심혈관계

Cardiovascular system II

The Cardiovascular Pathways

(1) Systemic circulation
(2) Pulmonary circulation.

Systemic circulation is the part of the cardiovascular system which carries oxygenated blood away from the heart to the body, and returns deoxygenated blood back to the heart.

Pulmonary circulation is the half portion of the cardiovascular system which carries oxygen-depleted blood away from the heart, to the lungs, and returns oxygenated (oxygen-rich) blood back to the heart.

Relationship b/w blood flow velocity and pressure.

A. Definitions and measurements

1. BP : measured in mmHg ; displacement of a column of mercury.
2. Flow : volume/time ; ml/sec/
3. Velocity : distance/time ; mm/sec/.

Relationship b/w blood flow velocity and pressure.

B. Resistance

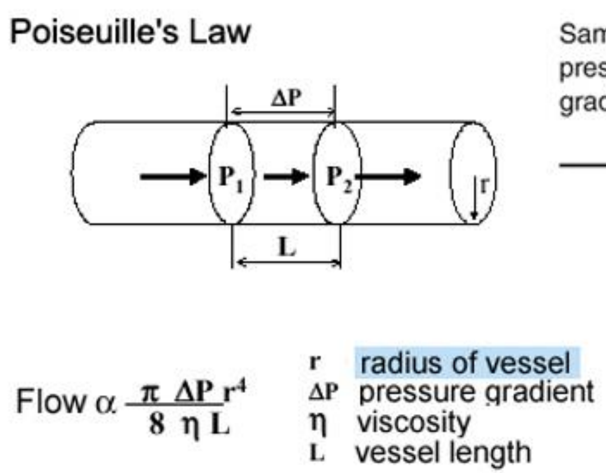
1. Resistance arises mainly from friction between blood and walls of vessels.
2. By definition, $R = \Delta P/F$ where: ΔP = press. diff. or
   $F = \Delta P/R$ where: F = flow.
3. Resistance depends on dimensions of vessel and properties of blood. Some insight from Poiseuille's Law for flow of fluid through glass tubes

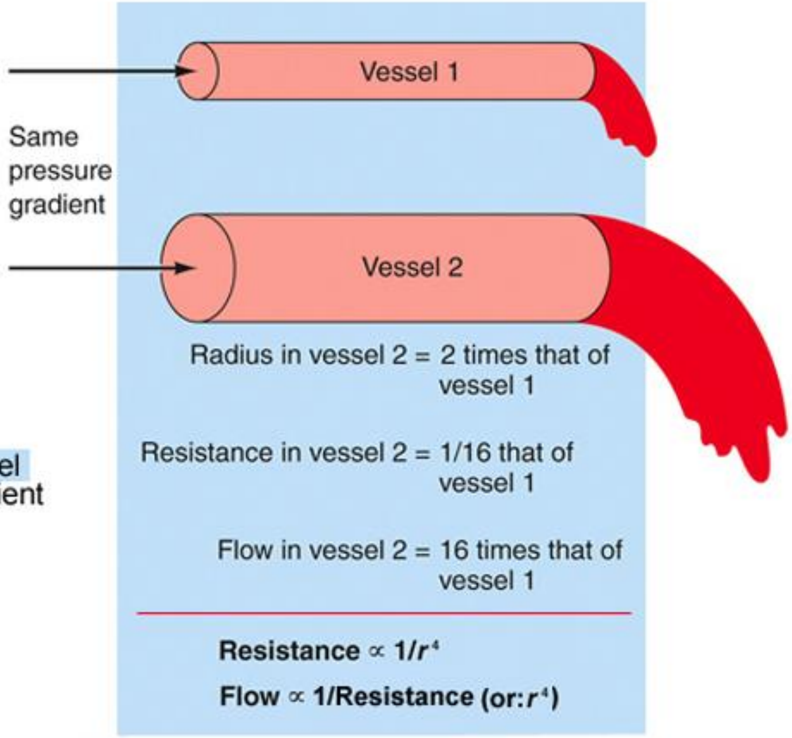
$$\mathbf{F = (\Delta P \pi r^4)/(8 L \eta)}$$

Where: r is tube radius, L is length, and η is the viscosity coefficient

Assumptions for Poiseuille's Law to strictly hold :

1) Laminar flow : true for blood except in turbulent regions;
2) Steady flow (non-pulsatile);
3) Constant viscosity (no change with vessel diameter).





Vascular Compliance

- The ability of a blood vessel wall to expand and contract passively with changes in pressure
- It is an important function of large arteries and veins.
- This ability of a vessel to distend and increase volume with increasing **transmural pressure** (inside minus outside pressure) is quantified as vessel compliance (C), which is the change in volume (ΔV) divided by the change in pressure (ΔP).

$$C = \frac{\Delta V}{\Delta P}$$

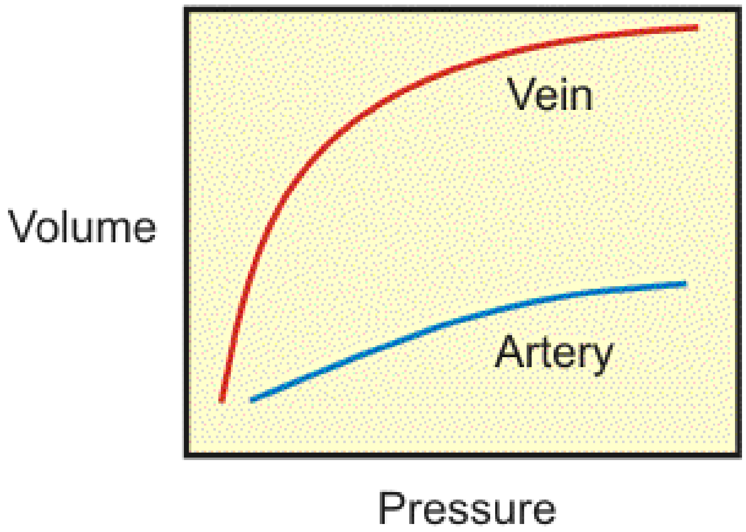


Figure 1. Compliance curve for an artery and vein. The slope of the curve is the compliance. At low pressures, venous compliance is10 to 20-times greater than arterial compliance, but arterial and venous compliance are similar at high pressures.

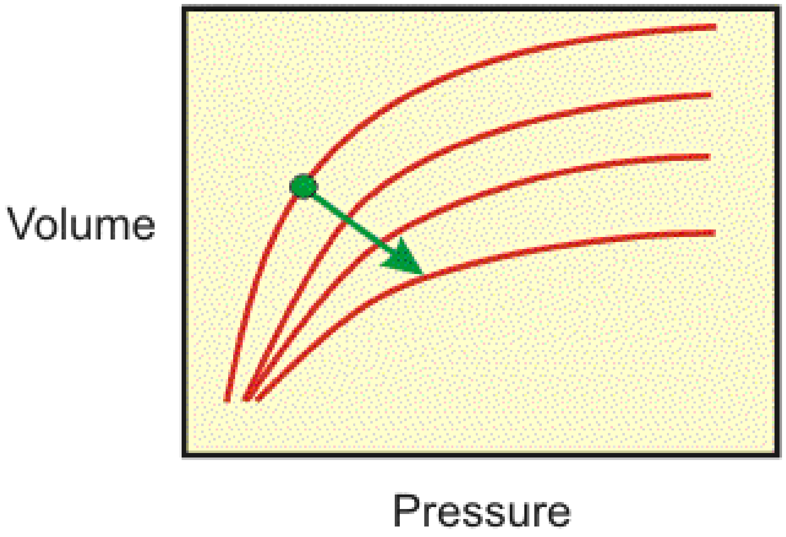


Figure 2. Compliance curves for a vein showing how increasing smooth muscle contraction (arrow) decreases venous volume and increases venous pressure by decreasing compliance. Qualitatively similar changes occur in arteries.

- The slope is not linear because the blood vessel wall is a heterogeneous tissue.

- High compliance means a vessel can distend to partly compensate for increased pressure.
- At lower pressures, the compliance of a vein is about 10 to 20-times greater than an artery. Therefore, veins can accommodate a large changes in blood volume with only a small change in pressure.
- However, at higher pressures and volumes, venous compliance (slope of compliance curve) becomes similar to arterial compliance. This makes veins suitable for use as arterial by-pass grafts.

- Importance of compliance :

  a. If arteries were rigid tubes and could not expand during systole, then systolic pressure would be very high and diastolic pressure would be zero.

  b. Volume equal to the entire SV would be delivered to the microcirculation during systole and none during diastole.

  c. With a compliant vessel, 1/3 of SV moves into the microcirculation while 2/3 of SV moves into the microcirculation during diastole (Windkessel Effect).

Windkessel when loosely translated from German to English means 'air chamber', but is generally taken to imply an *elastic reservoir*.

Functional anatomy of the peripheral circulation.

A. Arteries

- Arteries are blood vessels which carry blood away from the heart.
- All of which, with the exception of the pulmonary artery, carry oxygenated blood.
- The most widely known artery within the human body is the Aorta.
- Total cross sectional area small : high velocity.
- Low resistance.
- High compliance : tends to convert pulsating flow into steady flow, although this isn't complete until arterioles. "Windkessel vessels"

