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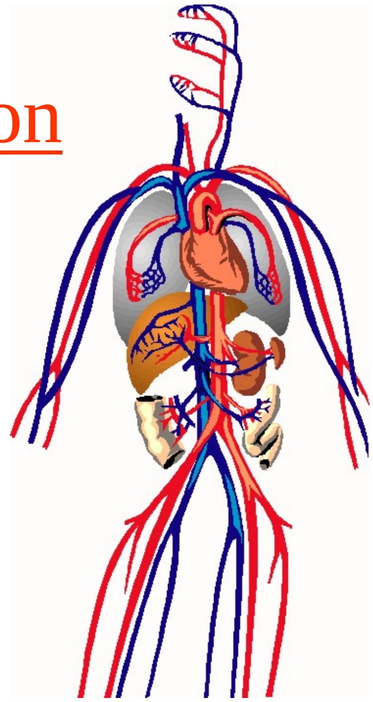
The Circulation

REVISED
8:56 pm, Feb 16, 2007



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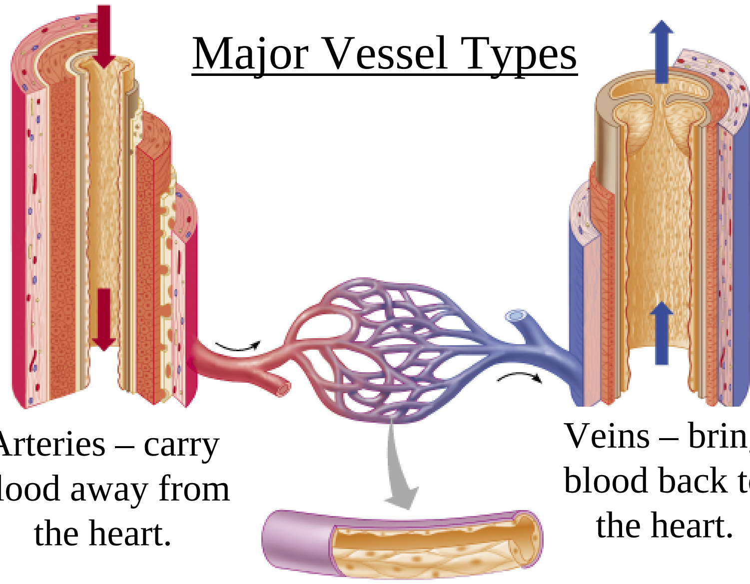
Major Vessel Types



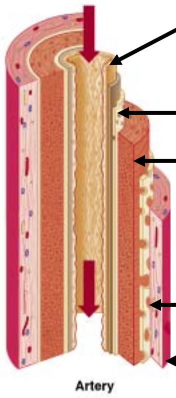
Arteries – carry blood away from the heart.

Veins – bring blood back to the heart.

Capillaries – allow transport between blood and tissues.

Figure 19.1

Arteries



Tunica intima (interna) - continuous endothelium lining the entire cardiovascular system

Internal elastic membrane

Tunica media - smooth muscle with some elastic tissue

External elastic membrane

Tunica adventitia - fibrous covering (externa)

3

Arteries carry blood away from the heart and are much thicker than veins due to the pressure they carry.

Elastic arteries - the aorta and its branches to the organs and tissue areas. Virtually all of the arteries listed in your objectives are elastic arteries. They are called **conducting arteries** because they conduct blood to these major areas. Along with the connective **tunica adventitia** (**externa**) and endothelial **tunica interna** (**intima**) elastic arteries have thick walls with a **tunica media** made of smooth muscle and elastic tissue, including an internal and sometimes an external elastic lamina. The elastic tissue enables these arteries to withstand the pulse pressure. In the largest arteries smooth muscle provides support in the arterial wall as elastic tissue damps (absorbs) the pulse pressure.

Aorta and its major branches .

Elastic Arteries

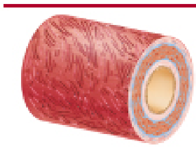
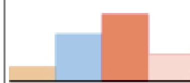
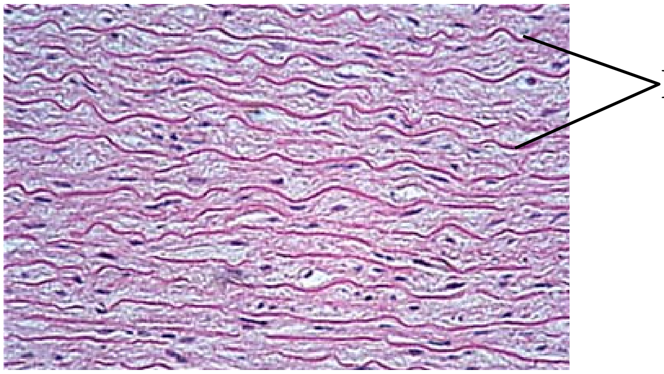
TABLE 20.1	Summary of Blood Vessel Anatomy				
Vessel type/ illustration	*Average lumen diameter (D) and wall thickness (T)*	*Relative tissue makeup*			
		Endothelium	*Elastic tissues*	*Smooth muscles*	*Fibrous (collagenous) tissues*
 Elastic artery	D: 1.5 cm T: 1.0 mm				

Table 20.1

- thick walls
- much elastic tissue- absorbs pulse pressure.
- smooth muscle layer for structural support
- called **conducting arteries** because they conduct blood to major body regions and organs.
- greatest pulse pressure

Abundant elastic tissue absorbs the pulse pressure and actually contributes to the onward flow of blood by its recoil. The aorta and its major branches are elastic arteries.

Tunica Media in the Aorta



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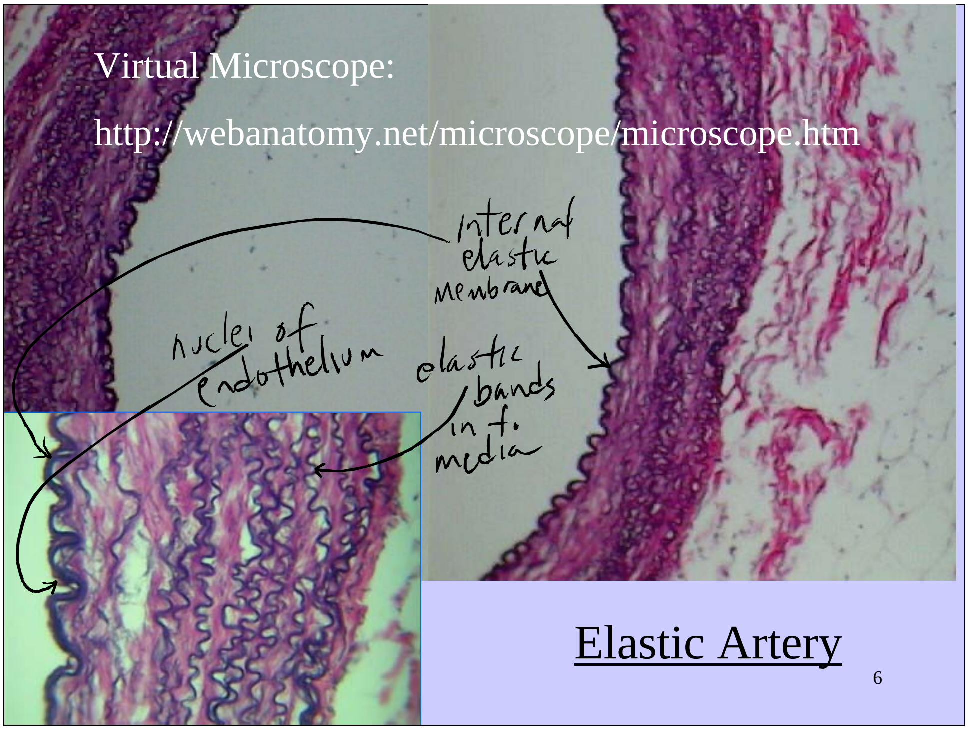
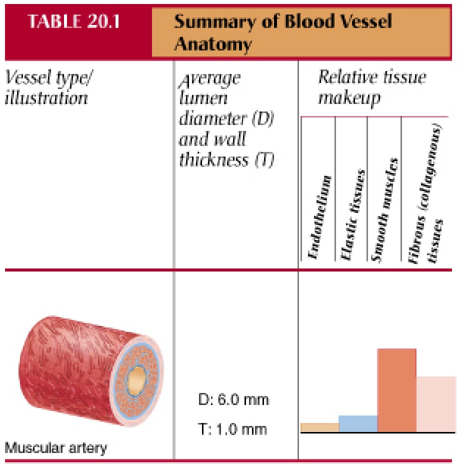
Distinct bands of elastic tissue are seen throughout the tunica media of the aorta and its largest distributaries.



Note the distinct internal elastic membrane and elastic tissue that is part of the tunica media.

Muscular Arteries

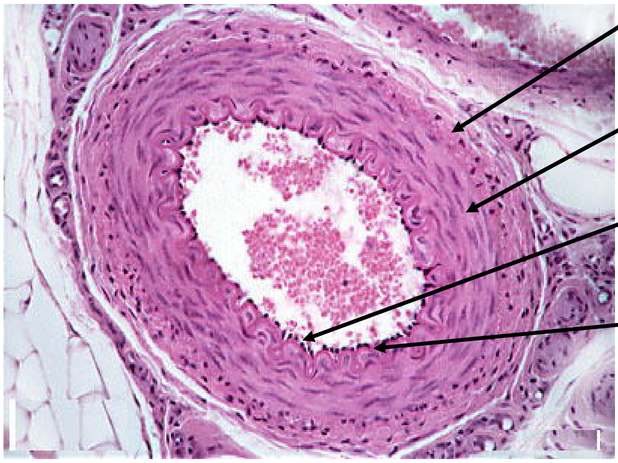


- little elastic tissue
- smooth muscle layer important for vasoconstriction to regulate blood pressure
- called **distributing arteries** because they distribute blood within tissues and organs.
- reduced pulse pressure

7

Smaller **muscular arteries** are the distributing vessels which carry blood into an organ and tissue area. They have little or no elastic tissue, experience much less pulse pressure, but their muscle is important for vasoconstriction in regulating blood pressure. The pulse pressure has significantly declined when the blood enters the muscular arteries within organs. Elastic tissue becomes less important in favor of smooth muscle to regulate blood flow through vasoconstriction and dilation.

A Medium Size Artery



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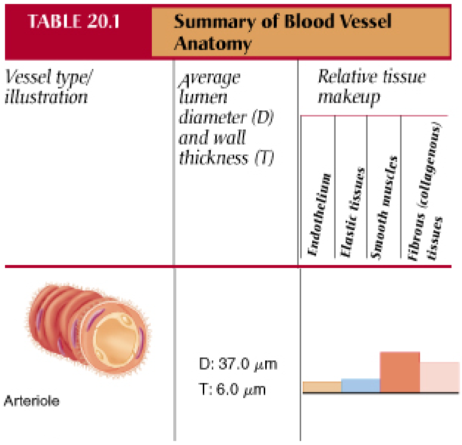
This would be one of the larger muscular arteries which still has a significant amount of elastic tissue. Note the distinct convoluted appearance of the **internal elastic membrane**.

