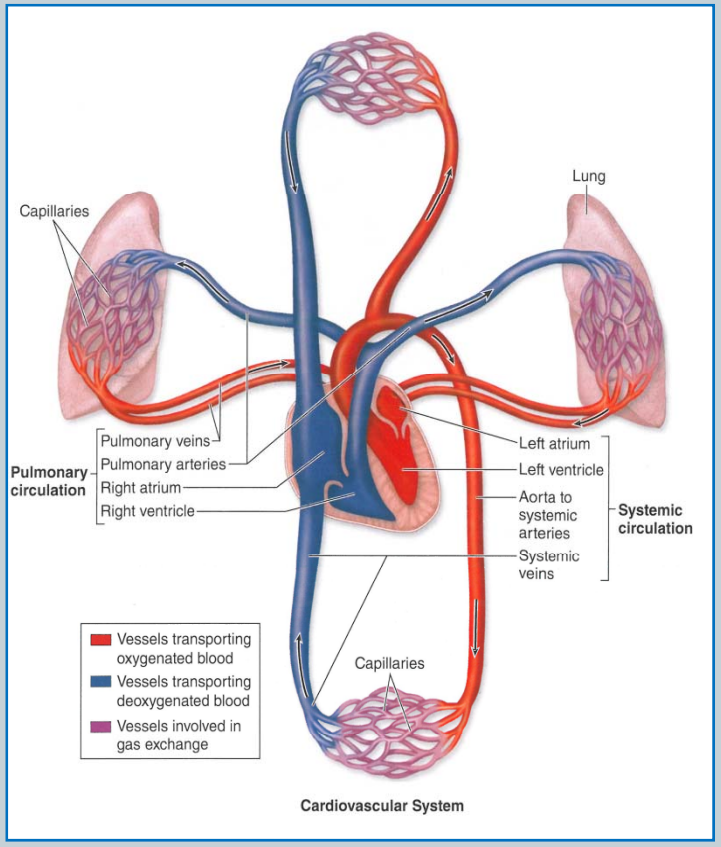
The Circulatory system

Circulatory system

- Blood (cardiovascular) vascular system
- Lymphatic vascular system
- 100,000-150.000 km



- Endothelium (single layer of squamous epithelium
- Interface between blood & organs

- Endothelial cells

1. Selective permeability
2. Antithrombogenic
3. When & where WBC leave the circulation
4. Paracrine factors for vessle contraction & cell growth

Heart

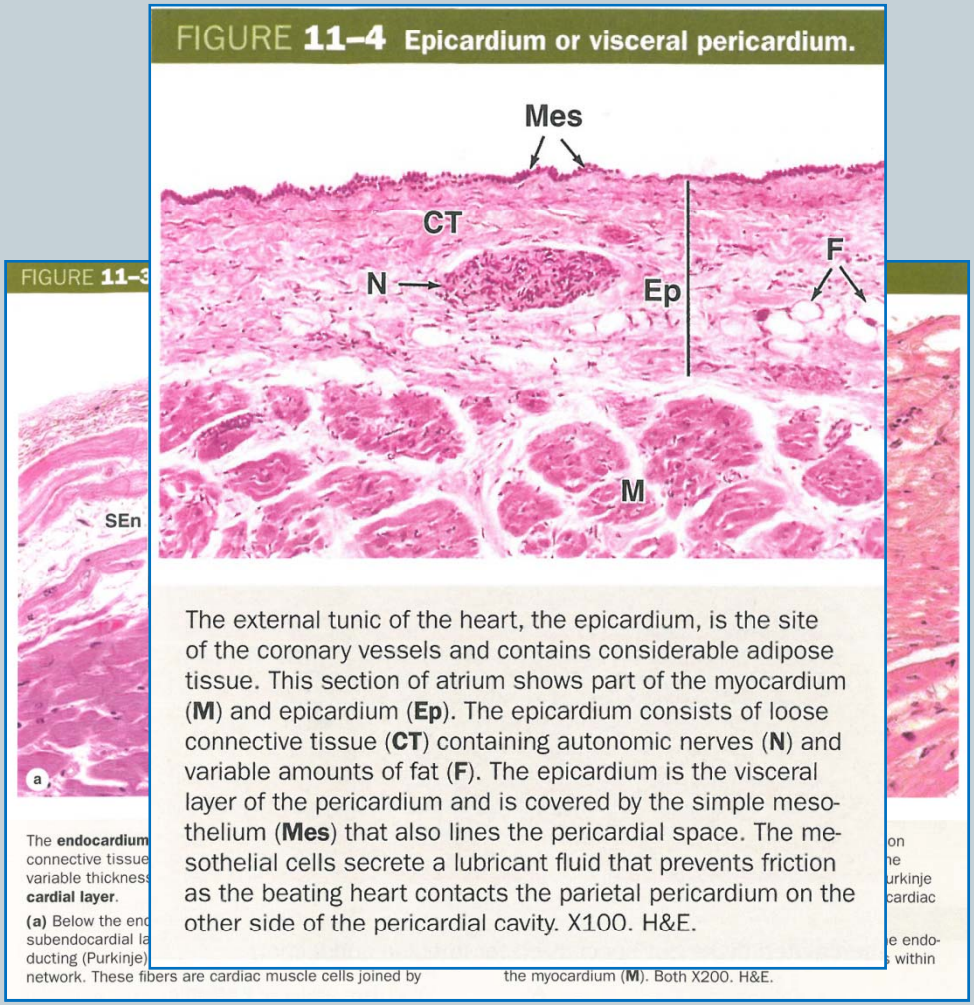
Three major layers

- Endocardium (inner layer)
  - Endothelium & Supporting Connective tissue
  - Myoelastic layer of smooth muscle
  - Deep layer of connective tissue subendocardial layer
- Myocardium
- Epicardium
  - Single layer of squamous mesothelium
  - Supporting loose connective tissue (nerve & vessel)

- **pericardium**

Visceral layer (epicardium)
Parietal layer

Adipose tissue in epicardium protect the heart
Lubricant fluid of mesothelium layer



Interventricular & interatrial septa (dense fibrous connective tissue)

- Anchoring and supporting the heart valves
- Providing firm points of insertion for cardiac muscle
- Helping coordinate the heartbeat by acting as electrical insulation between atria and ventricles

Conductive system of the heart
(subendocardium layer)
2 nodes:

1. Synoatrial (SA) node (pacemaker)
2. Atrioventricular node (AV)

Atrioventricular bundle (His)
conducting network (left & right)
in apex purkinje fibers

Ganglionic nerve near the nodes
Sympathetic & parasympathetic
Afferent free nerve ending (Between myocardium fiber)
Angina pectoris

FIGURE **11–5** Valve leaflet and cardiac skeleton.

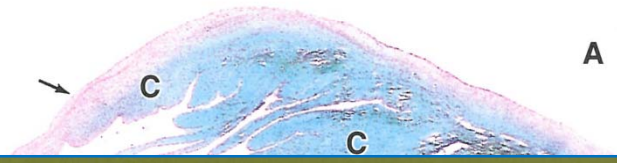
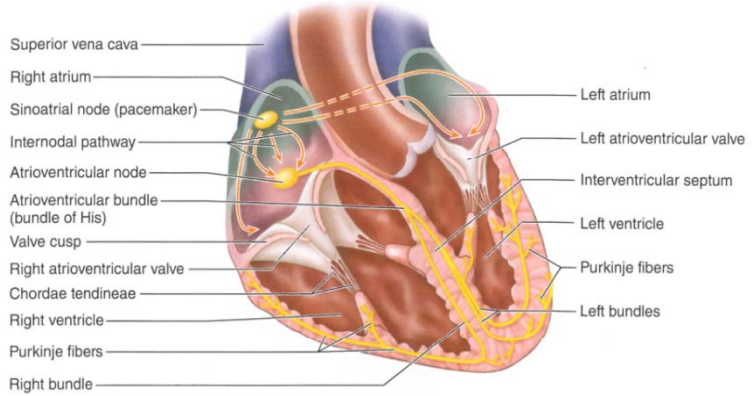


FIGURE **11–2** Important features of the heart.



As seen in the diagram, the human heart has two **atria** and two **ventricles**. The myocardium of the ventricular walls is thicker than that of the atria. The **valves** are basically flaps of connective tissue anchored in the heart's dense connective tissue, or **cardiac skeleton**, concentrated in the regions shown in white. This fibrous tissue includes the chordae tendineae, cords that extend from the cusps of both atrioventricular valves and attach to papillary muscles, preventing the valves from turning inside-out during ventricular contraction. Valves and cords are covered by the nonthrombogenic endothelium.

Shown in yellow are parts of the cardiac **conducting system**, which initiates the electrical impulse for contraction (heartbeat) and spreads it through the ventricular myocardium. Both the **sinoatrial (SA) node (pacemaker)**, in the right atrial wall, and the **atrioventricular (AV) node**, in the floor of the right atrium, consist of myocardial tissue that is difficult to distinguish histologically from surrounding cardiac muscle. The AV node is continuous with specialized bundles of cardiac muscle fibers, the **AV bundles** (of His) that run along the interventricular septum to the apex of the heart, where they branch further as **conducting (Purkinje) fibers** that extend into myocardium of the ventricles.

- Defects of heart valves structure

Scars

Infections

Cardiovascular problems

- Additional sound
- Heart murmur

- Heart enlargement
- Surgery (valves)
- No endothelium
- Anticoagulant to prevent thrombosis

>> MEDICAL APPLICATION

Abnormalities in the structure of heart valves can be produced by developmental defects, scarring after certain infections, or cardiovascular problems such as hypertension. Such abnormal valves may not close tightly, allowing slight regurgitation and backflow of blood. This produces an abnormal heart sound referred to as a **heart murmur**. If the valve defect is severe, the heart will have to work harder to circulate the normal amount of blood, eventually enlarging to accommodate the increased workload. Defective heart valves often may be repaired surgically or replaced by an artificial valve or one from a large animal donor. Because such valve replacements lack a complete endothelial covering, the patients require exogenous anticoagulant agents to prevent thrombus formation at these sites.

Tissue of the vascular wall

- Endothelium
- Smooth muscle
- Connective tissue

Endothelium

- Semipermeable barrier

Simple & active transport
Receptor mediated endocytosis
Transcytosis

- Squamous, Elongated polyhedral
- Very differentiated basal lamina

Endothelial cell function

- **Metabolic exchange**

- **Nonthrombogenic surface**

Heparin, Tissue plasminogen activator, Von willebrand factor

- **Vascular tone & blood flow (sctering factors)**

Smooth muscle contraction (endothelin I, angiotencin converting enzyme)
Smooth muscle relaxation (NO)

- **Inflammation & local immune response**

P-Selectin
Weible-palade bodies
Interleukins

- **Growth factor secretion**

VEGF (vasculogenesis & angiogenesis)
Angiopoietin

›› MEDICAL APPLICATION

The normal vascular endothelium is antithrombogenic, allowing adhesion of no blood cells or platelets and preventing blood clot formation. When endothelial cells of the microvasculature are damaged by tissue injury, collagen is exposed in the subendothelial tissues and induces the aggregation of blood platelets. These platelets release factors that initiate a cascade of events that produce fibrin from circulating plasma fibrinogen. An intravascular clot, or **thrombus** (plural, thrombi), with a fibrin framework quickly forms to stop blood loss from the damaged vessels.