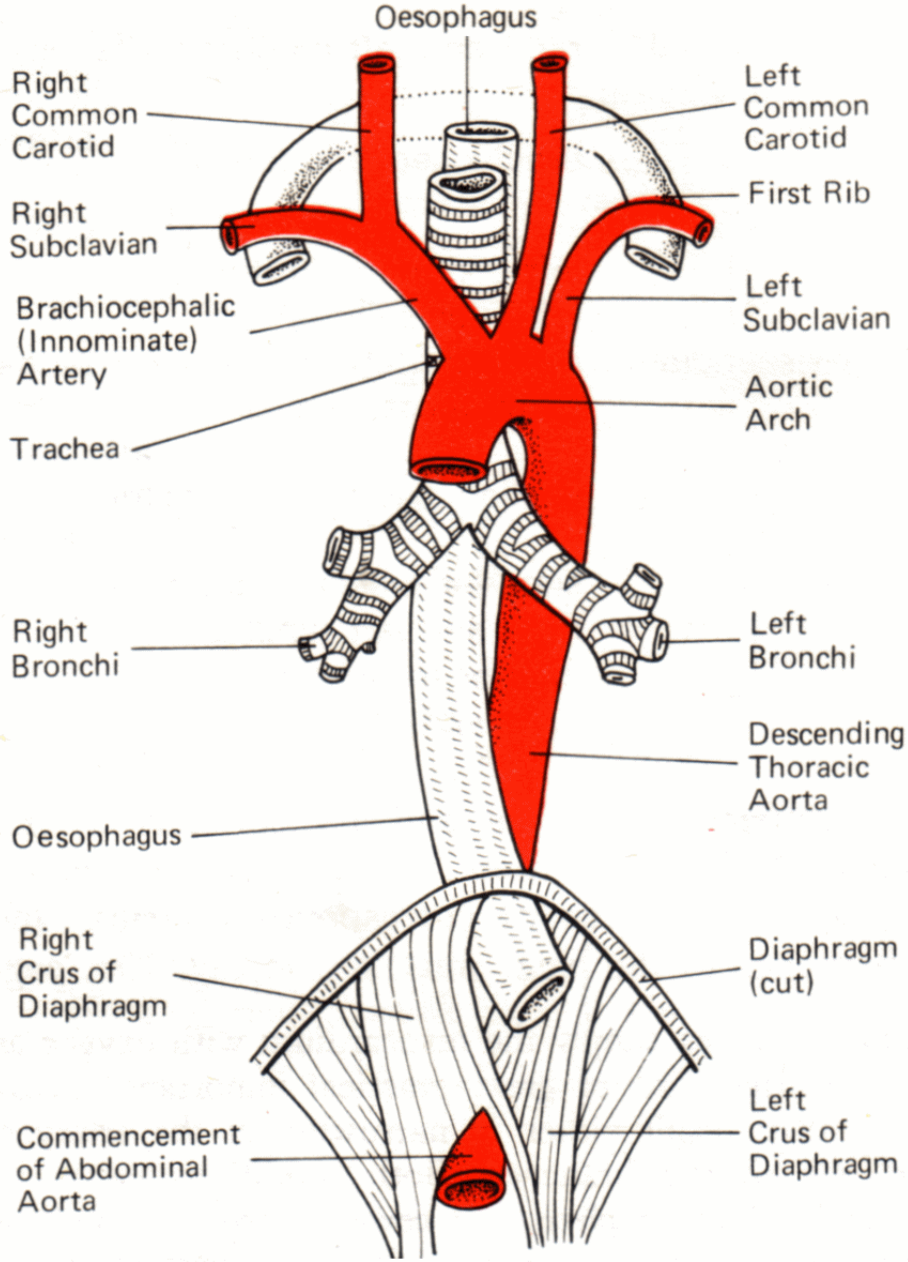
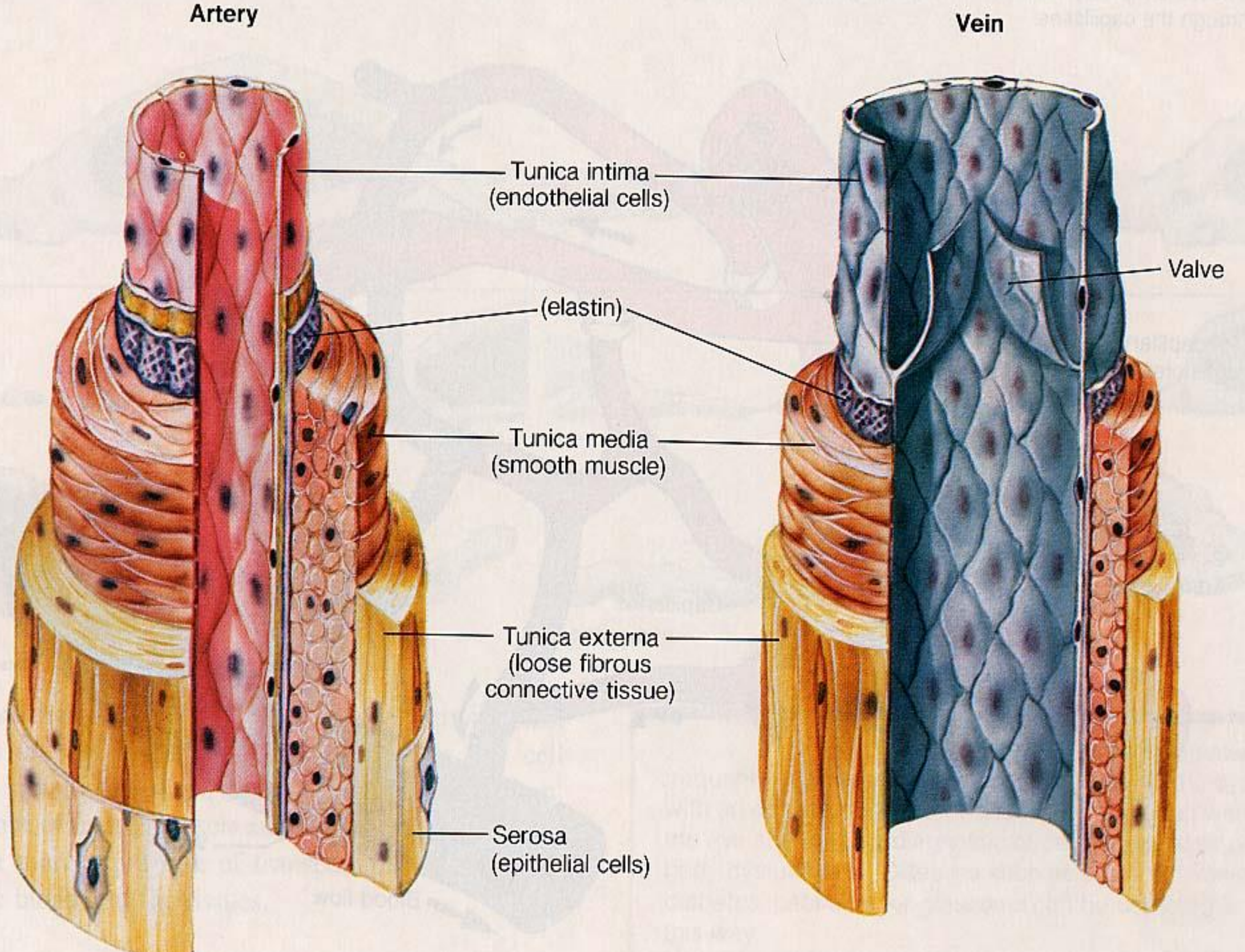


Diagram of the thoracic aorta.

The artery walls consist of three layers:

- **Tunica Adventitia:** This is the strong outer covering of arteries and veins which consists of connective tissues, collagen and elastic fibres.
- **Tunica Media:** This is the middle layer and consists of smooth muscle and elastic fibres. This layer is thicker in arteries than veins.
- **Tunica Intima:** This is the inner layer which is in direct contact with the blood flowing through the artery. It consists of an elastic membrane and smooth endothelial cells. The hollow centre through which blood flows is called the lumen.

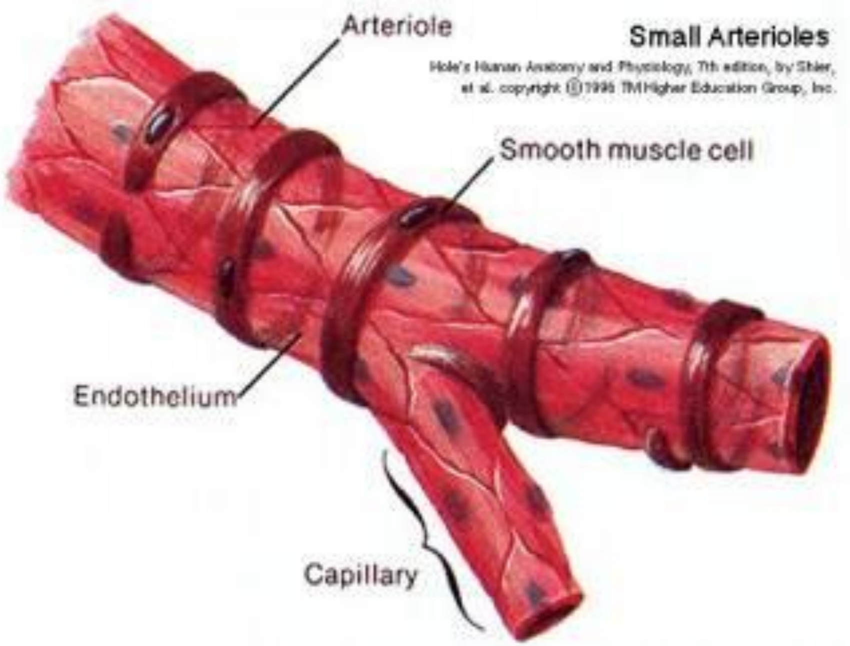
Figure 16.20. The structure of a medium-sized artery and vein showing the relative thickness and composition of the tunics.

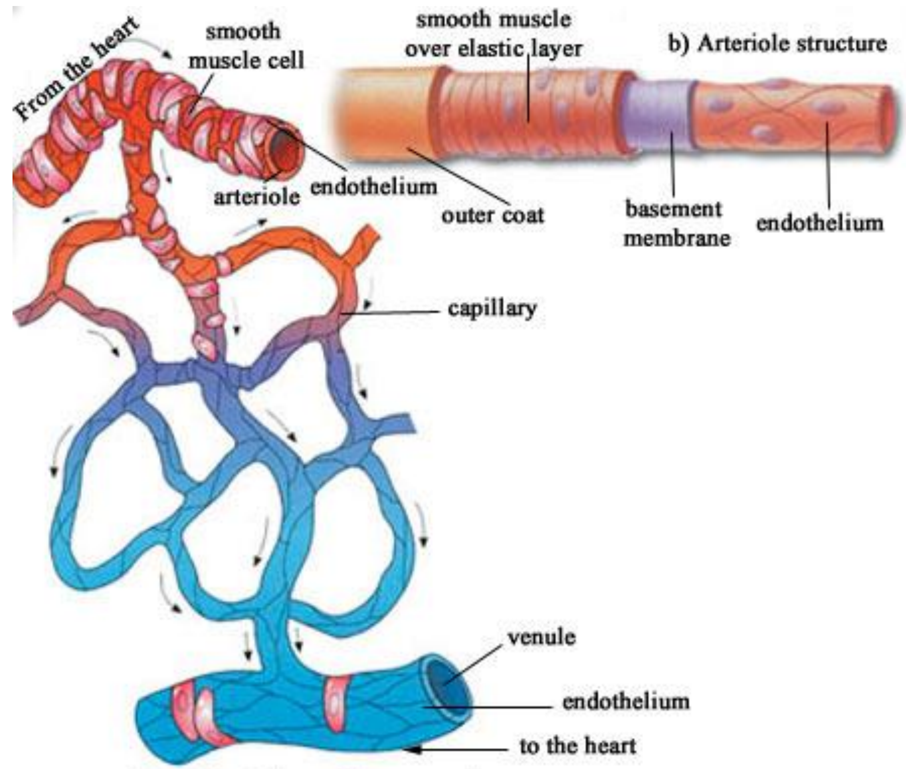


B. Arterioles: arterial connection points

- Arterioles are the smallest branches in the arterial system—the arteries' final state before they finally lead into capillaries.
- These serve as control valves in sending blood to the capillaries.
- Arterioles possess a most important powerful muscular system capable of completely closing themselves or else widening several fold, mainly to alter the blood flow reaching the capillaries, and to be able to send the tissues as much oxygen and nutrients as they need.
- They prevent these very delicate vessels from being damaged by the sudden entry of high-pressure blood.
- The resistance of the arterioles accounts for approximately half of the resistance in the entire systemic circulation, which is greater than anywhere else in the circulation.

1. **Medium cross sectional area, medium velocity.**
2. **Main site of resistance.**
3. **Smooth muscle(SM) cells surrounding vessels so that resistance can be controlled.**





a) Details of the capillary network

C. Precapillary sphincters

- The **precapillary sphincter** is a band of smooth muscle that adjusts the blood flow into each capillary.
- At the point where each true capillary originates from a metarteriole, a smooth muscle fiber usually encircles the capillary.
- This is called the precapillary sphincter.
- This sphincter can open and close the entrance to the capillary.
- Blood flow in a capillary changes as vasomotion occurs.
- The entire capillary bed may be bypassed by blood flow through arteriovenous anastomoses.