Arterioles

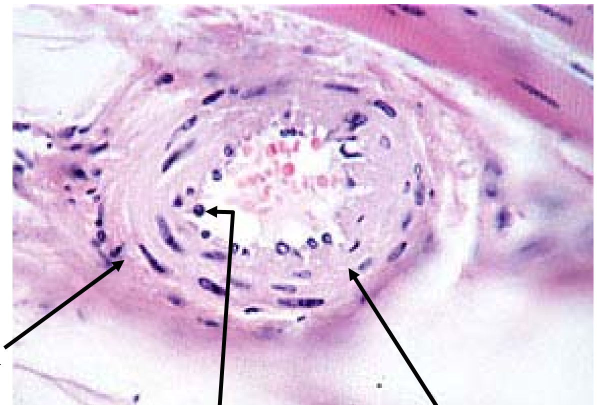


- very thin, little except endothelium and smooth muscle
- smooth muscle in bands important in regulating blood flow
- pulse pressure disappears

9

Arterioles are the smallest arteries and are the most important in regulating blood flow into the various capillary beds through smooth muscle bands in the arterioles and at the entrance to capillaries.

An Arteriole



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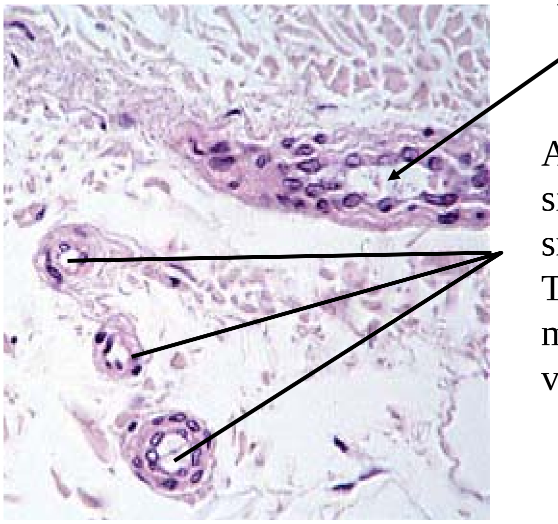
Little is left of the vascular wall except the endothelium and a small amount of smooth muscle. A remnant of adventitia holds the wall together.

Arterioles



Arterioles vary in size and amount of smooth muscle. Their smooth muscle functions in vasoconstriction.

11

Smaller arterioles have even less in their walls than that seen in the previous slide.

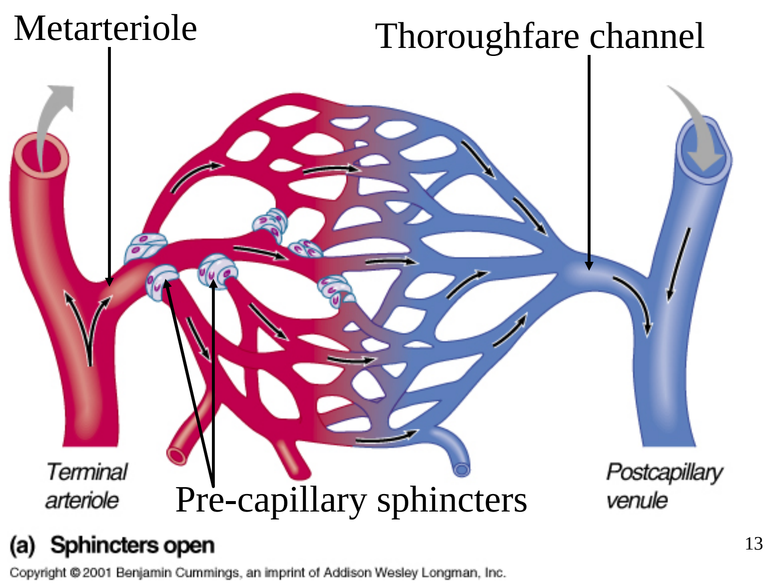
Arteriovenous Anastomosis

A vessel that directly interconnects an artery and a vein, and that acts as a shunt to bypass the capillary bed.

12

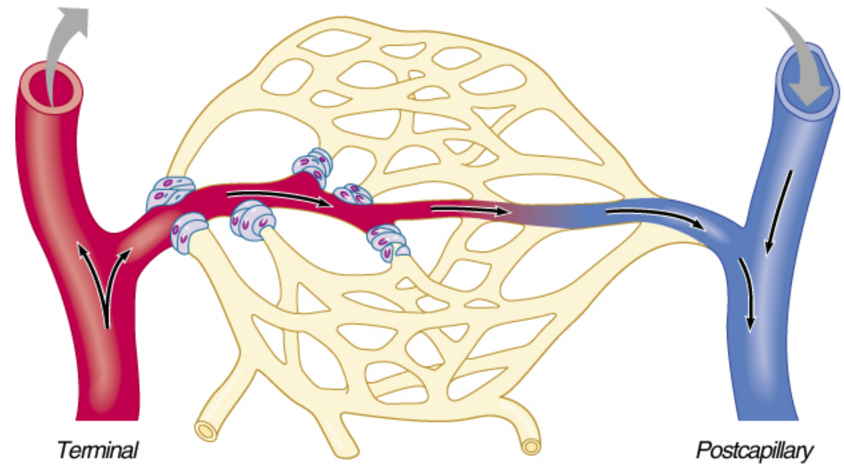
Arteriovenous anastomoses are found in the skin and GI tract and other places where under certain conditions the capillaries must be bypassed in favor of venous return.

The Role of a Metarteriole: Capillaries Open



Metarterioles are arteriovenous anastomoses. They allow blood to enter the capillary bed when pre-capillary sphincters are open…

The Role of a Metarteriole: Capillaries Bypassed



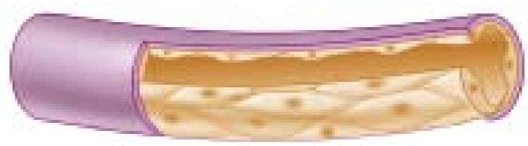
…and they act as a shunt to bypass capillary beds when the sphincters are closed.

Capillaries

TABLE 20.1 Summary of Blood Vessel Anatomy

Vessel type/ illustration	*Average lumen diameter (D) and wall thickness (T)*	*Relative tissue makeup*			
		Endothelium	*Elastic tissues*	*Smooth muscles*	*Fibrous (collagenous) tissues*
 Capillary	D: 9.0 μm T: 0.5 μm				

- only endothelial cells – thinnest walls (including basement membrane)
- tight junctions of varying permeability
- no pulse pressure



15

Capillaries: These are the thinnest vessels, functioning to allow transport through their walls to and from the blood and tissues. They come in several types:

1) Continuous capillaries – tight junctions restrict transport. Found in most tissues and organs, e.g. brain, skeletal muscle, etc.

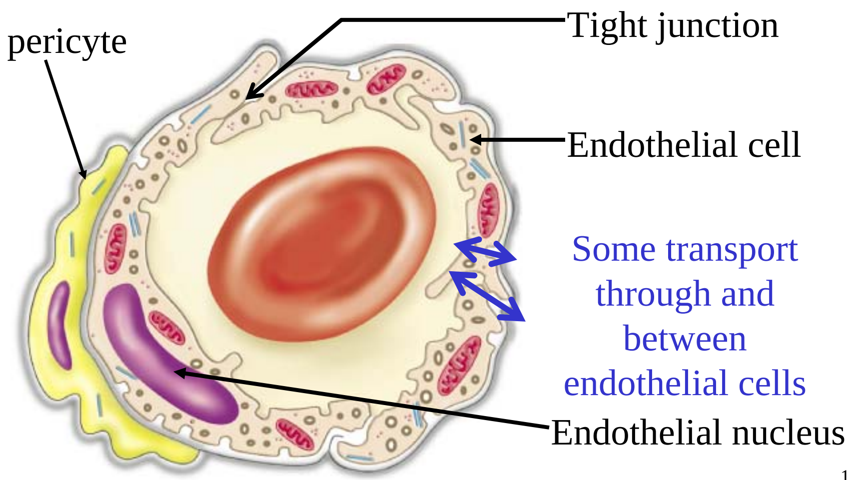


Figure 19.3

16

Continuous capillaries are formed of a single layer of simple squamous epithelium, a continuation of the endothelial lining, held together by tight junctions allowing only small molecules to pass. They are found in the brain, muscles, the skin, the lungs and many other organs.

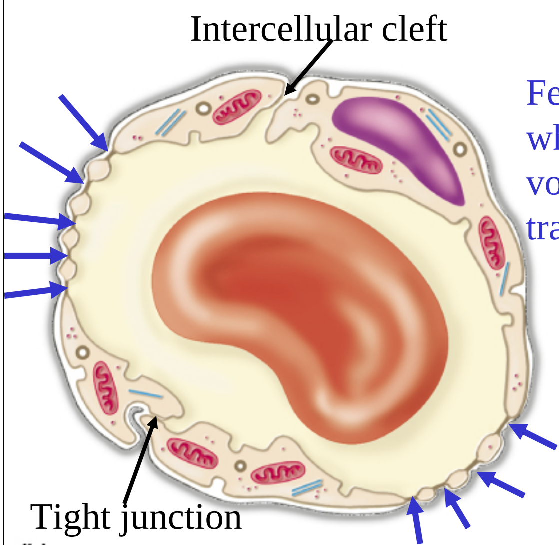
Continuous Capillary in Skeletal Muscle

Red blood cells

17

Note that rbc can pass through these continuous capillaries one cell at a time.

Fenestrated Capillaries



Fenestrations – pores which increase the volume and rate of transport.

Found in glands, GI lining, glomerulus in kidneys.

18

Fenestrated capillaries have pores to increase transport. They are found in the absorptive capillaries in the GI tract, in glands, in the glomerulus of kidneys, etc.

A Fenestrated Capillary

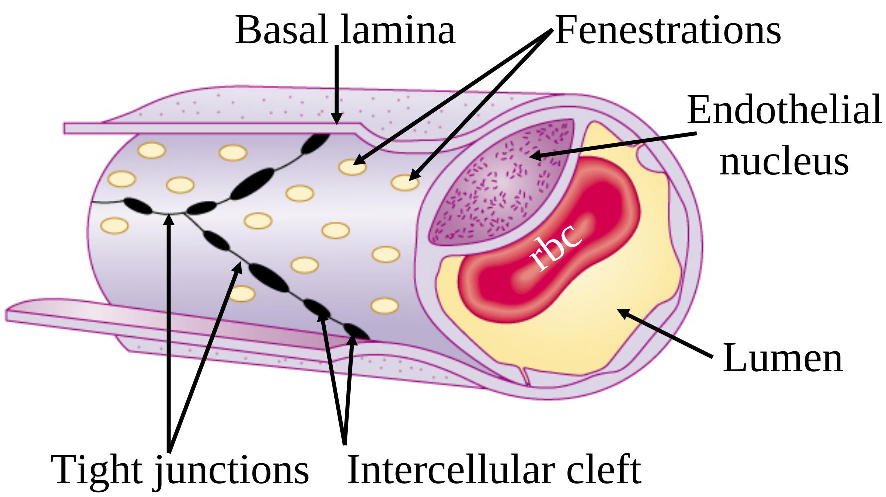
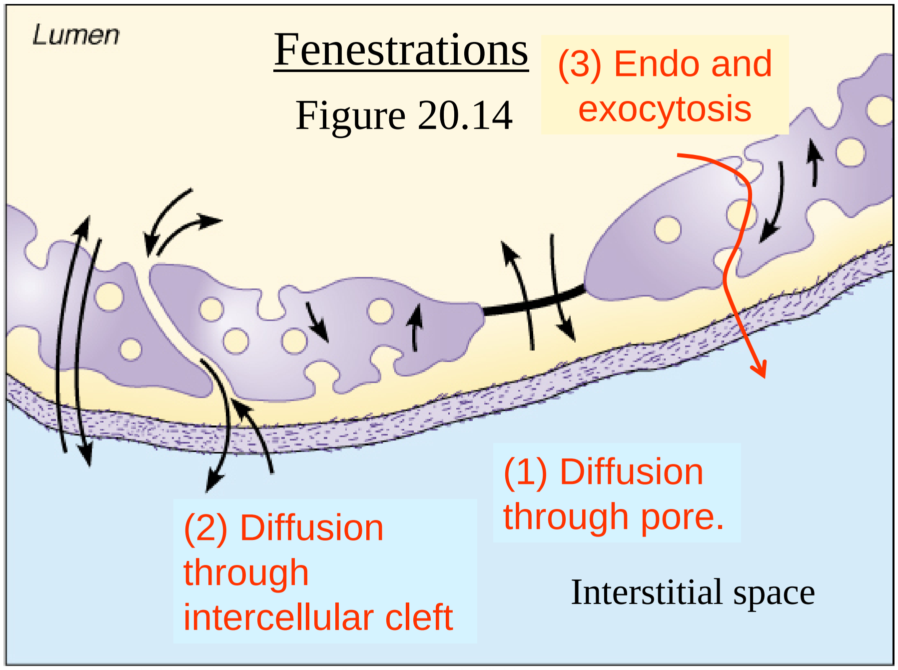