From large thrombi, solid masses called **emboli** (singular, embolus) may detach and be carried by the blood to obstruct distant vessels. In both cases vascular flow may be blocked, producing a potentially life-threatening condition. Thus, the integrity of the endothelial layer preventing contact between platelets and the subendothelial connective tissue is an important antithrombogenic mechanism.

Individuals in the initial stages of medical conditions involving thrombus formation, such as myocardial infarct, stroke, or pulmonary embolism, are treated intravenously with tissue plasminogen activator, commonly abbreviated as tPA. This is a serine protease that breaks down fibrin and quickly dissolves the clot.

- **Helical Smooth muscle fibers (gap j.)**

- **Connective tissue components**
- **Fibers**

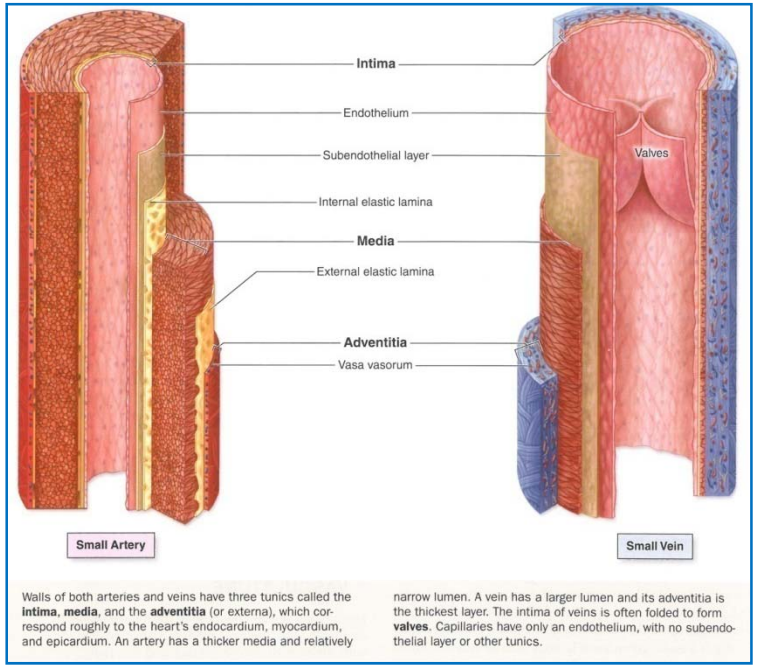
Collagen (subendothium. Between smooth muscle fibers, outer covering)
Elastic fibers (elastin in large arteries parallel lamella between muscles)

- **Ground substances**

(hyaloronate & proteoglycans affect physical & metabolic activities & permeability)

Large vessel wall contains:

1. Tunica intima
2. Tunica media
3. Tunica externa (advantitia)



Walls of both arteries and veins have three tunics called the **intima**, **media**, and the **adventitia** (or externa), which correspond roughly to the heart's endocardium, myocardium, and epicardium. An artery has a thicker media and relatively narrow lumen. A vein has a larger lumen and its adventitia is the thickest layer. The intima of veins is often folded to form **valves**. Capillaries have only an endothelium, with no subendothelial layer or other tunics.

- **Tunica intima**

1. Endothelium
2. Subendothelial layer (loose con. T. & smooth muscle fibers)
3. Internal elastic lamina (in large vessels, elastin & pores)

- **Tunica media**

1. Layers of smooth muscles (elastic fibers, reticular fibers, PrG.)
2. External elastic lamina (in large vessel)

- **Tunica externa (advantitia)**

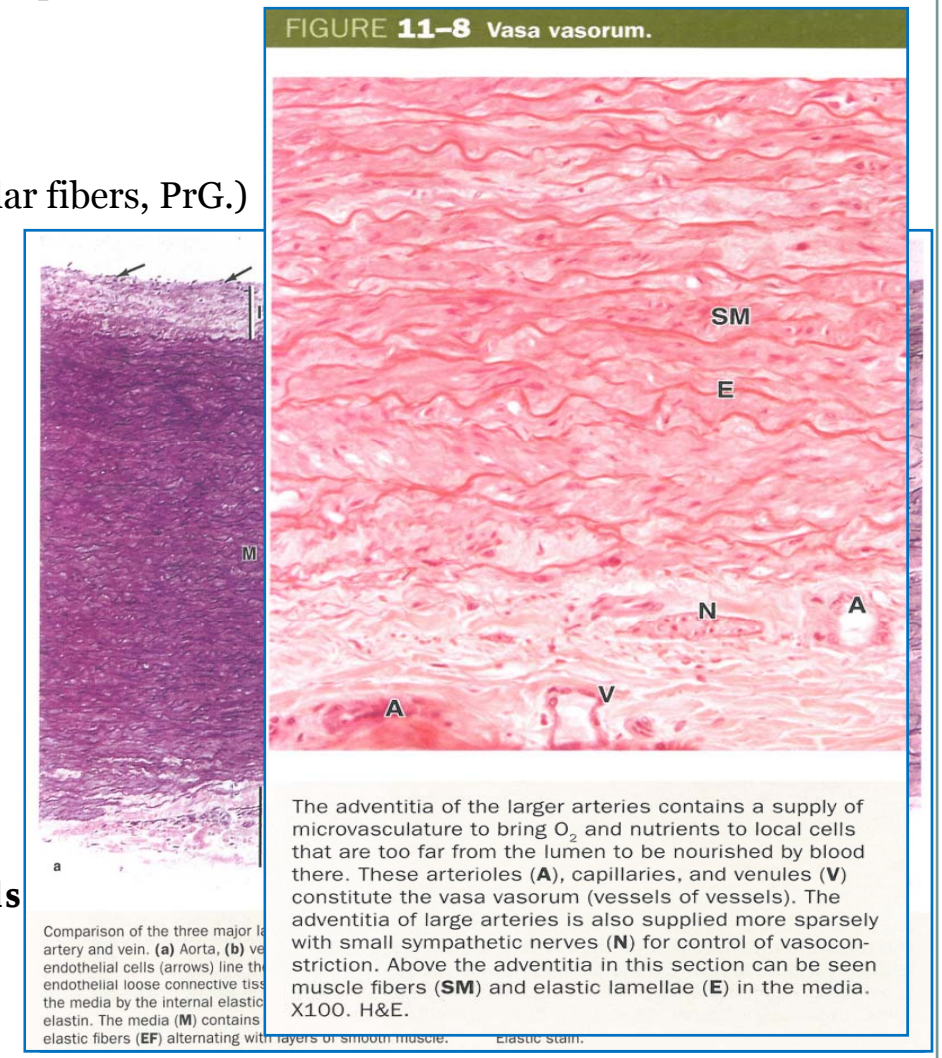
Collagen & elastic fibers

Vasa vasorum in large vessels

(in advantitia & external part of media)

Unmyelinated autonomic nerve in large vessels

Norepinephrine (vasoconstrictor specially arteries)



Vasculature

- Elastic artery
- Muscular artery
- Small artery
- Arteriole
- Capillary
- Venule
- Small vein
- Medium vein
- Large vein

TABLE 11–1 Size ranges, major features, and important roles of major blood vessel types.

Type of Artery	Outer Diameter (Approx. Range)	Intima	Media	Adventitia	Roles in Circulatory System
Elastic arteries	>10 mm	Endothelium; connective tissue with smooth muscle	Many elastic lamellae alternating with smooth muscle	Connective tissue, thinner than media, with vasa vasorum	Conduct blood from heart and with elastic recoil help move blood forward under steady pressure
Muscular arteries	10-1 mm	Endothelium; connective tissue with smooth muscle, internal elastic lamina prominent	Many smooth muscle layers, with much less elastic material	Connective tissue, thinner than media; vasa vasorum may be present	Distribute blood to all organs and maintain steady blood pressure and flow with vasodilation and constriction
Small arteries	1-0.1 mm	Endothelium; connective tissue less smooth muscle	3-10 layers of smooth muscle	Connective tissue, thinner than media; no vasa vasorum	Distribute blood to arterioles, adjusting flow with vasodilation and constriction
Arterioles	100-10 μm	Endothelium; no connective tissue or smooth muscle	1-3 layers of smooth muscle	Very thin connective tissue layer	Resist and control blood flow to capillaries; major determinant of systemic blood pressure
Capillaries	10-4 μm	Endothelium only	Pericytes only	None	Exchange metabolites by diffusion to and from cells
Venules (postcapillary, collecting, and muscular)	10-100 μm	Endothelium; no valves	Scattered smooth muscle cells	None	Drain capillary beds; site of leukocyte exit from vasculature
Small veins	0.1-1 mm	Endothelium; connective tissue with scattered smooth muscle fibers	Thin, 2-3 loose layers of smooth muscle cells	Connective tissue, thicker than media	Collect blood from venules
Medium veins	1-10 mm	Endothelium; connective tissue, with valves	3-5 more distinct layers of smooth muscle	Thicker than media; longitudinal smooth muscle may be present	Carry blood to larger veins, with no backflow
Large veins	>10 mm	Endothelium; connective tissue, smooth muscle cells; prominent valves	>5 layers of smooth muscle, with much collagen	Thickest layer, with bundled longitudinal smooth muscle	Return blood to heart

Elastic (conducting) artery

- Aorta
- Pulmonary artery
- Their large branches

Properties:

- ***large tunica media**

Elastic lamella(10 μ) between muscle fibers (50 in aorta)

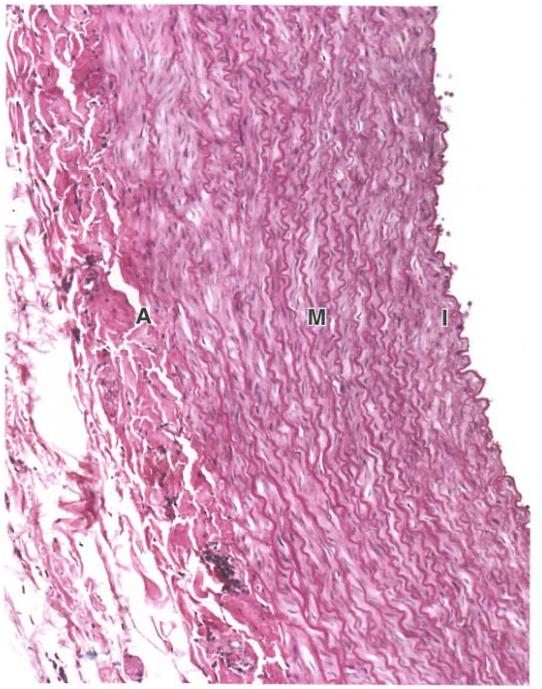
- **Well developed intima**

Smooth muscle fibers in subendothelium
Internal elastic lamella (not easily visible)

- **Thin adventitia** (rather than media)

Elastic layers:
Uniform blood flow (elastin, collagen)

FIGURE **11–9** Elastic artery.



The largest arteries contain considerable elastic material and expand with blood when the heart contracts. A transverse section through part of a large elastic artery shows a thick media (**M**) consisting largely of many well-developed elastic lamellae. Strong pressure of blood pulsating into such arteries during systole expands the arterial wall, reducing the pressure and allowing strong blood flow to continue during diastole. The intima (**I**) of the empty aorta is typically folded, and the dense irregular connective tissue of the adventitia (**A**) is thinner than the media. X200. PT.

