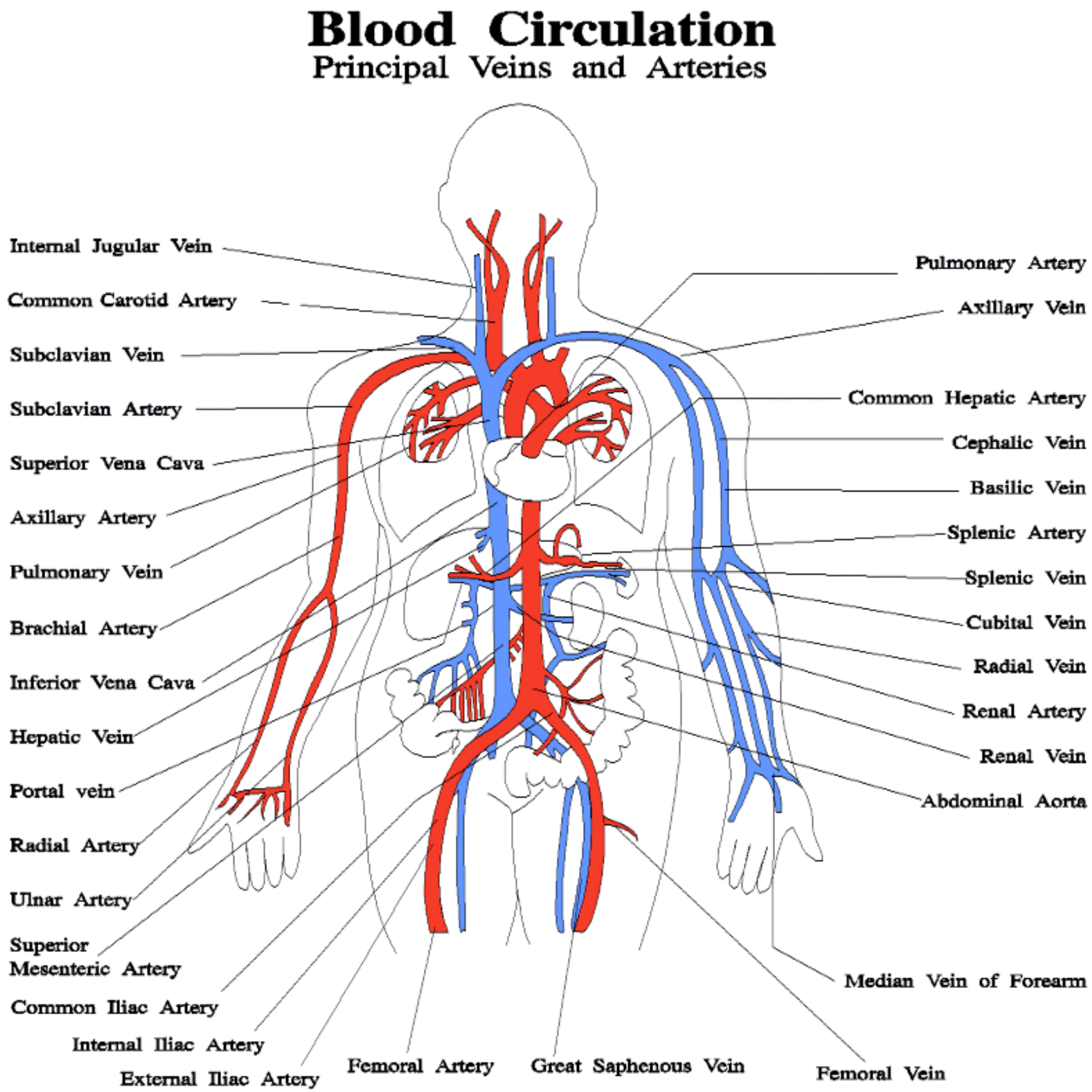
Chapitre 2
Système cardiovasculaire

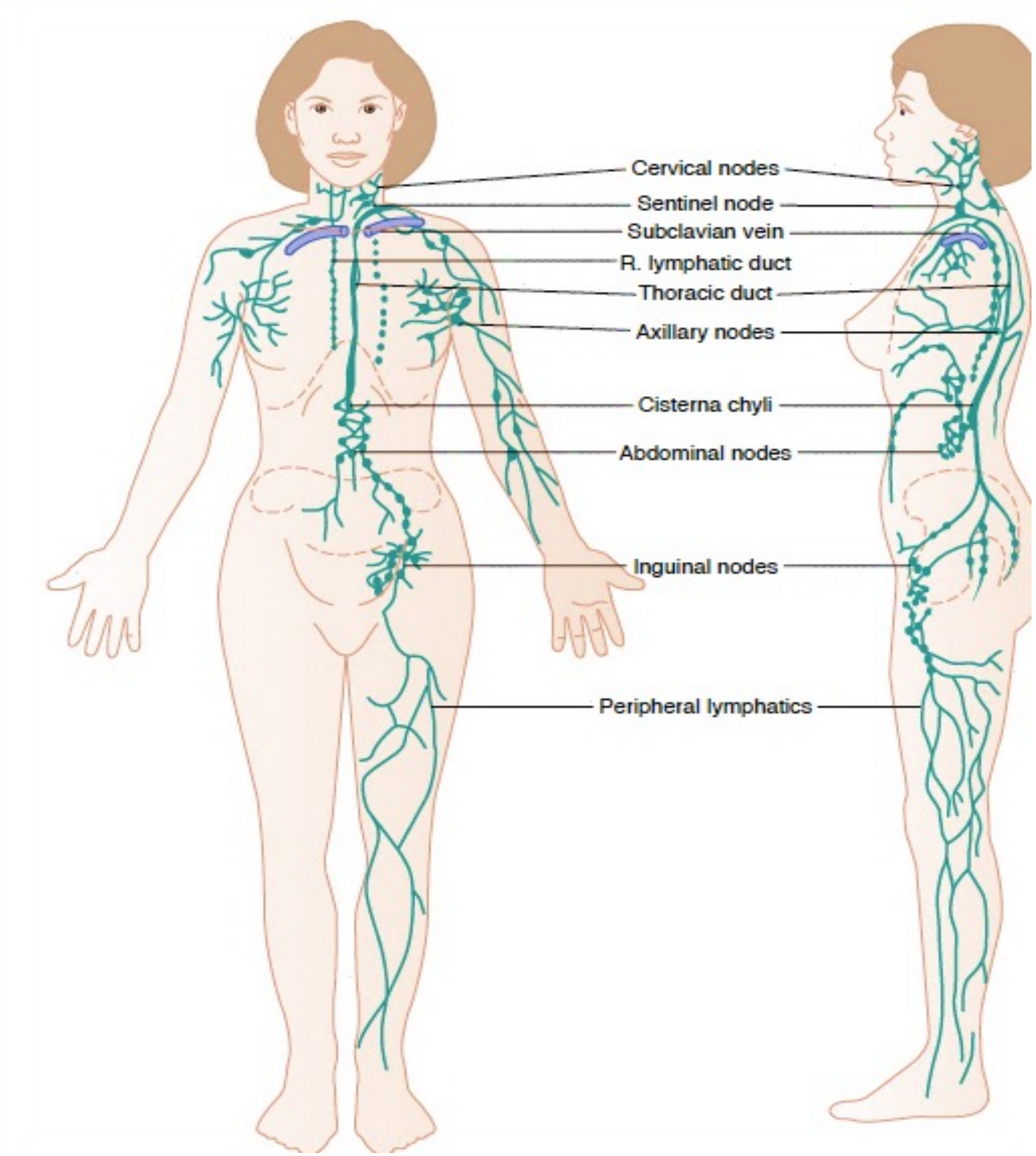
Système cardiovasculaire: finalité et utilité

- Finalité du système cœur-vaisseaux
- Couplage cœur et vaisseaux (circulation périphérique et centrale)
- Régulation locale et générale de la fonction cardiovasculaire
- Organisation avec les autres systèmes

Système cardiovasculaire



Système cardiovasculaire



Système cardiovasculaire: principes généraux

- Gérer un problème de dimension (diffusion)
- Transport de matière, d’énergie et d’information
- Matières transportées: Comburant-Carburant-Messagers-Produits du métabolisme
- Requiert de l’énergie (travail fournit)
- Vecteur du transport de l’information hormonale

Système cardiovasculaire

- Transport par convection entre organes
- Apport de nourriture et O_2
- Apport d'hormones et régulateurs
- Système immun et plaquettes
- Facteurs de la coagulation
- Elimination des déchets et CO_2
- Soumis à une régulation
    1. *globale*
    2. *locale*

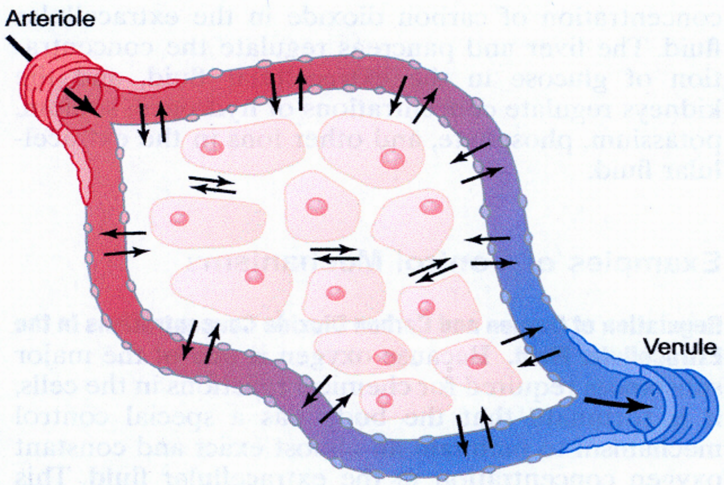


Figure 1–2

Diffusion of fluid and dissolved constituents through the capillary walls and through the interstitial spaces.

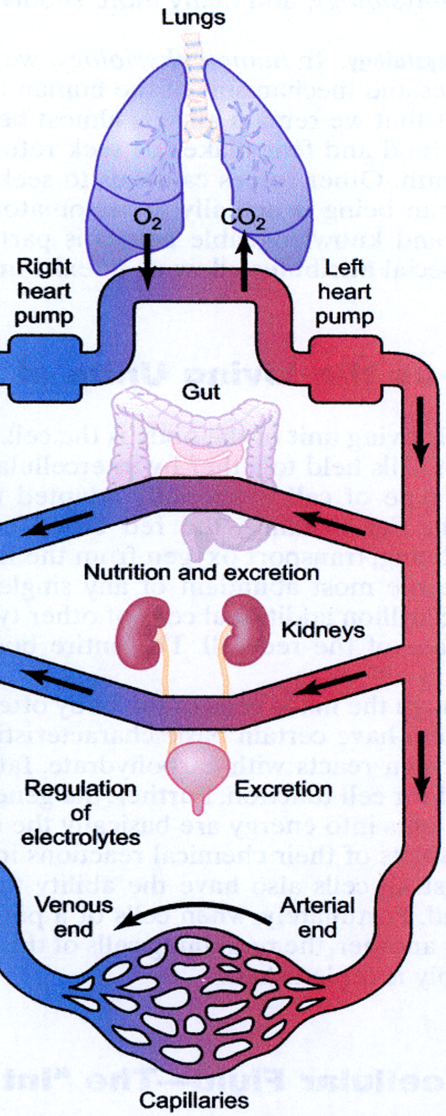
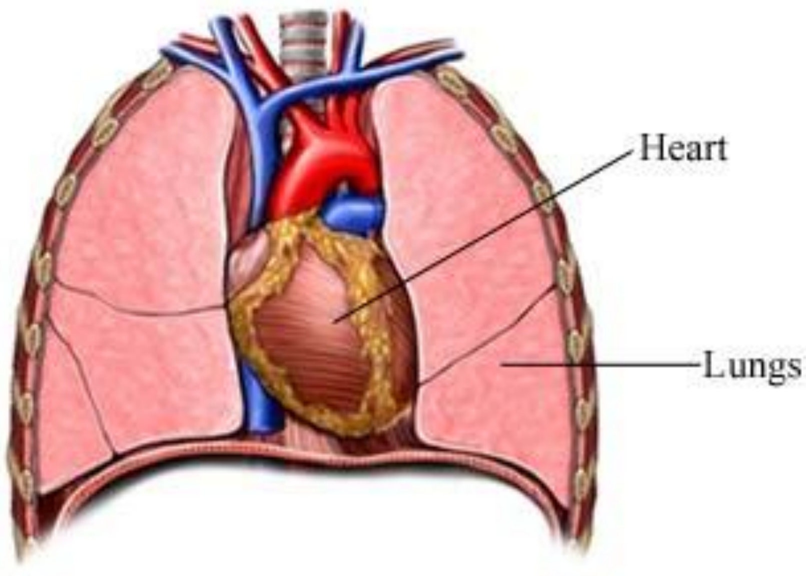
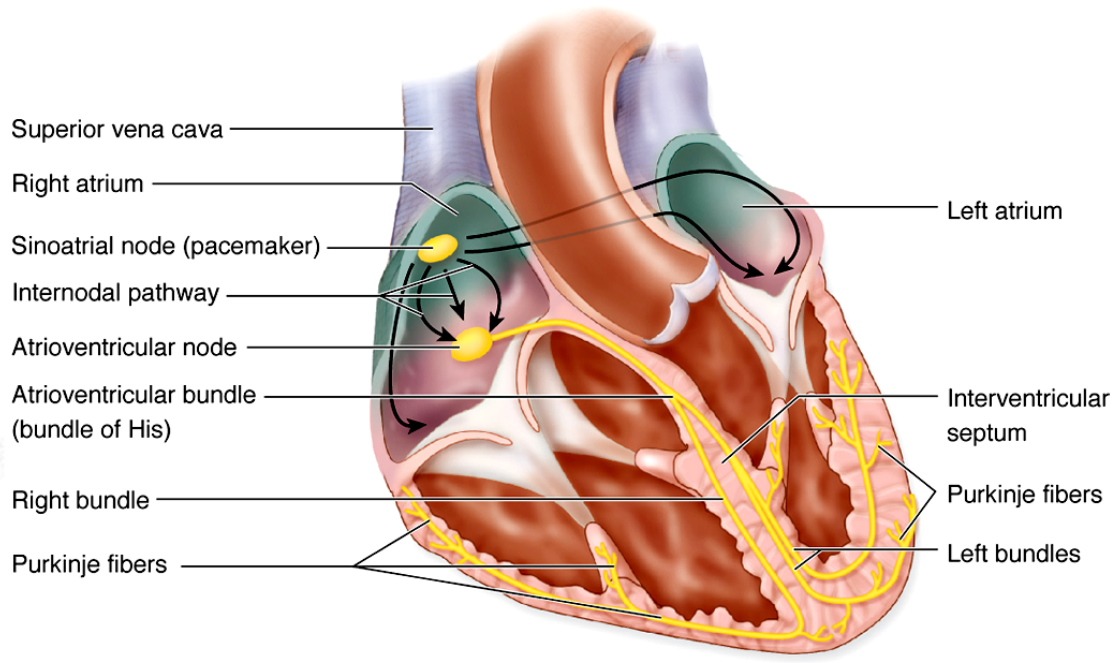


Figure 1–1

General organization of the circulatory system.