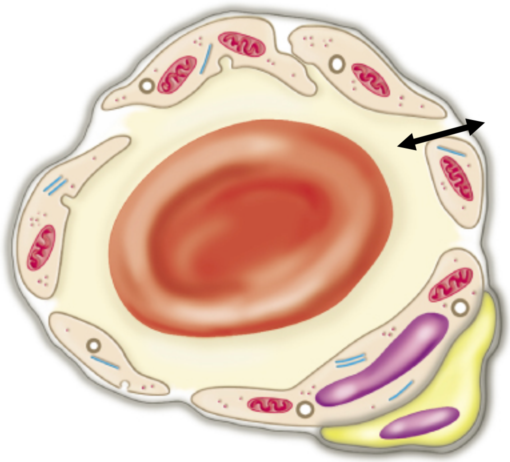
Figure 19.14 a



This diagram shows the way in which substances are transported through the fenestrations (pores) in the capillary endothelium, and then must pass through endothelial basement membrane to enter interstitial space (1). Substances can also pass through intercellular clefts (2), and some substances pass through capillary wall by endo and exocytosis. In each case the basement membrane plays a role in what is transported into the interstitial space.

Discontinuous Capillaries

(Sinusoids)

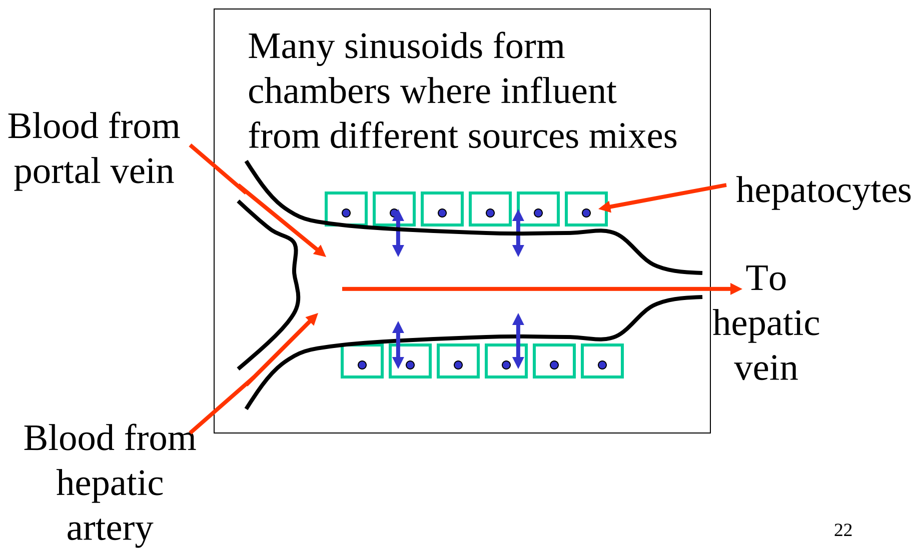


Much larger intercellular clefts permit large molecules as well as red and white blood cells to pass between sinusoids and interstitial space.

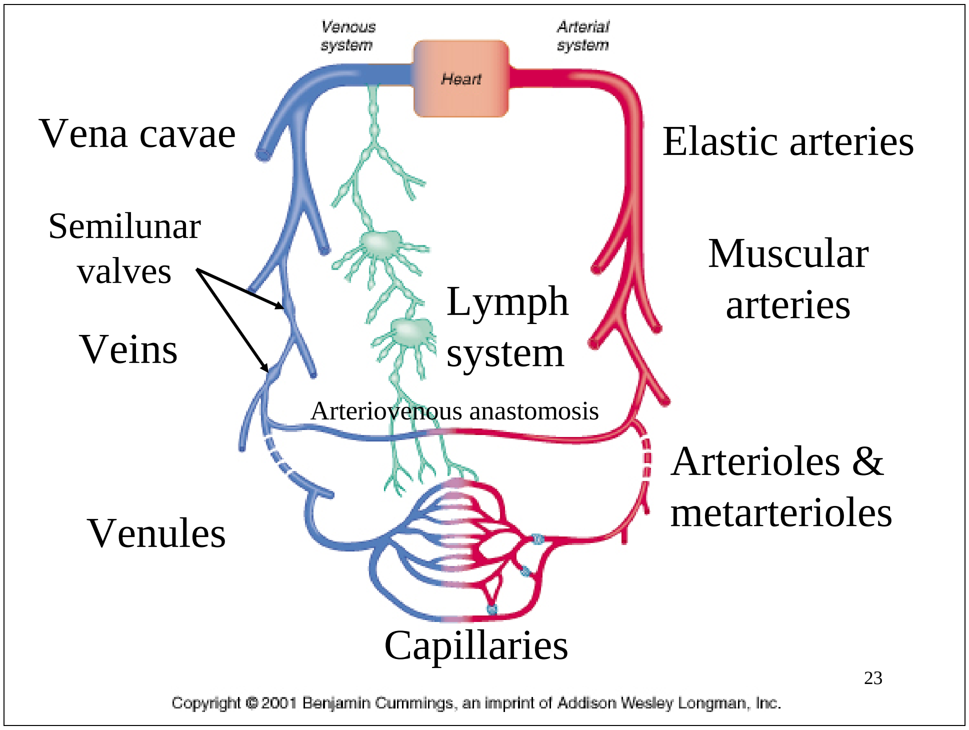
Found in the liver, spleen, lymph nodes, and certain glands.

Sinusoids are found only in certain locations such as the liver, spleen, lymph nodes, and certain glands. Sinusoids often allow influent from different sources to mix in the loose-walled passages.

Sinusoids in the Liver



In the liver blood from the hepatic portal vein (deoxygenated, carrying digestive end-products) and blood from the hepatic artery (oxygenated) mix and pass through the sinusoids where the hepatocytes processes nutrients and wastes from the blood.

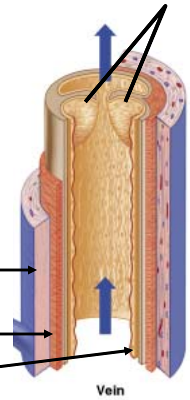


The lymph system is an accessory to the circulation functioning to return excess fluid filtered into the interstitial space back to the circulation. The lymph system also contains lymph nodes and other tissue in which mature lymphocytes proliferate.

<u>The Venous System</u>

- thinner walls than arteries
- little tunica media
- little elastic tissue
- semilunar valves in large veins

Semilunar valves



t. Adventitia

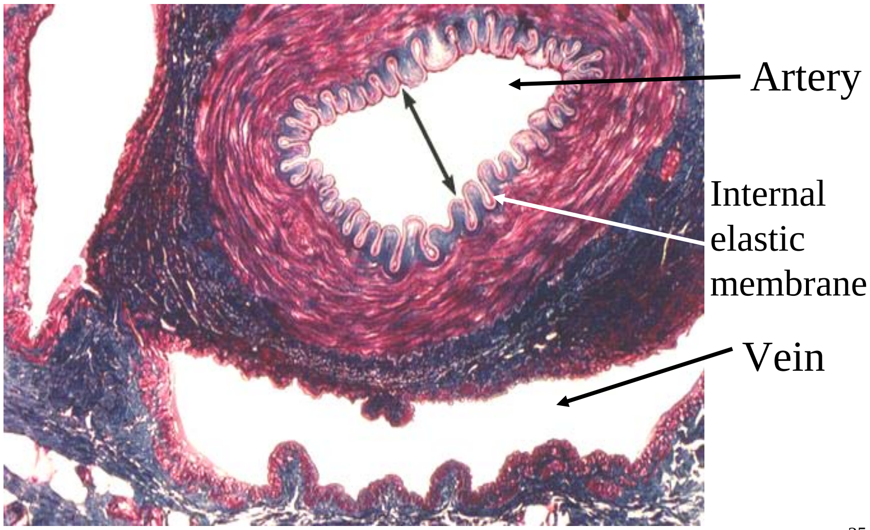
t. Media

t. interna

24

Blood leaving the capillaries returns to the heart through the venous system, beginning with **venules** and progressing to larger and larger veins which lead to the superior and inferior vena cavae which enter the right atrium. These veins are low resistance conduits back to the heart. They are thin walled, usually flowing partially collapsed, and are larger in internal diameter that arteries and the same level. The pressure in veins is very low and actually dips below zero during right ventricular diastole. At rest about 60% of your total blood volume is in your systemic veins, this blood acting as a reservoir which can be moved into the systemic arterial system to distribute to the muscles or skin during exercise. Exercise stimulates venous return (and lymph return) through the **skeletal muscular pump** and the semilunar valves of the large veins and lymph vessels.

Artery and Vein



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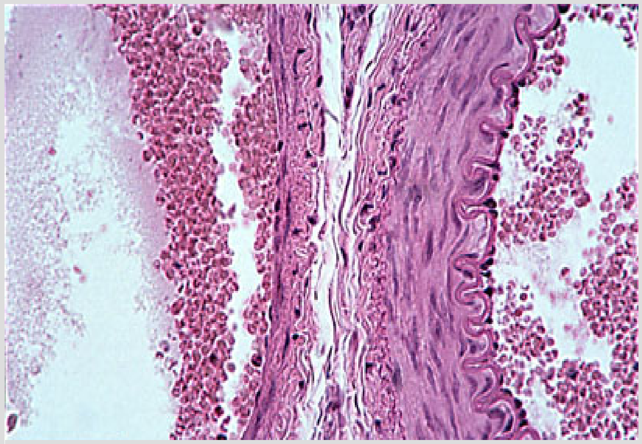
In the comparison between artery and vein note the significantly thinner wall of the vein and distinctive internal elastic membrane of the artery. Note the collapsed shape typical of veins.

