membrane of the epithelium, cornea of the eye, epidermis of skin, hair, nail, and articular hyaline cartilage.

Types of Capillaries

- Continuous capillaries.
- Fenestrated capillaries.
- Sinusoids.

Continuous Capillaries

- In continuous capillaries, adjacent endothelial cells are joined by tight junctions, forming a continuous wall.
- Exchange of materials takes place through the cytoplasm of endothelial cells represented by pinocytotic vesicles in the cytoplasm and caveolae (depression) on the cell surface (**Fig. 10.5**).

Location of Continuous Capillaries

- Muscle, lung, brain, skin, connective tissue, and testis.

Fenestrated Capillaries

- In these types of capillaries, adjacent endothelial cells are separated by apertures or gaps closed by a thin electron-dense diaphragm.
- Diffusion of substances takes place through these apertures (**Fig. 10.6**).

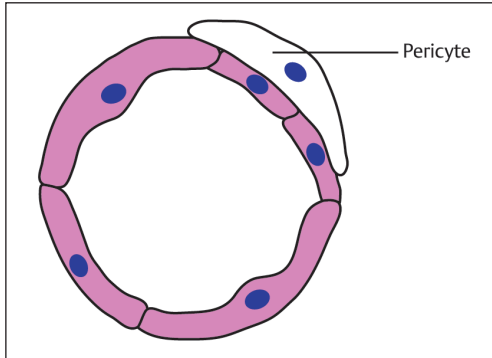


Fig. 10.5 Schematic diagram of continuous capillaries.

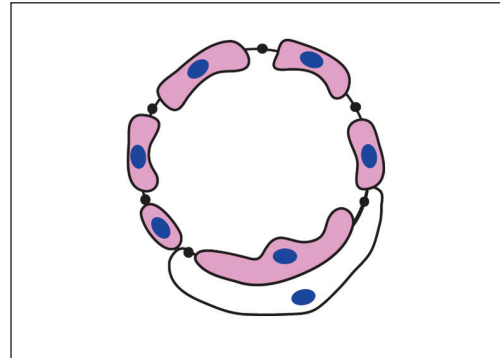


Fig. 10.6 Schematic diagram of fenestrated capillaries.

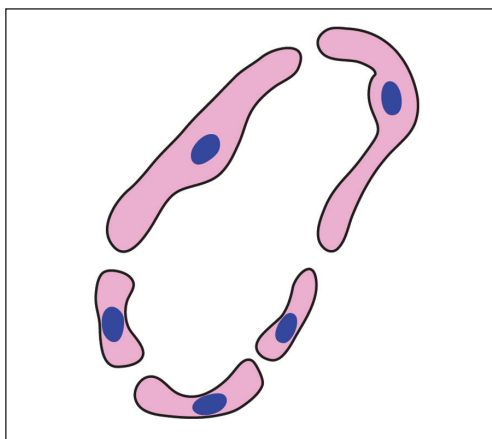


Fig. 10.7 Schematic diagram of sinusoids.

Location of Fenestrated Capillaries

- Endocrine glands, gallbladder, and kidney.

Sinusoids

- Sinusoids are large, irregularly shaped, discontinuous capillaries.
- Endothelial cells are separated by slits or apertures, which are not covered by the diaphragm (**Fig. 10.7**).
- Some endothelial cells are phagocytic, as seen in Kupffer cells of hepatic sinusoids.
- The lumen of sinusoids is irregular, allowing the sluggish blood flow through them, enabling the exchange of substances between blood and tissue fluids.

Location of Sinusoids

- Reticuloendothelial organs, such as the liver, bone marrow, and spleen.

Veins

- Tunics of the veins are not as well defined as those of arteries.
- The walls of the veins are thinner than those of the arteries.
- The tunica media comprises more collagen and fewer smooth muscles and elastic fibers. Hence, the wall of the vein will be easily compressed.
- The tunica adventitia is the thickest among the three layers.
- It contains elastic fibers and smooth muscle fibers, which run in the longitudinal direction and allow the shortening of veins.
- Depending upon the size, veins are divided into the following four types:
 - Venules.
 - Small veins.
 - Medium veins.
 - Large veins.

Venules

- They are the smallest veins with a diameter of 0.1 mm.

- They are of the following two types:
 - Postcapillary venules:
 - These are lined by the endothelium, basal lamina, pericytes, and thin adventitia.
 - Muscular venules:
 - In addition to the above-mentioned layers seen in the postcapillary venules, muscular venules also contain two to three layers of smooth muscles in the tunica media.

Small Veins

They have a diameter of less than 1 mm.

Medium Veins

They usually accompany the arteries and have a diameter of as much as 10 mm.

Structure of Medium Veins

The following three tunics observed in arteries are also seen here:

- *Tunica intima*: It consists of the endothelium with a basal lamina, subendothelial

connective tissue, and a thin internal elastic lamina.

- *Tunica media*: It is much thinner than that of arteries, comprising circularly arranged smooth muscles with collagen and elastic fibers.
- *Tunica adventitia*: It is thicker than the tunica media, comprising collagen and elastic fibers (**Figs. 10.8** and **10.9**).