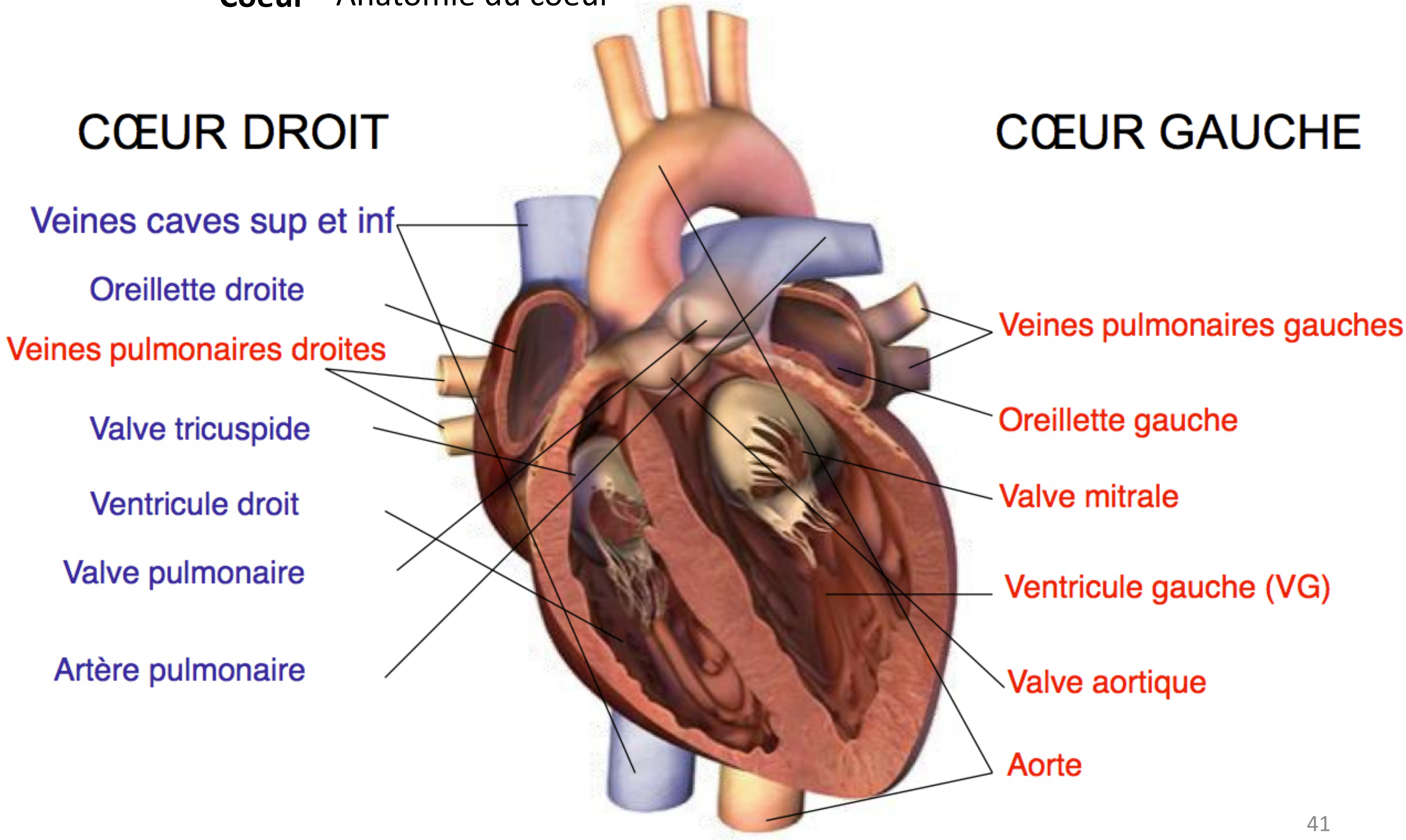
Coeur Anatomie du coeur





Major anatomical features of the heart. Longitudinal view of human heart showing the *two atria and two ventricles*. The ventricular walls are thicker than those of the atria, principally because of the much thicker myocardium. The *valves* are basically flaps of connective tissue anchored in the heart's dense fibrous skeleton region, shown in white. Other parts of the fibrous skeleton are the *chordae tendinae*, cords of dense connective tissue extending from the valves and attached to *papillary muscles* that help prevent valves from turning inside—out during ventricular contraction. All these parts of the fibrous skeleton are covered by endothelium. Shown in yellow are parts of the cardiac conducting system, which initiates the electrical impulse for heart's contraction (heartbeat) and spreads it through the ventricular myocardium. Both the sinoatrial (**SA**) node (pacemaker), in the posterior wall of the right atrium, 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 bundle (of His) which run along the interventricular septum to the apex of the heart, where they branch further as conducting (**Purkinje**) fibers which extend into myocardium of both ventricles.

Coeur Anatomie du coeur



La vascularisation du cœur

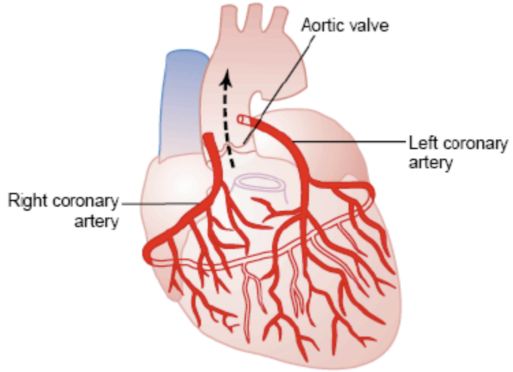


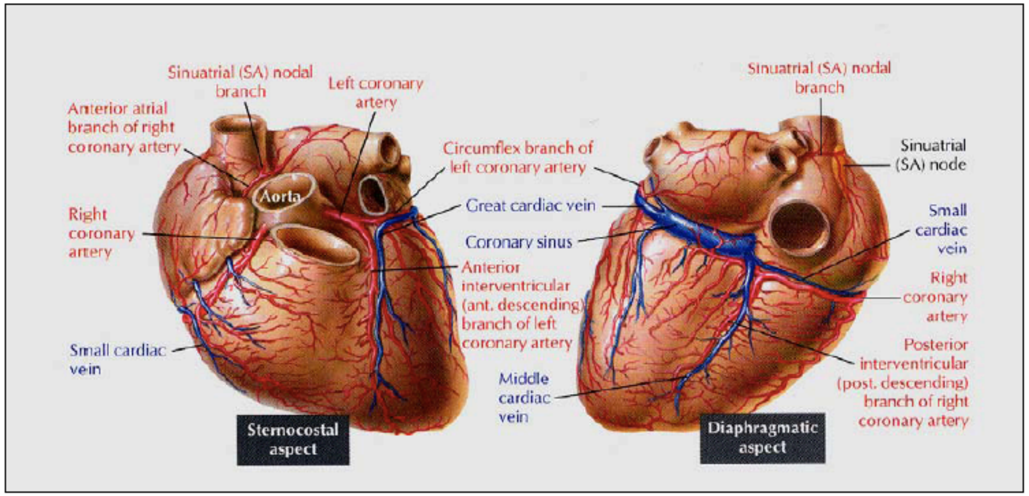
Figure 21–3

The coronary arteries.

Figure 21–3 shows the heart and its coronary blood supply. Note that the main coronary arteries lie on the surface of the heart and smaller arteries then penetrate from the surface into the cardiac muscle mass. It is almost entirely through these arteries that the heart receives its nutritive blood supply. Only the inner 1/10 millimeter of the endocardial surface can obtain significant nutrition directly from the blood inside the cardiac chambers, so that this source of muscle nutrition is minuscule.

The *left coronary artery* supplies mainly the anterior and left lateral portions of the left ventricle, whereas the *right coronary artery* supplies most of the right ventricle as well as the posterior part of the left ventricle in 80 to 90 per cent of people.

Most of the coronary venous blood flow from the left ventricular muscle returns to the right atrium of the heart by way of the *coronary sinus*—which is about 75 per cent of the total coronary blood flow. And most of the coronary venous blood from the right ventricular muscle returns through small *anterior cardiac veins* that flow directly into the right atrium, not by way of the coronary sinus. A very small amount of coronary venous blood also flows back into the heart through very minute *thebesian* veins, which empty directly into all chambers of the heart.



From Netter Atlas of Physiology

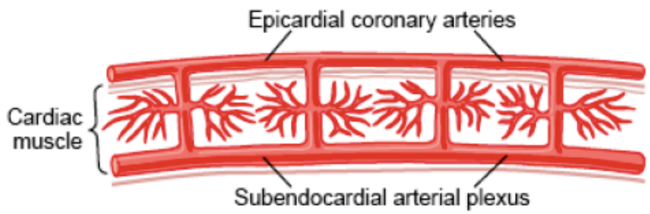


Figure 21–5

Diagram of the epicardial, intramuscular, and subendocardial coronary vasculature.

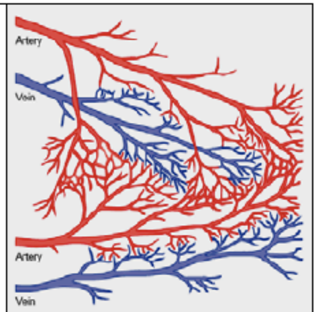
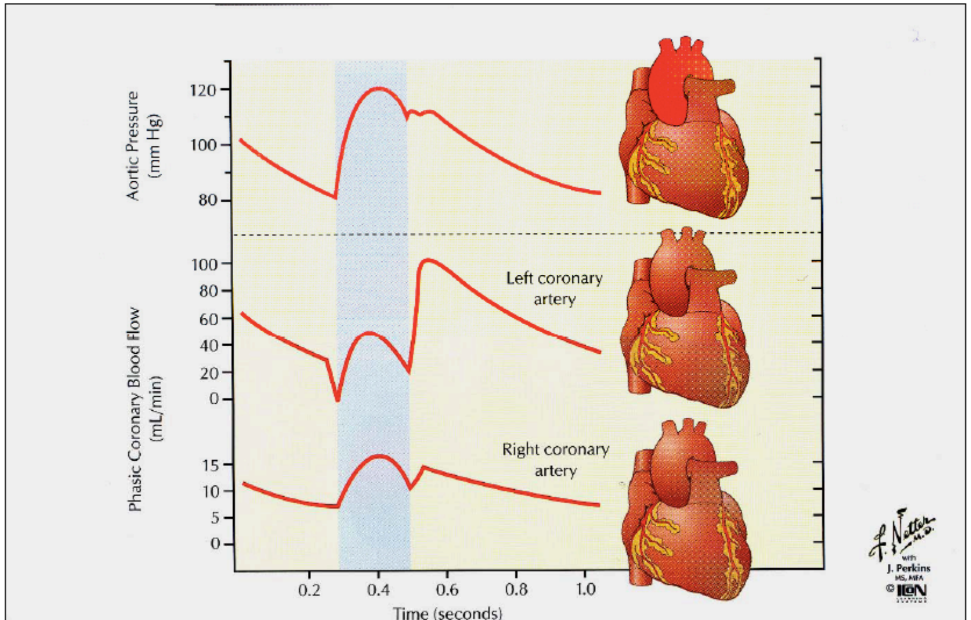


Figure 21-6

Minute anastomoses in the normal coronary arterial system.

From Guyton Textbook of Physiology

Coeur Vascularisation du cœur et rôle des coronaires

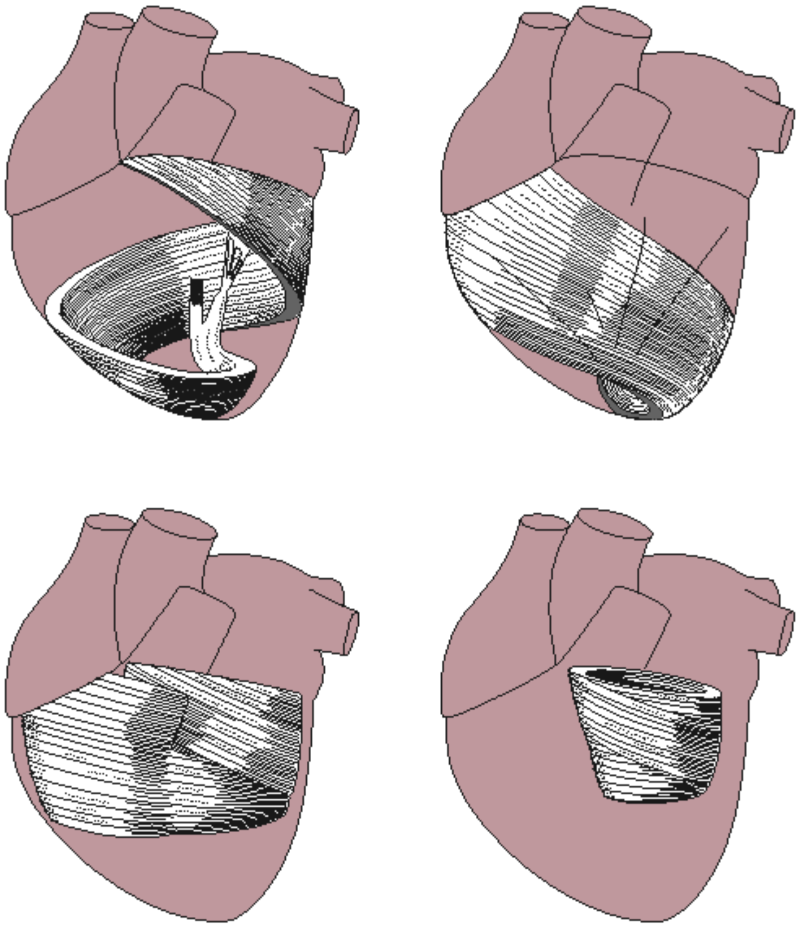


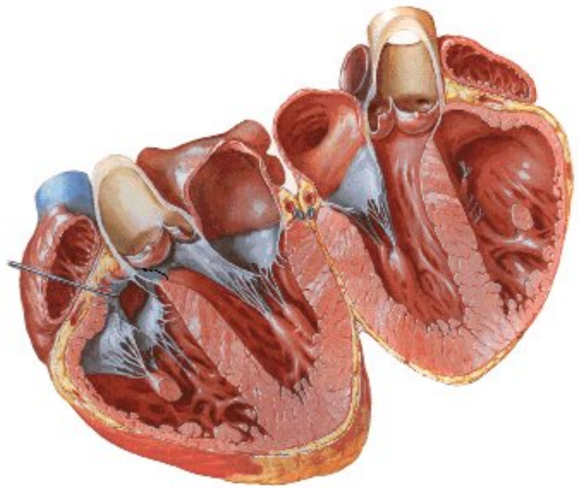
From Netter Atlas of Physiology

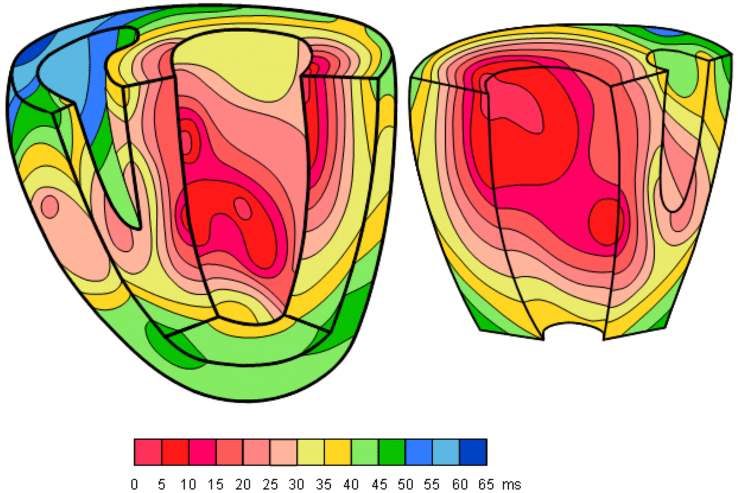
Artère coronaire gauche: → artère circonflexe
→ artère interventriculaire antérieure

Artère coronaire droite: → artère interventriculaire postérieure

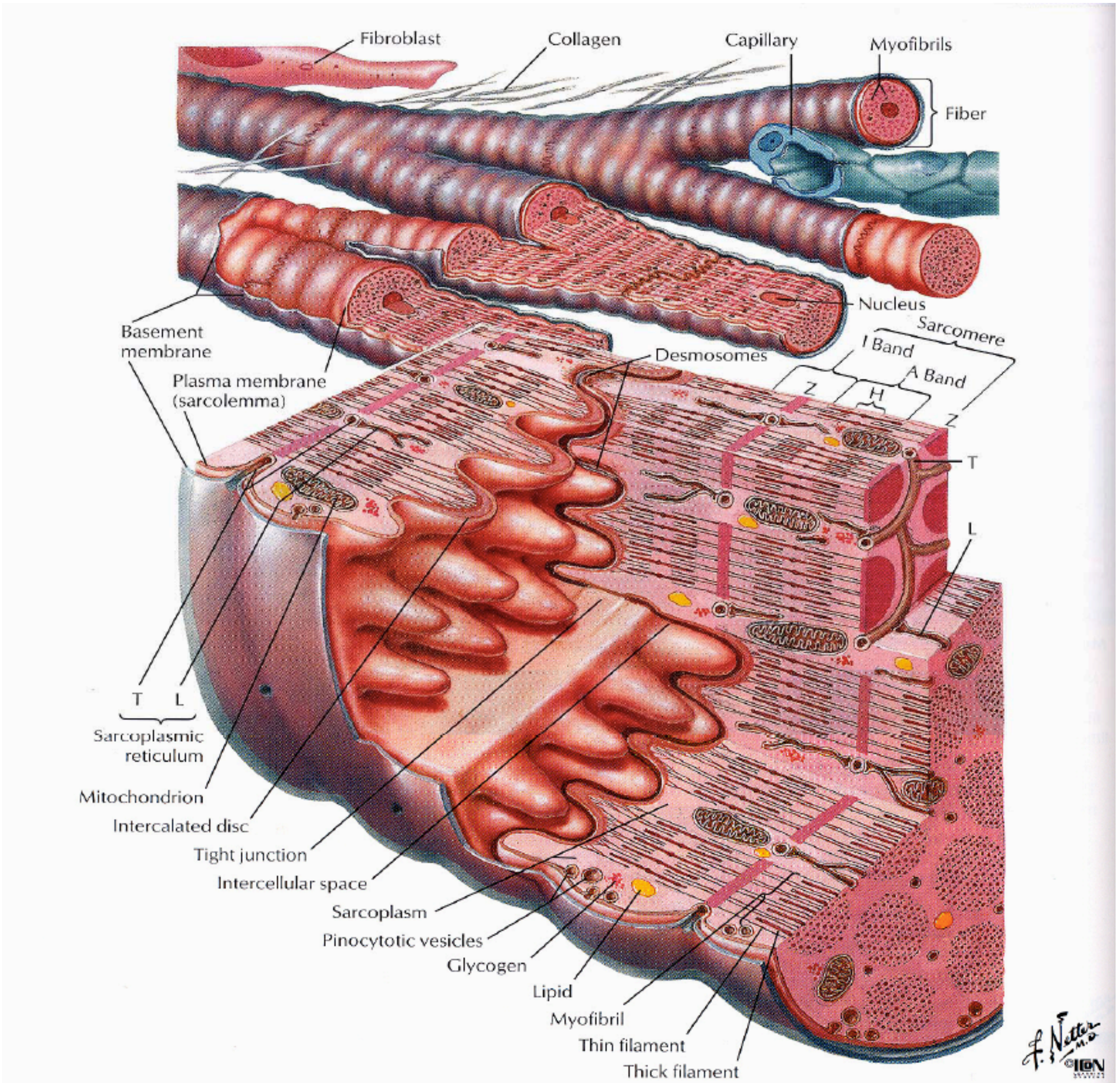
Coeur Orientation des fibres cardiaques lors de la contraction