Comparison of Artery and Vein

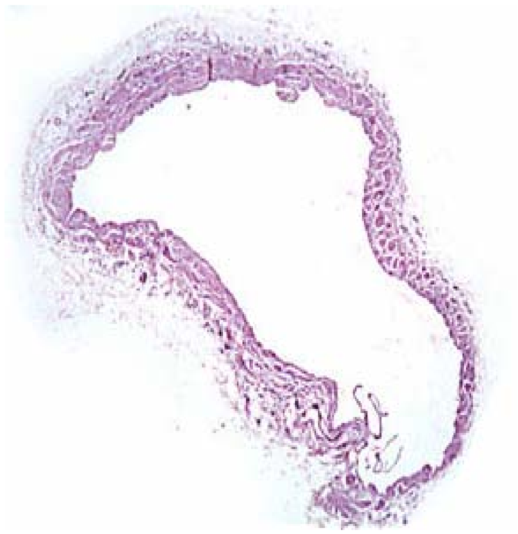


Which is the artery and which the vein?

26

The artery is the one with the thicker wall and visible elastic membrane.
The vein has the very thin wall, and little tunica media.

The Thoracic Lymph Duct

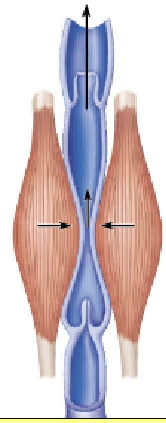


Lymphatic vessels and ducts are like veins, but much thinner, with poorly organized tissues in their walls.

27

The lymph vessels and ducts are very thin, and have very disorganized structure. For this reason they cannot be visualized in dissection unless injected first with dye.

Figure 19.6 The Muscular Pump

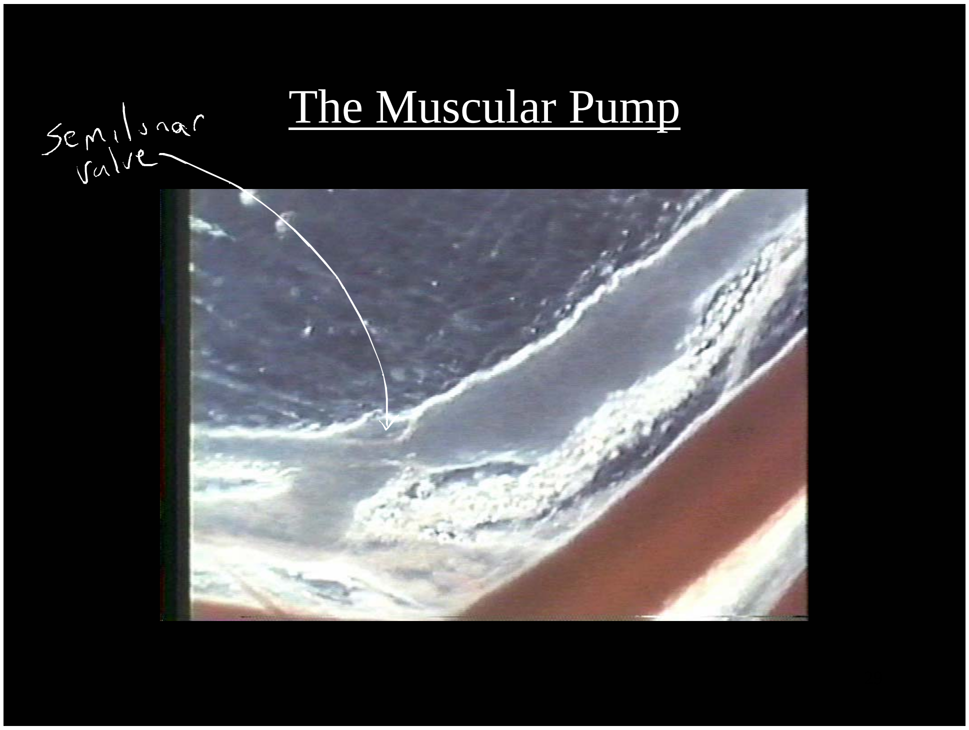


- Relies on the semilunar valves of the large veins
- Moves blood toward heart when muscles contract
- Moves blood out of the venous reservoir during exercise

60% of the blood volume at rest is present in the large systemic veins.

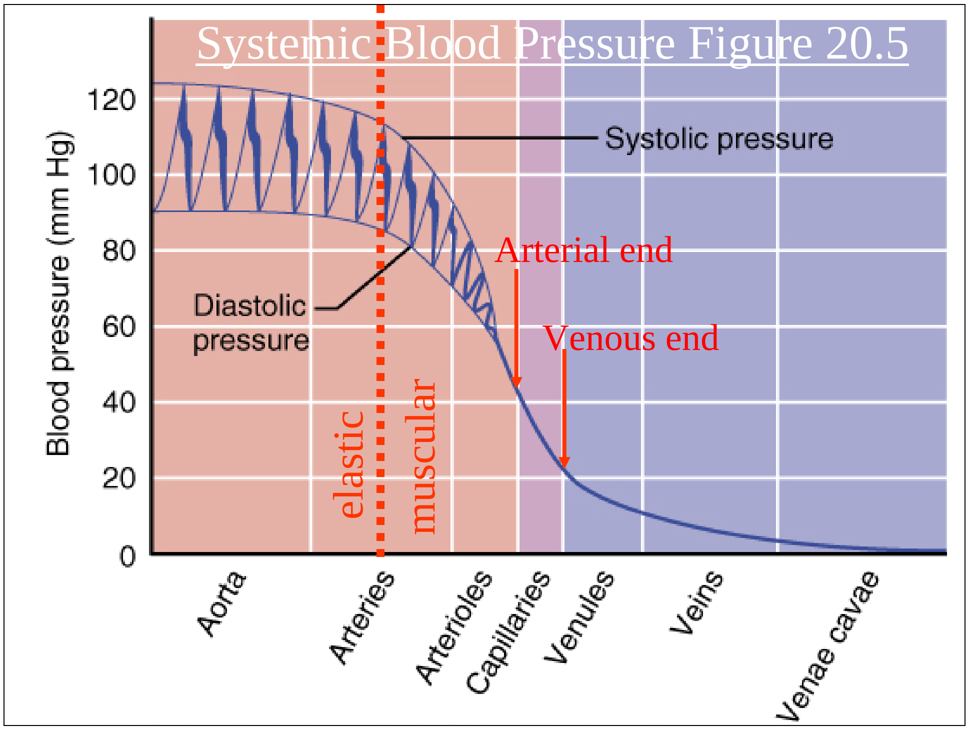
28

60% of the blood volume at rest in present in the large systemic veins. This blood is moved out of this venous reservoir to be pumped out to muscles and the skin during exercise.



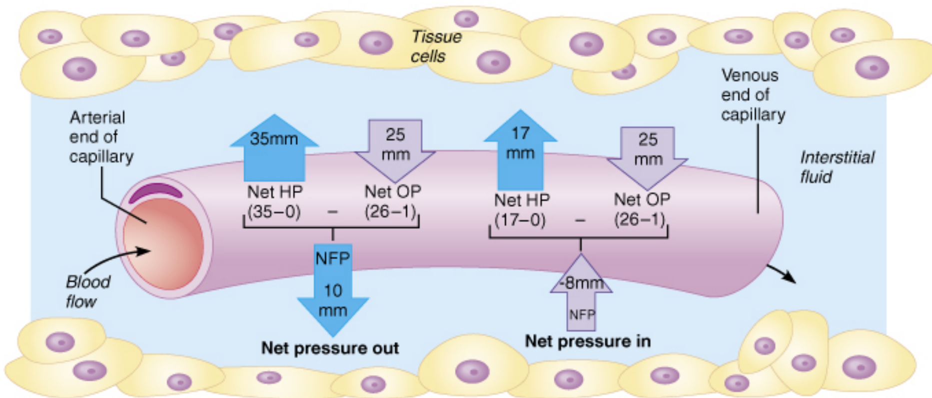
This video shows a lymph vein as it “pumps” the lymph forward when adjacent muscles contract. The muscular pump works the same way in the veins of the cirulation.

Video Clip: Muscular Pump



Mean blood pressure is greatest in the aorta and the large elastic arteries. They also experience the greatest pulse pressure. Pulse pressure and average pressure decline as the blood enters the smaller muscular arteries and disappears within the arterioles. The capillaries have no pulse pressure! Capillary pressure is highest at their arterial ends and declines precipitously to their venous end. In the venous system the slope of decline ebbs and lowest pressure is seen in the vena cave. In fact the pressure goes below zero (a negative or pulling pressure) when the ventricle relaxes.

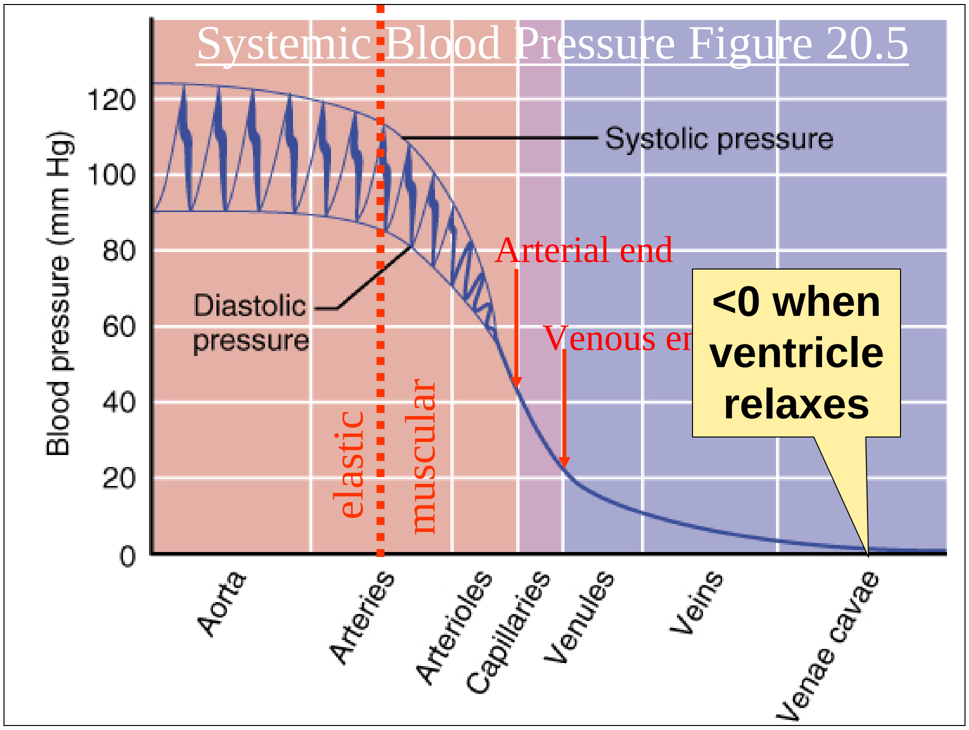
Starlings Law of the Capillaries



Filtration – hydrostatic pressure forces water and dissolved substances out of the blood into the interstitial space.

31

Hydrostatic pressure is greatest at the arterial end of capillaries. This forces water and dissolved substances out into the interstitial fluid. Net filtration pressure (NFP=Hydrostatic Pressure – Osmotic Pressure) is 10 mmHg. As fluid is lost the hydrostatic pressure decreases, becoming only 17 mmHg at the venous end. If you assume that osmotic pressure remains the same (it doesn't!) there is now an inward pressure of 8 mmHg, (NFP=-8). This returns most, but not all, of the lost fluid to the circulation. The remainder must be collected and returned by the lymphatic system.