Large Veins

These veins have a diameter greater than 10 mm.

Microscopic Structure of Large Veins

The microscopic structure of large veins is depicted in **Figs. 10.10** and **10.11**.

- *Tunica intima*:
 - It is made up of the endothelium with a basal lamina and subendothelial connective tissue with smooth muscles.
 - There is no definite boundary between the tunica media and the tunica intima.

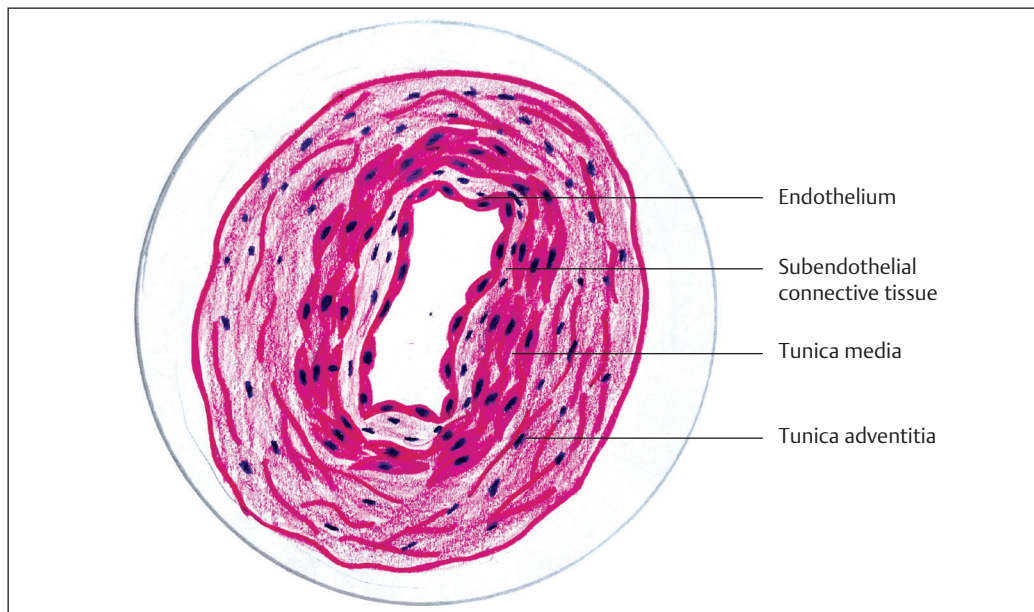


Fig. 10.8 Diagram of a medium-sized vein (H&E Stain). H&E, hematoxylin and eosin.

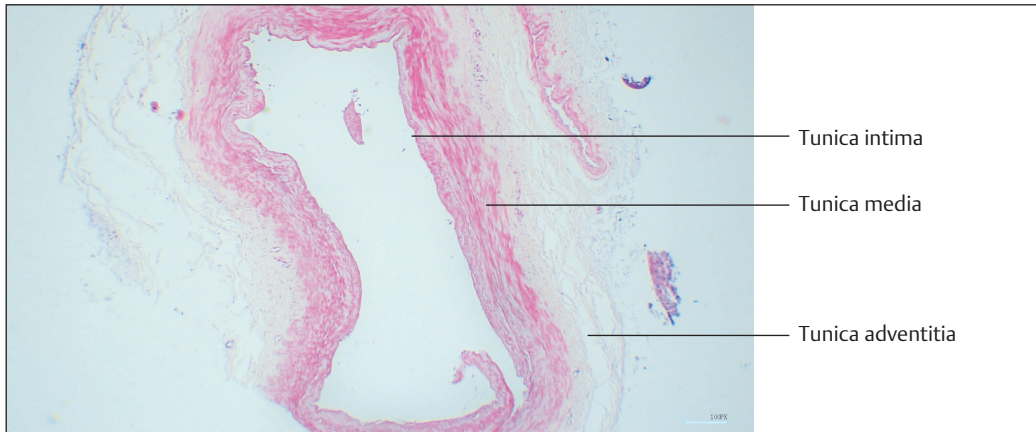


Fig. 10.9 Section of a medium-sized vein in low magnification (H&E Stain). H&E, hematoxylin and eosin.

Identification Points (Fig. 10.9)

1. The tunica intima is composed of the endothelium and a basal lamina with subendothelial connective tissue.
2. The tunica media is composed of collagen fibers, reticular fibers, and smooth muscles.
3. The tunica adventitia is composed of collagen fibers with fibroblasts.