Atherosclerosis

- Damaged Endothelial cells (LDL Oxidation)
- Macrophage to intima
- LDL phagocytosis
- Foam cell
- Fatty streak
- Atheroma (fibro-fatty plaque)

Smooth muscle cells, lymphocytes, foam cells. Col. fiber

- Reasons:

HDL

Glucose

Hypertension

Smoking

Aneurism

›› MEDICAL APPLICATION

Atherosclerosis (Gr. *athero*, gruel or porridge, and *sclerosis*, hardening) is a disease of elastic arteries and large muscular arteries that may play a role in nearly half of all deaths in developed parts of the world. It is initiated by damaged or dysfunctional endothelial cells oxidizing low-density lipoproteins (LDLs) in the tunica intima, which induces adhesion and intima entry of monocytes/macrophages to remove the modified LDL. Lipid-filled macrophages (called **foam cells**) accumulate and, along with the free LDL, produce a pathologic sign of early atherosclerosis called **fatty streaks**. During disease progression these develop into **fibro-fatty plaques**, or **atheromas**, consisting of a gruel-like mix of smooth muscle cells, collagen fibers, and lymphocytes with necrotic regions of lipid, debris, and foam cells. Predisposing factors include dyslipidemia (>3:1 ratios of LDL to HDL [high-density lipoprotein]), hyperglycemia of diabetes, hypertension, and the presence of toxins introduced by smoking.

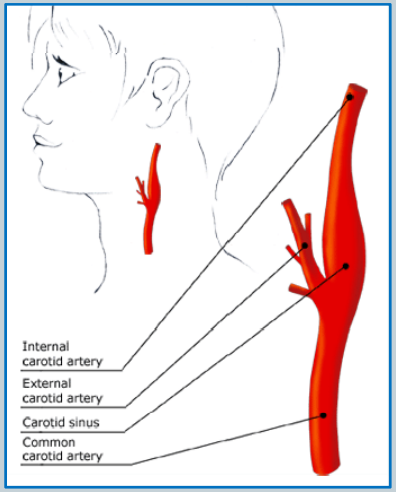
In elastic arteries atheromas produce localized destruction within the wall, weakening it and causing arterial bulges or **aneurysms** that can rupture. In muscular arteries such as the coronary arteries, atheromas can occlude blood flow to downstream vessels, leading to ischemic heart disease.

Arterial sensory structures

Carotid sinus (proximal internal carotid)

- Baroreceptor
- Thinner media
- Adventitia (many sensory nerve ending from IX cranial nerve)

Baroreceptor in aortic arch



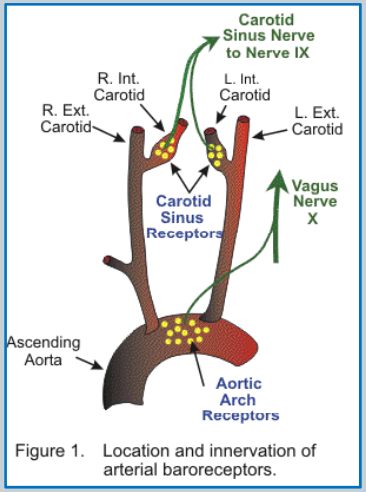


Figure 1. Location and innervation of arterial baroreceptors.

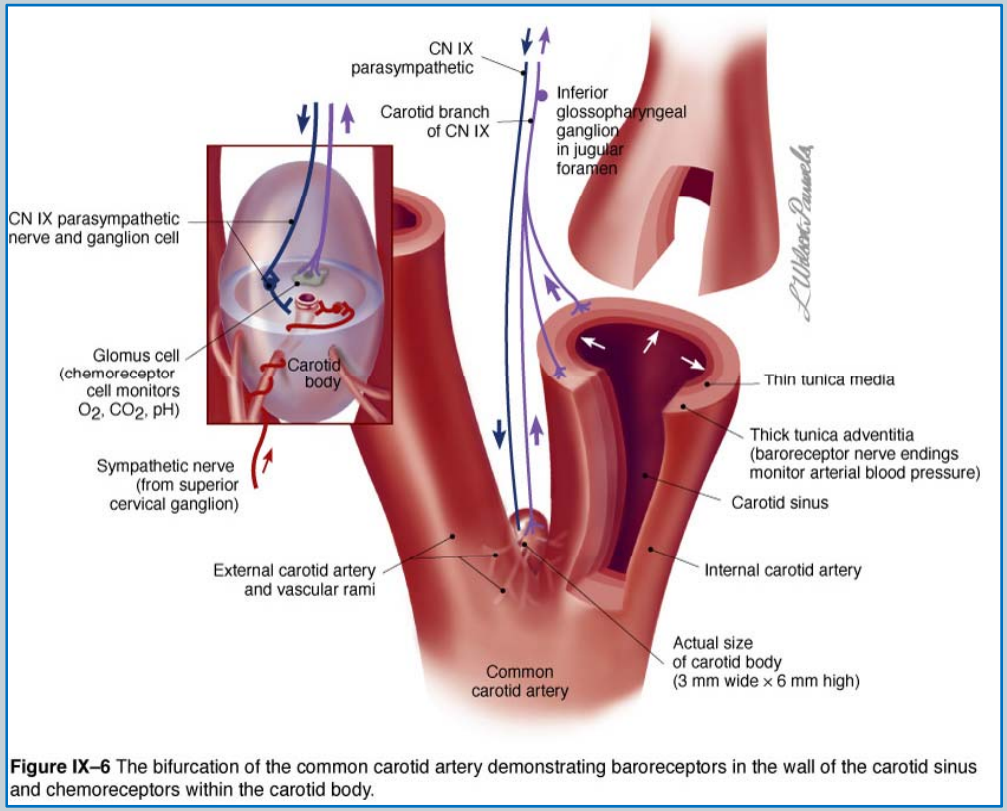


Figure IX–6 The bifurcation of the common carotid artery demonstrating baroreceptors in the wall of the carotid sinus and chemoreceptors within the carotid body.

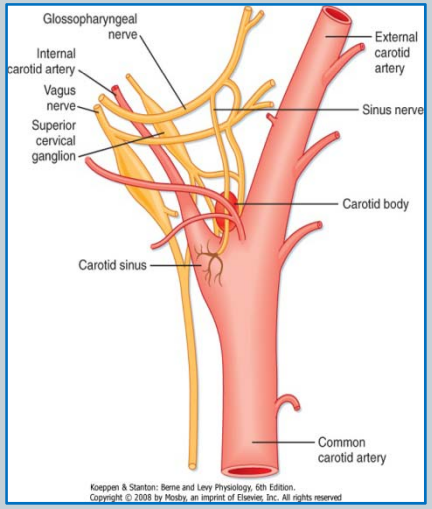
Arterial sensory structures

Carotid bodies (carotid sinus) & Aortic bodies (aortic arch)

- Chemoreceptor (O_2,CO_2,PH)
- Autonom system (paragangelion)
- Expanded network of capillaries
- Surrounded by glomus

(neural crest cells contain dopamine & acetylcholine)

- Glomus protect by satellite cells
- Cranial nerve IX



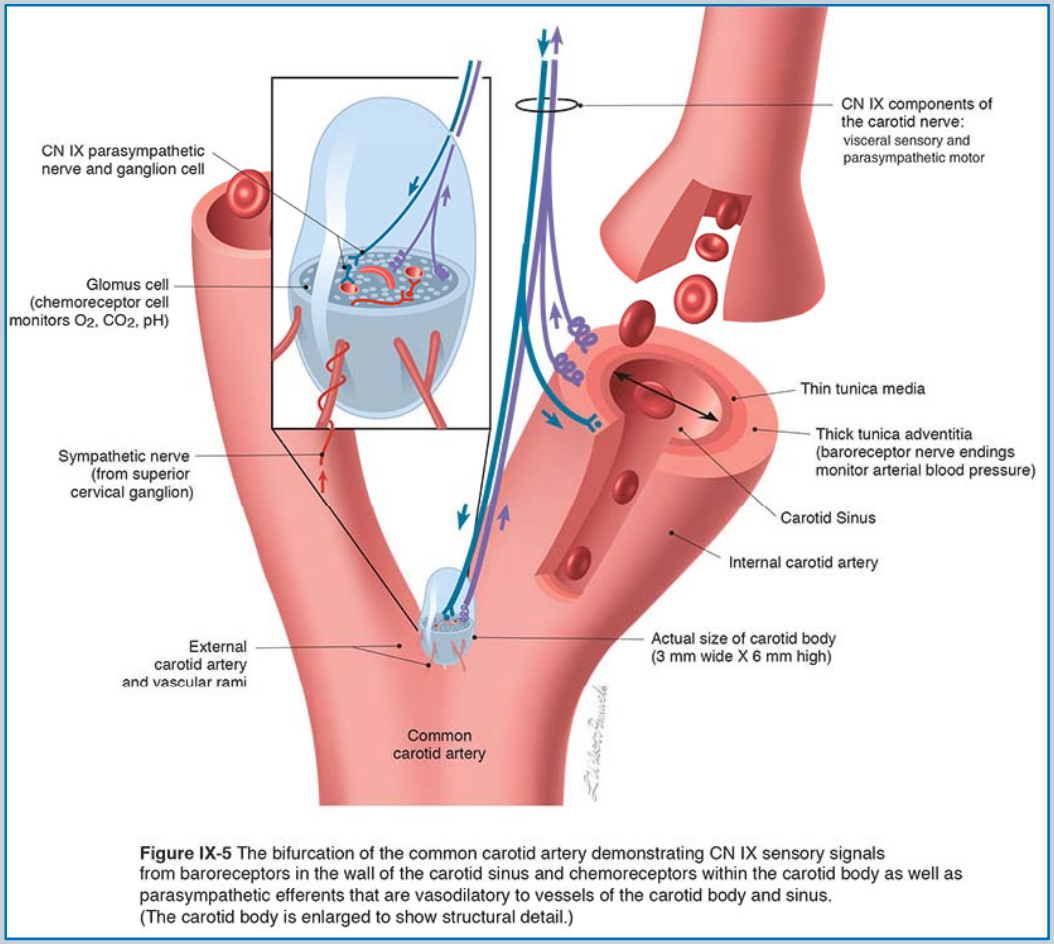


Figure IX-5 The bifurcation of the common carotid artery demonstrating CN IX sensory signals from baroreceptors in the wall of the carotid sinus and chemoreceptors within the carotid body as well as parasympathetic efferents that are vasodilatory to vessels of the carotid body and sinus. (The carotid body is enlarged to show structural detail.)