C. Precapillary sphincters

- A precapillary sphincter encircles each capillary branch at the point where it branches from the arteriole.
- Contraction of the precapillary sphincter can close the branches off to blood flow.
- If the sphincter is damaged or can not contract, blood can flow into the capillary bed at high pressures. When capillary pressures are high (and this can be the result of gravity), fluid passes out of the capillaries into the interstitial space, and edema or fluid swelling is the result.

1. Rings of SM at ends of arterioles.
2. Can open or shut distribute flow specific capillary beds.

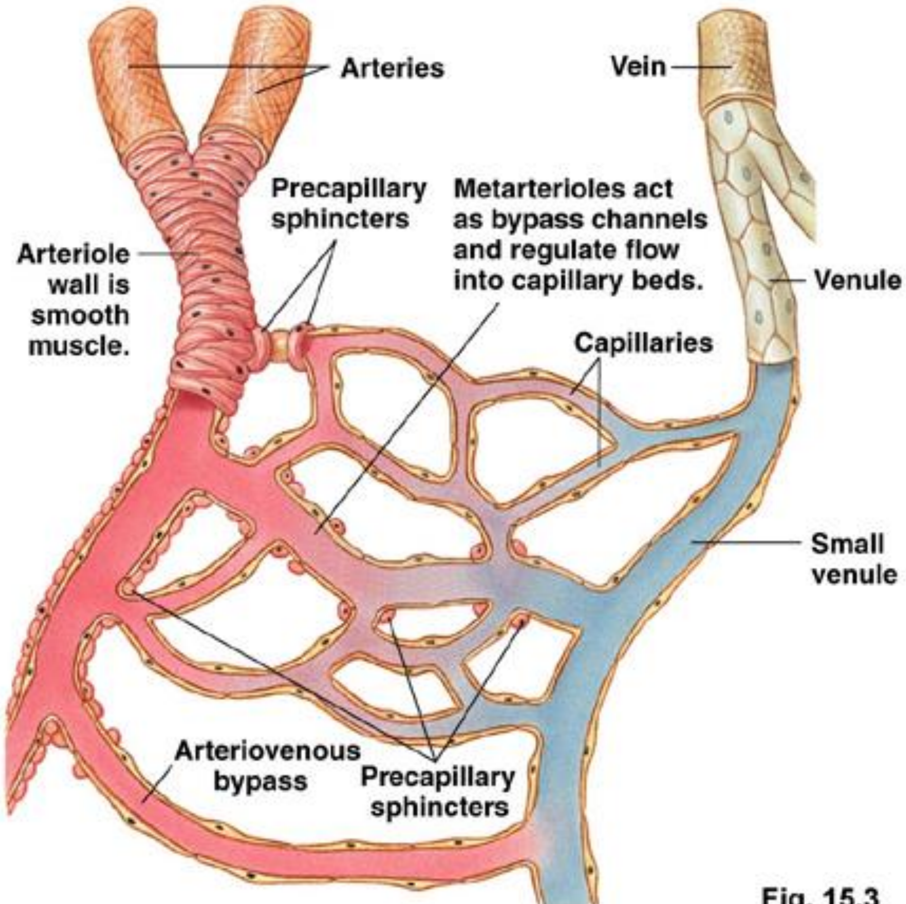


Fig. 15.3

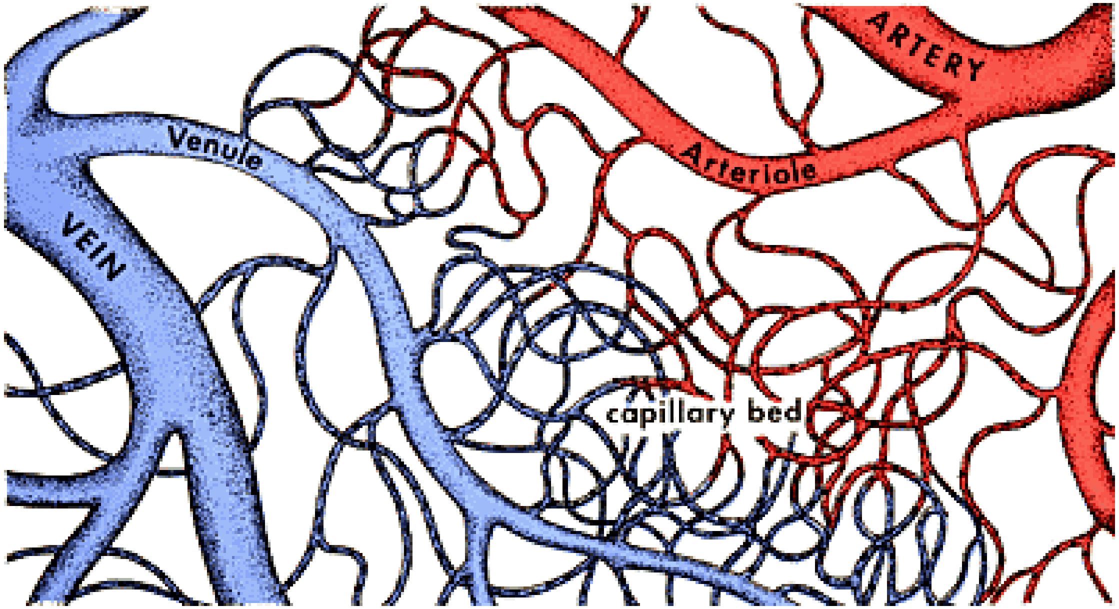
D. Capillaries

- A capillary is an extremely small blood vessel located within the tissues of the body, that transports blood from arteries to veins.
- Capillaries are most abundant in tissues and organs that are metabolically active. For example, muscle tissues and the kidneys have a greater amount of capillary networks than do connective tissues.
- Capillaries are so small that red blood cells can only travel through them in single file.

D. Capillaries

- Capillaries measure in size from about 5-10 microns in diameter.
- Capillary walls are thin and are composed of endothelium (a type of simple squamous epithelial tissue).
- Oxygen, carbon dioxide, nutrients and wastes are exchanged through the thin walls of the capillaries.

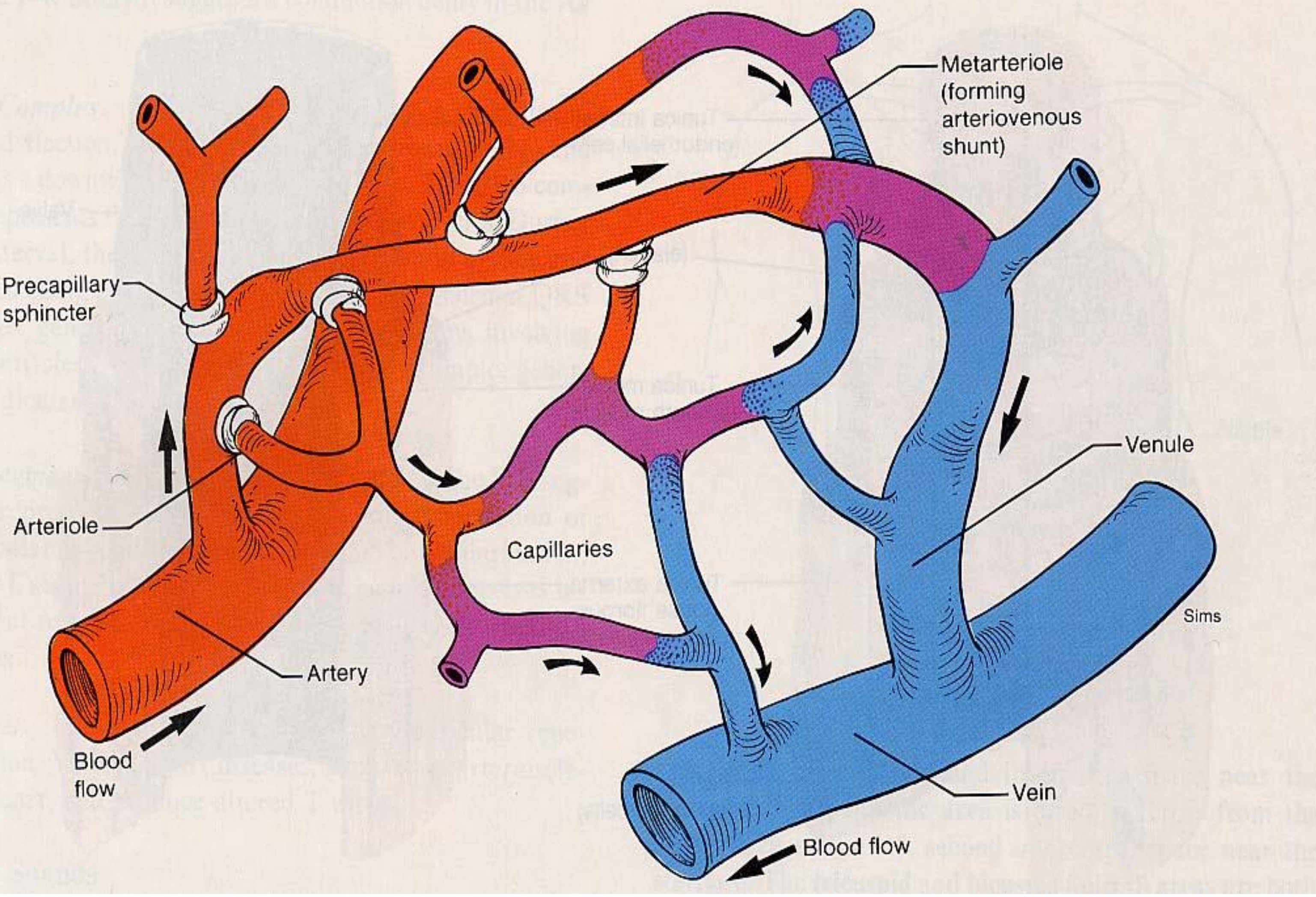
1. Very high total cross-sectional area, very low velocity (helping complete exchange to occur). However, these are the shortest vessels in the circulation.
2. No SM : walls are single layer of endothelial cells.
3. Primary function is exchange of gases and nutrients between blood and tissue.



E. Venules

- Venules link the capillaries to the veins when blood is being transported back to the heart and lungs.
- A vein is much larger than a venule and can carry a much higher volume of blood. Many venules will join with a single vein to transport the blood.
- Semi-lunar valves are present within each **venule** and vein to stop the blood from flowing back down the vein or **venule**.
- Some contain smooth muscle : most venules are passive vessels.
- Can regulate their pressure and thus affect pressure in capillaries.

Figure 16.21. The microcirculation. Metarterioles (arteriovenous anastomoses) provide a path of least resistance between arterioles and venules. Precapillary sphincter muscles regulate the flow of blood through the capillaries.



F. Small and large veins

1. Contain smooth muscle and can regulate their diameter.
2. Extremely compliant : 20 times more than arteries.
3. Serve as reservoir of blood with a volume that can be regulated over a wide range.
   - Normally, 60% of all blood is in veins.
     (Capacitance vessels)

G. Shunts

1. Direct connections between arterioles and venules - bypasses capillaries (called metarterioles).
2. Mainly in skin.
3. Under neural control : helps regulate capillary flow.
4. Normally, very small flow through shunts.