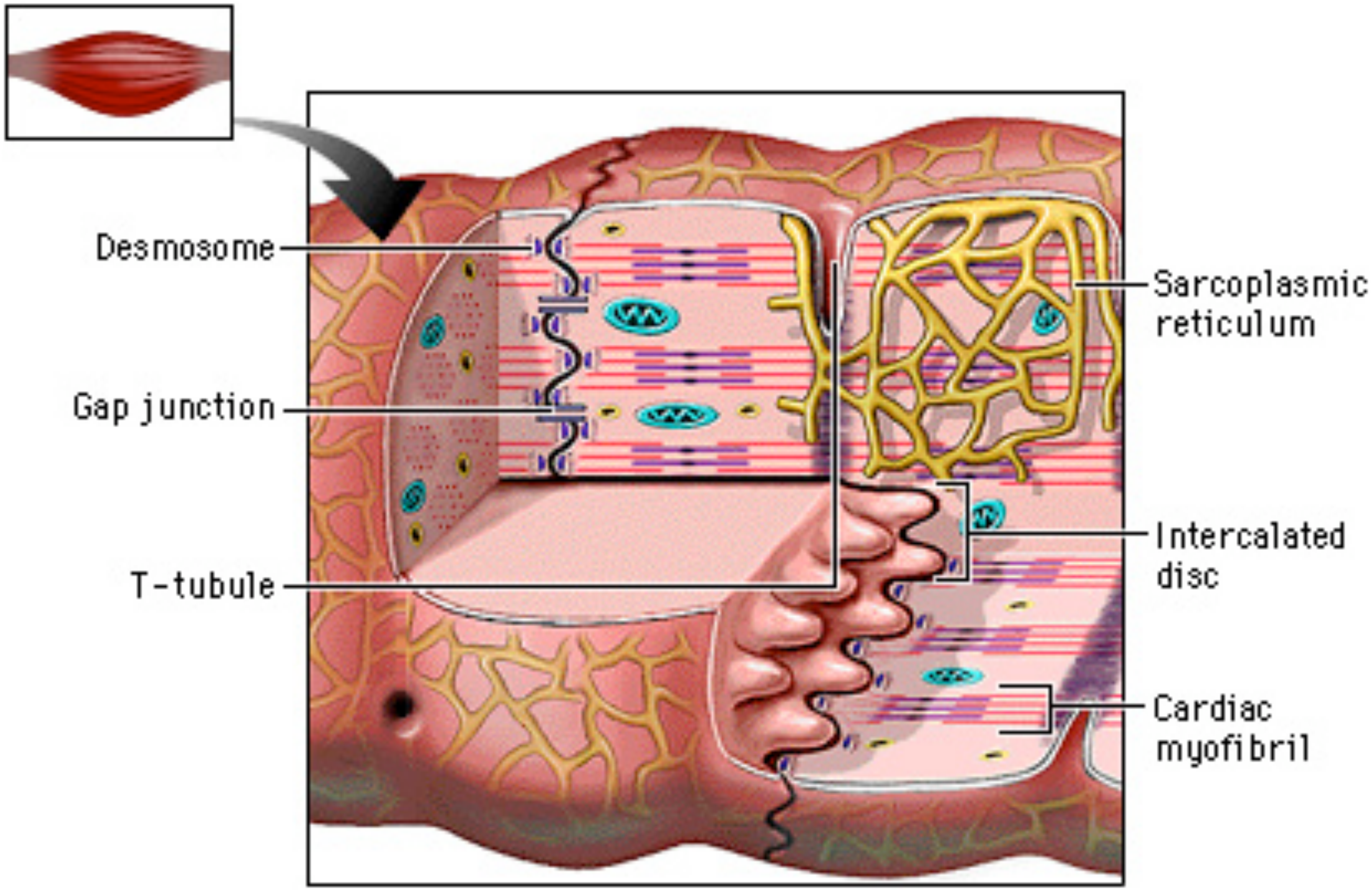




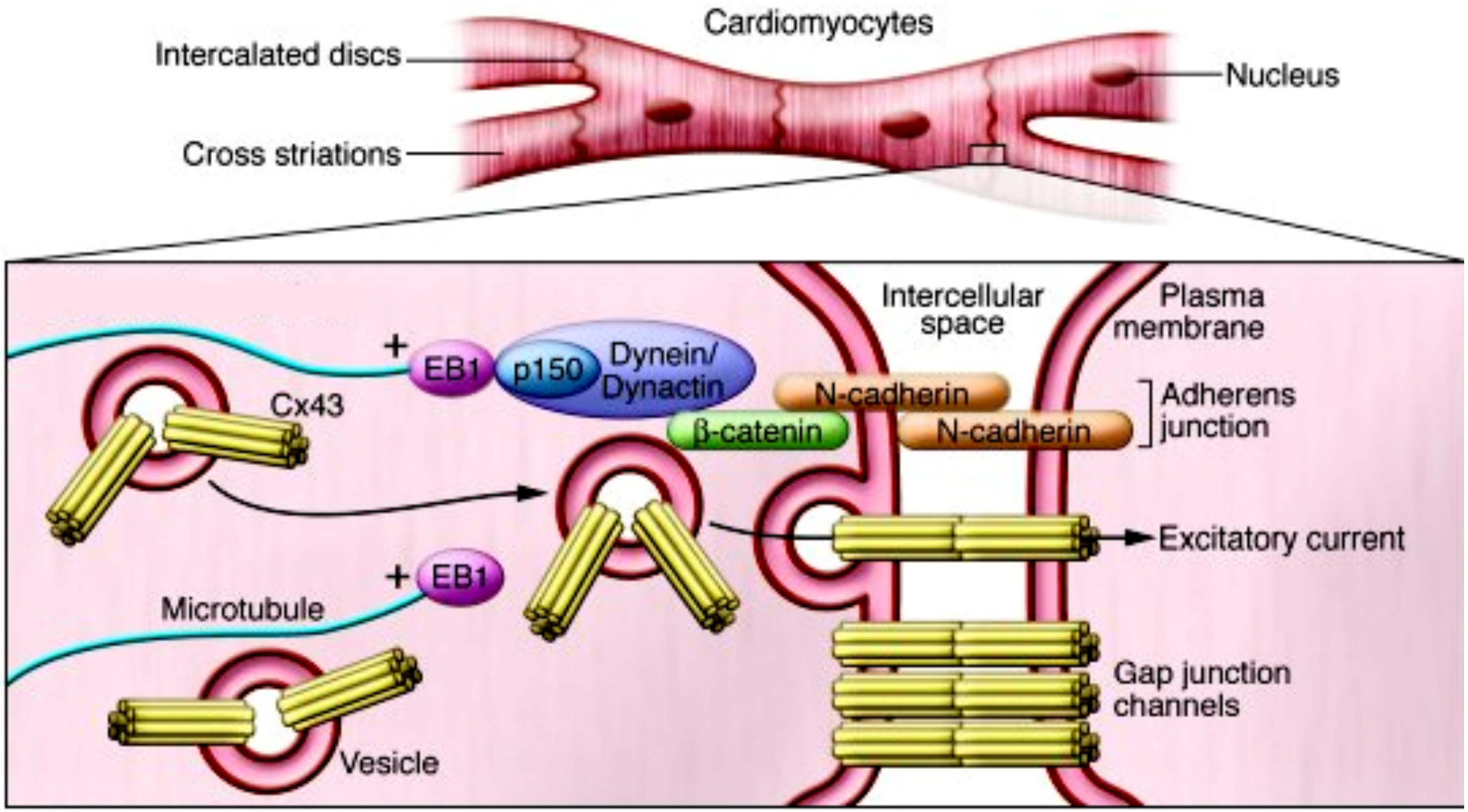
Coeur Anatomie des fibres cardiaques



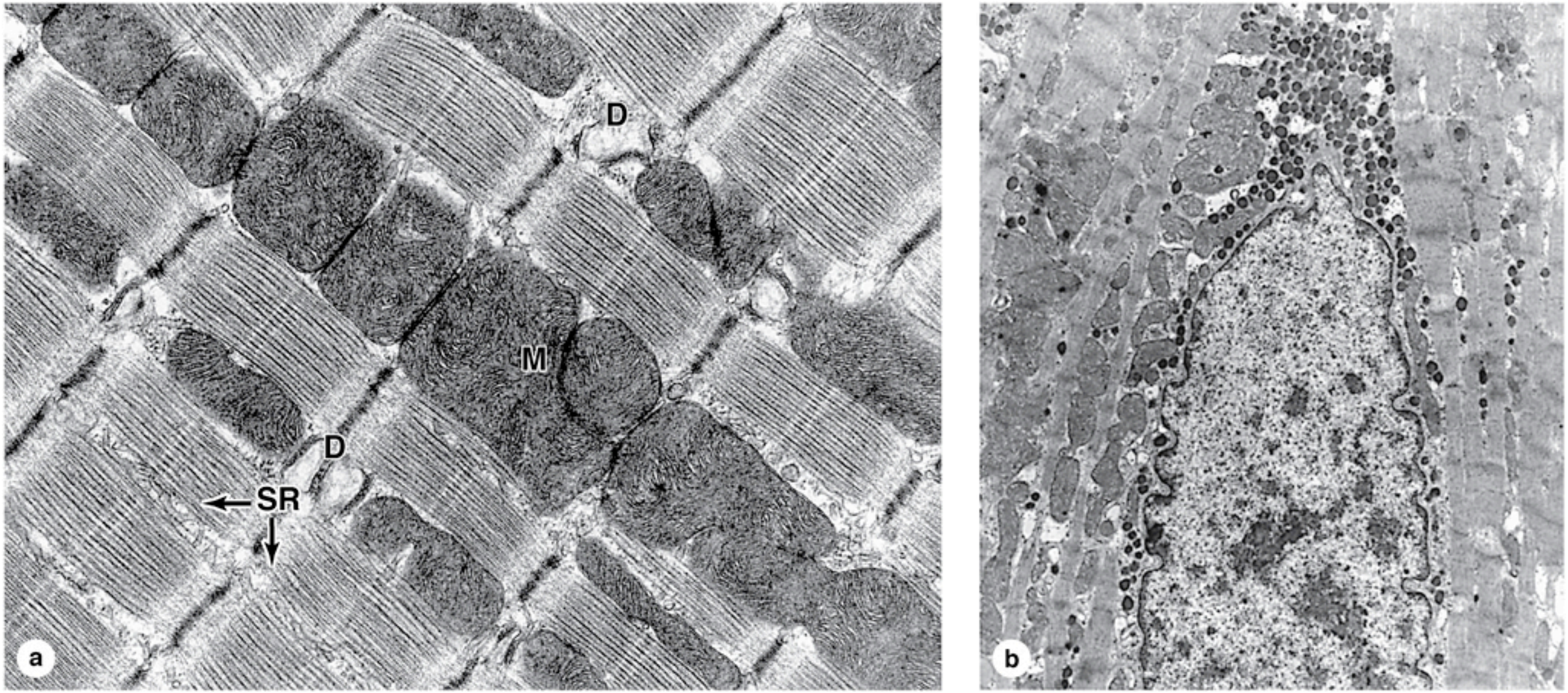
Coeur Anatomie des fibres cardiaques



Coeur Anatomie des fibres cardiaques



Coeur Anatomie des fibres cardiaques



Cardiac muscle ultrastructure. (a): TEM of cardiac muscle shows an abundance of mitochondria (**M**) and rather sparse sarcoplasmic reticulum (**SR**) in the areas between myofibrils. T tubules are less well—organized and are usually associated with one expanded terminal cisterna of SR, forming dyads (**D**) rather than the triads of skeletal muscle. Functionally these structures are similar in these two muscle types. X30,000. (b): Muscle cell from the cardiac atrium shows the presence of membrane—bound granules aggregated at the nuclear poles. These granules are most abundant in muscle cells of the right atrium (~600 per cell), but smaller quantities are also found in the left atrium and the ventricles. The atrial granules contain the precursor of a polypeptide hormone, atrial natriuretic factor (**ANF**). ANF targets cells of the kidneys to bring about sodium and water loss (natriuresis and diuresis). This hormone thus opposes the actions of aldosterone and antidiuretic hormone, whose effects on kidneys result in sodium and water conservation. X10,000. x, (Figure 10—18c, with permission, from Dr. J. C. Nogueira, Department of Morphology, Federal University of Minas Gerais, Belo Horizonte, Brazil.)

Coeur

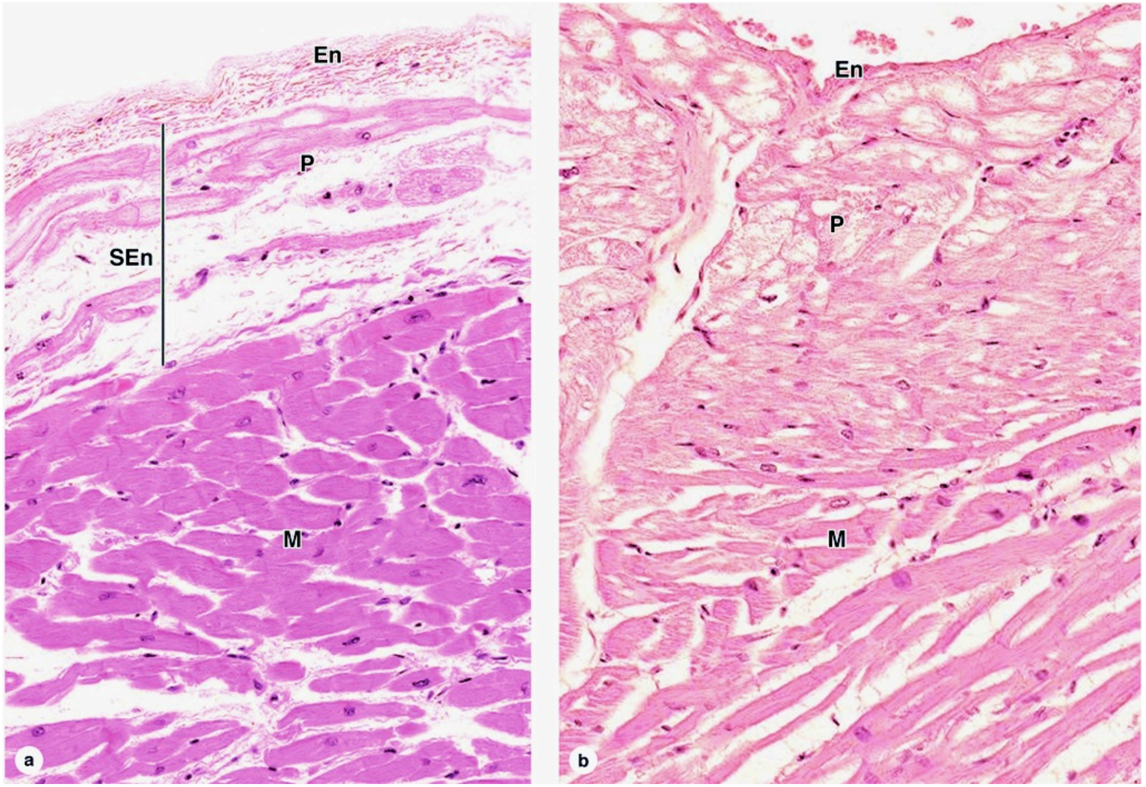
CHART 3.1 COMPARISION OF MUSCLE STRUCTURE AND FUNCTION

	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Structure			
Morphology	Long; cylindrical	Branched	Spindle or fusiform
Nuclei	Multiple; located peripherally	One (sometimes two); located centrally	One; located centrally
Sarcomere	Yes; striated pattern	Yes; striated pattern	No
T tubules	Yes; forms triad with sarcoplasmic reticulum	Yes; forms dyad with sarcoplasmic reticulum	No; caveolae
Electrical coupling of cells	No	Yes; intercalated discs contain gap junctions	Yes; gap junctions
Regeneration	Yes; via satellite cells	No	Yes
Mitosis	No	No	Yes
Physiology			
Extracellular Ca^{2+} required for contraction	No	Yes	Yes
Regulation of cross-bridge formation	Ca^{2+} binding to troponin	Ca^{2+} binding to troponin	Ca^{2+}-calmodulin activation of myosin kinase and phosphorylation of myosin
Control of contraction	Motor neurons	Autonomic nerves; β-adrenergic agonists	Autonomic nerves; hormones
Summation of twitches by increased stimulus frequency	Yes	No*	Yes
Tension varies with filament overlap	Yes	Yes	Yes