Chemoreceptor

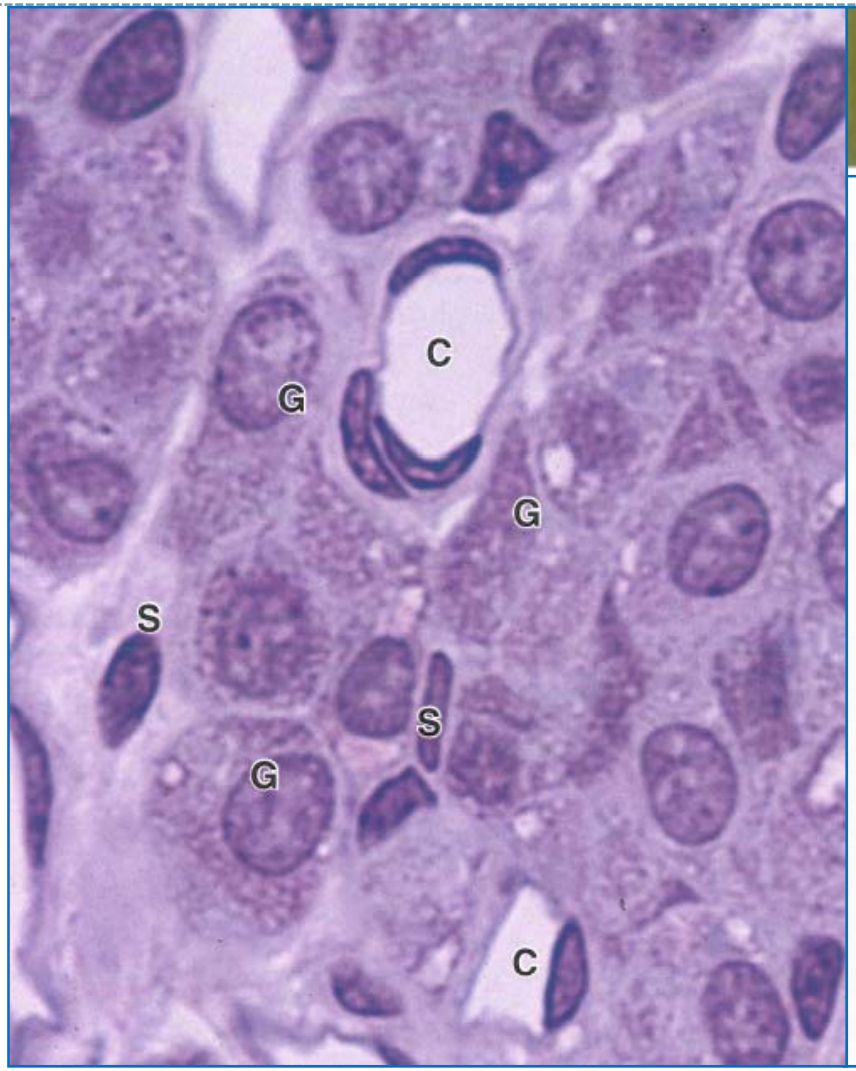


FIGURE **11–10** **Cells and capillaries in a glomus body.**

Specialized regions in the walls of certain elastic arteries contain tissues acting as chemoreceptors that provide information to the brain regarding blood chemistry. The glomus bodies are two small (0.5–5 mm-diameter) ganglion-like structures found near the common carotid arteries. They contain many large capillaries (**C**) intermingled with clusters of large glomus cells (**G**) filled with vesicles of various neurotransmitters. Supportive satellite cells (**S**) with elongated nuclei ensheath each glomus cell. Glomus cells form synaptic connections with sensory fibers. Significant changes in the blood CO_2, O_2, or H^+ concentrations are detected by the chemoreceptive glomus cells, which then release a neurotransmitter that activates the sensory nerve to relay this information to the brain. X400. PT.

Muscular artery

- **Tunica Intima**

Very thin subendothelium
Prominent internal elastic lamella

- **Tunica Media**

Muscle layer s(40) in external lamella
External elastic lamella (only in large muscular artery)

- **Adventitia (connective tissue)**

Lymphatic capillary, vasa vasarum, nerve
Up to external of tunica media

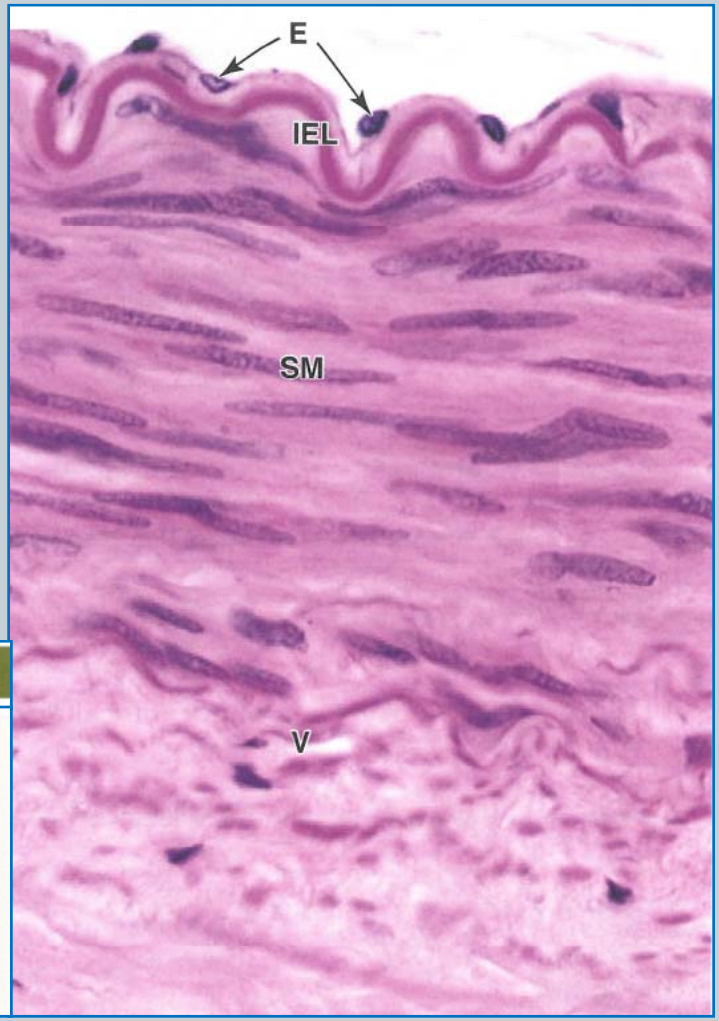


FIGURE **11–11** **Muscular artery.**

With distance from the heart, arteries gradually have relatively less elastin and more smooth muscle in their walls. Most arteries, large enough to have names, are of the muscular type. A transverse section through a muscular (medium-caliber) artery shows a slightly folded intima with only sparse connective tissue between the endothelial cells (**E**) and internal elastic lamina (**IEL**). Multiple layers of smooth muscle (**SM**) in the media (**M**) are thicker than the elastic lamellae and fibers with which they intersperse. Vasa vasorum (**V**) are seen in the adventitia. X100. H&E.

Arteriole

- 3-4 smooth muscle layers in small muscular artery
- **1-2 smooth muscle layers in arteriole (0.1 mm)**
- Then microvasculature

- **Small subendothelium**
- **No elastic lamella**
- **Smooth muscle cell**
- **Very thin & invisible Adventitia**

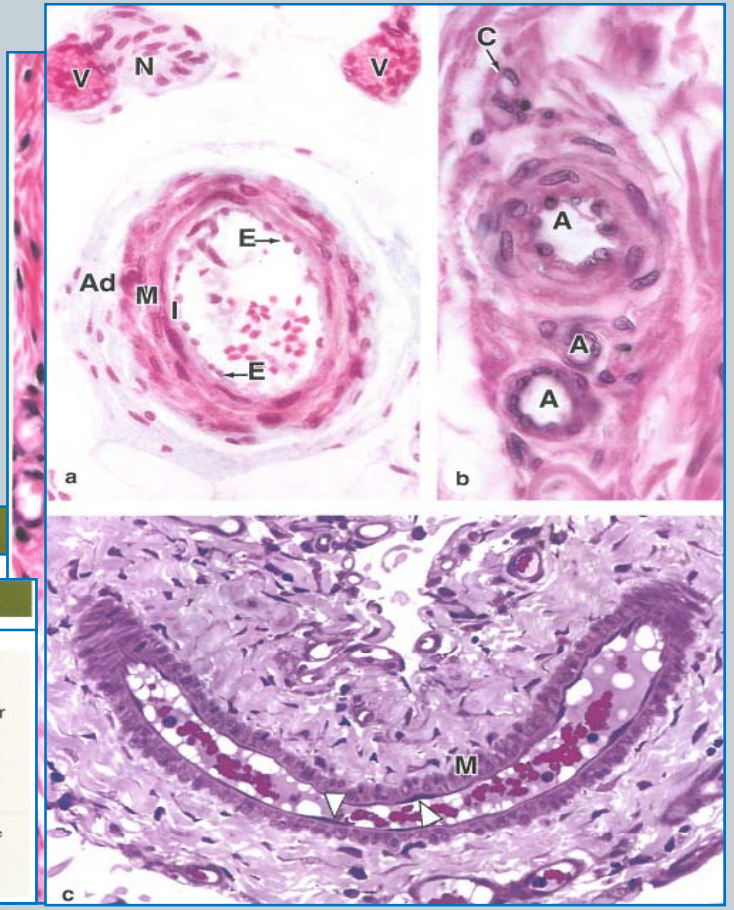


FIGURE **11–12** Microvasculature.

FIGURE **11–14** Arterioles.

(a) Arterioles are microvessels with an intima (**I**) consisting only of endothelium (**E**), in which the cells may have rounded nuclei. They have media (**M**) tunics with only one or two layers of smooth muscle, and usually thin, inconspicuous adventitia (**Ad**). X350. Masson trichrome. **(b)** Three arterioles (**A**) of various sizes and a capillary (**C**) are shown here. X400. H&E. **(c)** A large mesenteric arteriole cut obliquely and longitudinally clearly shows the endothelial cells (arrow heads) and one or two layers of smooth muscle cells (**M**) cut transversely. Adventitia merges imperceptibly with neighboring connective tissue. X300. PT.

- Branch to form anatomizing network or capillary bed
- smooth muscle fibers as an sphincter

(periodic blood flow)

Arterioles called resistance vessels

Determinant of systemic blood pressure

» MEDICAL APPLICATION

Blood pressure depends on cardiac output and the total peripheral resistance to blood flow, which is mostly due to the resistance of arterioles. **Hypertension** or elevated blood pressure may occur secondarily to renal or endocrine problems, but is more commonly essential hypertension, due to a wide variety of mechanisms that increase arteriolar constriction.