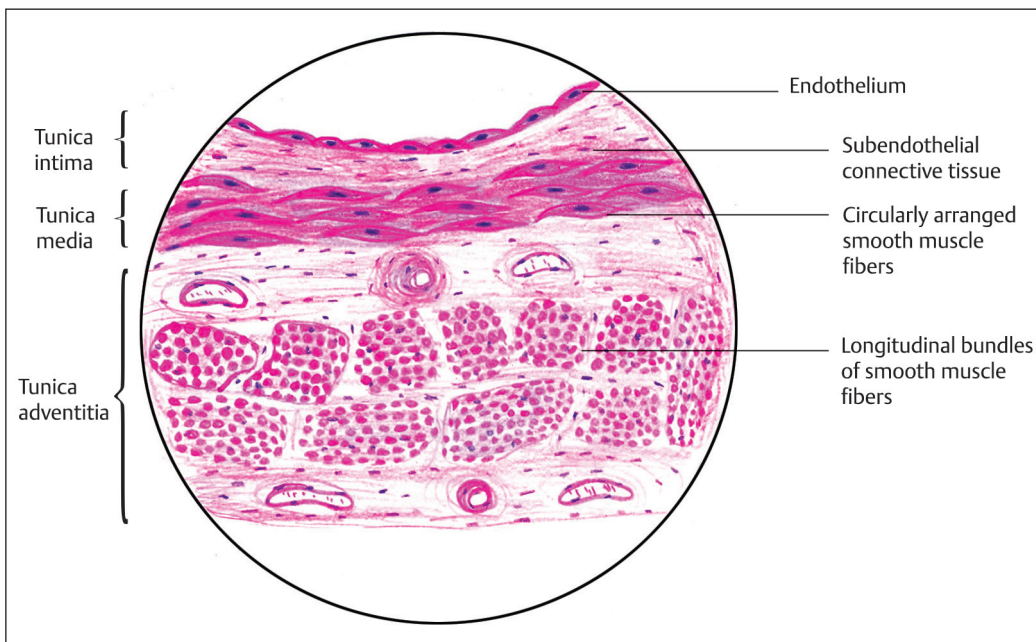


Fig. 10.10 Diagram of a large vein (H&E pencil). H&E, hematoxylin and eosin.

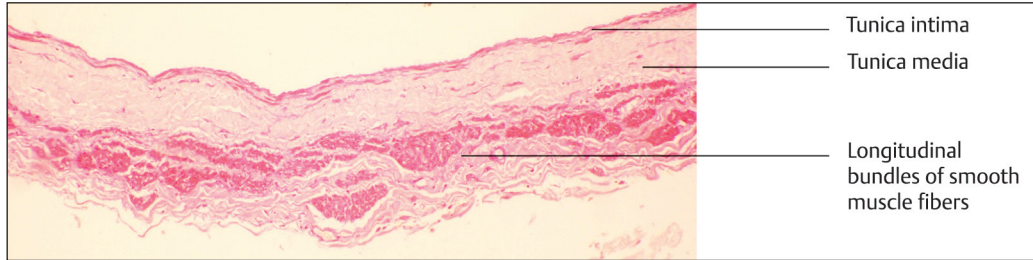


Fig. 10.11 Section of a large vein in low magnification (H&E Stain). H&E, hematoxylin and eosin.

Identification Points (Fig. 10.11)

1. A large-sized vein consists of three layers: tunica intima, tunica media, and tunica adventitia.
2. The tunica adventitia is the thickest; it contains longitudinally running smooth muscle fibers.

- **Tunica media:**
 - It is thin and contains circumferentially arranged smooth muscles, collagen fibers, and fibroblasts.
- **Tunica adventitia:**
 - It is the thickest layer, comprising longitudinally disposed smooth muscles along with collagen and elastic fibers.

Venous Valves

- Folds (flaps) of the tunica intima projecting into the lumen of a vein.
- Each flap is made up of connective tissue covered by endothelium.
- The free margin of valve flaps is directed toward blood flow.

The differences between arteries and veins are presented in **Table 10.1**.

Applied Aspects

- **Atherosclerosis:**
 - It is a condition in which there is a deposition of atheromatous plaques in the vessel wall (tunica intima), leading to narrowing of the vessel wall.
 - Atheromatous plaques are made up of lipids, macrophages, lymphocytes, smooth muscles, and cell debris.
 - In advanced cases, blood stasis and clotting may lead to occlusion of vessels.
- **Arteriosclerosis:**
 - Age-related changes in the vessel wall characterized by thickening of the intima due to lipid accumulation.
- **Aneurysm:**
 - This condition is characterized by an abnormal saccular dilatation of the vessel wall because of the replacement of elastic fibers by collagen fibers.
 - It is commonly seen in large arteries associated with systemic diseases, such as syphilis and Marfan's syndrome.
- **Hypertension:**
 - In hypertensive individuals, smooth muscle cells of the tunica media multiply, leading to increased thickness of the media.
 - Some smooth muscles accumulate lipid, which may act as a precursor for atherosclerosis.
- **Aortic dissection:**
 - It is an intimal tear causing bleeding between the layers of the vessel wall, forcing them apart.

Questions

1. Name the different layers of blood vessels.
2. Enumerate the differences between an artery and a vein.
3. Why are the internal and external elastic laminae not prominent in elastic arteries?
4. What is vasa vasorum?
5. List the differences between medium- and large-sized arteries.
6. What are capillaries? Name the different types of capillaries with examples.