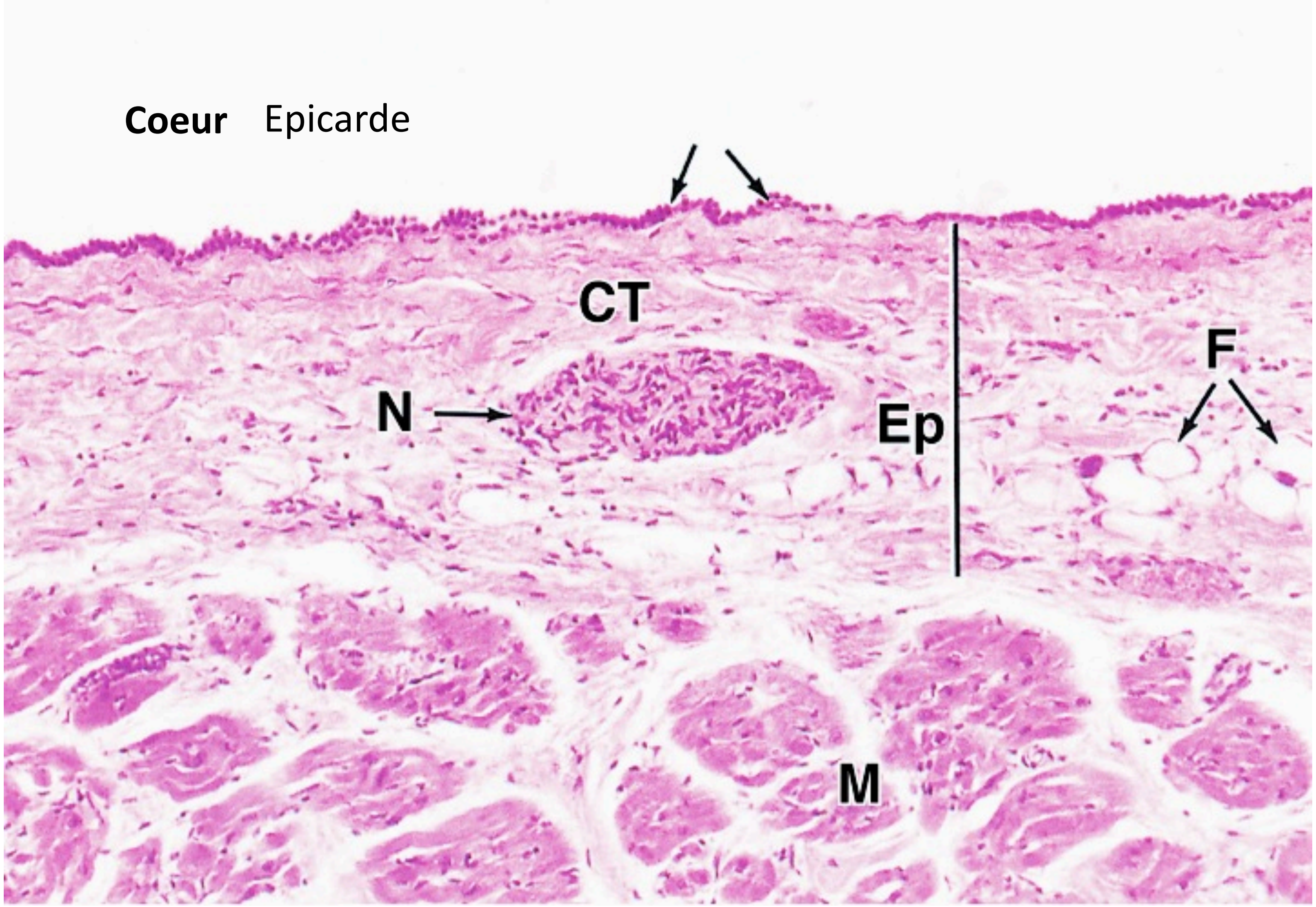
Major differences in structure and function of skeletal, cardiac, and smooth muscle are indicted.
*Cardiac muscle cannot be tetanized, but the force of contraction will increase at high stimulus frequency because of an increase in intracellular [Ca^{2+}], a phenomenon termed "Treppe."

Nettler Atlas of Anatomy

Coeur Endocarde et réseau de conduction

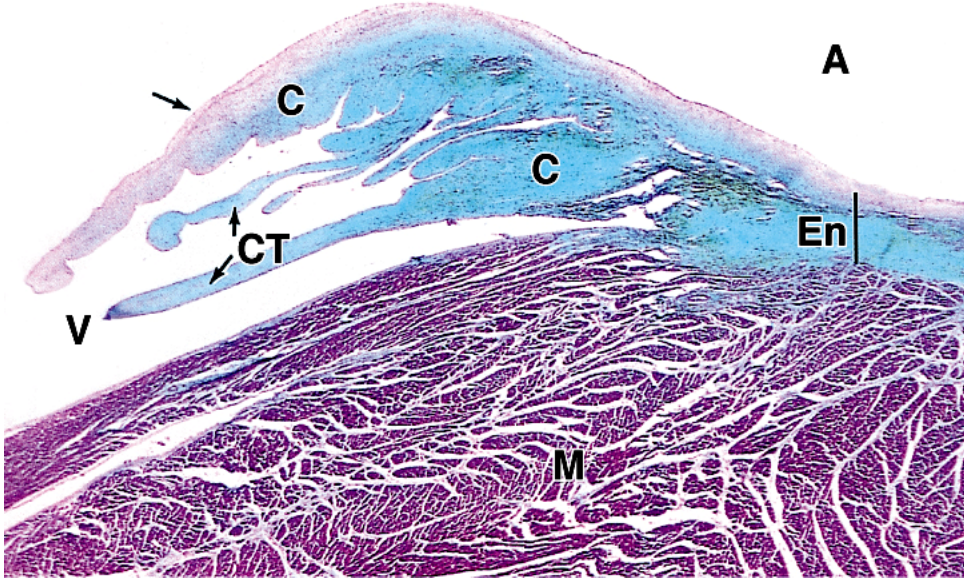


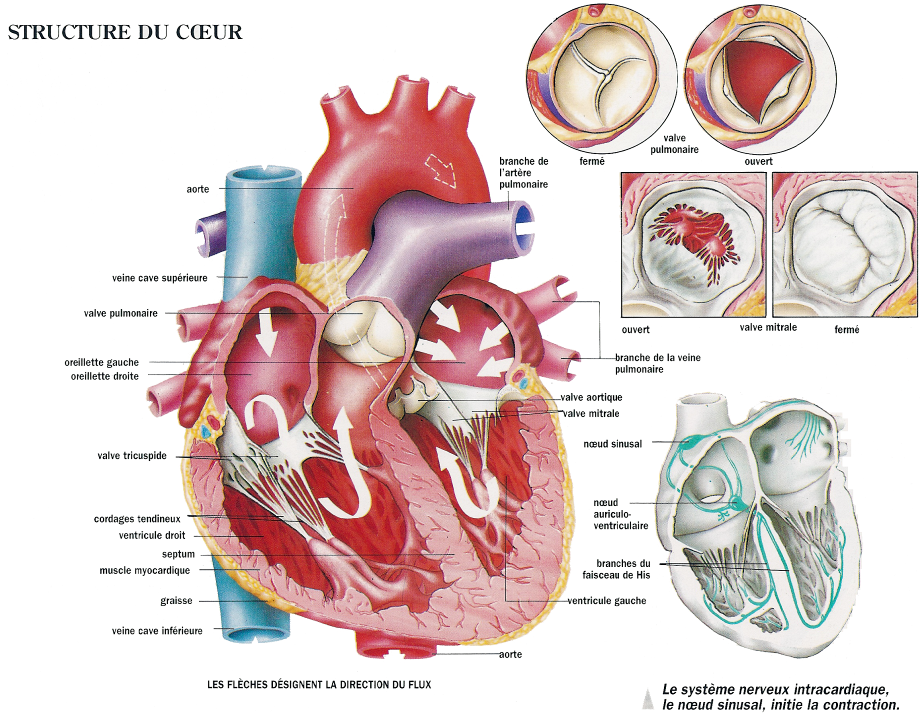
Endocardium & subendocardial conducting network.
(a) The **endocardium** (**En**) is a thin layer of connective tissue lined by *simple squamous endothelium*. Between the endocardium and myocardium is a layer of variable thickness called **the subendocardial layer** (**SEn**) containing small nerves and in the ventricles the **conducting (Purkinje) fibers** (**P**) of the subendocardial conducting network. These fibers are cardiac muscle cells *joined by intercalated disk*s but specialized for impulse conduction rather than contraction. *Purkinje fibers are usually larger than contractile cardiac muscle* fibers with large amounts of lightly stained glycogen filling most of the cytoplasm and displacing sparse myofibrils to the periphery. (a): Purkinje fibers running separately within the subendocardial layer. (b): **Purkinje fibers intermingling with contractile fibers** within the myocardium (**M**). Along with the nodes of specialized cardiac muscle in the right atrium which generate the electrical impulse, the network of conducting fibers comprises the conducting system of the heart. Both X200. H&E.



Epicardium or visceral pericardium.
The external tunic of the heart, the epicardium, is the site of the coronary vessels and contains considerable adipose tissue. This section of atrium shows part of the **myocardium** (**M**) **and epicardium** (**Ep**). The epicardium consists of loose **connective tissue** (**CT**) containing both **autonomic nerves** (**N**) **and fat** (**F**). The epicardium is the visceral layer of the pericardium and is covered by the simple squamous—to—cuboidal epithelium (arrows) that also lines the pericardial space. These mesothelial cells secrete a lubricate fluid that prevents friction as the beating heart contacts the parietal pericardium on the other side of the pericardial cavity. X100. H&E.

Coeur Anatomie des valves





Valve leaflet and fibrous skeleton

The fibrous skeleton of the heart consists of masses of dense connective tissue in the endocardium which anchors the valves and surrounds the two atrioventricular canals, maintaining their proper shape. Section through a leaflet of the left atrioventricular valve (arrows) shows that valves are largely dense connective tissue (**C**) covered with a thin layer of endothelium. The collagen—rich connective tissue of the valves is stained pale green here and is continuous with the fibrous ring of connective tissue at the base of the valves, which fills the endocardium (**En**) of this area between the atrium (**A**) and ventricle (**V**). The chordae tendinae (**CT**), small strands of connective tissue which bind distal parts of valve leaflets, can also be seen here. The interwoven nature of the cardiac muscle fibers, with many small fascicles, in the myocardium (**M**) is also shown. X20. Masson trichrome.

Coeur Anatomie des valves

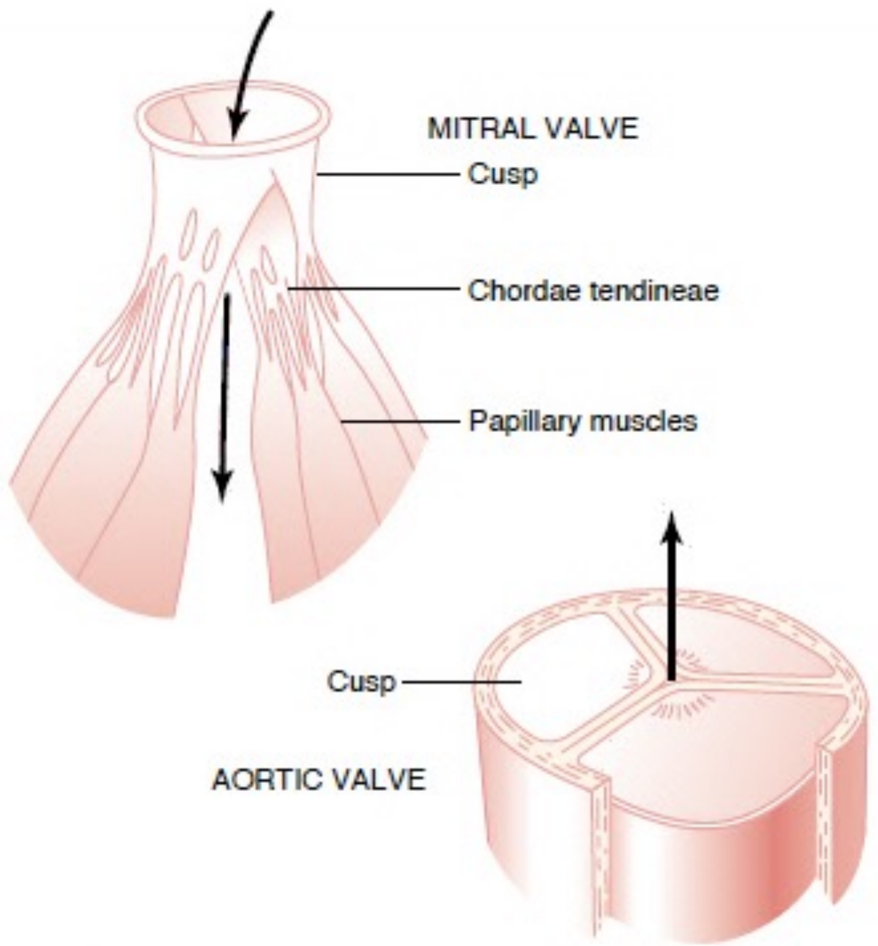


Figure 9–6

Mitral and aortic valves (the left ventricular valves).

Function of the Papillary Muscles.
Figure 9–6 also shows papillary muscles that attach to the vanes of the A-V valves by the *chordae tendineae. The papillary* muscles contract when the ventricular walls contract, but contrary to what might be expected, they *do not* help the valves to close. Instead, they pull the vanes of the valves inward toward the ventricles to prevent their bulging too far backward toward the atria during ventricular contraction. If a chorda tendinea becomes ruptured or if one of the papillary muscles becomes paralyzed, the valve bulges far backward during ventricular contraction, sometimes so far that it leaks severely and results in severe or even lethal cardiac incapacity.