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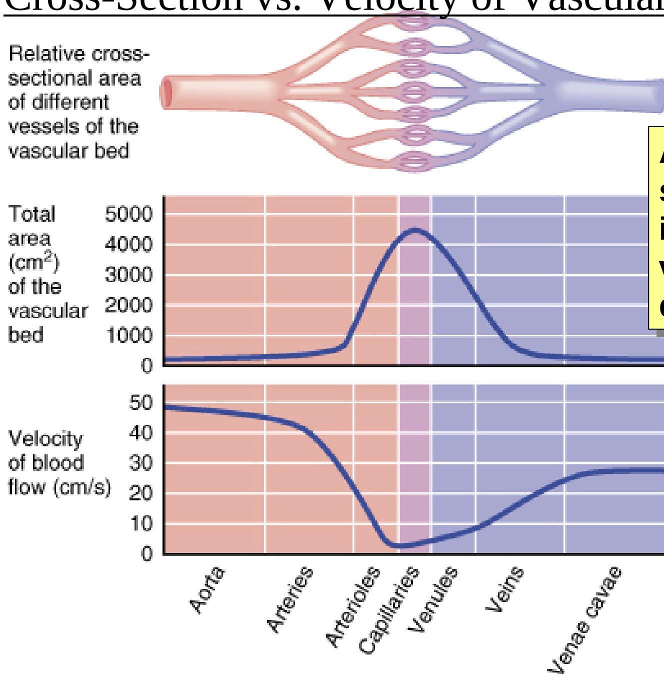
Cross-Section vs. Velocity of Vascular Comonents



As cross sectional area increase, velocity decreases.

33

Cross sectional area is greatest in the capillary component, producing the slowest velocity. This facilitates transport from capillaries to interstitial fluid. Cross sectional areas are lower, and velocities higher, in the arteries and veins. Since the cross-sectiional area corresponds geometrically to the surface area of the vessel, the capillaries also have the greatest contact surface area, about 50 square meters in both the systemic tissues and the lungs.

Atherosclerosis

•Fatty cholesterol-containing (LDL-cholesterol) plaque develops along the lining of arteries.

•Damage to vessel walls, e.g. from hypertension, smoking, etc. causes LDL-cholesterol to enter vascular wall and become oxidized.

•Macrophages responding to this cause inflammation and begin to accumulate abundant LDL-cholesterol.

•Smooth muscle cells grow into the lining and form the framework of the plaque incorporating the fat-laden macrophages.

Arteriosclerosis

- Hardening of the arteries due to calcification.
- Makes walls inflexible, increases blood pressure.
- Often found together with atherosclerosis.

35

Ischemia - reduced oxygen supply to tissue.

- Angina pectoris in heart
- TIAs (transient ischemic attack) in brain

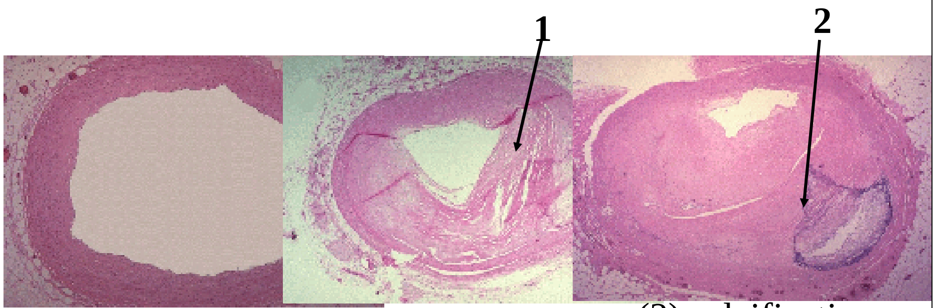
Thrombosis – development of a clot (thrombus) due to exposure to collagen, etc.

- Coronary thrombosis leading to myocardial infarction (heart attack)
- Stroke (brain attack)

36

This plaque reduces the blood causing ischemia (reduced oxygenated blood supply). When this happens in the coronary arteries of the heart it leads to impaired myocardial metabolism. Myocardial cells cannot function without oxygen quickly forming lactic acid and becoming fatigued. The lactic acid produces the burning felt as chest pain. In the brain the result is TIAs, Transient Ischemic Attacks with symptoms of dizziness or fainting, visual impairment, slurred speech, etc. Damage to the endothelium exposes the blood to collagen plus other clot-stimulating chemicals. This encourages the formation of a clot or **thrombus** which can totally block oxygenated blood flow. This results in **myocardial infarction** in the coronary arteries, a heart attack. (Infarction means tissue death resulting from inadequate oxygenated blood supply.) In the brain, infarction causes a stroke, now often called a "brain attack".

Coronary Artery Disease



A normal coronary artery.

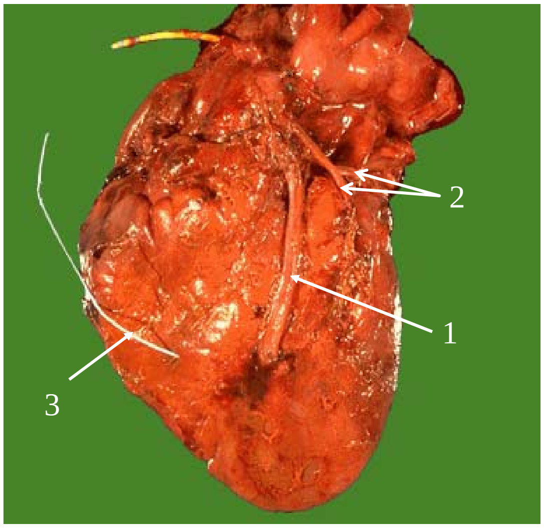
(1) Atherosclerotic plaque.

(2) calcification

37

Note how the smooth muscle has incorporated itself into the fatty plaque to become part of the arterial wall in (1). Calcium deposition has further reduced the lumen and flexibility in (2).

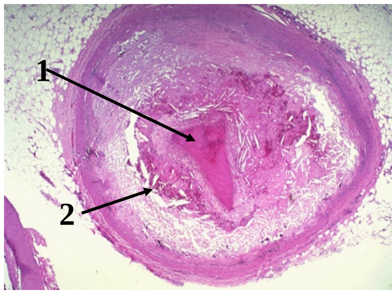
Coronary Artery Bypass

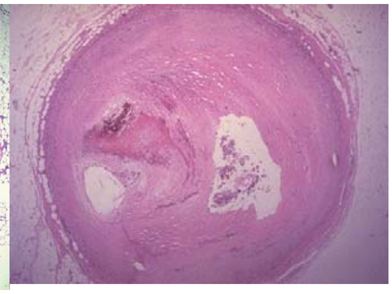


Autogenous (derived from oneself, the saphenous vein) grafts. A white temporary pacing wire (3) extends from the mid left surface.

38

Coronary Thrombosis





(1) recent thrombosis

(2) cholesterol clefts.

Re-canalization leaves only two small, narrow channels.

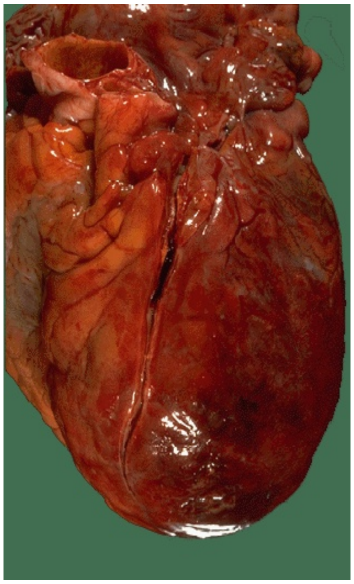
39

Myocardial Infarction

Necrotic muscle appears yellow-tan. Surrounding this is a zone of red hyperemia. Remaining viable myocardium is reddish- brown.

40

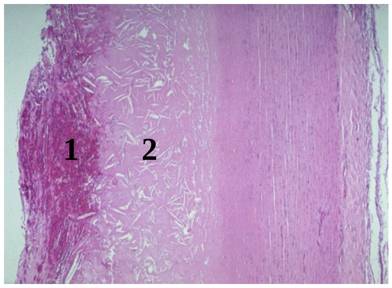
Coronary Thrombosis with Infarction

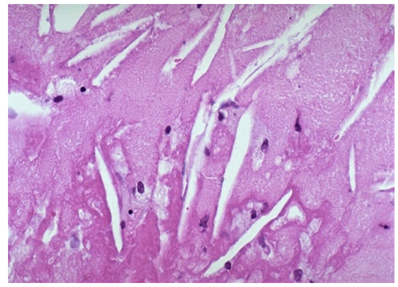


The anterior surface of the heart demonstrates an opened left anterior descending coronary artery. Within the lumen of the coronary can be seen a dark red recent coronary thrombosis.

41

Aortic Atheromas





(1) Atheroma

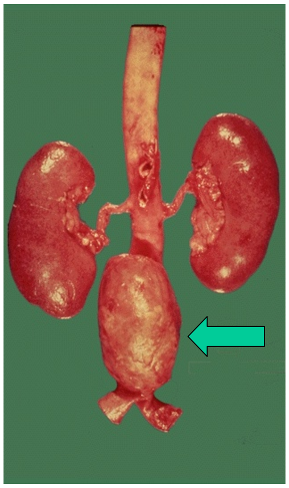
(2) Cholesterol clefts

The surface on the far left shows ulceration and hemorrhage.

Aortic atheroma with foam cells and cholesterol clefts (the white radiating streaks).

42

Aortic Aneurysm



43

Here is an example of an atherosclerotic aneurysm of the aorta in which a large "bulge" appears just above the aortic bifurcation.Such aneurysms are prone to rupture when they reach about 6 to 7 cm in size. They may be palpated as a pulsating mass in the abdomen. Many such aneurysms are conveniently located below the renal arteries so that surgical resection can be performed with placement of a dacron graft.

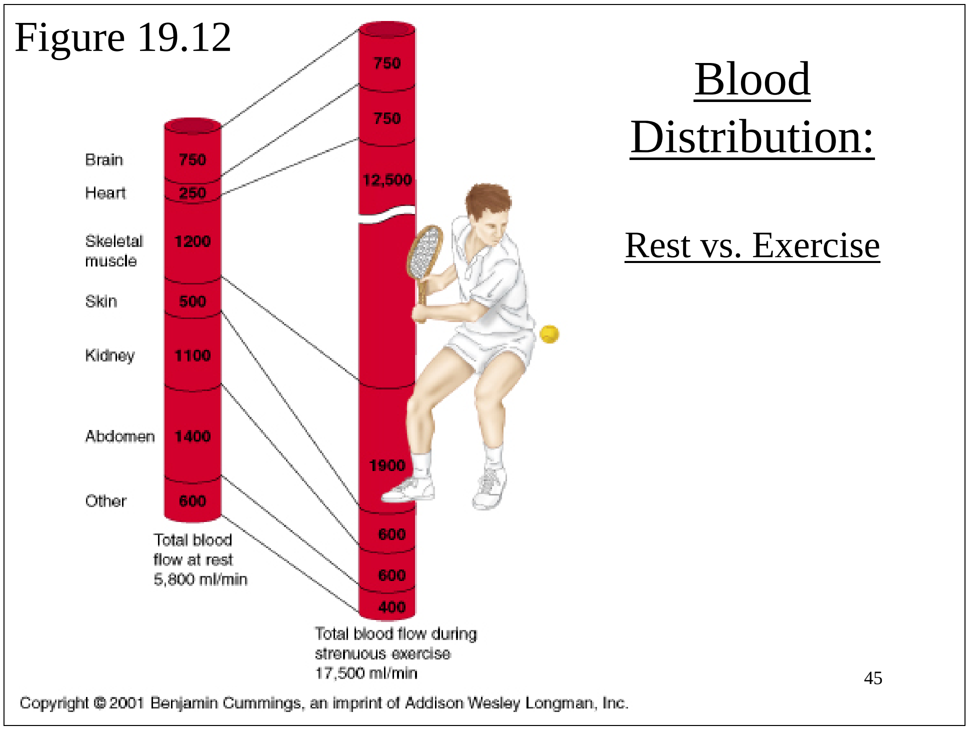
Varicose Veins - stretched veins and semilunar valves.