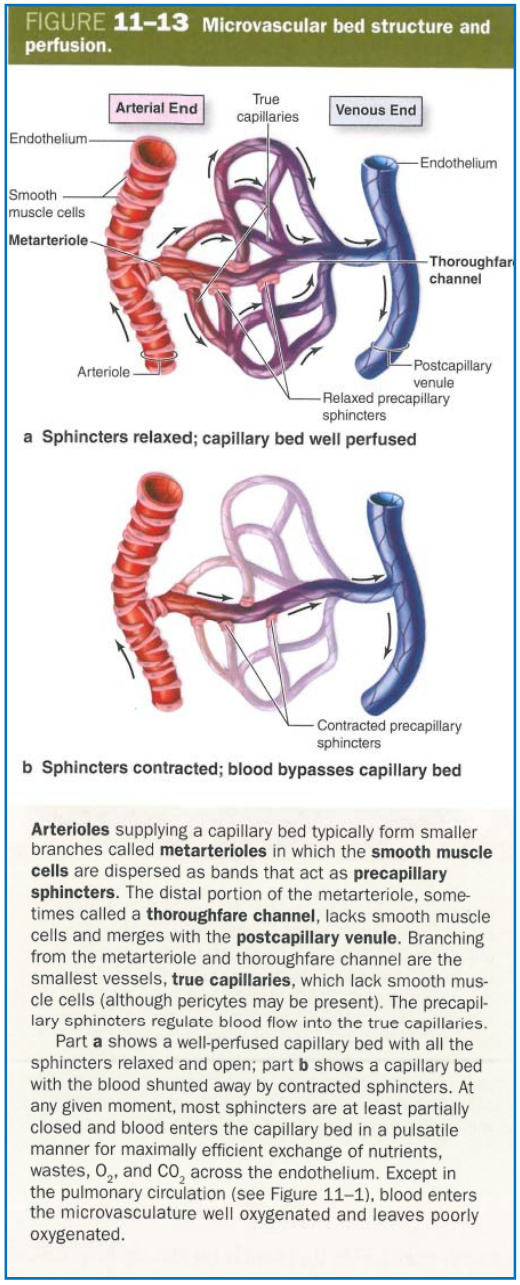


FIGURE **11–13** **Microvascular bed structure and perfusion.**

Arterioles supplying a capillary bed typically form smaller branches called **metarterioles** in which the **smooth muscle cells** are dispersed as bands that act as **precapillary sphincters**. The distal portion of the metarteriole, sometimes called a **thoroughfare channel**, lacks smooth muscle cells and merges with the **postcapillary venule**. Branching from the metarteriole and thoroughfare channel are the smallest vessels, **true capillaries**, which lack smooth muscle cells (although pericytes may be present). The precapillary sphincters regulate blood flow into the true capillaries.

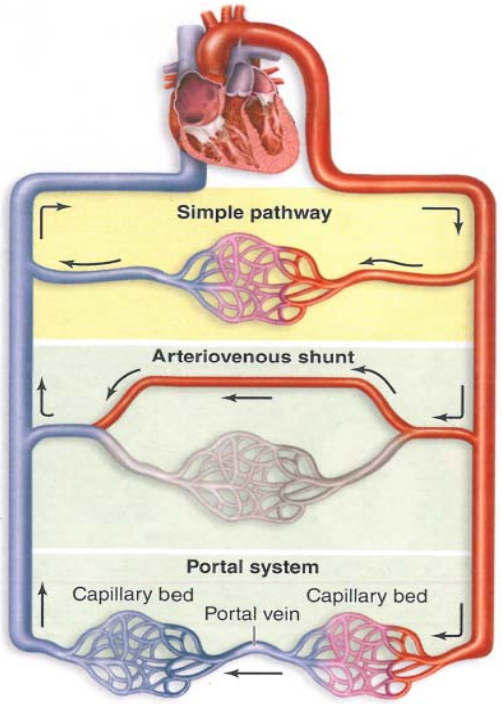
Part **a** shows a well-perfused capillary bed with all the sphincters relaxed and open; part **b** shows a capillary bed with the blood shunted away by contracted sphincters. At any given moment, most sphincters are at least partially closed and blood enters the capillary bed in a pulsatile manner for maximally efficient exchange of nutrients, wastes, O_2, and CO_2 across the endothelium. Except in the pulmonary circulation (see Figure 11–1), blood enters the microvasculature well oxygenated and leaves poorly oxygenated.

- **Simple pathway**

- **Arteriovenous shunt (Anastomosis)**
  - Thicker media & adventitia
  - Sympathetic & parasympathetic enervation

- **Portal system**
  - Liver
  - Hypothalamus- hypophise

FIGURE **11–15** **Comparison of the simple microvascular pathway with arteriovenous shunts and portal systems.**



Most capillary beds are supplied by arterioles and drain into venules, but alternative pathways are found in certain organs. In skin blood flow can be varied according to external conditions by **arteriovenous (AV) shunts**, or anastomoses, commonly coiled, which directly connect the arterial and venous systems and temporarily bypass capillaries.

In **venous portal systems** one capillary bed drains into a vein that then branches again into another capillary bed. This arrangement allows molecules entering the blood in the first set of capillaries to be delivered quickly and at high concentrations to surrounding tissues at the second capillary bed, which is important in the anterior pituitary gland and liver.

Not shown are **arterial portal system** (afferent arteriole → capillaries → efferent arteriole) which occur in the kidney.

Capillary bed

Depend on:
- Organ metabolic activity

- Arteriole
- Metarteriole
- Thoroughfare channel
- Post capillary venule

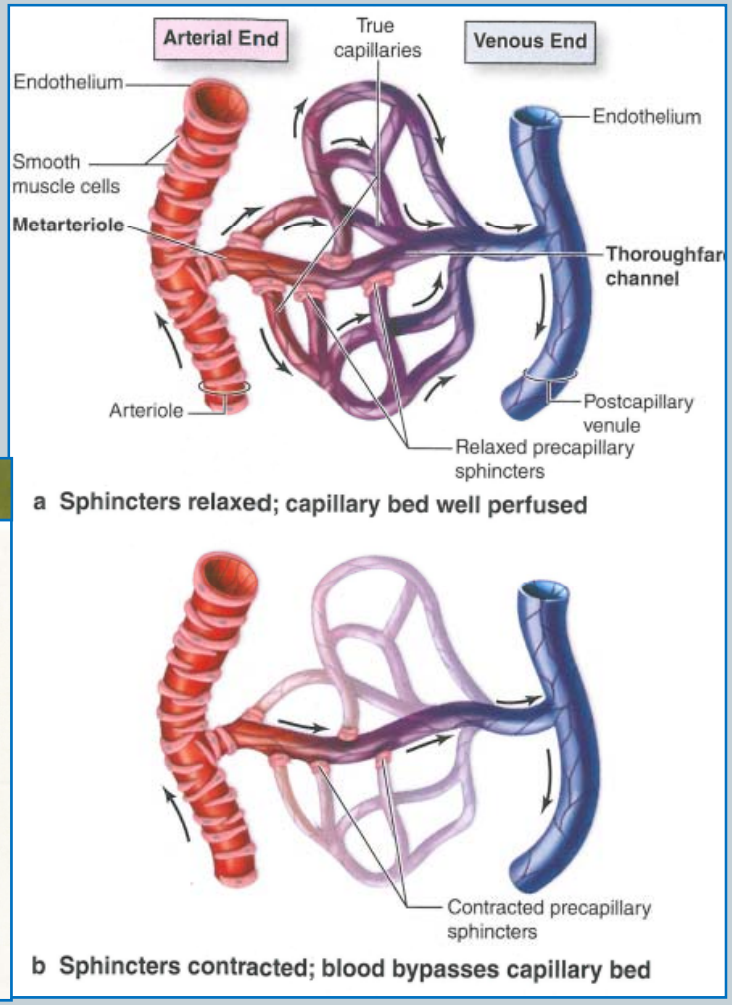
- **Precapillary sphincter**

- **Capillary:**

single endothelial layer
0.4-1 µ diameter
50 µ length

90% of all blood vessel
5% of all blood (300 ml)

Endothelial cell:
- 0.25 µ thickness
- curved nucleus



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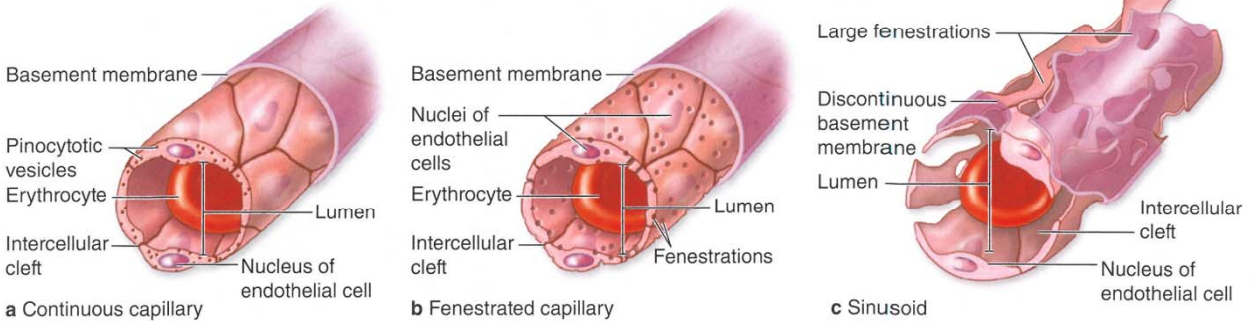
Different levels of metabolic exchange

- Endothelial continuity
- External lamina
- 3 types

- **Continuous capillaries**
- **fenestrated capillaries**
- **Discontinuous capillaries (sinusoids)**

FIGURE **11–17** **Types of capillaries.**



The vessels between arterioles and venules can be any of three types. **(a) Continuous capillaries**, the most common type, have tight, occluding junctions sealing the intercellular clefts between all the endothelial cells to produce minimal fluid leakage. All molecules exchanged across the endothelium must cross the cells by diffusion or transcytosis.

(b) Fenestrated capillaries also have tight junctions, but perforations (fenestrations) through the endothelial cells allow greater exchange across the endothelium. The basement membrane is continuous in both these capillary types. Fenestrated capillaries are found in organs where molecular exchange with the blood is important, such as endocrine organs, intestinal walls, and choroid plexus.

(c) Sinusoids, or discontinuous capillaries, usually have a wider diameter than the other types and have discontinuities between the endothelial cells, large fenestrations through the cells, and a partial, discontinuous basement membrane. Sinusoids are found in organs where exchange of macromolecules and cells occurs readily between tissue and blood, such as in bone marrow, liver, and spleen.

Continuous capillaries

- Most common type
- Many tight j.
- Many transcytisis vesicles
- In:

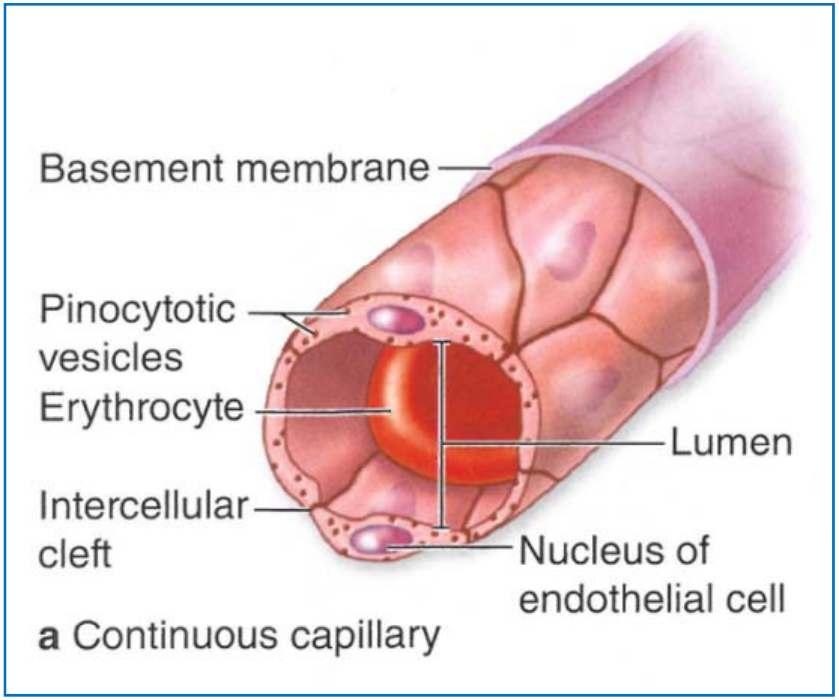
Muscular tissue

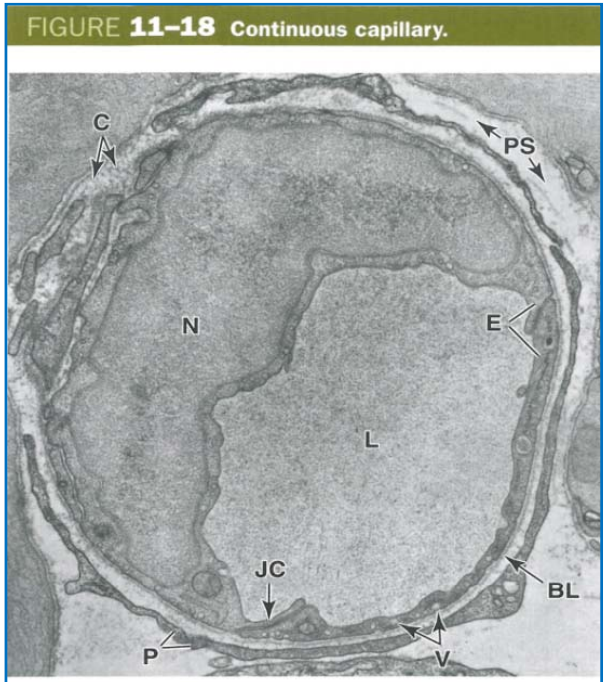
Connective tissue

Lung,

Exocrine glands

nervous tissue





Continuous capillaries exert the tightest control over what molecules leave and enter the capillary lumen (**L**). The TEM shows a continuous capillary in transverse section. An endothelial cell nucleus (**N**) is prominent, and tight or occluding junctions are abundant in the junctional complexes (**JC**) at overlapping folds between the endothelial cells (**E**). Numerous transcytotic vesicles (**V**) are evident. All material that crosses continuous capillary endothelium must pass *through* the cells, usually by diffusion or transcytosis.

Around the capillary are a basal lamina (**BL**) and thin cytoplasmic extensions from pericytes (**P**). Collagen fibers (**C**) and other extracellular material are present in the perivascular space (**PS**). X10,000.

Fenestrated capillaries

- Sieve-like structure
- Fenestrated cells (fenestra: 80 nm)
- Proteoglycan diaphragm
- Continuous basement membrane (covering the fenestra)
- Fast exchange
- In:

Kidney
Endocrine glands
Intestine
Choroid plexus

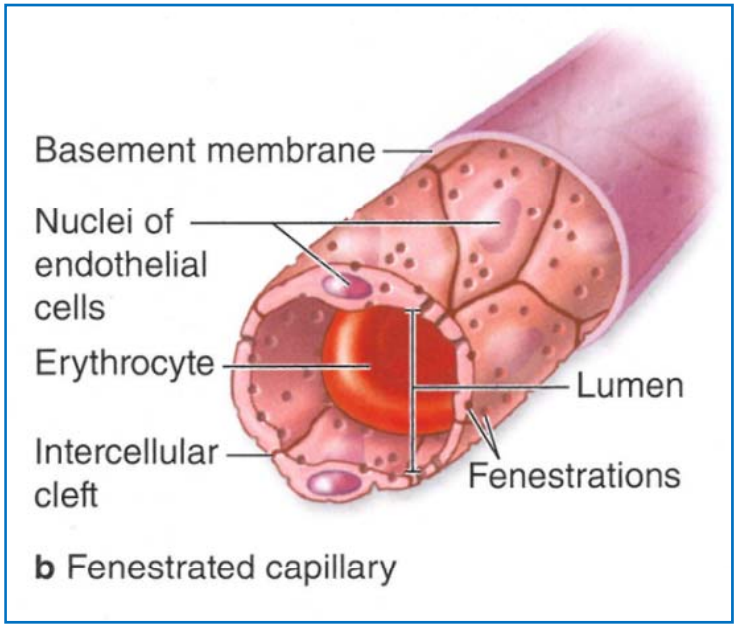
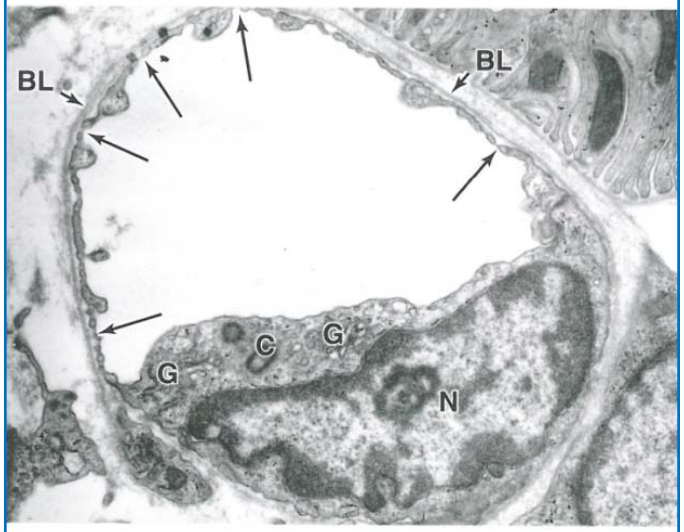


FIGURE **11–19** **Fenestrated capillary.**



Fenestrated capillaries are specialized for uptake of molecules such as hormones in endocrine glands or for outflow of molecules such as in the kidney's filtration system. TEM of a transversely sectioned fenestrated capillary in the peritubular region of the kidney shows many typical fenestrae closed by diaphragms (arrows), with a continuous basal lamina surrounding the endothelial cell (**BL**). In this cell the Golgi apparatus (**G**), nucleus (**N**), and centrioles (**C**) can also be seen. Fenestrated capillaries allow a freer exchange of molecules than continuous capillaries and are found in the intestinal wall, kidneys, and endocrine glands. X10,000.

(With permission, from Dr Johannes Rhodin, Department of Cell Biology, New York University School of Medicine.)

Discontinuous capillaries (sinusoids)

- Maximal macromolecule exchange
- Large perforating without diaphragm
- Discontinuous layer of cells
- Discontinuous basal membrane (30-40 μ)
- Slow blood flow
- In:

some endocrine glands

Liver

Spleen

Bone marrow

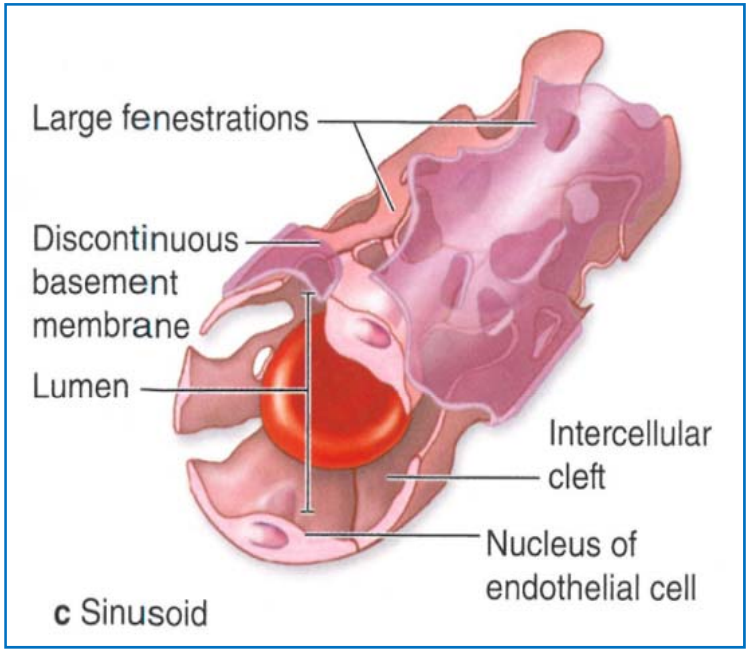
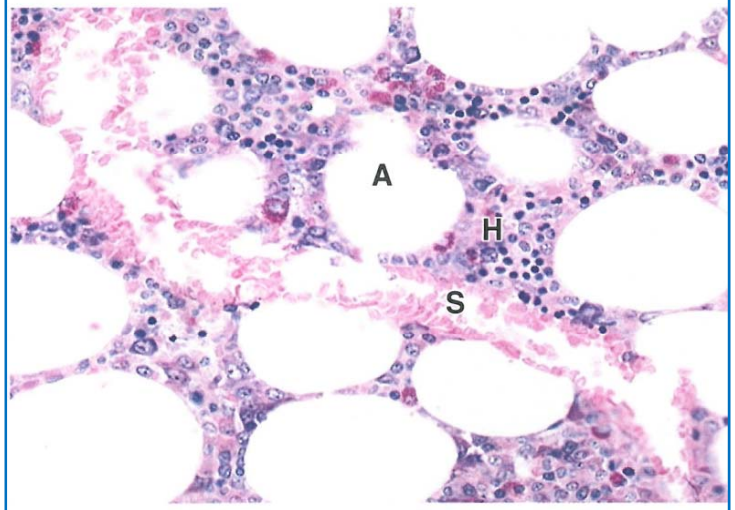


FIGURE **11–20** Sinusoidal capillary.



Sinusoidal capillaries or sinusoids generally have much greater diameters than most capillaries and are specialized not only for maximal molecular exchange between blood and surrounding tissue but also for easy movement of blood cells across the endothelium. The sinusoid (**S**) shown here is in bone marrow and is surrounded by tissue containing adipocytes (**A**) and masses of hematopoietic cells (**H**). The endothelial cells are very thin and cell nuclei are more difficult to find than in smaller capillaries. Ultrastructurally sinusoidal capillaries are seen to have large fenestrations through the cells and large discontinuities between the cells and through the basal lamina. X200. H&E.

Different levels of metabolic exchange

- Endothelial continuity
- External lamina
- 3 types

Continuous capillaries

- Most common type
- Many tight j.
- In muscular tissue. Connective tissue, lun
- Many vesicles for transcytisis

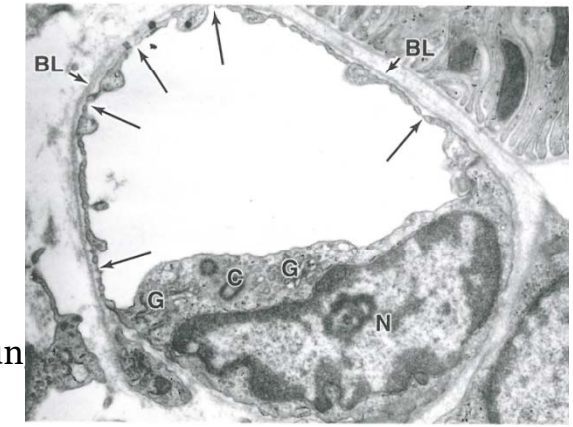
fenestrated capillaries

- Sieve-like structure
- Fenestrated cells (fenestra: 80 nm)
- Proteoglycan diaphragm
- Continuous basement membrane (coverir
- Fast exchange
- Kidney, endocrine glands, intestine, choroid plexus

Discontinuous capillaries (sinusoids)

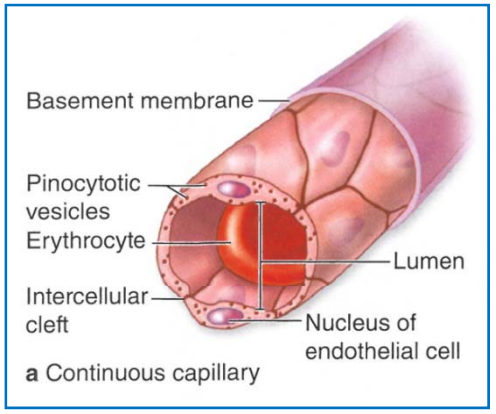
- Maximal macromolecule exchange
- Large perforating without diaphragm
- Discontinuous layer of cells
- Discontinuous basal membrane (30-40 μ)
- Slow blood flow
- In liver, spleen, some endocrine glands, bone marrow

FIGURE 11–19 Fenestrated capillary.