Vaisseaux

Le système circulatoire
selon R.V. KRSTIC

A = Artery

V = Veins

MB = microvascular bed

A = musculatur artery

Art = Arteriole

Met = Metarteriole

CAP = capillary network

PS = Precapillary sphincters

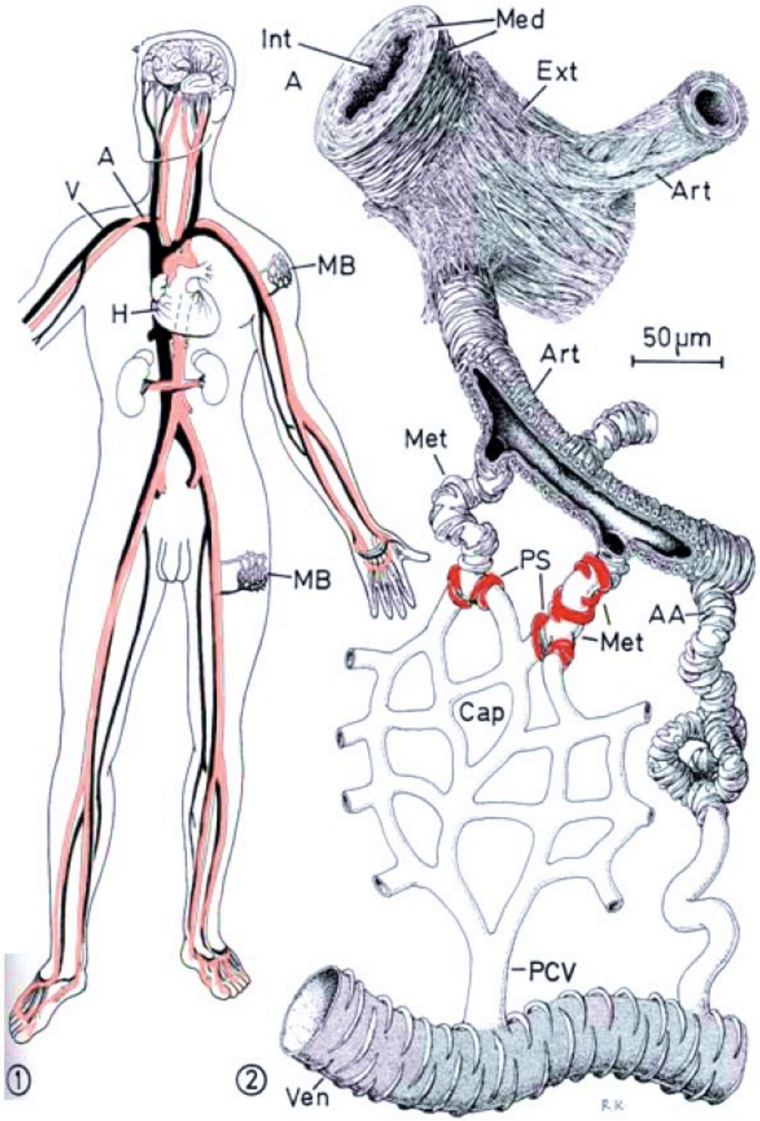
PCV =postcapillary venules

AA = arteriovenous anastomosis

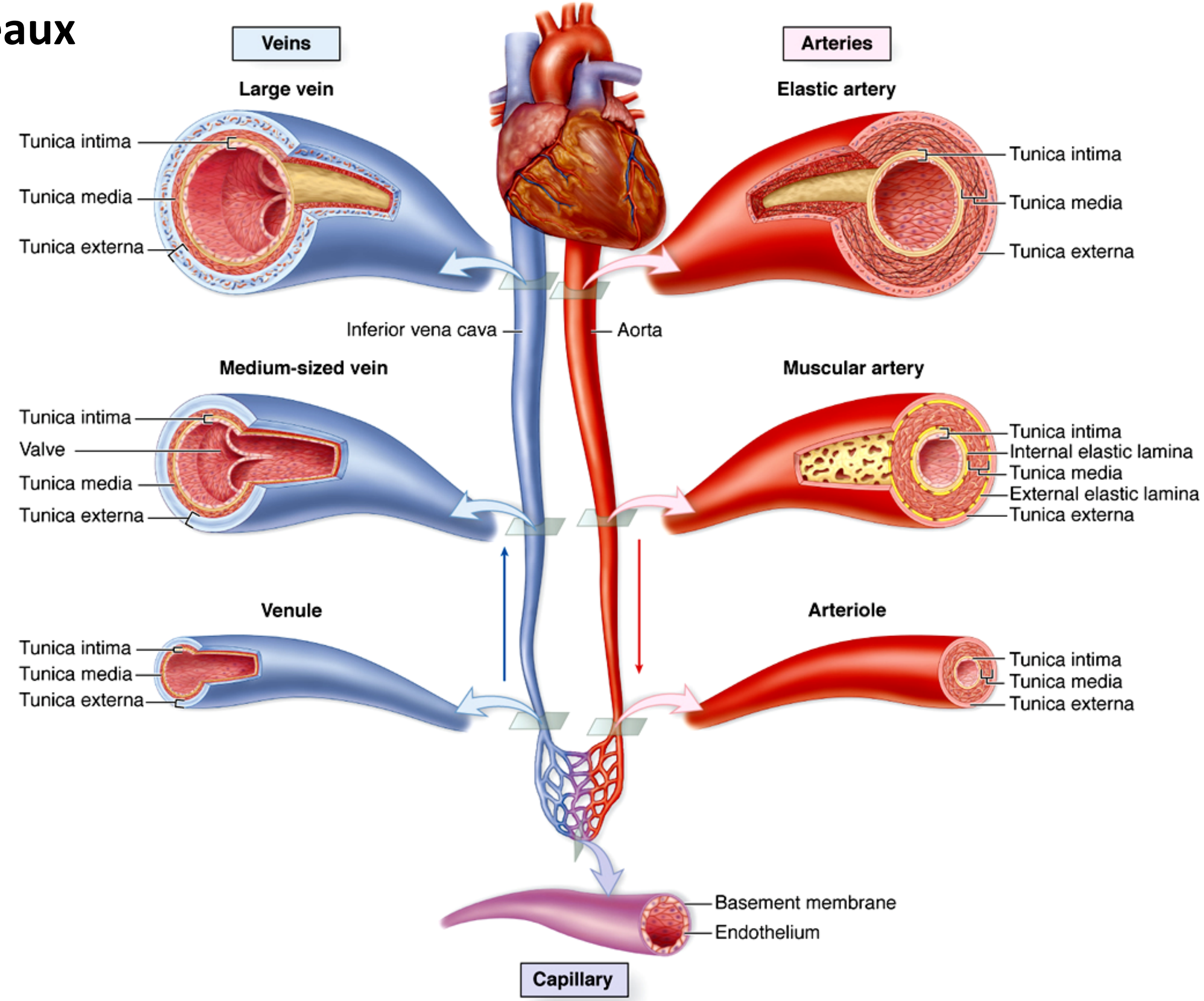
Int = tunica intima

Med = tunica media

Ext = Tunica externa

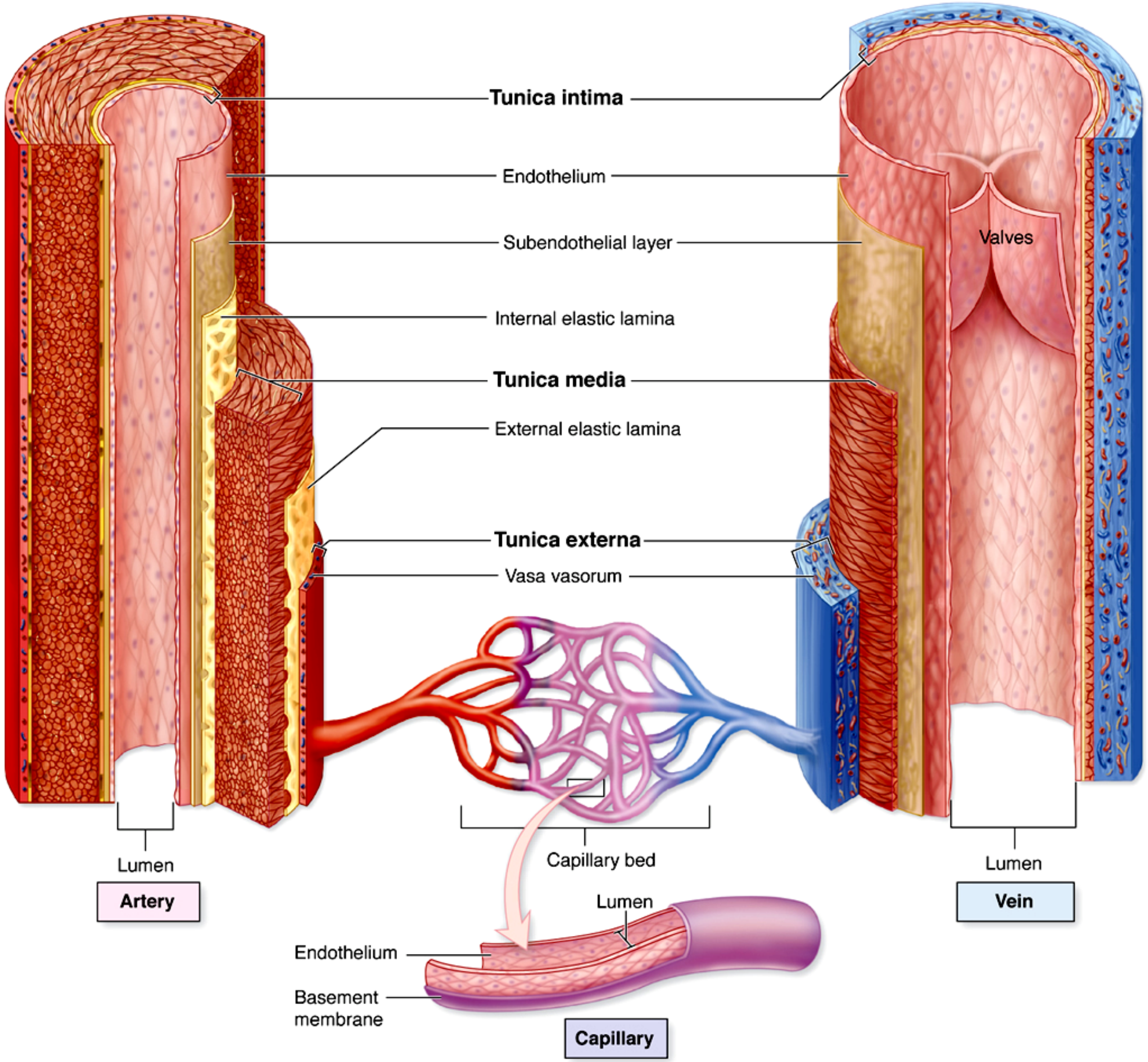


Vaisseaux



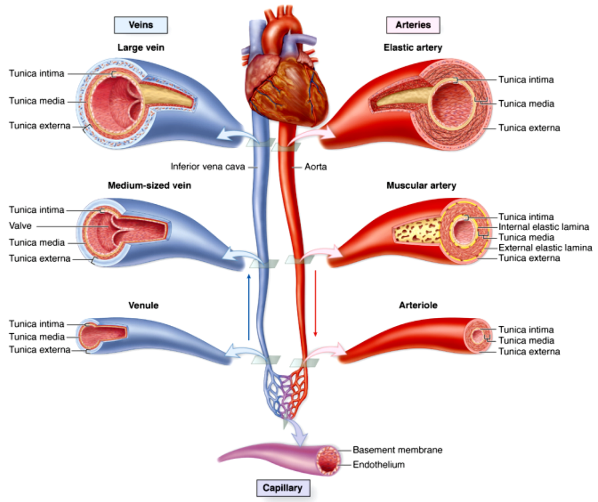
The heart is the principal organ of the blood circulatory system, pumping blood throughout the body and providing the force by which nutrients leave the capillaries and enter tissues. Large elastic arteries leave the heart and branch to form muscular arteries. These arteries branch further and enter organs, where they branch much further to form arterioles. These arterioles branch into the smallest vessels, the capillaries, the site of exchange between blood and surrounding tissue. Capillaries then merge to form venules, which merge further into small and then medium—sized veins. These veins leave organs, form larger veins which eventually bring blood back to the heart.

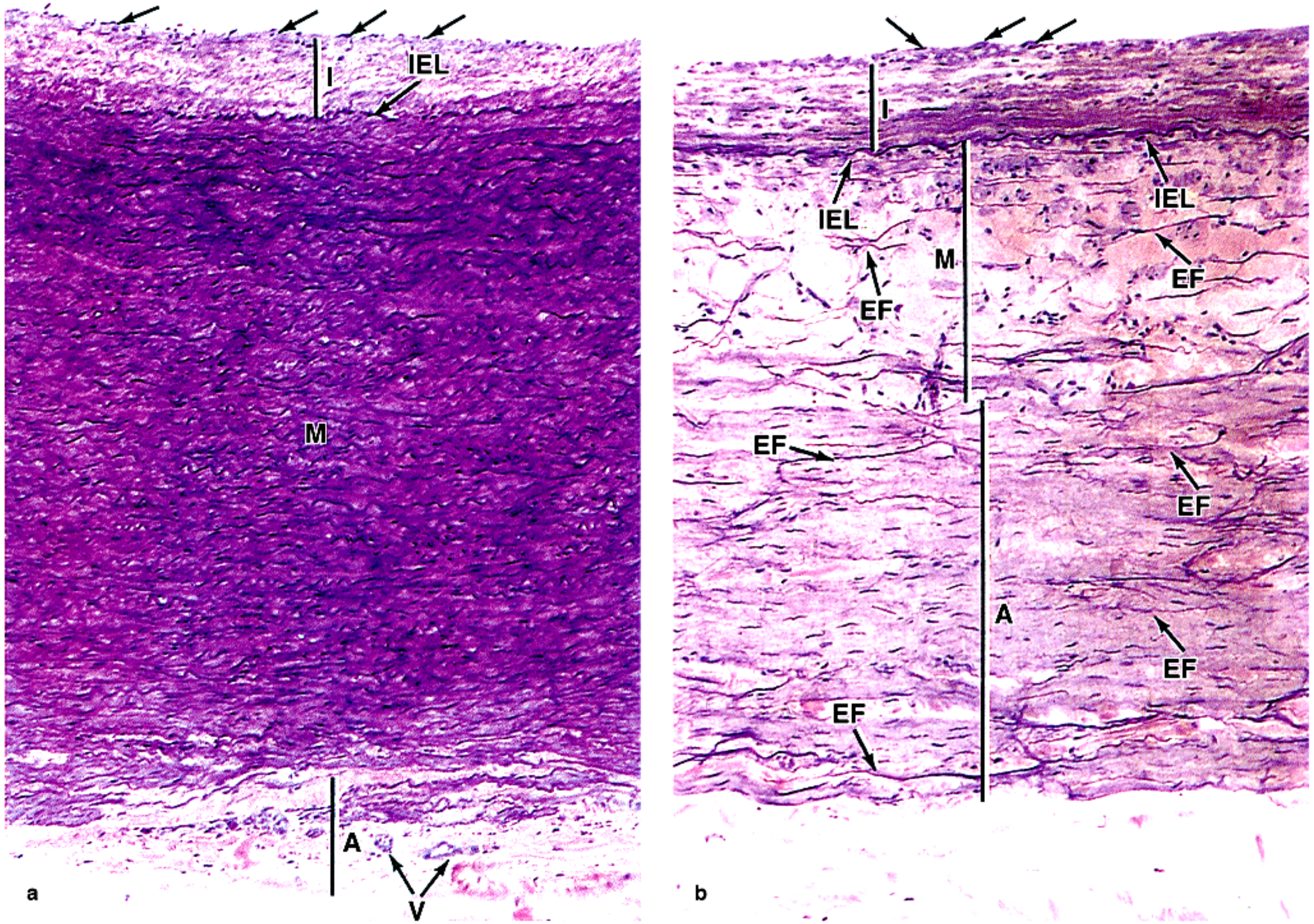
Vaisseaux



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

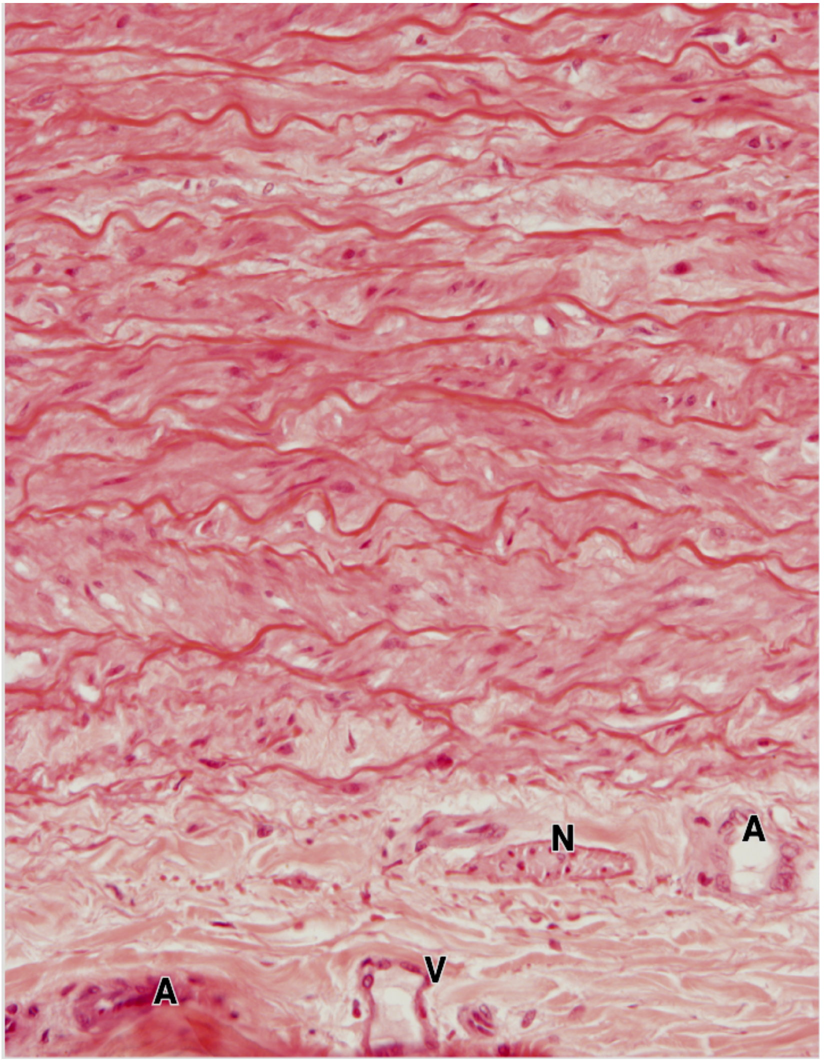
Vaisseaux



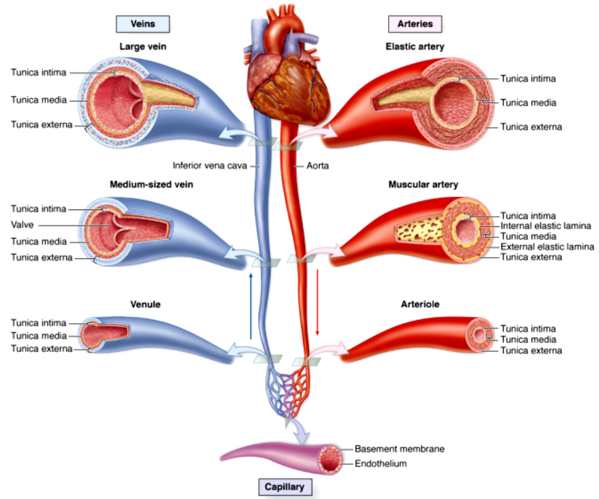


Comparison of the three major layers or tunics in the largest artery and vein. (a)**: aorta** (b): **vena cava.** Simple squamous endothelial cells (arrows) line the **tunica intima (I**) which has subendothelial loose connective tissue and is separated from the tunica media by **the internal elastic lamina** (**IEL**), a prominent sheet of **elastin**. The media (**M**) contains elastic lamellae and fibers (**EF**) and multiple layers of smooth muscle not seen well here. The tunica media is much thicker in large arteries than veins, with relatively more elastin. Elastic fibers are also present in the outer tunica adventitia (**A**), which is relatively thicker in large veins. **Vasa vasorum** (**V**) are seen in the adventitia of the aorta. The connective tissue of the adventitia always merges with the less dense connective tissue around it. Both X122. Elastic.