- Hereditary malformations exacerbated by standing for long periods and sedentary lifestyle
- "spider veins" seen under the skin
- hemorrhoids in the rectum
- esophageal varicies in alcoholics.

Phlebitis – inflammation of a vein, often with thrombosis.

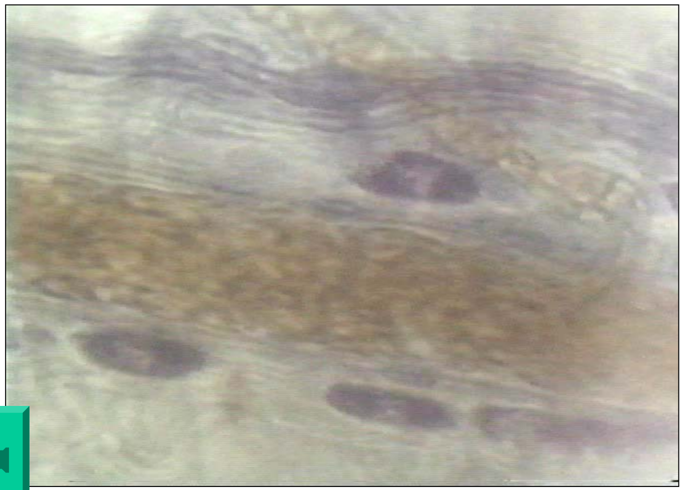
44

Varicose veins are hereditary malformations in which the veins and/or their semilunar valves are stretched and ineffective in returning blood to the heart. The condition is exacerbated by standing for long periods, or other activities which allow the blood to pool due to inertia. A sedentary lifestyle also contributes because exercise is an important component in venous return via the muscular pump. (See Figure 19.6) Varicose veins also form the "spider veins" seen under the skin, hemorrhoids when they occur in the large intestine, and esophageal varicies in alcoholics. Varicose veins usually lead to **phlebitis** and subsequent **thrombosis**.



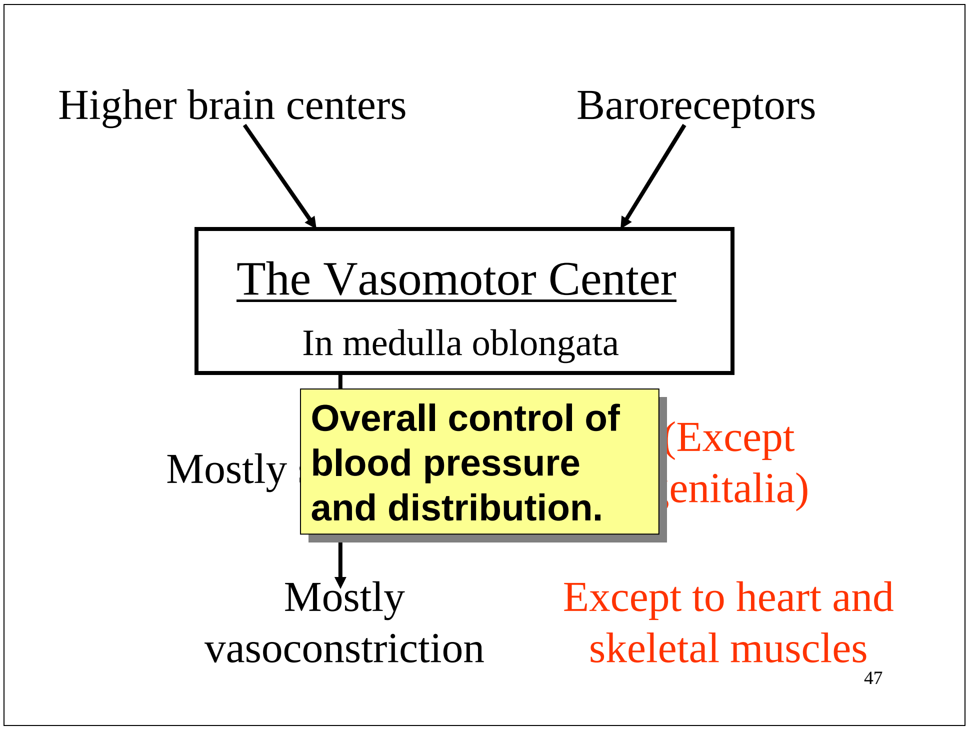
Examining Figure 19.12 shows how blood is distributed at rest and compares it to the distribution with exercise. Notice that distribution to the brain does not change, while much more blood goes to the muscles and the skin at the expense of the kidneys and GI tract. A very important component which provides blood for this redistribution is the venous reservoir.

Blood Flow and Distribution



46

Check the video clip on the [**Blood Flow**] to see how blood is moved from one place to another.



The vasomotor center in the medulla of the brain is responsible for the overall control of blood distribution and pressure throughout the body. Impulses from the vasomotor center are mostly in the sympathetic nervous system (exception: those to the genitalia) and mostly cause vasoconstriction (exception: the skeletal muscles and coronary arteries which are vasodilated). Inputs to the vasomotor center are similar to those innervating the cardiac center: baroreceptors located throughout the body and the hypothalamus. The baroreceptors allow maintenance of normal blood pressure. The hypothalamus stimulates responses associated with exercise, emotions, "Fight or Flight", and thermoregulation.

Autoregulation - local control of blood flow to an organ or tissue area according to tissue needs.

Autoregulation is usually short-term and can enhance or override the vasomotor center.

48

Types of Autoregulation

myogenic - a direct response of smooth muscle to maintain normal blood flow.

↑ pressure → arteries and arterioles vasoconstrict, thus maintaining constant blood flow despite the increase in pressure.

metabolic - controls blood supply in response to oxygen, carbon dioxide, nutrients, wastes, metabolites, pH, etc.

49

The brain exhibits both types of autoregulation, myogenic to regulate pressure and blood flow, and metabolic to reduce harmful substances from entering the brain such as excessive CO_2.

Other organs utilize primarily metabolic autoregulation.

Examples of Autoregulation

Skeletal muscle – 10 x in active muscles during exercise

Heart – 3 to 4 x during exercise

Skin – temporary blood flow to prevent hypoxia during cold

Brain – constant blood flow and pressure during most conditions

Lungs – divert blood to well ventilated areas.

50

In the case of the blood flow to the skeletal muscle and heart autoregulation enhances what the vasomotor center is already doing.

In the skin and brain, autoregulation usually overrides what the vasomotor center is doing for a brief period.

In the lungs it is unrelated to vasomotor center function.

Examples of Autoregulation

skeletal muscle:

↑ CO_2, metabolites

↓ O_2

→ Vasodilation of incoming vessels

51

skeletal muscle: the response to increased carbon dioxide, increased metabolites, and decreased oxygen is vasodilation of the supplying blood vessels. This results in the most blood directed to the most active muscles. This is part of the exercise hyperemia (increased blood supply) which can reach tenfold.

Autoregulation in the Heart

↑ CO_2 → Vasodilation in coronary arteries.

52

The coronary arteries vasodilate only in response to increased carbon dioxide. Circulation to the heart can increase 3 to 4 times with exercise.

Unfortunately, the heart does not respond to ischemia to vasodilate the coronary arteries. Increased metabolites such as lactic acid, which is the primary cause of chest pain, do not cause vasodilation either. For that you need medical treatment, such as the administration of **nitroglycerin**.

Autoregulation in the Brain

1) Myogenic response of cerebral arteries acts to maintain nearly constant blood flow and pressure.

↑ b.p. → vasoconstriction maintain blood flow

2) Sensitivity to carbon dioxide and lowered pH, as well as other toxins.

↑ CO_2 → vasodilation to flush CO2 through

↑↑ CO_2 → vasoconstriction to protect brain.

53

Blood supply to the brain is maintained nearly constant under all conditions. The main mechanism responsible for this is **myogenic autoregulation** of cerebral arteries. In addition, the brain is very sensitive to carbon dioxide and the lowered pH it brings, as well as other toxins. In response to a moderate increase in CO_2 the cerebral arteries vasodilate somewhat to flush more blood through the brain. In response to a significant increase in CO_2 however the arteries vasoconstrict. Since CO_2 is coming from outside the brain this effectively shuts of the source. The brain will literally go into a coma to protect it from the damaging effects of low pH.

Autoregulation in the Skin

Maintains blood flow to avoid ischemia during cold temperature vasoconstriction.

54

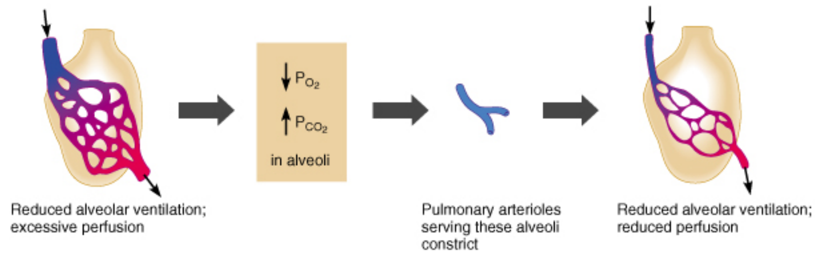
During low temperature the vasomotor center will reduce blood flow to the skin to conserve heat. In order to protect local areas from damaging ischemia blood will be restored briefly through local auto-regulatory vasodilation.

Autoregulation in the Lungs

Diverts blood flow to well-ventilated alveoli.