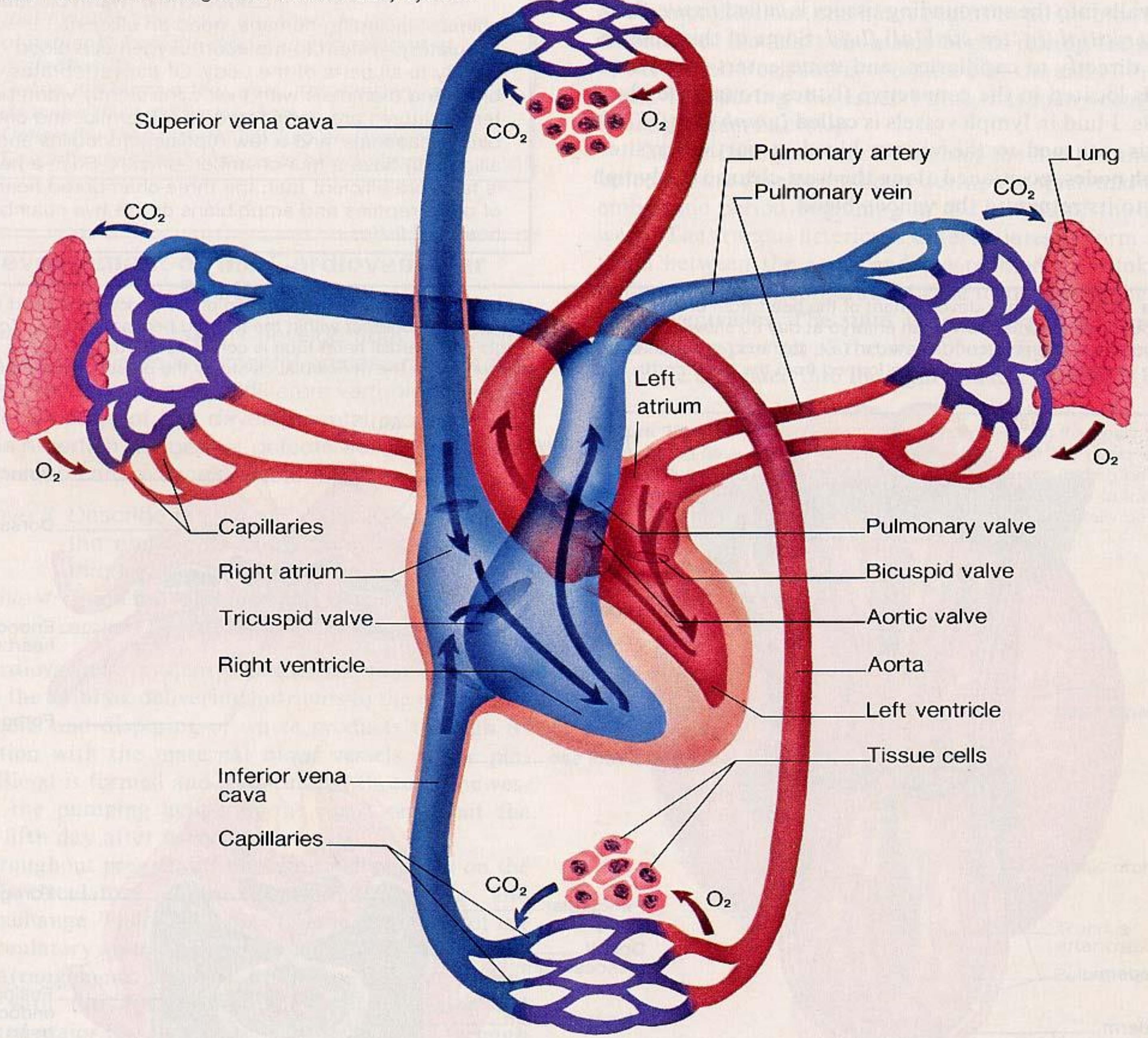


Figure 16.2. A schematic diagram of the circulatory system.

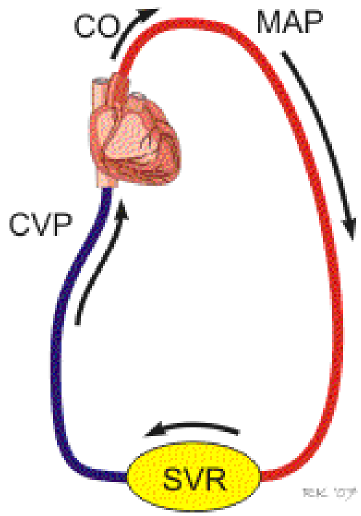
H. Systemic circulation properties.

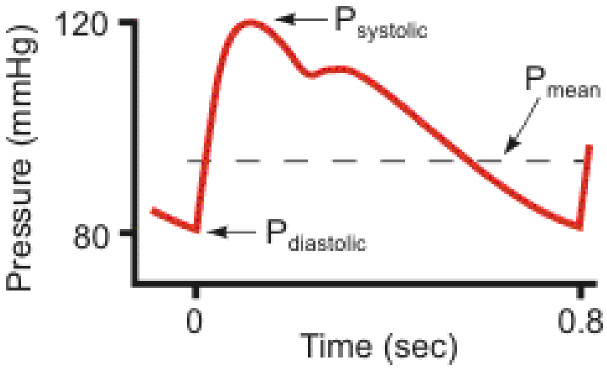
1. Total cross-sectional area is largest at capillaries and venules.
2. Distribution of blood :
   a) capillaries contain little blood,
   b) majority of blood volume is in veins, small veins and venules.
3. Greatest pressure drop occurs in arterioles.
4. Highest resistance to flow - in arterioles.

Systolic and diastolic pressure

A. Systolic pressure : highest point of pressure pulse(120mmHg).
B. Diastolic pressure : lowest point of pressure pulse(80mmHg).
C. Pulse pressure = Systolic - Diastolic = 40mmHg.
D. Mean arterial pressure :
  1. Area under pressure pulse curve divided by time.
  2. Mean arterial pressure (MAP) = Diastolic pressure + 1/3 Pulse pressure

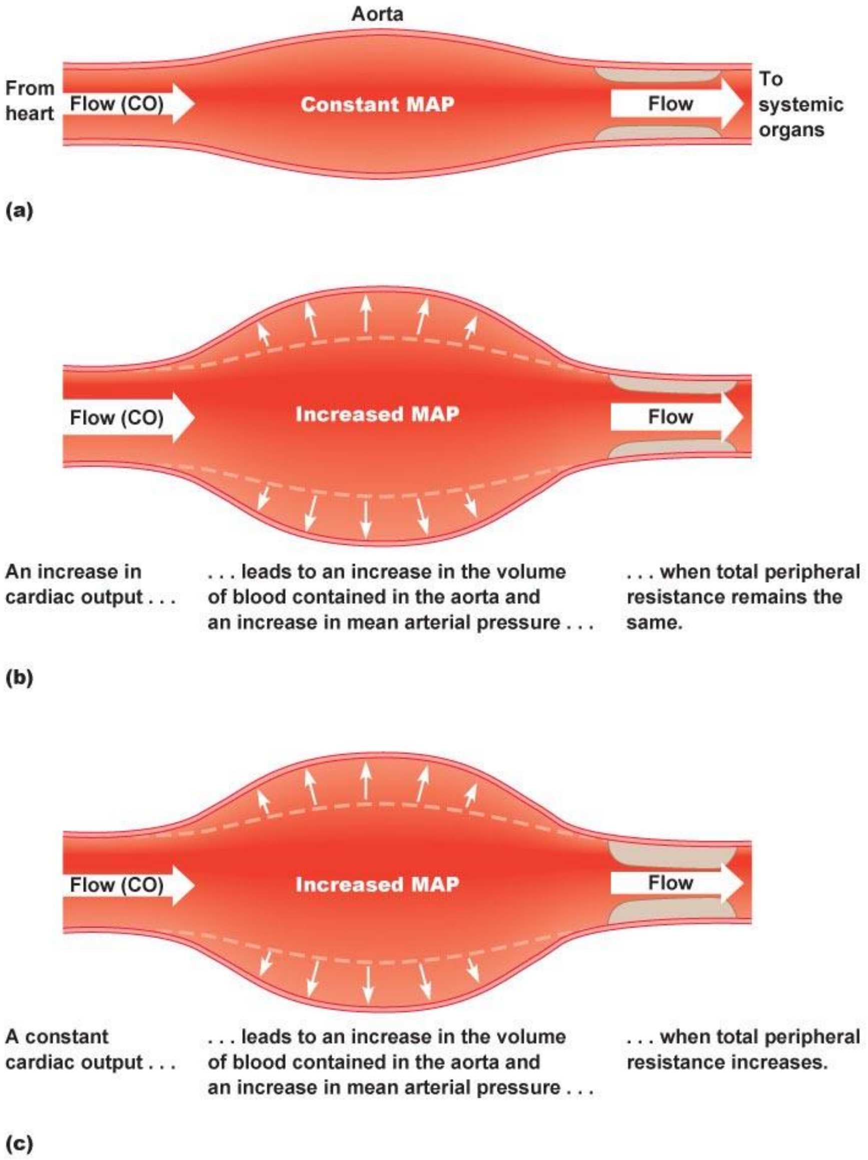
$$MAP \cong P_{dias} + \frac{1}{3}\left(P_{sys} - P_{dias}\right)$$





Mean arterial pressure is determined by :

1. **Heart rate**
2. **Stroke volume**
3. **Total peripheral resistance**



Regulation of Blood Pressure

Control of pressure in systemic circulation

- Pressure = Flow x Resistance

  Where:

  - ✓ Flow = cardiac output (CO);
  - ✓ Resistance = Total Peripheral Resistance (TPR), controlled mainly by arterioles.
  - ✓ P around entire system approx equal to aortic pressure since venous pressure is very low;

$$MAP = CO \times TPR$$

Regulation of Mean Arterial Pressure

A. Neural Control of MAP

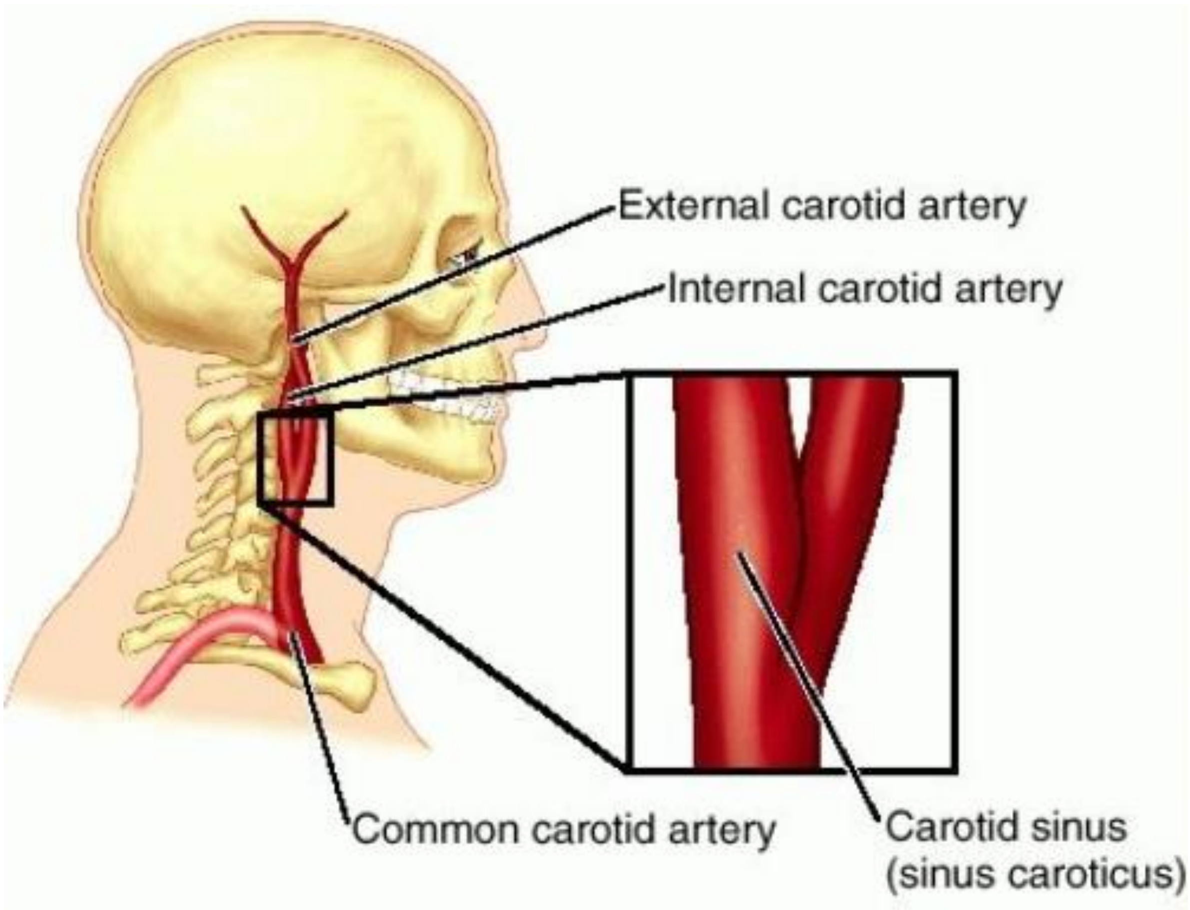
MAP is the **regulated variable** that is monitored by **arterial baroreceptors sensors.**

Arterial Baroreceptors are found in:

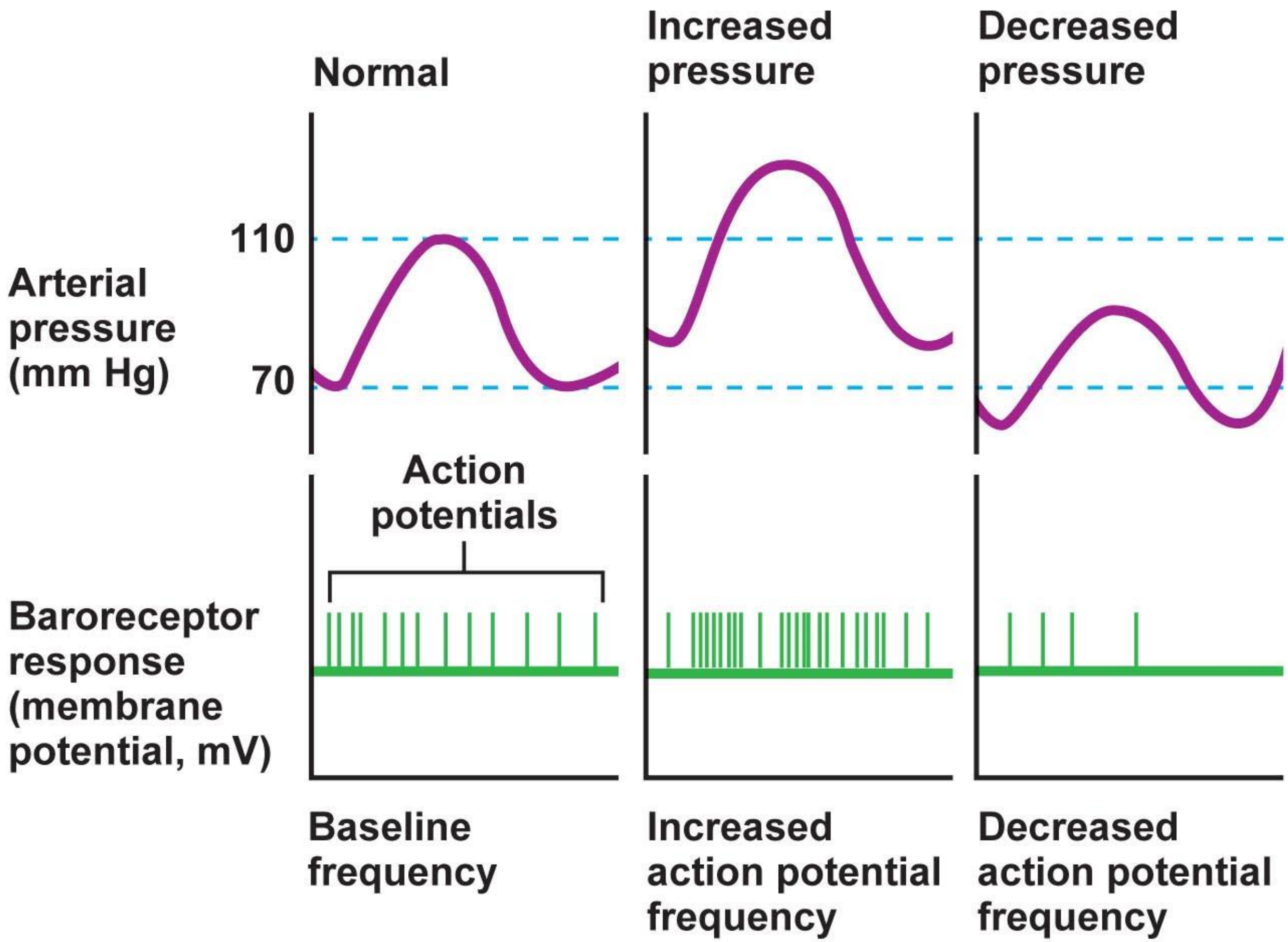
1. Aortic arch

2. Carotid sinuses of the carotid arteries

- Baroreceptors respond to changes in **pressure** within the CV system.
- When the walls of arteries **stretch** in response to an increase in **pressure** the sensory endings of baroreceptors neurons are **stretched** and this induces **depolarization**.
- The depolarization triggers action potentials that then travel to the central nervous system.



External carotid artery
Internal carotid artery
Common carotid artery
Carotid sinus
(sinus caroticus)

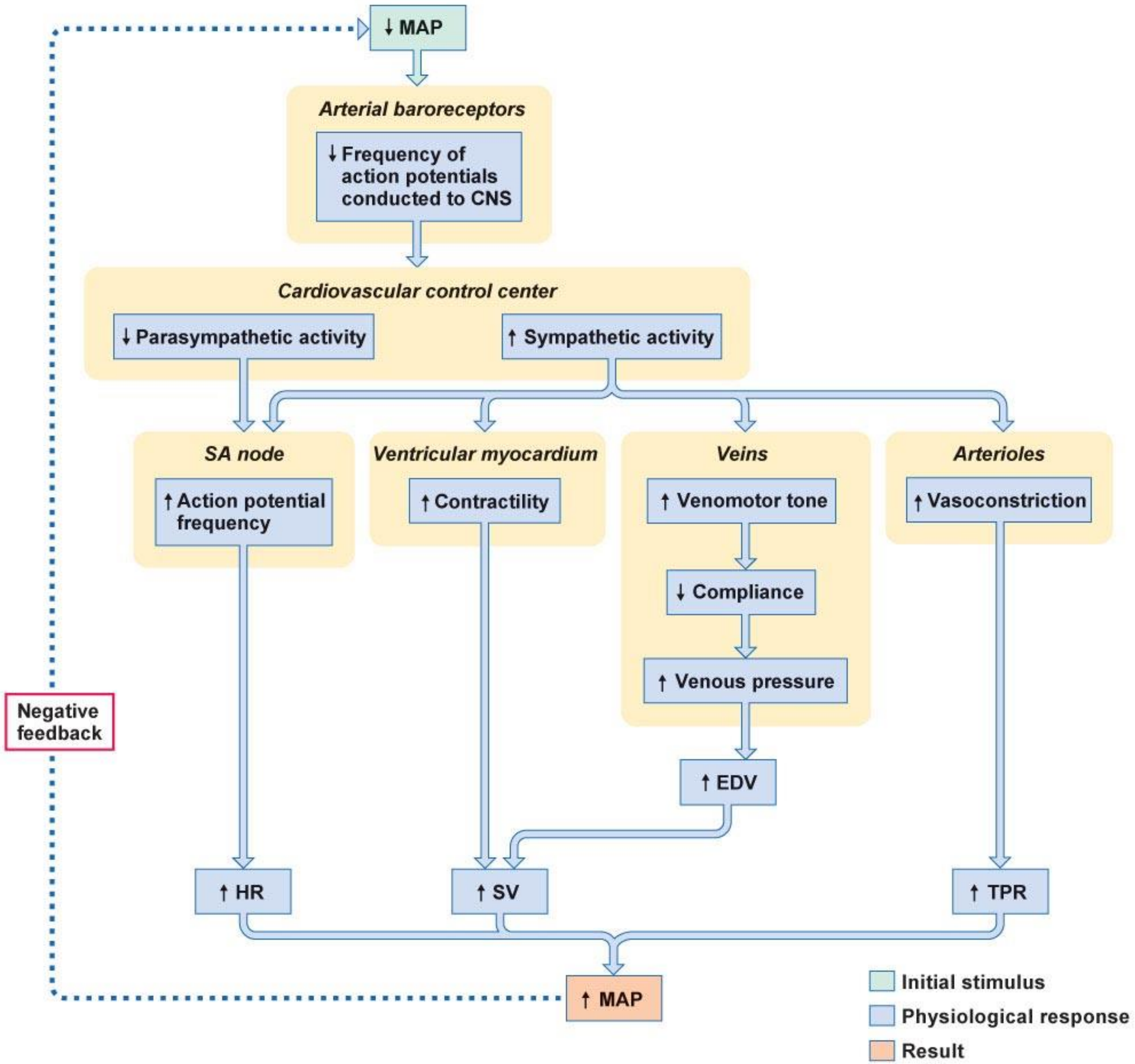

Normal
Increased pressure
Decreased pressure
Arterial pressure (mm Hg)
110
70
Action potentials
Baroreceptor response (membrane potential, mV)
Baseline frequency
Increased action potential frequency
Decreased action potential frequency

Cardiovascular Control Center of Medulla Oblongata

The neural control of mean arterial pressure resides primarily in the medulla oblongata. Sensory input to the medulla include:

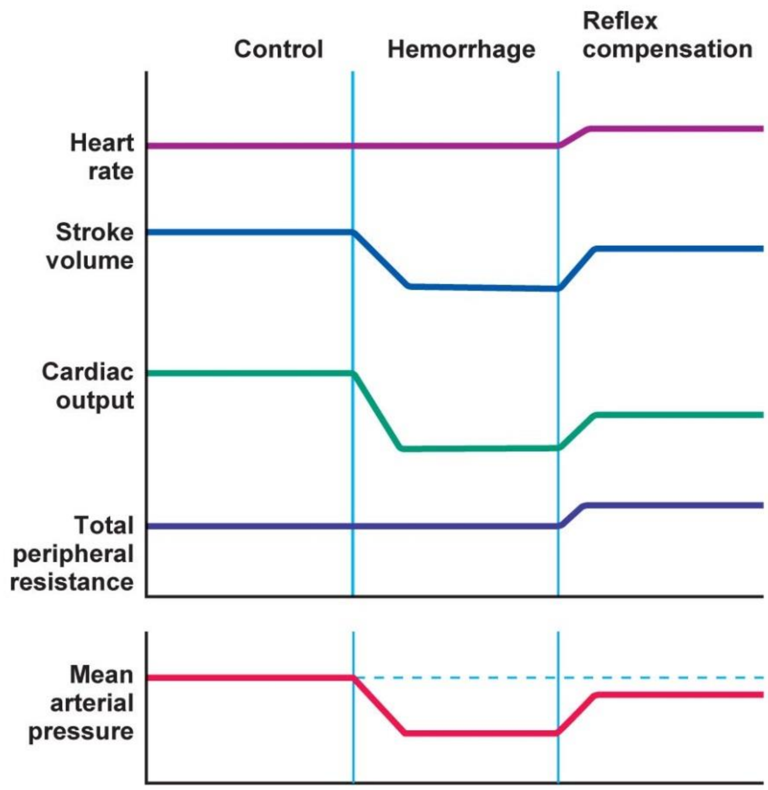
1. Arterial baroreceptors
2. Baroreceptors in the heart and large systemic veins that sense venous pressure (volume receptors).
3. Chemoreceptors that sense oxygen, carbon dioxide and hydrogen ion concentration
4. Proprioceptors in skeletal muscle and joints
5. Receptors in internal organs

Autonomic Inputs to Cardiovascular Effectors



Baroreceptor Reflex

- A **drop** in MAP is detected by arterial baroreceptors and this results in a **decrease** in frequency of action potentials.
- This results in **decreased parasympathetic** activity and **increased sympathetic** activity.
- The increased sympathetic activity results in **increased heart rate**, **stroke volume** and **total peripheral resistance** all which increase MAP.



B. Hormonal Control of MAP

Epinephrine

- Epinephrine affects both **cardiac output** and **total peripheral resistance**
- At the heart, epinephrine binds to receptors at the SA node and **increases heart rate** by increasing the **frequency of action potentials.**
- Epinephrine also binds to receptors on the **ventricular myocardium** which increases **cardiac contractility.**
- At the vasculature, epinephrine causes **vasoconstriction** in **most** vascular beds but can cause vasodilation in **skeletal** and **cardiac muscle**.
- Most often the effect of epinephrine is to **increase** total peripheral resistance.
- Hence, epinephrine **increases** mean arterial pressure by increasing heart rate, stroke volume and total peripheral resistance.

Microcirculation, Venous System, Pulmonary and Coronary Circulation

I. Microcirculation

A. Composition of microcirculation.
1. Arterioles, capillaries, and venules.

B. Capillaries
1. Vessel wall contains only endothelial cells.
2. No SM cells therefore no regulation of vessel diameter.
3. Diameter about 3.5㎛ : RBC diameter about 7.5㎛ : RBC's change shape when in capillary.
4. Small pores in vessel wall allows water, glucose, urea, and other small molecules to diffuse in and out. Some leakage of protein, but not appreciable amounts.
5. O_2 and CO_2 are lipid soluble and can pass directly through endothelial walls.

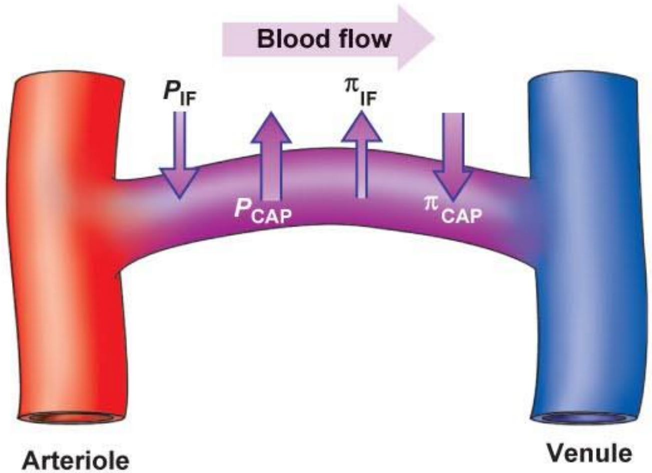
The forces that drive movement of fluid into and out of capillaries are called **Starling forces** and includes:

1. **Capillary hydrostatic pressure (P_{cap})** or the hydrostatic pressure of fluid in the capillaries.

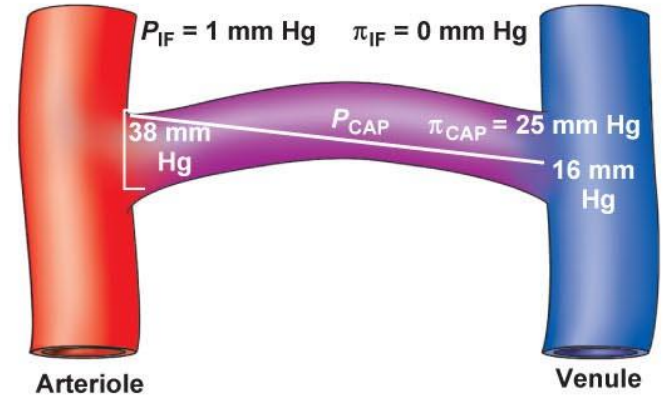
2. **Interstitial hydrostatic pressure (P_{if})** or the hydrostatic pressure of fluid outside the capillary.

3. **Capillary osmotic pressure (Π_{cap})** due to the presence of non-permeating solutes inside the capillaries.

4. **Interstitial fluid osmotic pressure (Π_{if})** due to the presence of non-permeating solutes outside the capillaries.



(a)



Arteriole end

Filtration pressure:	Absorption pressure:
P_{CAP} = 38 mm Hg	π_{CAP} = 25 mm Hg
π_{IF} = 0 mm Hg	P_{IF} = 1 mm Hg
38 mm Hg	26 mm Hg

NFP = Filtration pressure – Absorption pressure

= 38 mm Hg – 26 mm Hg = 12 mm Hg

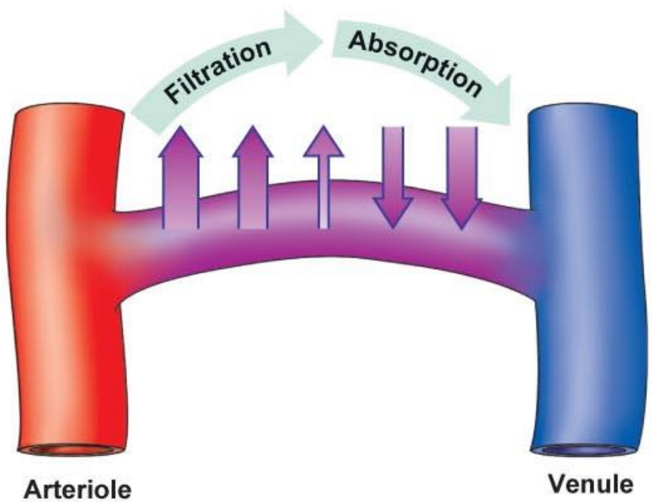
Venule end

Filtration pressure:	Absorption pressure:
P_{CAP} = 16 mm Hg	π_{CAP} = 25 mm Hg
π_{IF} = 0 mm Hg	P_{IF} = 1 mm Hg
16 mm Hg	26 mm Hg

NFP = Filtration pressure – Absorption pressure

= 16 mm Hg – 26 mm Hg = –10 mm Hg

(b)



(c)

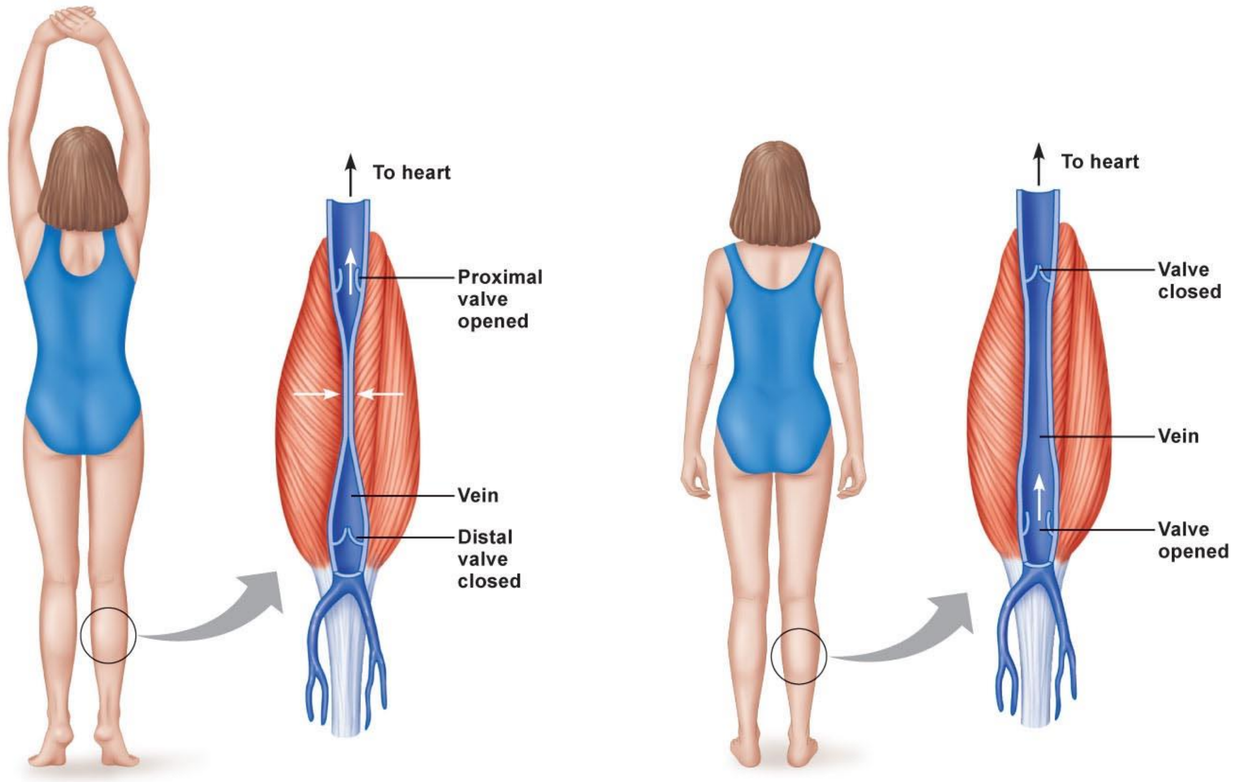
II. Venous System

Forces helping return blood to heart through veins.