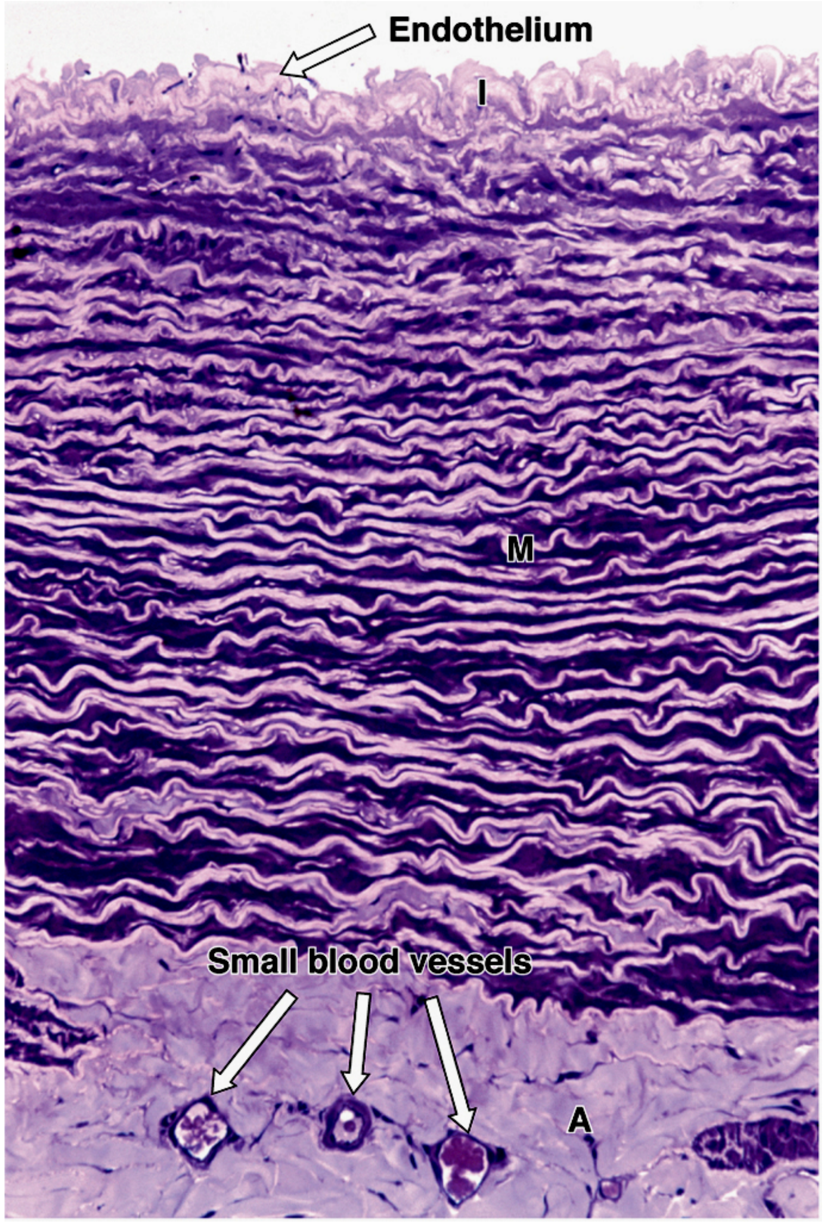
Vaisseaux Vasa vasorum



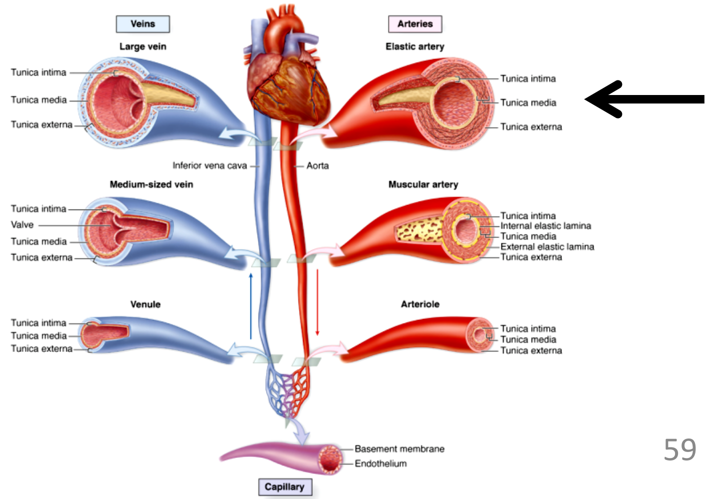
Walls of the larger vessels, as the aorta, contain in the tunica adventitia a supply of microvasculature to bring O_2 and nutrients to local cells too far from the lumen to be nourished by blood there. These arterioles (**A**), capillaries and venules (**V**) constitute the **vasa vasorum** (vessels of vessels). The adventitia of large arteries is also supplied more sparsely with small **sympathetic nerves** (**N**) for control of vasoconstriction. X100. H&E.



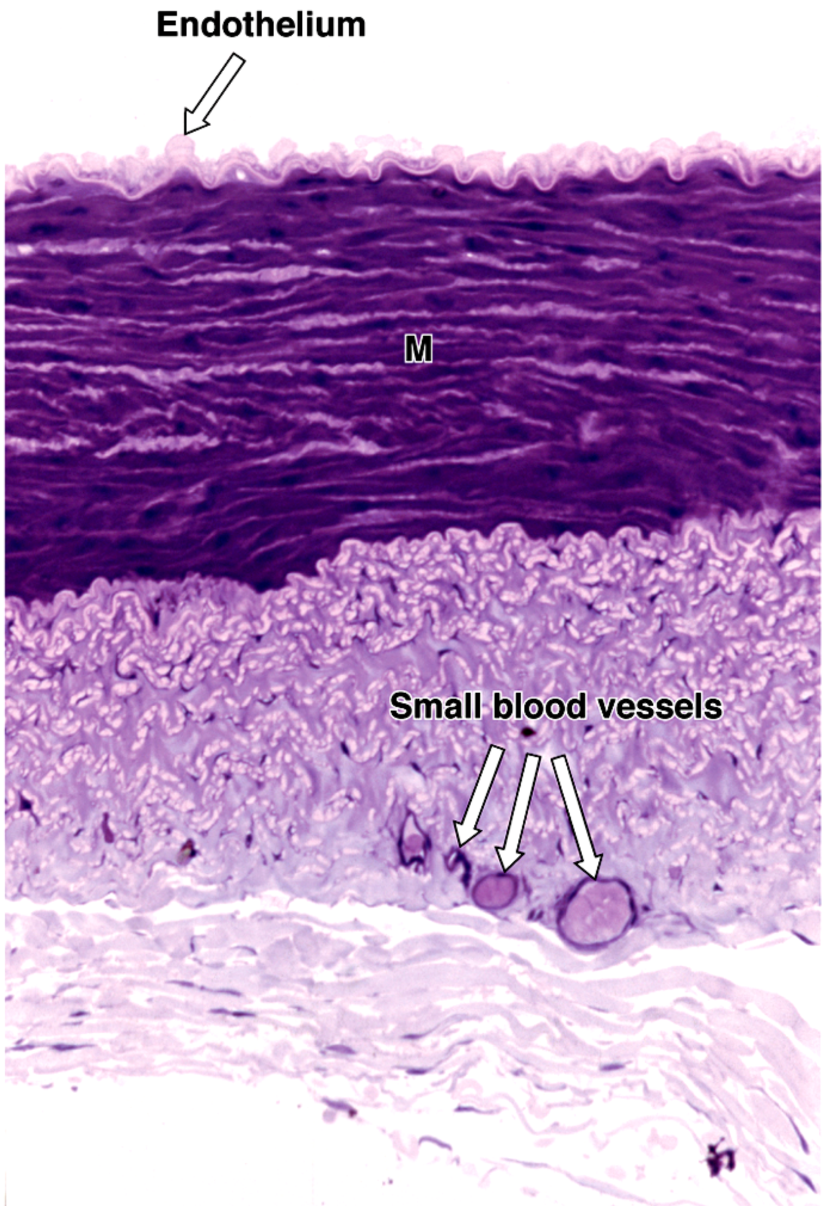
Vaisseaux Artère élastique



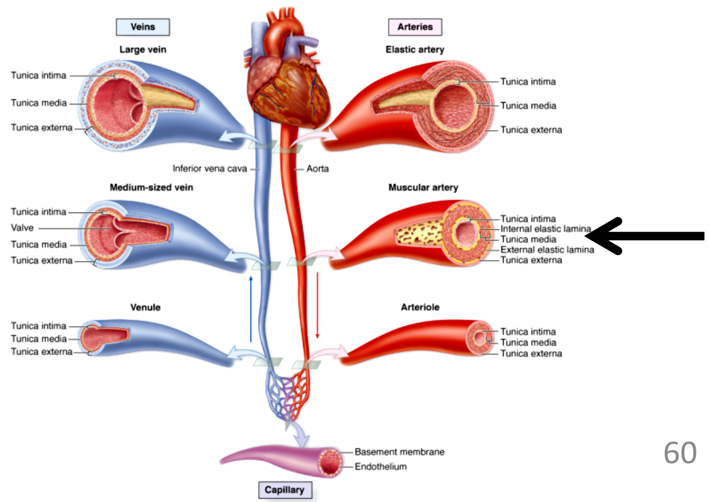
The largest arteries contain considerable elastic material and expand with blood when the heart contracts. A transverse section through part of a large elastic artery shows a thick tunica media (**M**) consisting largely of many well—developed elastic lamellae. Strong pressure of blood pulsating into 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 adventitia (**A**) contains vasa vasorum. X200. PT.



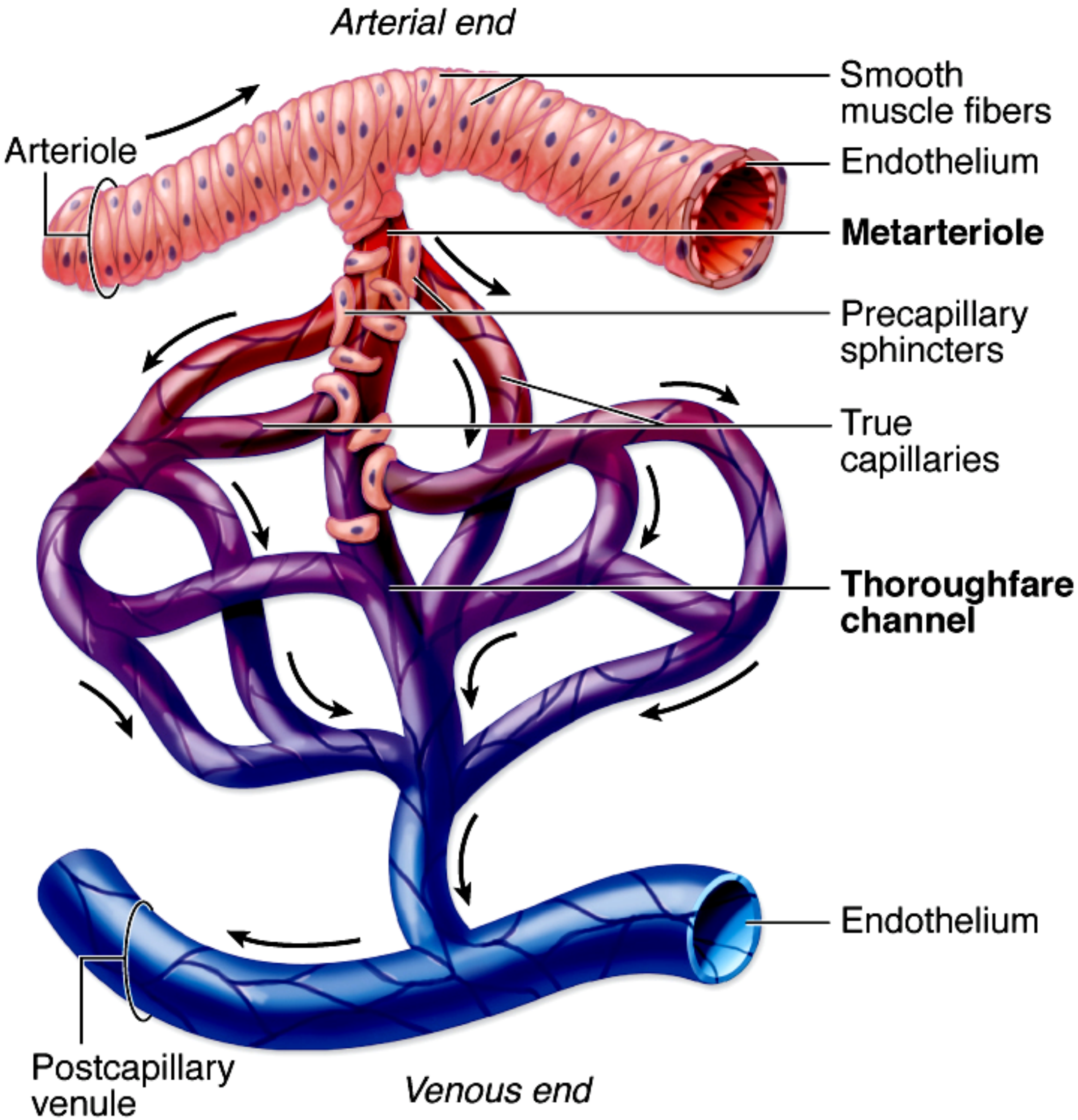
Vaisseaux Artère musculaire



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 this muscular type. A transverse section through a muscular (medium caliber) artery shows **multiple layers of smooth muscle** in the media (**M**). The smooth muscle layers are more prominent than the elastic lamellae and fibers with which they intersperse. Vasa vasorum are seen in the tunica adventitia. X200. PT.