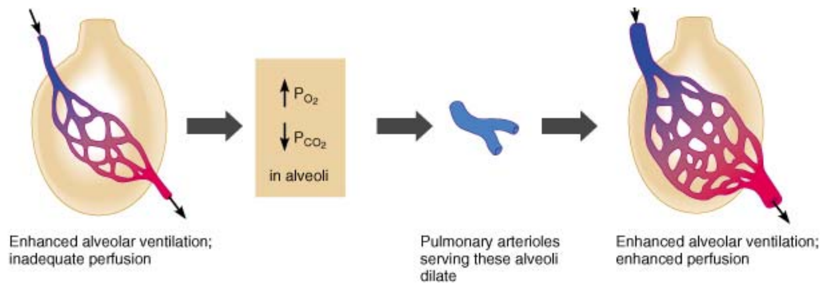
[See Figure 22.19]

Reduced alveolar ventilation → ↑CO_2 ↓ O_2 → vasoconstriction in supplying arterioles



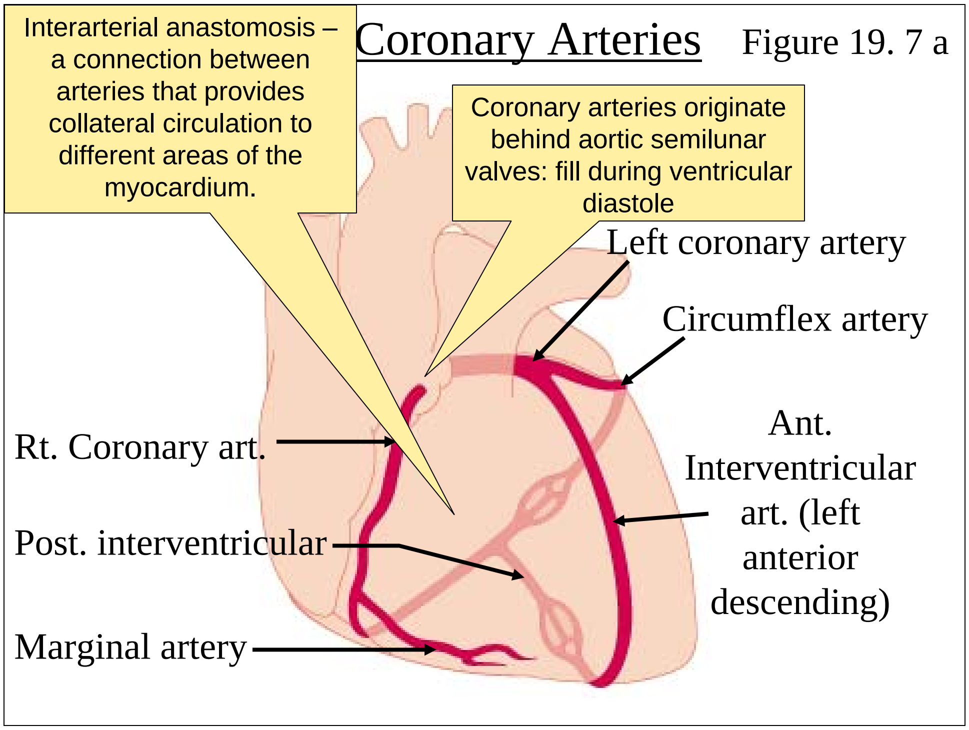
Since the lungs are the source for blood oxygenation the auto-regulatory mechanisms here are opposite in effect to those in systemic organs. The object of autoregulation in the lungs is to route blood to the best ventilated alveoli (air sacks which allow gas transport into/out of the blood). In response to increased oxygen in blood draining a segment of the lungs arteries leading to that segment will ***vasodilate***, thus increasing the blood entering that area. Low oxygen will stimulate vasoconstriction of the vessels, thus routing blood away from those less well ventilated areas

Increased alveolar ventilation → ↓ CO_2 ↑ O_2 → vasodilation in supplying arterioles



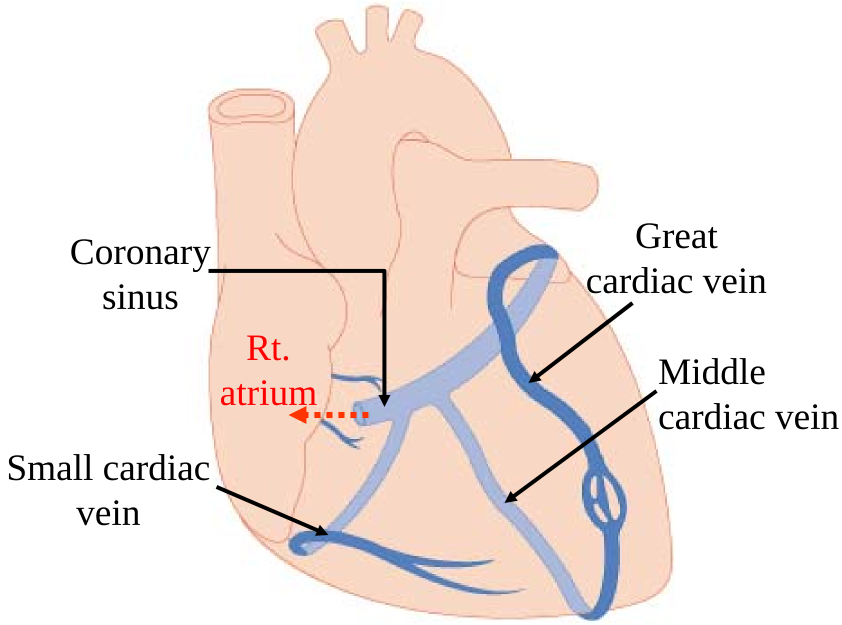
56

When reduced oxygen and increased CO_2 in the blood of one area produces vasoconstriction to that area, reduced CO_2 and increased oxygen in the blood of other areas lead to vasodilation in their incoming vessels.



Note the anastomoses between the coronary arteries. This is an **interarterial anastomosis** which provides collateral circulation to different parts of the myocardium. The fact that the coronary arteries fill during ventricular diastole allows them to overcome the resistance which would be too great during ventricular diastole.

The Coronary Veins



All coronary veins empty into the coronary sinus, which enters the right atrium directly, without going through either the inferior or superior vena cave. This is the only systemic venous drainage which does this. Note the anastomosis of these veins as well.

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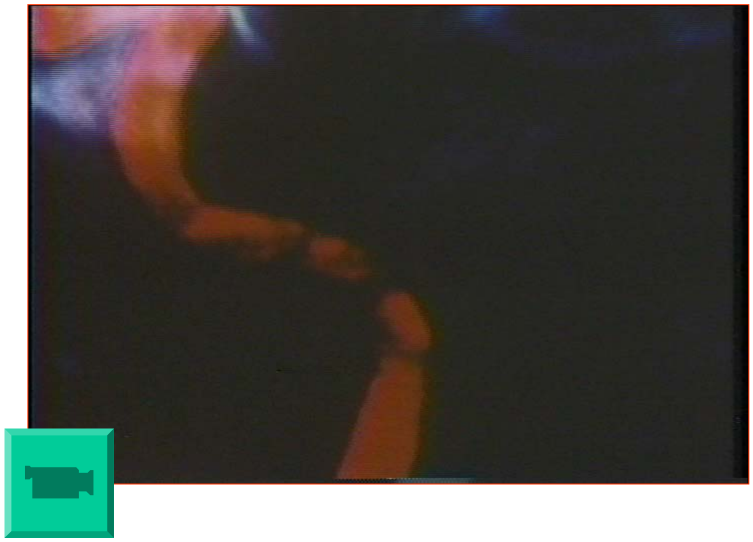
The Coronary Arteries



59

[**Click Here**] to see the video clip of the coronary arteries.

The Circle of Willis

- provides collateral circulation to the brain.

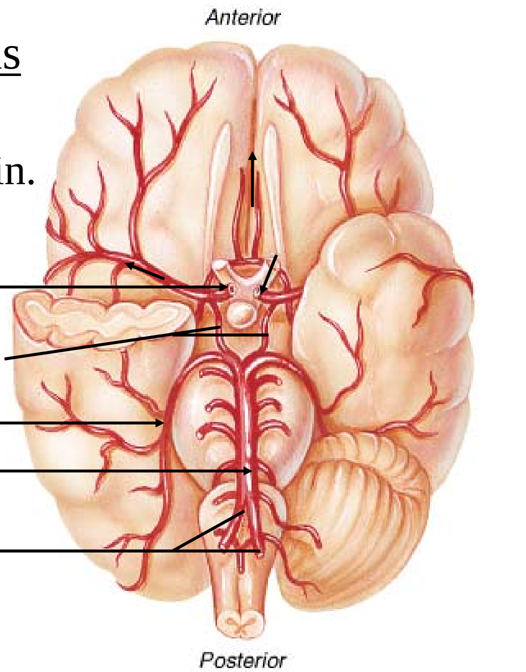


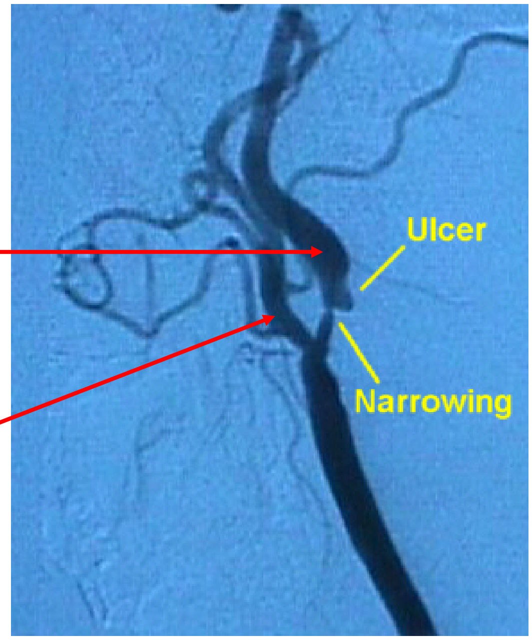
Figure 20.20 a

The Circle of Willis is an arterial anastomosis which provides collateral circulation to the brain. Four arteries, the two internal carotid arteries and the two vertebral arteries (through the basilar artery) provide blood flow to the Circle which then leads to the brain through cerebral arteries. If one or more of the supplying arteries is partially occluded, the brain can continue to receive normal perfusion through the Circle of Willis.