1. Veins in legs have one-way valves. With skel. muscle contraction, this acts as a pump to aid return of blood back to the heart.
2. Respiration : thorax has negative pressure (especially during inspiration), abdomen has positive pressure.
3. Atria are stretched slightly during systole of the ventricles. This creates a slight suction helping return venous blood.
4. None of these 3 are absolutely necessary : most important is high arterial pressure.

Factors that affects venous pressure include:

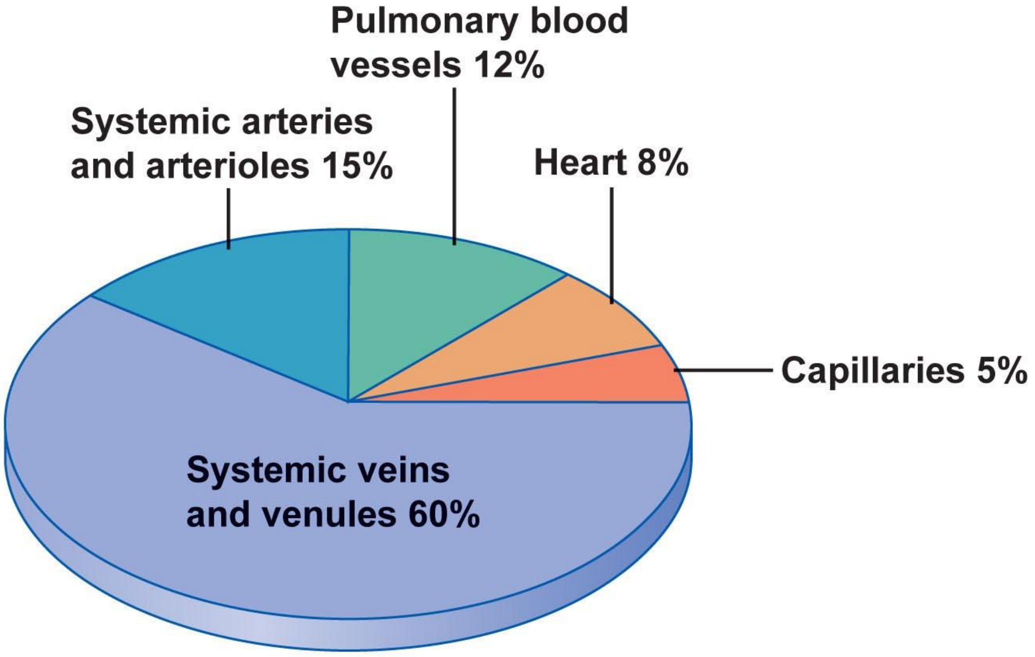
Skeletal Muscle Pump



(a) Skeletal muscle contracted **(b) Skeletal muscle relaxed**

Veins Serve as a Volume Reservoir

- Veins can accommodate a large **increase** in **blood volume** because of their **high compliance** (expansion due to pressure).
- This enables the veins to hold a large volume of blood at a given pressure.
- Veins also contain a **larger proportion** of blood volume than any other part of the circulation.



Factors That Influence Venous Pressure

- Venous pressure has an important affect on mean arterial pressure because it affects venous return to the heart and influences **end-diastolic volume**.
- This in turn increases stroke volume and cardiac output according to Starling's law of the heart.
- Venous pressure is due to the **pressure difference** between the **peripheral veins** and the **right atrium**. It is about **15 mm Hg**.

III. Pulmonary Circulation

- **Pulmonary circulation** is the movement of blood from the heart, to the lungs, and back to the heart again.
- De-oxygenated blood leaves the heart, goes to the lungs, and then re-enters the heart; oxygen poor blood leaves through the right ventricle through the pulmonary artery, the only artery in the body that carries oxygen-poor blood, to the capillaries where carbon dioxide diffuses out of the blood cell into the alveoli, and oxygen diffuses out of the alveoli into the blood.
- Blood leaves the capillaries to the pulmonary vein, the only vein in the body that carries oxygen-rich blood in the body, to the heart, where it re-enters at the left atrium.

A. Pulmonary vs. Bronchial circulation

1. Pulmonary artery → alveolar capillaries → pulmonary veins

B. Vessels

1. Shorter, wider, thinner walls than systemic system

C. Pressures

1. Mean arterial pressure about 15 mmHg
2. Mean pulmonary cap.press. about 10 mmHg

D. Pulmonary resistance and compliance

1. Resistance normally 1/10 that of systemic circulation
2. Pulmonary arterioles have symp. and parasymp. innervation
   a. vasoconstrction on α stimulation
   b. vasodilation on β or cholinergic stimulation

Right heart

- Oxygen-depleted blood from the body leaves the systemic circulation when it enters the right heart, more specifically the right atrium through the superior (upper) vena cava and inferior (lower) vena cava.
- The blood is then pumped through the tricuspid valve (or right atrioventricular valve), into the right ventricle. Blood is then pumped through the semilunar valve and into the pulmonary artery.

Arteries

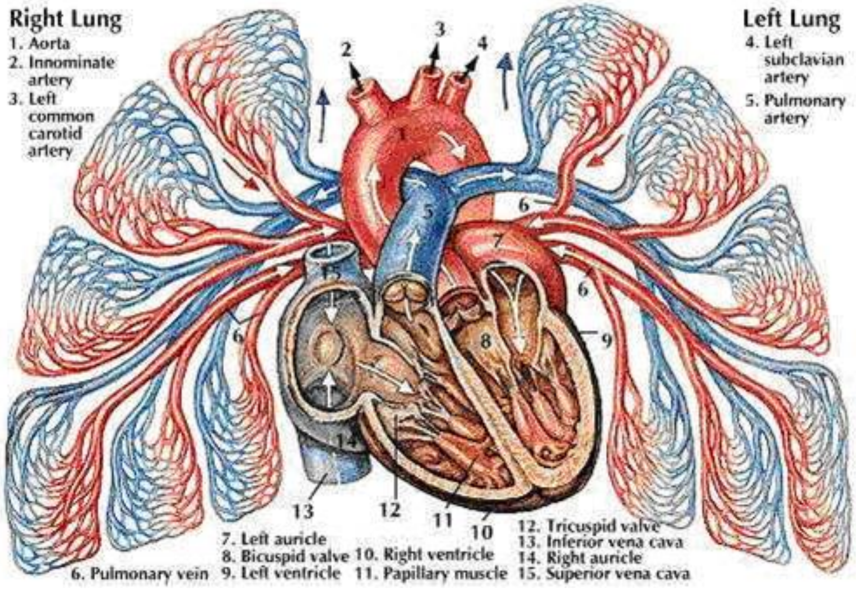
- From the right ventricle, blood is pumped through the pulmonary semilunar valve into the left and right pulmonary arteries (one for each lung) and travels through the lungs.

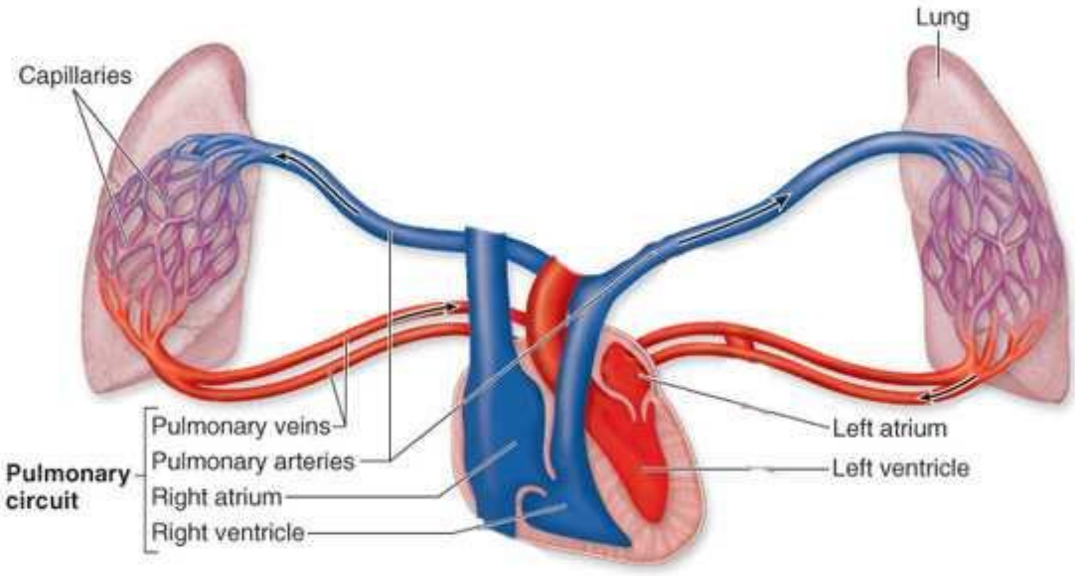
Lungs

- The pulmonary arteries carry deoxygenated blood to the lungs, where it releases carbon dioxide and pick up oxygen during respiration.
- Arteries are further divided in to very fine branches called the capillaries.
- In structure the capillaries are very thin walled. Their function is to carry blood to all cells of the body.

Veins

- The oxygenated blood then leaves the lungs through pulmonary veins, which return it to the left heart, completing the pulmonary cycle.
- This blood then enters the left atrium, which pumps it through the bicuspid valve, also called the mitral or left atrioventricular valve, into the left ventricle.
- The blood is then distributed to the body through the systemic circulation before returning again to the pulmonary circulation.


Right Lung
1. Aorta
2. Innominate artery
3. Left common carotid artery
Left Lung
4. Left subclavian artery
5. Pulmonary artery
6. Pulmonary vein
7. Left auricle
8. Bicuspid valve
9. Left ventricle
10. Right ventricle
11. Papillary muscle
12. Tricuspid valve
13. Inferior vena cava
14. Right auricle
15. Superior vena cava


Lung
Capillaries
Pulmonary circuit
Pulmonary veins
Pulmonary arteries
Right atrium
Right ventricle
Left atrium
Left ventricle