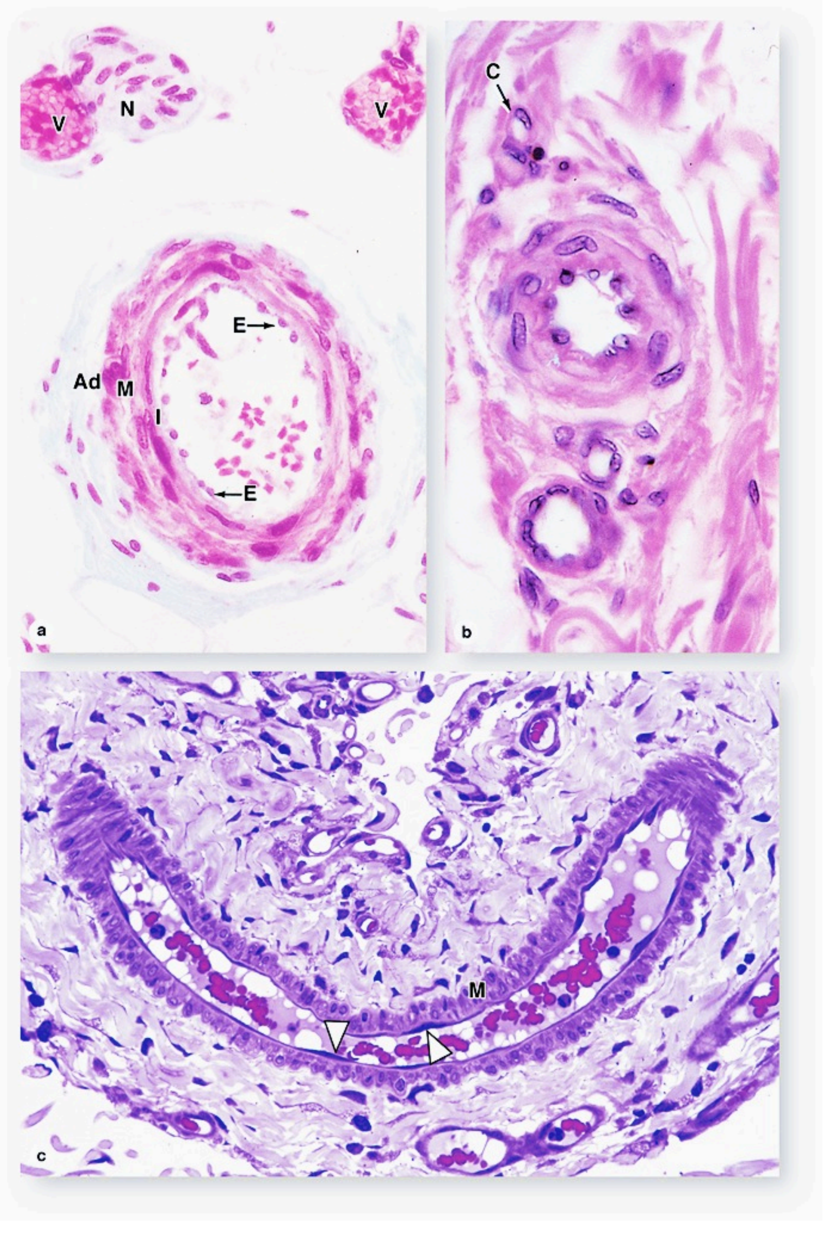


Vaisseaux Structure de la microvascularisation



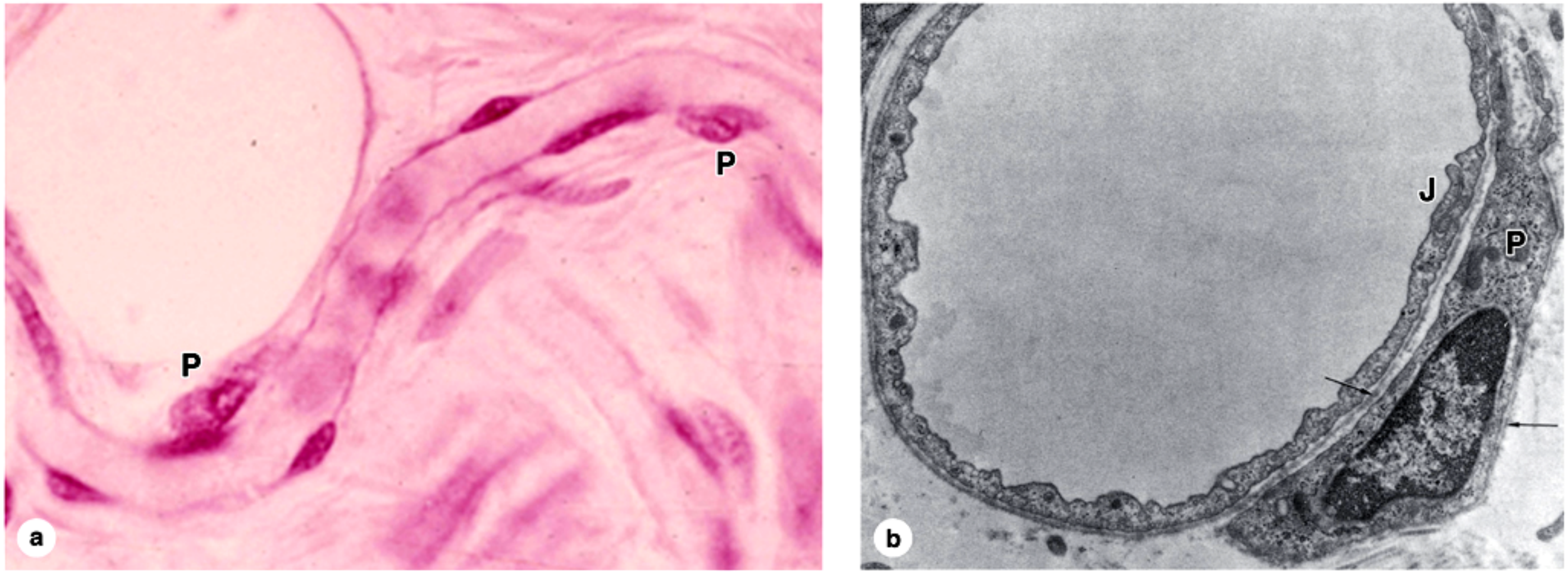
Microvasculature arises to meet nutritional needs of one organ or parts of one organ and consists of **blood vessels of less than 0.5 mm diameter**. Microvessels include arterioles and their smaller branches called metarterioles in which *the layer of smooth muscle cells is dispersed* as bands of cells that act *as precapillary sphincters*. The distal portion of the metarteriole, sometimes called a thoroughfare channel, lacks any smooth muscle cells. **The wall of capillaries lacks smooth muscle cells altogether**. The precapillary sphincters allow blood to enter the bed of capillaries in a pulsatile manner for maximally efficient exchange of nutrients, wastes, O_2, and CO_2 across the capillary wall. Capillaries and the metarteriole converge as postcapillary venules, the last component of the microvasculature. Blood enters microvasculature well—oxygenated and leaves poorly oxygenated.

Vaisseaux Artérioles



(a): **Arterioles are microvessels** with a tunica intima (**I**) that consists only of the endothelium (**E**), in which the cells may have rounded nuclei. They have **tunica media (M) with only one or two layers of smooth muscle**, and usually thin, inconspicuous adventitia (**Ad**). X350. Masson trichrome. (b): Three arterioles of various sizes are shown here and a capillary (**C**). X400. H&E. (c): A large mesenteric arteriole is cut obliquely and longitudinally and 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.

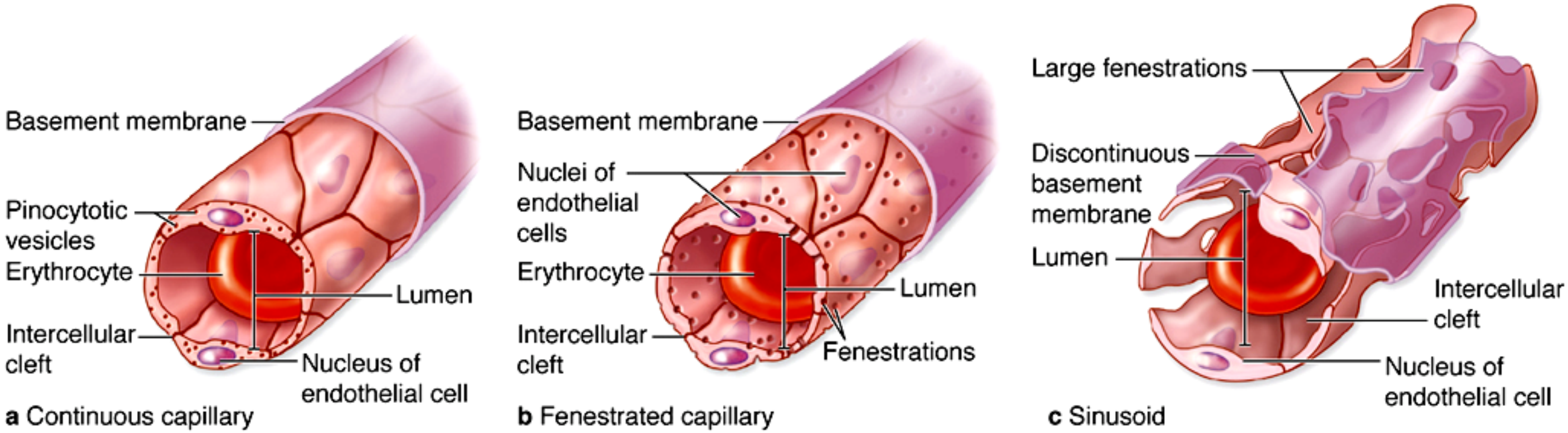
Vaisseaux Capillaires avec péricytes



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**) which have a variety of functions. The more flattened nuclei belong to endothelial cells. X400. H&E.
(b): TEM of a capillary cut transversely, showing the thin wall of one endothelial cell covered by an external lamina (arrows). Endothelial cells have numerous transcytotic vesicles and their edges overlap and are bound tightly together with occluding junctions (**J**). One pericyte (**P**) is shown, surrounded by its own external lamina. **Pericytes can proliferate to form smooth muscle cells when a capillary is transformed into an arteriole or venule after tissue injury and repair**. X13,000. (Figure 11–15b, reproduced, with permission, from Kelly DE, Wood RL, Enders AC (eds): Bailey's Textbook of Microscopic Anatomy, 18th ed. Williams & Wilkins, 1984. Reproduced, with permission, from Kelly D. E., Wood R.L., and Enders AC (eds): Bailey's Textbook of Microscopic Anatomy, 18th ed. Williams & Wilkins, 1984.)

Vaisseaux Types de capillaires



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 (fenestrae*) through the endothelial cells allow greater exchange across the endothelium. The external lamina 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** usually have a *wider diameter* than the other types of capillaries and *have discontinuities* between the endothelial cells, *large fenestrae* 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.

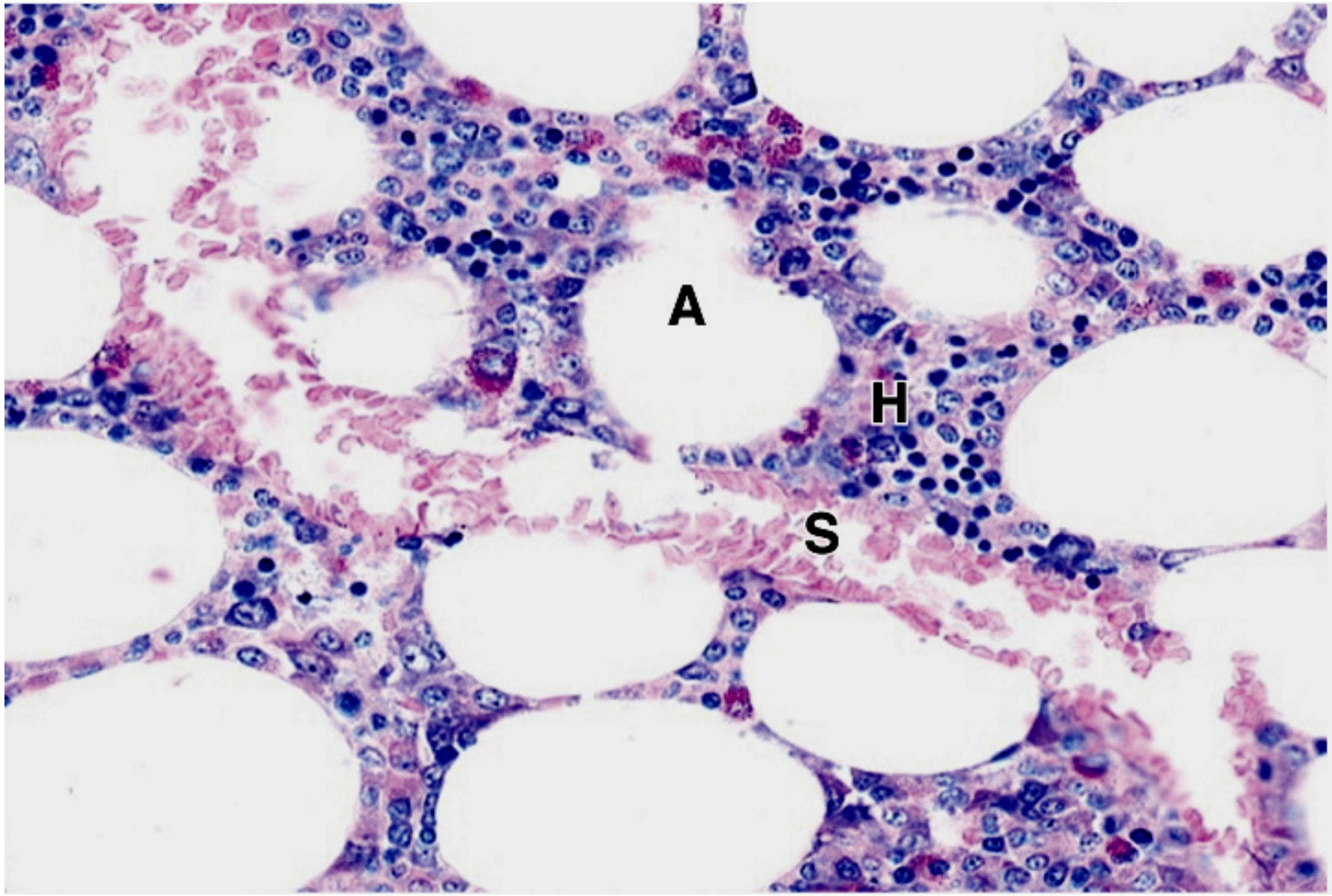
Vaisseaux Microscopie électronique d'un capillaire continu

Continuous capillaries exert the tightest control over what molecules leave across their walls. TEM shows a continuous capillary in transverse section. A nucleus (**N**) is prominent, but tight or occluding junctions along overlapping folds between two cells can also be seen (arrowheads). **Numerous transcytotic vesicles are evident** (small arrows). The long arrows show extensions of broad cytoplasmic sheets suggesting **phagocytosis**, which is consistent with the presence of vacuoles and electron—dense lysosomes. All material that crosses continuous capillary endothelium must pass through the cells, usually by **diffusion or transcytosis**. X10,000.

Vaisseaux Microscopie électronique d'un capillaire fenestré

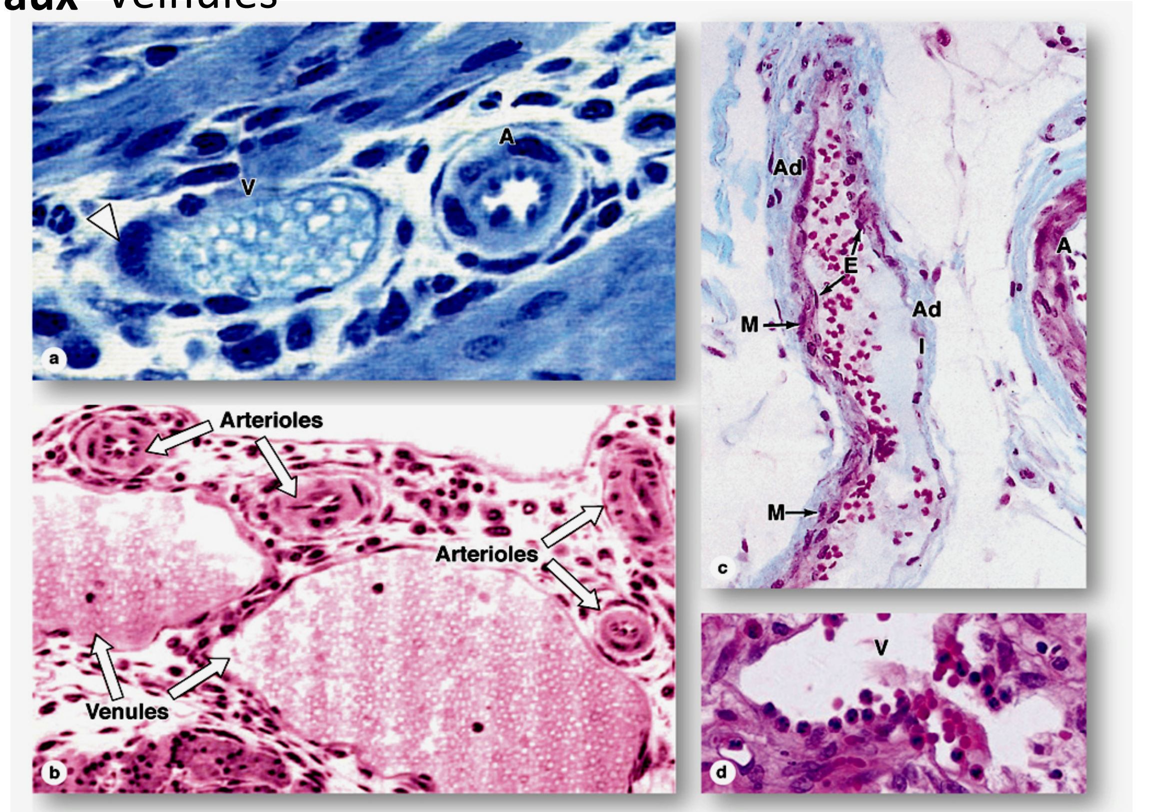
Fenestrated capillaries are specialized for uptake of molecules such as hormones in endocrine glands or for outflow of molecules such as in the kidney's filtration system. TEM of a transversely sectioned **fenestrated capillary in the peritubular region of the kidney** shows many typical **fenestrae closed by diaphragms** (arrows), with a continuous external lamina on the outer surface of the endothelial cell (double arrows). **The diaphragms contain heparan sulfate proteoglycans**, but their functional role is poorly understood at the molecular level. In this cell the Golgi apparatus (**G**), nucleus (**N**), and centrioles (**C**) can 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 Johannes Rhodin, Department of Cell Biology, New York University School of Medicine.)