Carotid Arteries

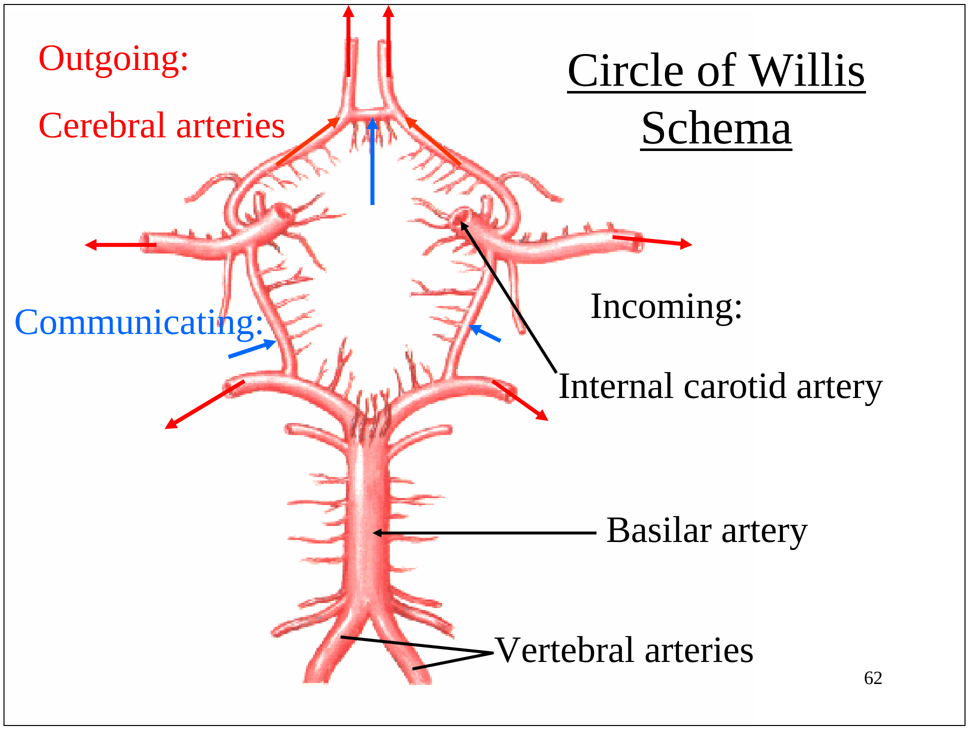
Internal carotid artery

External carotid artery



61

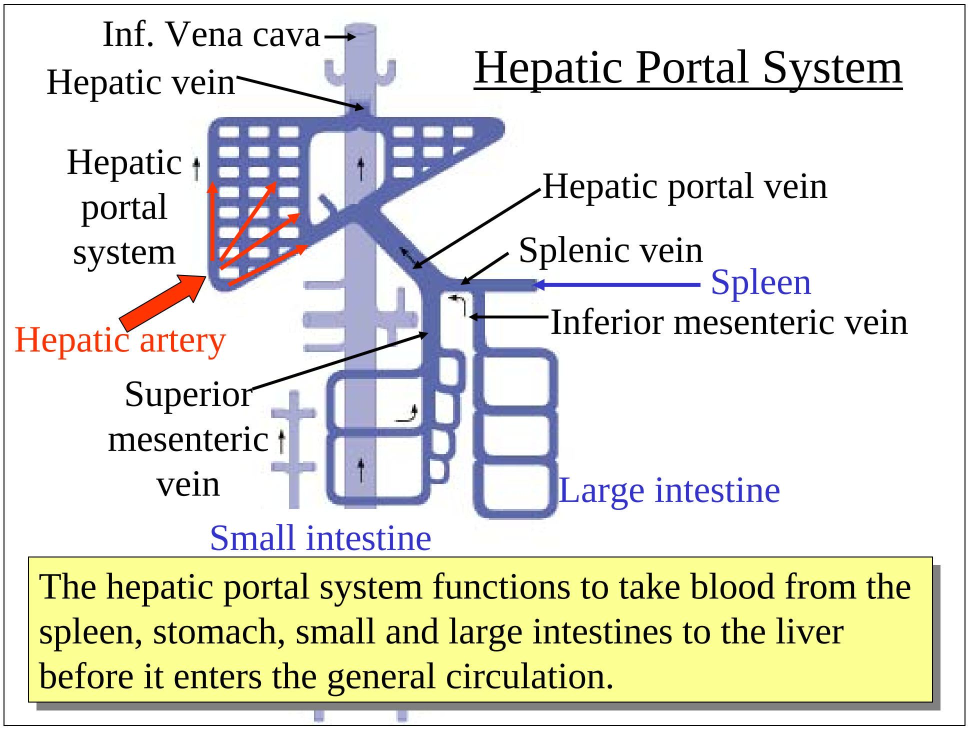
The internal carotid artery is a frequent site of stenosis (narrowing) to reduce blood flow as a result of atherosclerosis.


Circle of Willis
Schema
Outgoing:
Cerebral arteries
Communicating:
Incoming:
Internal carotid artery
Basilar artery
Vertebral arteries
62

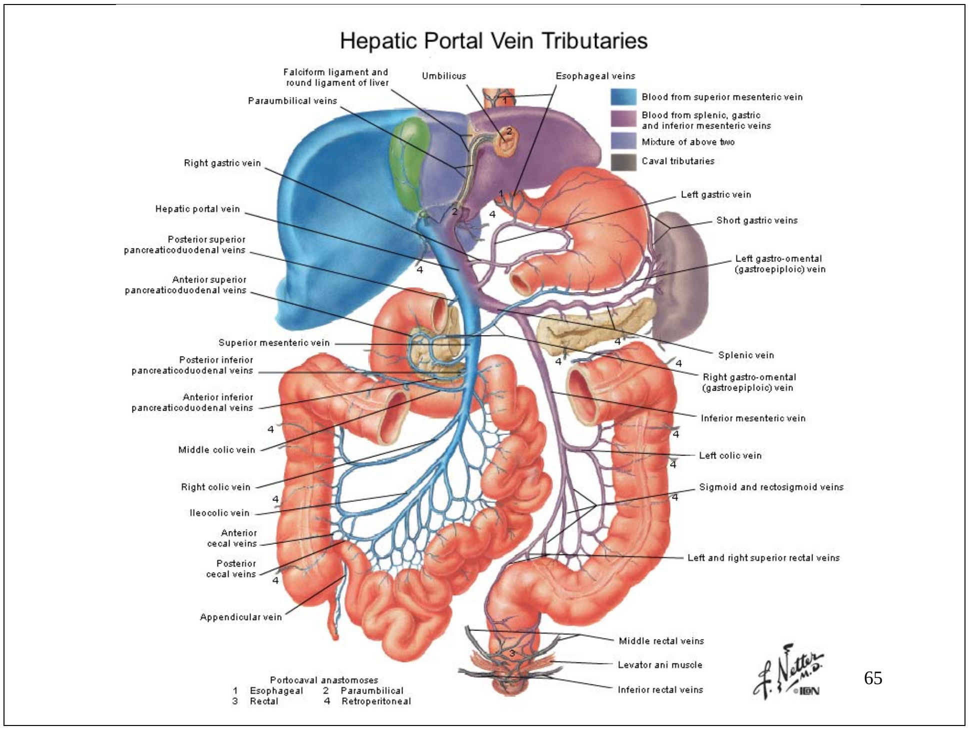
Circle of Willis Aneurism

Video Clip: Circle of Willis

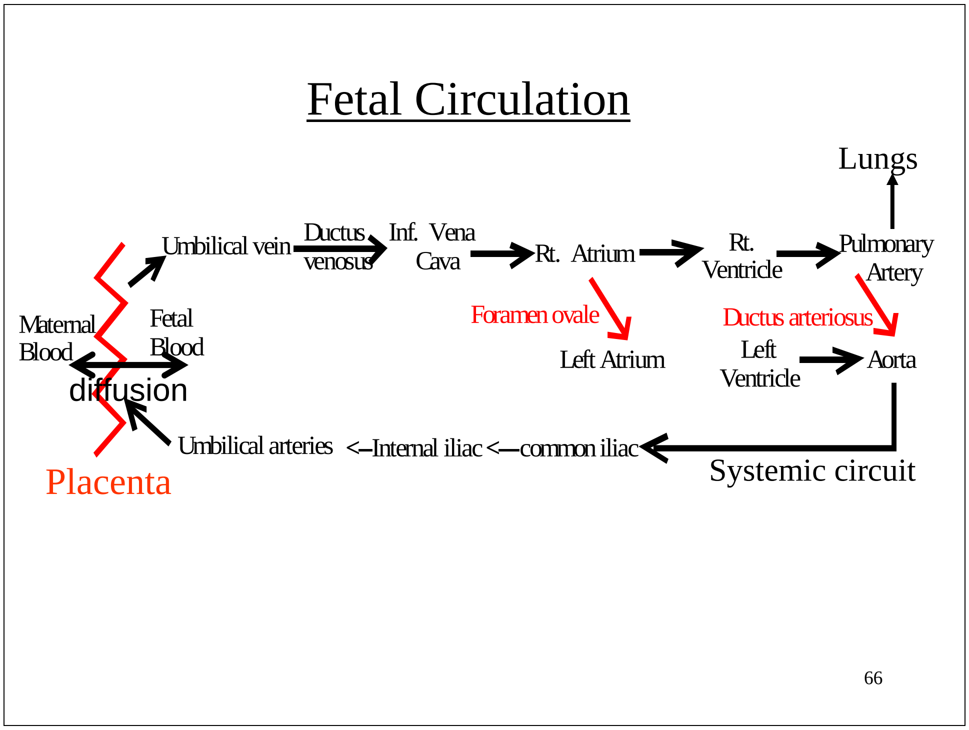
Note the aneurisms associated with the Circle of Willis, most actually part of the internal carotid artery.



The hepatic portal system functions to take blood from the spleen, stomach, small and large intestines to the liver before it enters the general circulation. This allows wastes, toxins, and digestive end-products to be processed by the liver.

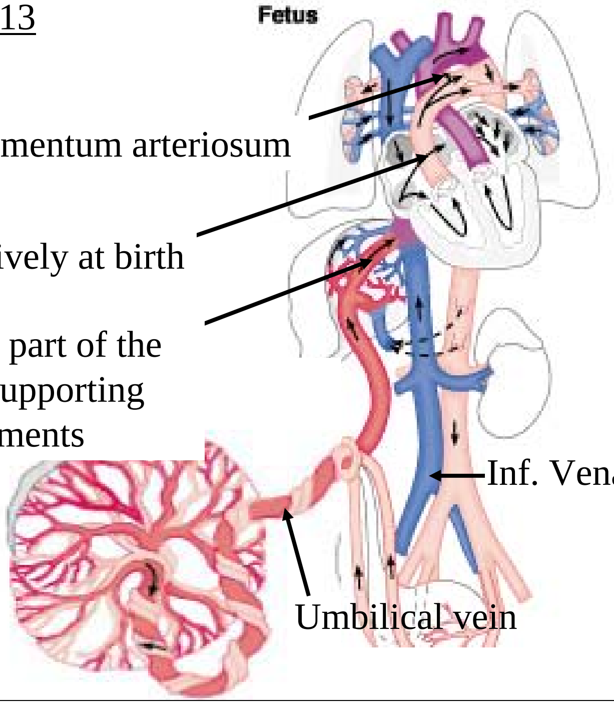


Here is the schematic for the hepatic portal system from the Netter Atlas of Anatomy. Note the drainage from the stomach, spleen, intestines (including the anal canal), and lower esophagus.



The fetal circulation operates to bypass the lungs, which are not functioning during fetal development. The lungs receive only about 10% of blood flow from the heart, enough for development. Oxygenation occurs in the placenta and the oxygenated blood is brought to the fetal bloodstream through the umbilical vein which leads through the **ductus venosus** to the inferior vena cava. From the inferior vena cava blood enters the right atrium as in the adult. But here there is a shortcut leading directly to the left atrium, the **foramen ovale**. About half of the blood takes this shortcut. The remainder travels to the right ventricle which pumps it into the pulmonary artery. Another shunt, the **ductus arteriosus**, takes most of this blood to the aorta and the systemic system.

Figure 29.13



Each of the fetal structures must cease function at birth:

The ductus venosus shrivels and later becomes part of the ligament supporting the liver;

The foramen ovale closes reflexively at birth and will grow completely shut within a short period. This may be seen later as the fossa ovalis in the septum of the right atrium;

The ductus arteriosus also closes reflexively and will become the ligamentum arteriosum seen in mature hearts.

Should these bypasses fail to close blood oxygenation is incomplete and surgical closure is necessary.

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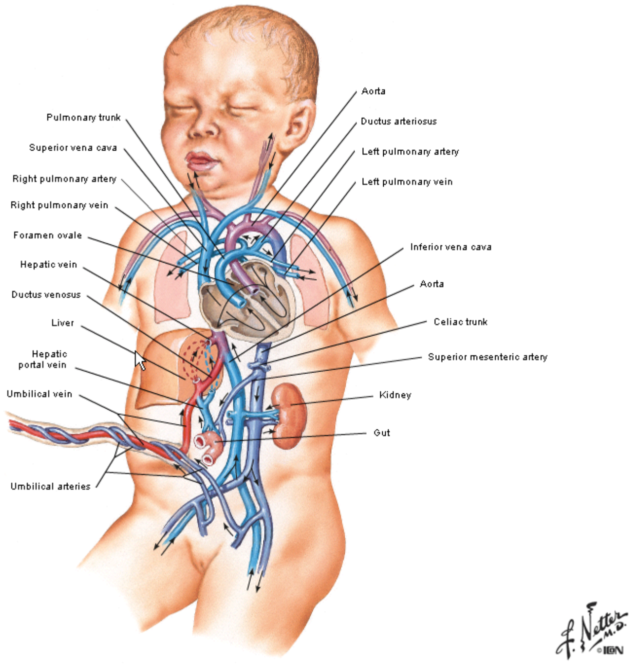
Prenatal Circulation



68

Prenatal Circulation from Netter.

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Study Assignment

Trace the flow of blood indicating all vessels etc. which occur in order:

1) small intestine to right arm

2) left arm to brain

3) right leg to kidney

69