IV. Coronary Circulation

A. Coronary arteries supply heart muscle

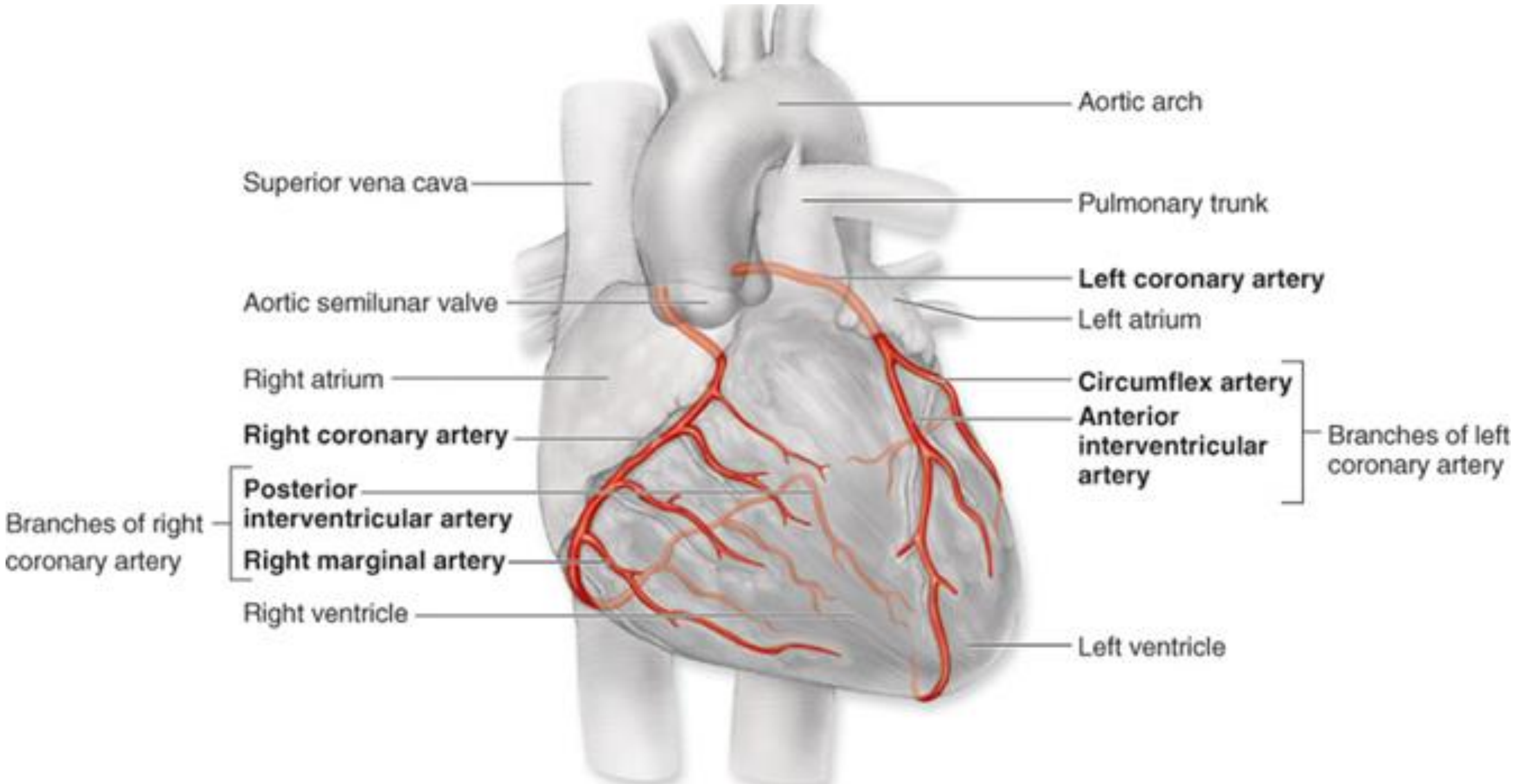
1. Begins at root of the aorta at sinus of Valsalva ; behind cusps of aortic valve
2. Coronary veins empty into the right atrium

B. Regulation of flow

1. Increased aortic pressure increases flow
2. Compression during systole inhibits flow. Most flow early in diastole, when aortic press. is still and ventricle wall tension is lowest.
3. Main regulation of flow is local metabolic reg., not neural reg.
4. Primary regulation by O_2 requirement of heart muscle : vasodilation of coronary vessels when more O_2 needed

Arteries:

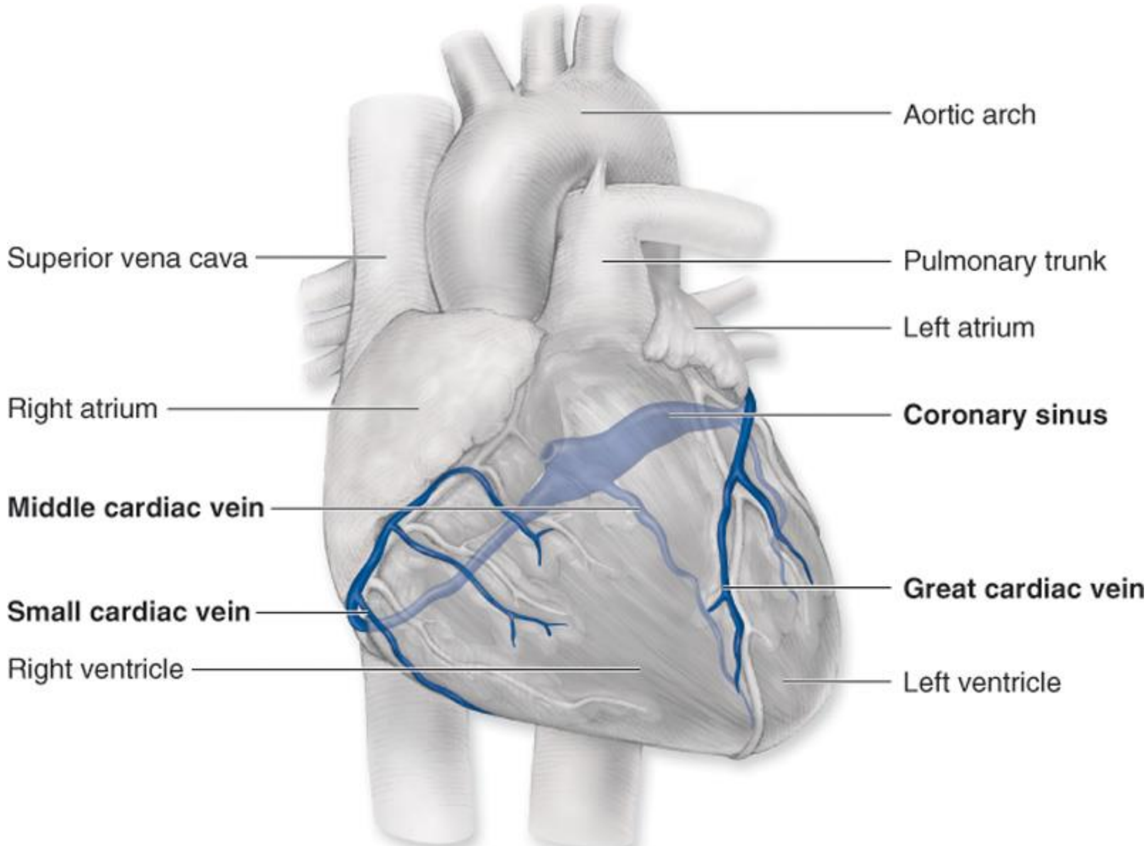
- ✓ Right coronary artery
- ✓ Marginal artery, or the Marginal Branch of the Right Coronary Artery
- ✓ Left coronary artery
- ✓ Circumflex artery, or the Circumflex Branch of the Left Coronary Artery



(a) Coronary arteries

<u>Veins</u>:

- ✓ Small cardiac vein
- ✓ Great cardiac vein
- ✓ Middle cardiac vein
- ✓ Coronary sinus



(b) Coronary veins

C. Coronary artery disease

1. Major cause of death in USA
2. Coronary atherosclerosis : build up of lipids and fibrous tissue in coronary arteries
3. Mild obstruction compensated for by vasodilation of downstream arterioles
4. With extra O_2 demands of exercise :
    a. Angina pectoris : treated with nitroglycerin or nifedipine : vasodilators ; lowers BP therefore less work
    b. Myocardial infarction : severely damaged heart tissue : may lead to death from heart failure of ventricular fibrillation

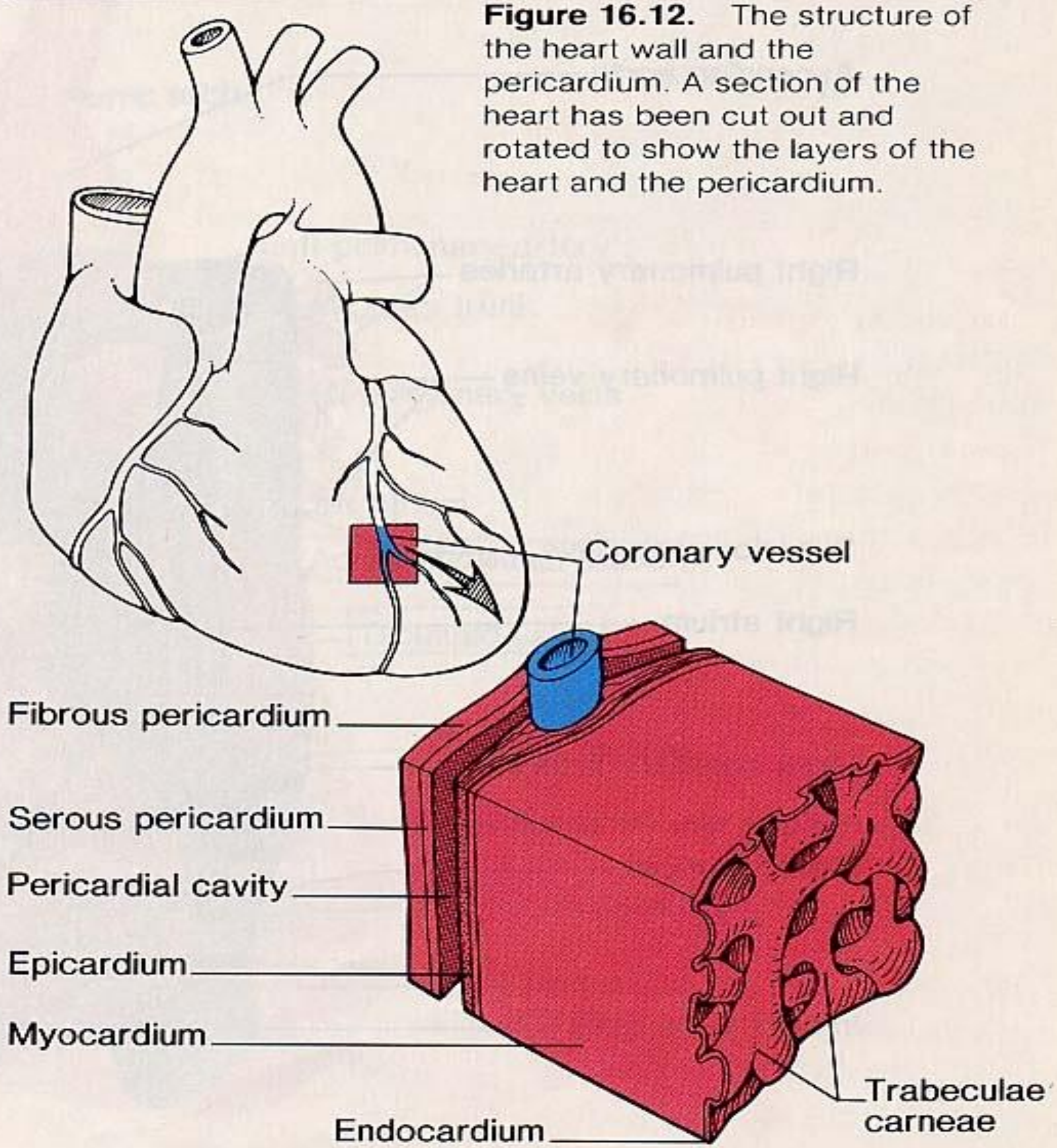


Figure 16.12. The structure of the heart wall and the pericardium. A section of the heart has been cut out and rotated to show the layers of the heart and the pericardium.