Vaisseaux Capillaire sinusoïde



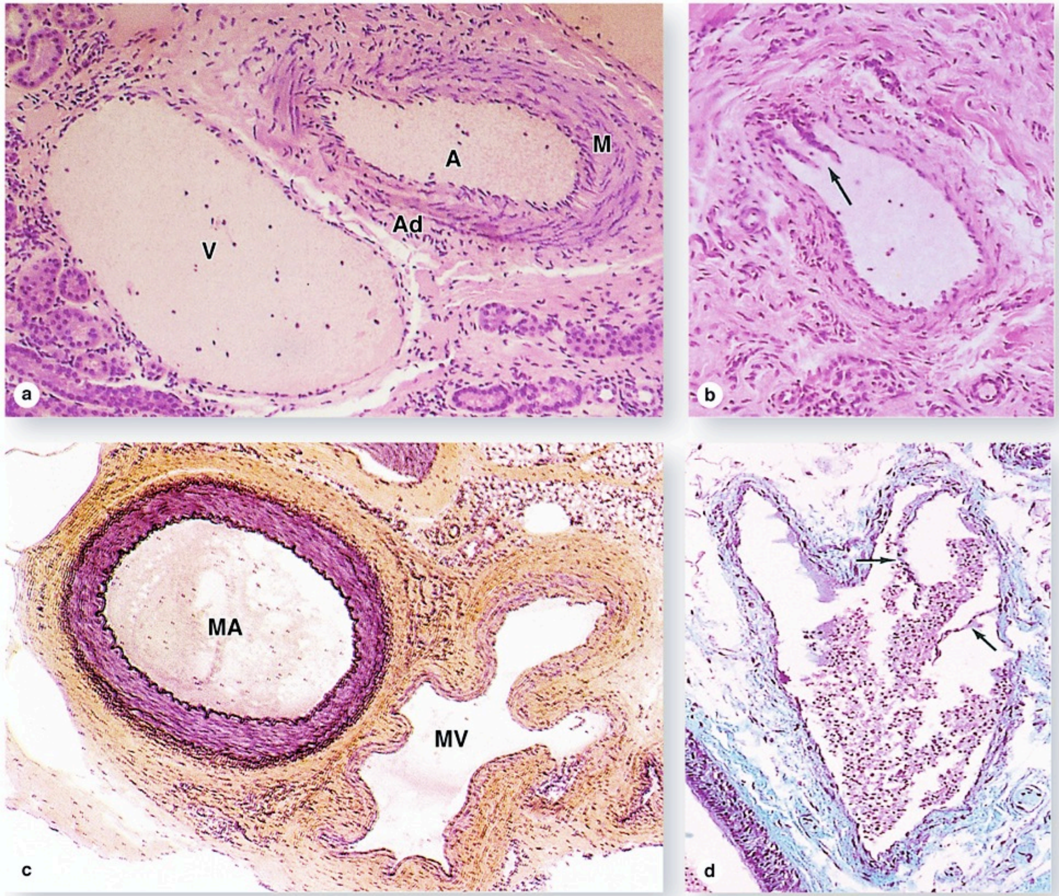
Sinusoidal capillaries or **sinusoid**s generally have *much greater diameters than most capillaries* and are specialized not only for maximal molecular exchange between blood and surrounding tissue, *but also for easy movement of blood cells across the endothelium*. The **sinusoid** (**S**) shown here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

Vaisseaux Veinules



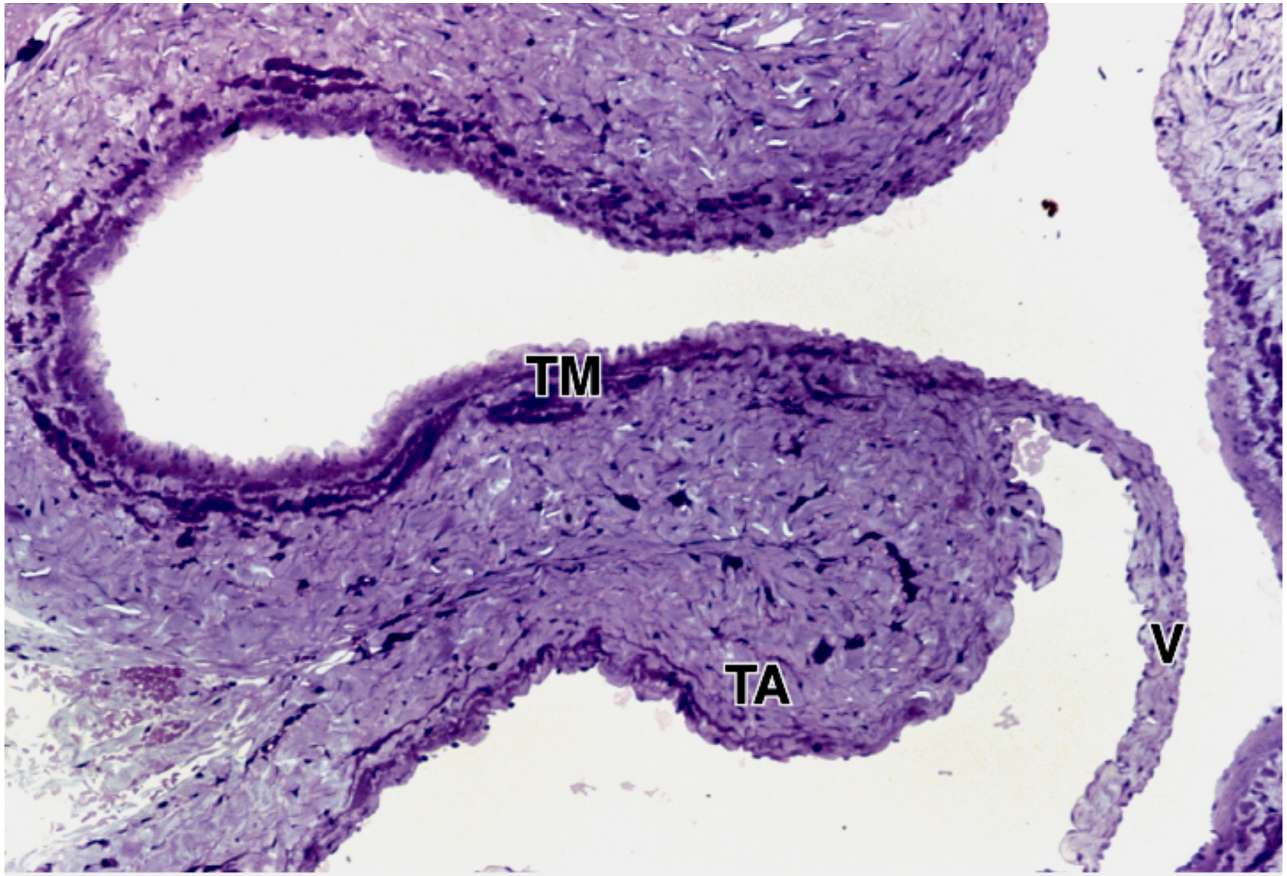
A series of increasingly larger and more organized venules lie between capillaries and veins. **(a): Postcapillary venules** resemble large capillaries, having only an endothelium *with occasional pericytes (arrowhead)*. Their lumens and overall diameters are greater than those of nearby arterioles. X400. TB. **(b): Large collecting venules** have much greater diameters than arterioles but the wall is still very thin, consisting of an endothelium with more *numerous pericytes or smooth muscle cells*. X200. TB. **(c): Muscular venule** has a better defined tunica media, with as many as three layers of smooth muscle (**M**) in some areas, a very thin intima (**I**) of endothelial cells (**E**), and a more distinct tunica adventitia (**Ad**). Part of an arteriole (**A**) is included for comparison. *Venules are the site in the vasculature where white blood cells leave the circulation to become functional in the interstitial space of surrounding tissues* when such tissues are inflamed or infected. Such conditions cause endothelial cells of venules to loosen intercellular junctions and express new protein receptors on their luminal surface. Surface proteins on passing leukocytes bind these receptors, causing the cells to stick to the endothelial cells in a process termed margination. This adhesion is quickly followed by emigration from the venule between endothelial cells. X200. Masson trichrome. **(d): Venule (V) from an infected small intestine** shows several leukocytes adhering to and migrating across the endothelium. X200. H&E.

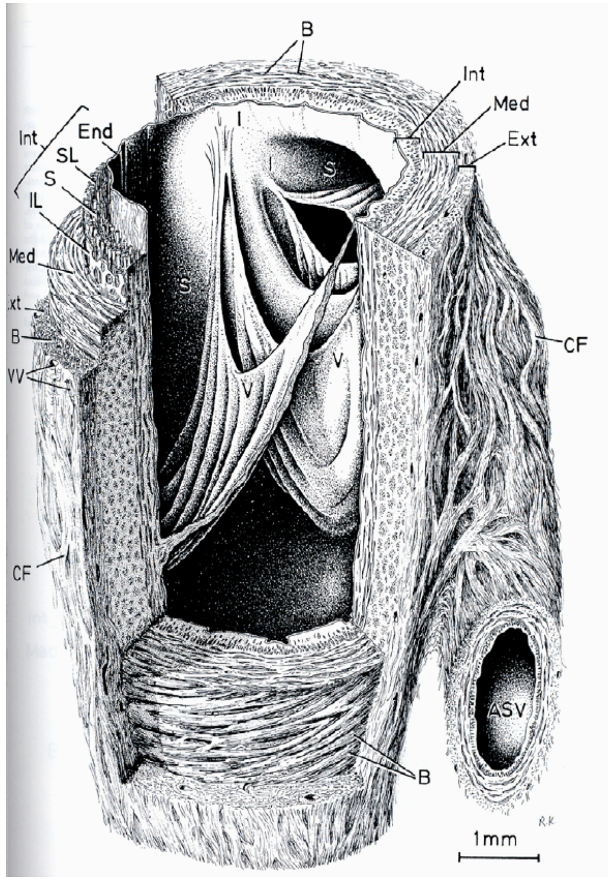
Vaisseaux Veines



Veins usually travel near 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 showing valves** (arrow). Valves are thin folds of tunica intima projecting well into the lumen which act to prevent backflow of blood. X200. H&E. **(c): Micrograph of a medium vein (MV) showing 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 containing blood and showing valve folds** (arrows). X200. Masson trichrome.

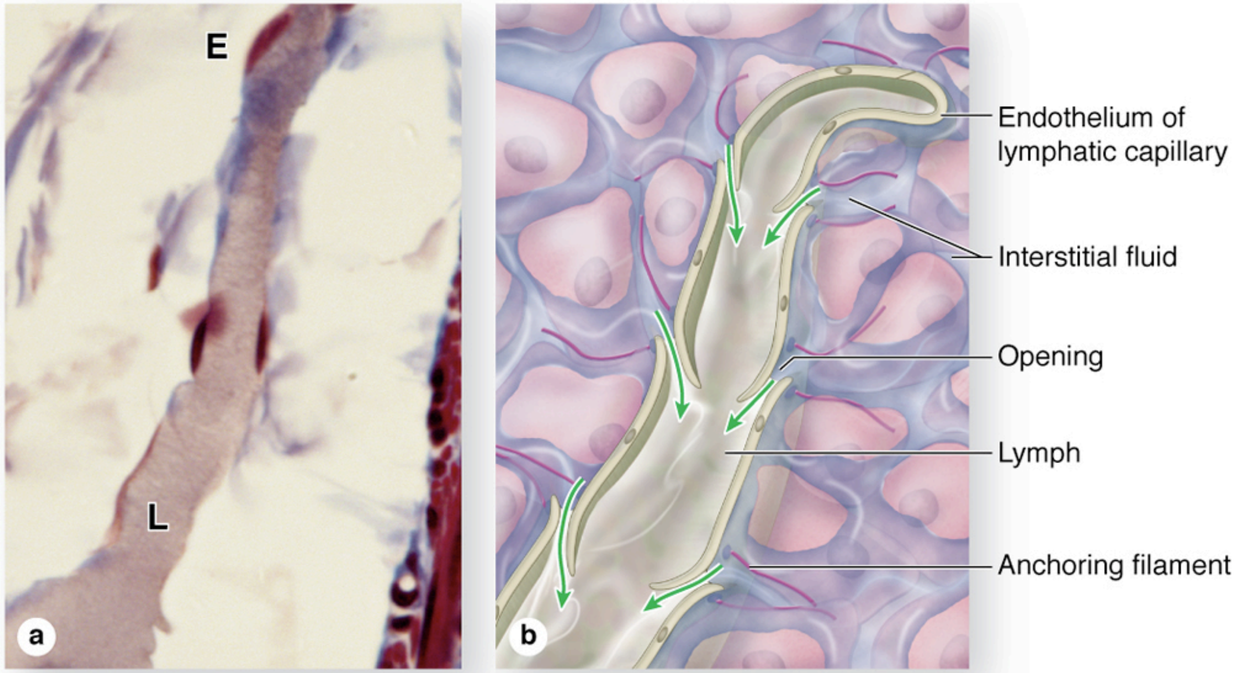
Vaisseaux Paroi de large veine avec valve



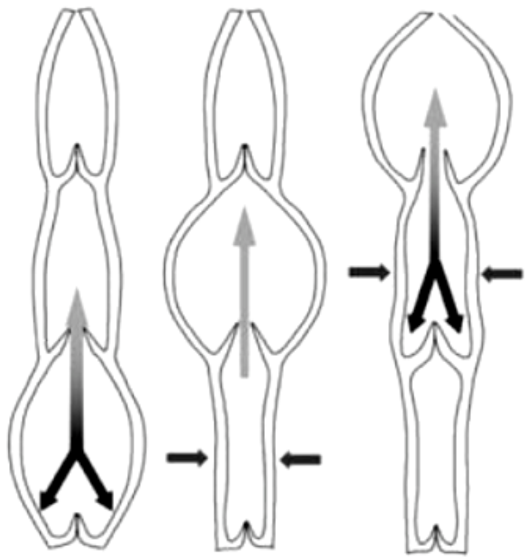


Large veins have a muscular tunica media that is very thin compared to the tunica adventitia composed of dense irregular connective tissue. The wall is often folded as shown here. The tunica intima here projects into the lumen as a valve, composed of the subendothelial connective tissue with endothelium on both sides. X100, PT.

Vaisseaux Capillaires lymphatiques

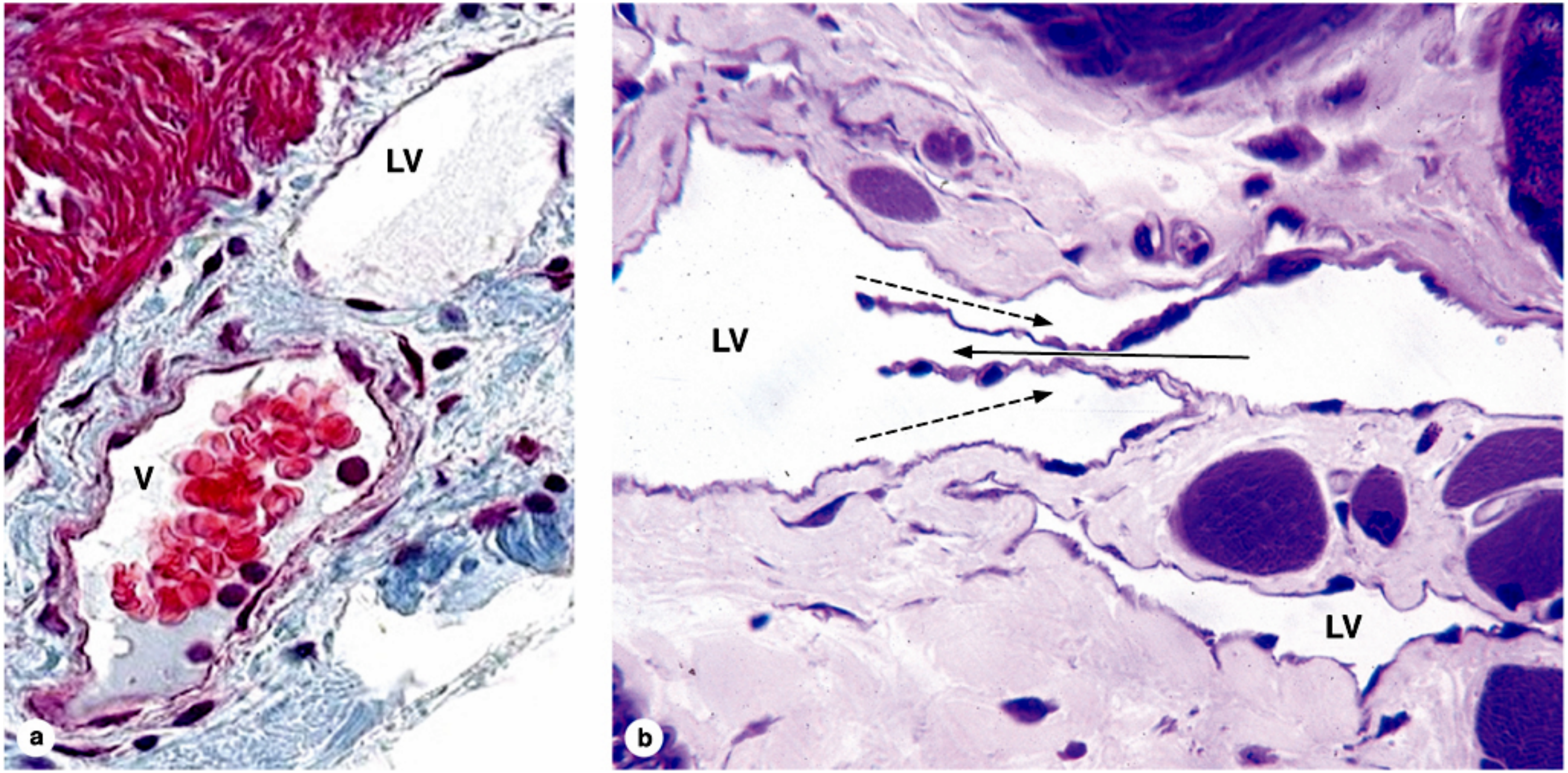


Lymphatic capillary



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 showing 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 details of lymphatics, including the openings between the endothelial cells.** The openings are held in place by anchoring filaments containing elastin and are covered by flaps of endothelium. 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 vessels.

Vaisseaux Vaisseaux lymphatiques avec valve



Lymphatic vessels are formed by the merger of lymphatic capillaries, but their walls remain extremely thin. (a): Cross—section showing 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 is cut longitudinally showing 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.