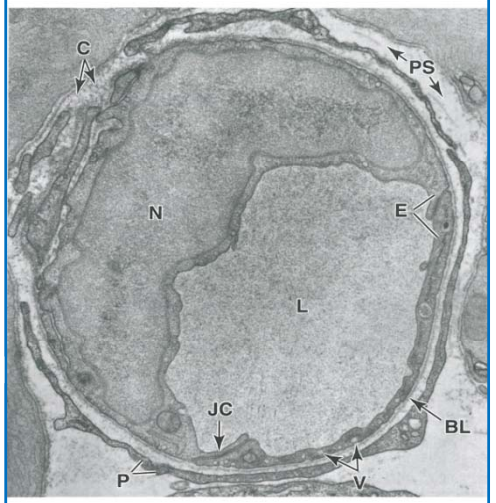
Fenestrated capillaries are specialized for uptake of molecules such as hormones in endocrine glands or for outflow of molecules such as in the kidney's filtration system. TEM of a transversely sectioned fenestrated capillary in the peritubular region of the kidney shows many typical fenestrae closed by diaphragms (arrows), with a continuous basal lamina surrounding the endothelial cell (**BL**). In this cell the Golgi apparatus (**G**), nucleus (**N**), and centrioles (**C**) can also be seen. Fenestrated capillaries allow a freer exchange of molecules than continuous capillaries and are found in the intestinal wall, kidneys, and endocrine glands. X10,000.

(With permission, from Dr Johannes Rhodin, Department of Cell Biology, New York University School of Medicine.)



a Continuous capillary

FIGURE 11–18 Continuous capillary.



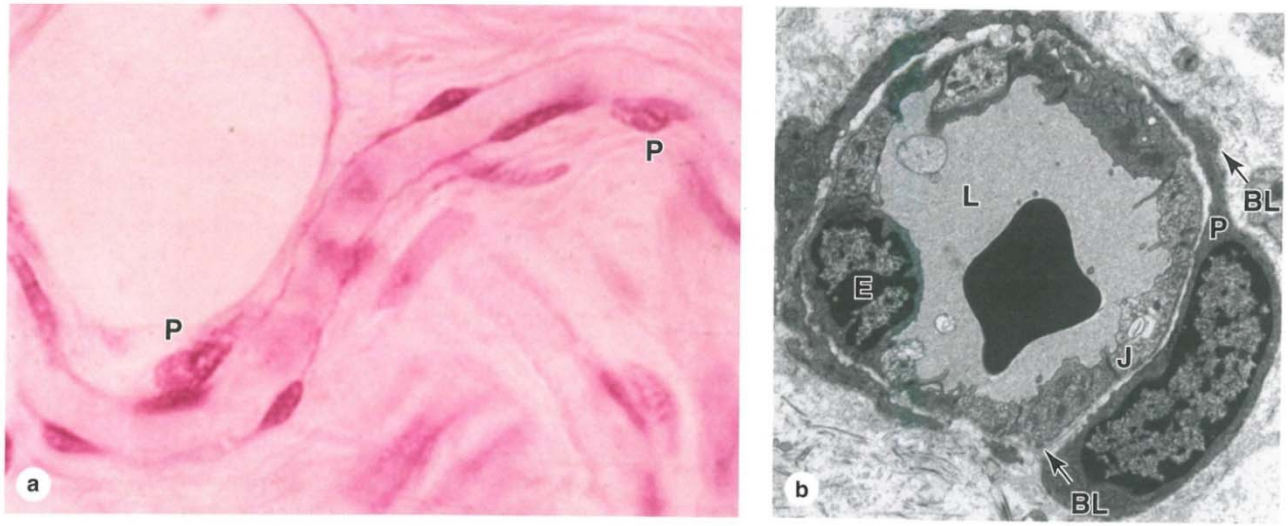
Continuous capillaries exert the tightest control over what molecules leave and enter the capillary lumen (**L**). The TEM shows a continuous capillary in transverse section. An endothelial cell nucleus (**N**) is prominent, and tight or occluding junctions are abundant in the junctional complexes (**JC**) at overlapping folds between the endothelial cells (**E**). Numerous transcytotic vesicles (**V**) are evident. All material that crosses continuous capillary endothelium must pass *through* the cells, usually by diffusion or transcytosis.

Around the capillary are a basal lamina (**BL**) and thin cytoplasmic extensions from pericytes (**P**). Collagen fibers (**C**) and other extracellular material are present in the perivascular space (**PS**). X10,000.

In continuous capillaries & post capillary venules

- Pericyte (mesenchymal cell)
- Long cytoplasmic protrusions
- Contractile (actin, myosin, tropomyosin)
- Proliferation & differentiation after tissue injuries

FIGURE **11–16** Capillary with pericytes.



Capillaries consist only of an endothelium rolled as a tube, across which molecular exchange occurs between blood and tissue fluid. **(a)** Capillaries are normally associated with perivascular contractile cells called **pericytes (P)** that have a variety of functions. The more flattened nuclei belong to endothelial cells. X400. H&E of a spread mesentery preparation.

(b) TEM of a capillary cut transversely, showing the nucleus of one thin capillary endothelial cell (**E**). Endothelial cells form the capillary lumen (**L**), are covered by a basal lamina (**BL**), and bound tightly together with junctional complexes (**J**). One pericyte (**P**) is shown, surrounded by its own basal lamina (**BL**) and with cytoplasmic extensions which surround the endothelial cells. X13,000.

- ***Hyperglycemia***

Diabetic microangiopathy

Thick & diffused basal lamina

Lower metabolic exchange in:

- Retina
- Kidney
- Skeletal muscle
- skin

>> MEDICAL APPLICATION

The **hyperglycemia** or excessive blood sugar that occurs with diabetes commonly leads to **diabetic microangiopathy**, a diffuse thickening of capillary basal laminae and concomitant decrease in metabolic exchange at these vessels, particularly in the kidneys, retina, skeletal muscle, and skin.

Venules

- **Post capillary venules**

like capillaries

Pericytes

15-20μ diameter

Adherence & leave site of WBCs

- **Collecting venules**

More contractile cells

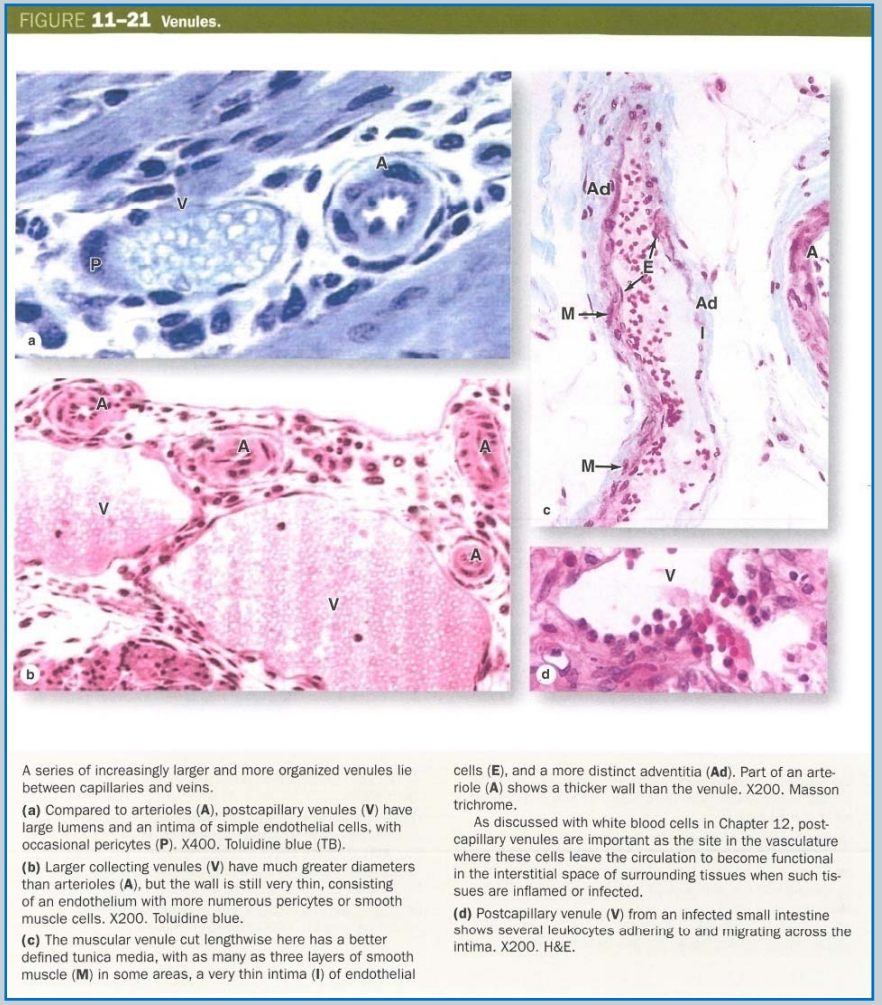
- **Muscular venule**

2-3 smooth muscle layers

- **Venules**

Large lumen diameter

Thinwall



Veins

In small & medium veins:
10mm or less

- **Intima**

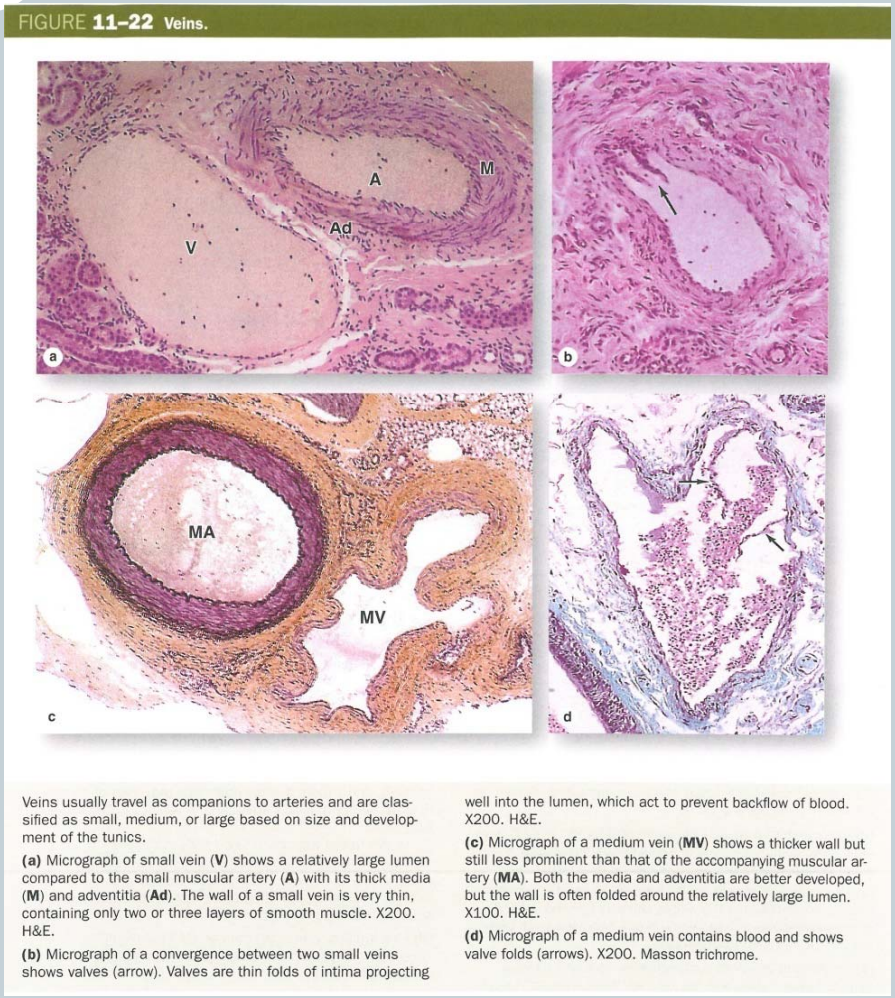
Thin subendothelial layer

- **Media**

Small bundle of smooth muscle
Reticular fibers
Fine network of elastic fibers

- **Adventitia**

Well developed collagen layer



Veins usually travel as companions to arteries and are classified as small, medium, or large based on size and development of the tunics.

(a) Micrograph of small vein (**V**) shows a relatively large lumen compared to the small muscular artery (**A**) with its thick media (**M**) and adventitia (**Ad**). The wall of a small vein is very thin, containing only two or three layers of smooth muscle. X200. H&E.

(b) Micrograph of a convergence between two small veins shows valves (arrow). Valves are thin folds of intima projecting well into the lumen, which act to prevent backflow of blood. X200. H&E.

(c) Micrograph of a medium vein (**MV**) shows a thicker wall but still less prominent than that of the accompanying muscular artery (**MA**). Both the media and adventitia are better developed, but the wall is often folded around the relatively large lumen. X100. H&E.

(d) Micrograph of a medium vein contains blood and shows valve folds (arrows). X200. Masson trichrome.

Large veins

- **Intima**

well developed

- **Media**

Thin
Alternating layers of smooth muscle
Connective tissue

- **Adventitia**

Thicker than media
Bundles of longitudinal smooth muscle
Elastic fibers

No internal & external elastic laminae

Medium & large veins
Valve
Paired folds of Intima
Rich in elastic fibers
Coverd by endothelium on both sides

›› MEDICAL APPLICATION

Junctions between endothelial cells of postcapillary venules are the loosest of the microvasculature. This facilitates transendothelial migration of leukocytes at these locations during **inflammation**, as well as a characteristic loss of fluid here during the inflammatory response, leading to tissue **edema**.

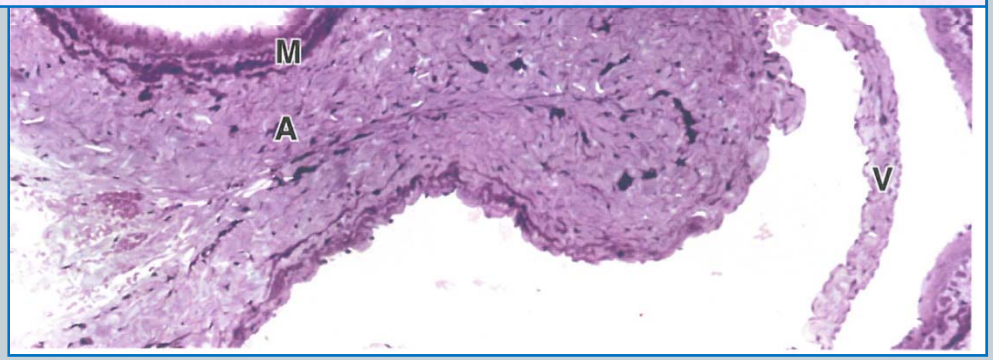


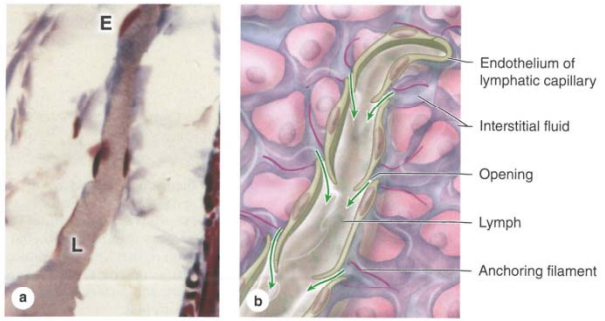
TABLE 11–1 Size ranges, major features, and important roles of major blood vessel types.

Type of Artery	Outer Diameter (Approx. Range)	Intima	Media	Adventitia	Roles in Circulatory System
Elastic arteries	>10 mm	Endothelium; connective tissue with smooth muscle	Many elastic lamellae alternating with smooth muscle	Connective tissue, thinner than media, with vasa vasorum	Conduct blood from heart and with elastic recoil help move blood forward under steady pressure
Muscular arteries	10-1 mm	Endothelium; connective tissue with smooth muscle, internal elastic lamina prominent	Many smooth muscle layers, with much less elastic material	Connective tissue, thinner than media; vasa vasorum may be present	Distribute blood to all organs and maintain steady blood pressure and flow with vasodilation and constriction
Small arteries	1-0.1 mm	Endothelium; connective tissue less smooth muscle	3-10 layers of smooth muscle	Connective tissue, thinner than media; no vasa vasorum	Distribute blood to arterioles, adjusting flow with vasodilation and constriction
Arterioles	100-10 μm	Endothelium; no connective tissue or smooth muscle	1-3 layers of smooth muscle	Very thin connective tissue layer	Resist and control blood flow to capillaries; major determinant of systemic blood pressure
Capillaries	10-4 μm	Endothelium only	Pericytes only	None	Exchange metabolites by diffusion to and from cells
Venules (postcapillary, collecting, and muscular)	10-100 μm	Endothelium; no valves	Scattered smooth muscle cells	None	Drain capillary beds; site of leukocyte exit from vasculature
Small veins	0.1-1 mm	Endothelium; connective tissue with scattered smooth muscle fibers	Thin, 2-3 loose layers of smooth muscle cells	Connective tissue, thicker than media	Collect blood from venules
Medium veins	1-10 mm	Endothelium; connective tissue, with valves	3-5 more distinct layers of smooth muscle	Thicker than media; longitudinal smooth muscle may be present	Carry blood to larger veins, with no backflow
Large veins	>10 mm	Endothelium; connective tissue, smooth muscle cells; prominent valves	>5 layers of smooth muscle, with much collagen	Thickest layer, with bundled longitudinal smooth muscle	Return blood to heart

Lymphatic vascular system

- Thin wall channel
- Collect interstitial fluid (lymph)
- No RBC
- Rich in lightly proteins
- Lymphatic capillaries
- Close ended vessel with thin endothelial cells
- On incomplete basal lamina
- Anchoring elastic fibers connect cells to connective tissue
- Lymphatic capillaries converge in to lymphatic vessels.
- Lymph nodes
- Lymph vessels in all organs exp. CNS& bone marrow

FIGURE **11–24** Lymphatic capillary.



Lymphatic capillaries drain interstitial fluid produced when the plasma forced from the microvasculature by hydrostatic pressure does not all return to blood by the action of osmotic pressure. **(a)** Micrograph shows a lymphatic capillary filled with this fluid called lymph (**L**). Lymphatics are blind-ended vessels with a wall of very thin endothelial cells (**E**) and are quite variable in diameter (10-50 μm). Lymph is rich in proteins and other material and often stains somewhat better than the surrounding ground substance, as seen here. X200. Mallory trichrome.

(b) Diagram indicating more details about lymphatics, including the **openings between the endothelial cells**. The openings are held in place by **anchoring filaments** containing elastin and are covered by extensions of the endothelial cells. **Interstitial fluid** enters primarily via these openings, and the endothelial folds prevent backflow of lymph into tissue spaces. Lymphatic endothelial cells are typically larger than those of blood capillaries.

Lymphatic vascular system

- Larger lymph vessel like veins
- Thinner & no distinct separation between tunica
- More internal valves
- Thoracic duct & right lymphatic duct
- many longitudinal & circular smooth muscle in media
- Underdeveloped adventitia with vasa vasorum & nerve

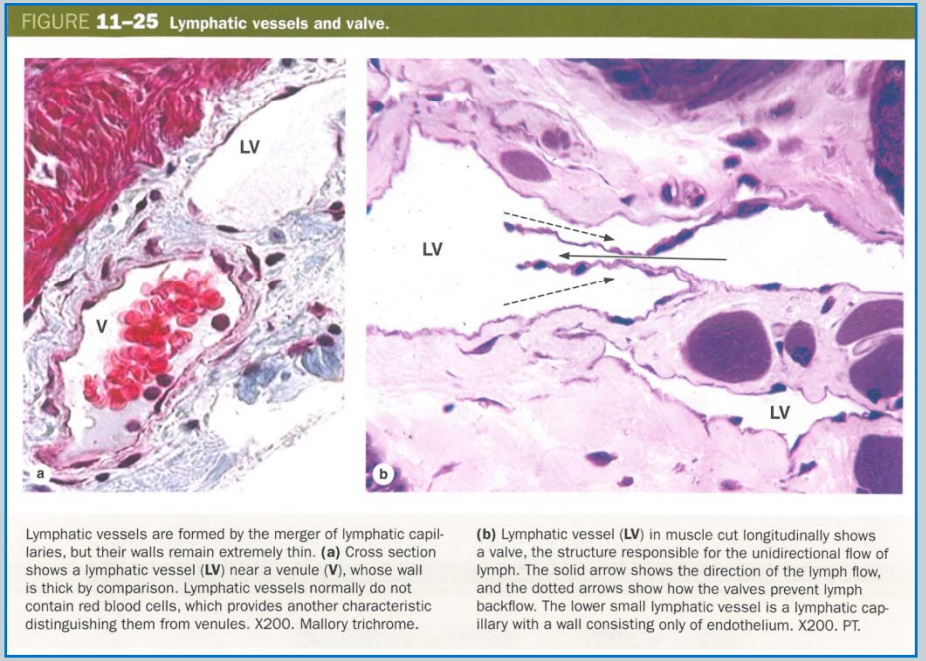


FIGURE **11–25** Lymphatic vessels and valve.

Lymphatic vessels are formed by the merger of lymphatic capillaries, but their walls remain extremely thin. **(a)** Cross section shows a lymphatic vessel (**LV**) near a venule (**V**), whose wall is thick by comparison. Lymphatic vessels normally do not contain red blood cells, which provides another characteristic distinguishing them from venules. X200. Mallory trichrome.

(b) Lymphatic vessel (**LV**) in muscle cut longitudinally shows a valve, the structure responsible for the unidirectional flow of lymph. The solid arrow shows the direction of the lymph flow, and the dotted arrows show how the valves prevent lymph backflow. The lower small lymphatic vessel is a lymphatic capillary with a wall consisting only of endothelium. X200. PT.