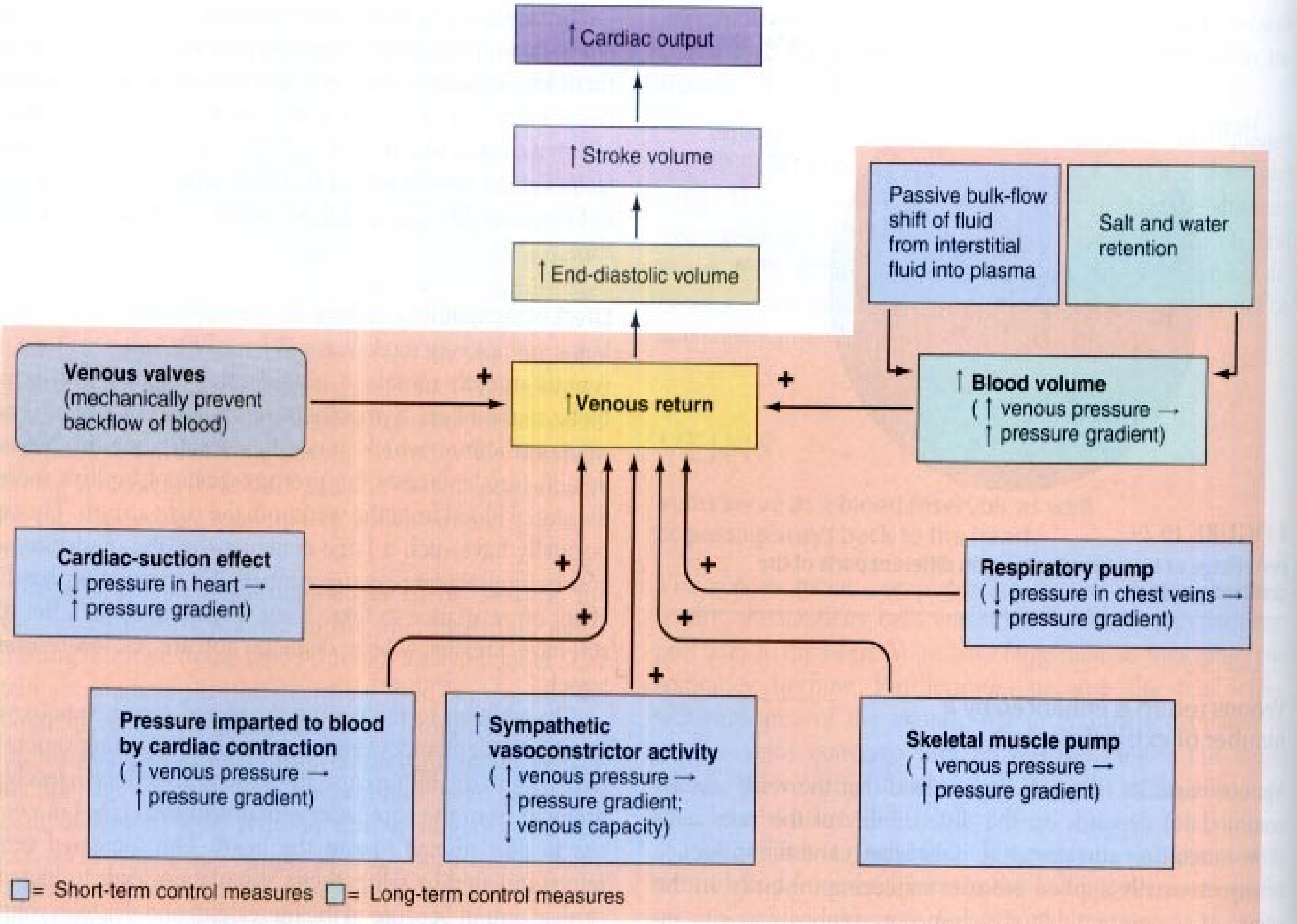
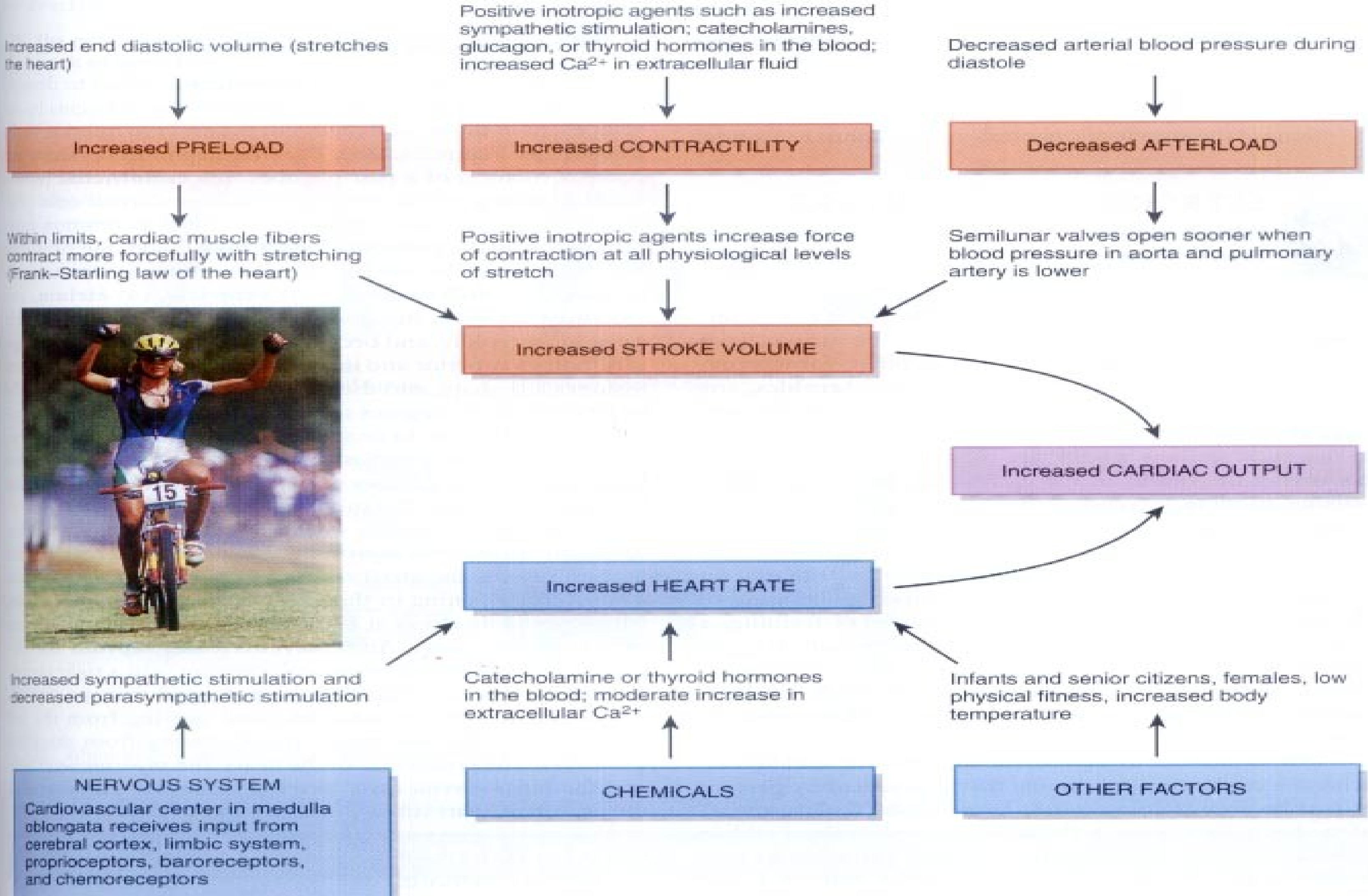
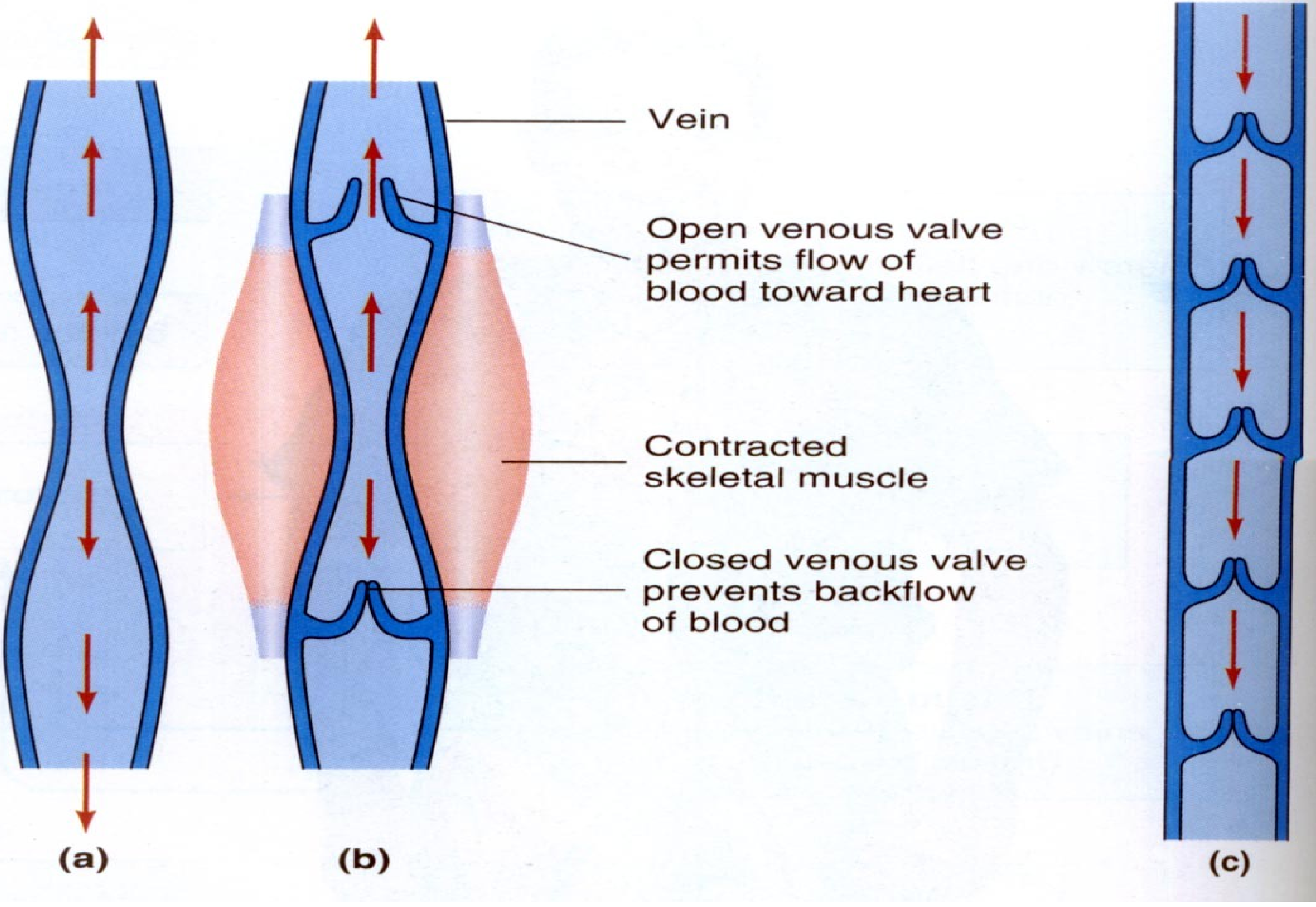

↑ Cardiac output
↑ Stroke volume
↑ End-diastolic volume
Passive bulk-flow shift of fluid from interstitial fluid into plasma
Salt and water retention
Venous valves (mechanically prevent backflow of blood)
+
↑ Venous return
+
↑ Blood volume (↑ venous pressure → ↑ pressure gradient)
Cardiac-suction effect (↓ pressure in heart → ↑ pressure gradient)
+
+
Respiratory pump (↓ pressure in chest veins → ↑ pressure gradient)
+
+
+
Pressure imparted to blood by cardiac contraction (↑ venous pressure → ↑ pressure gradient)
↑ Sympathetic vasoconstrictor activity (↑ venous pressure → ↑ pressure gradient; ↓ venous capacity)
Skeletal muscle pump (↑ venous pressure → ↑ pressure gradient)
= Short-term control measures
= Long-term control measures

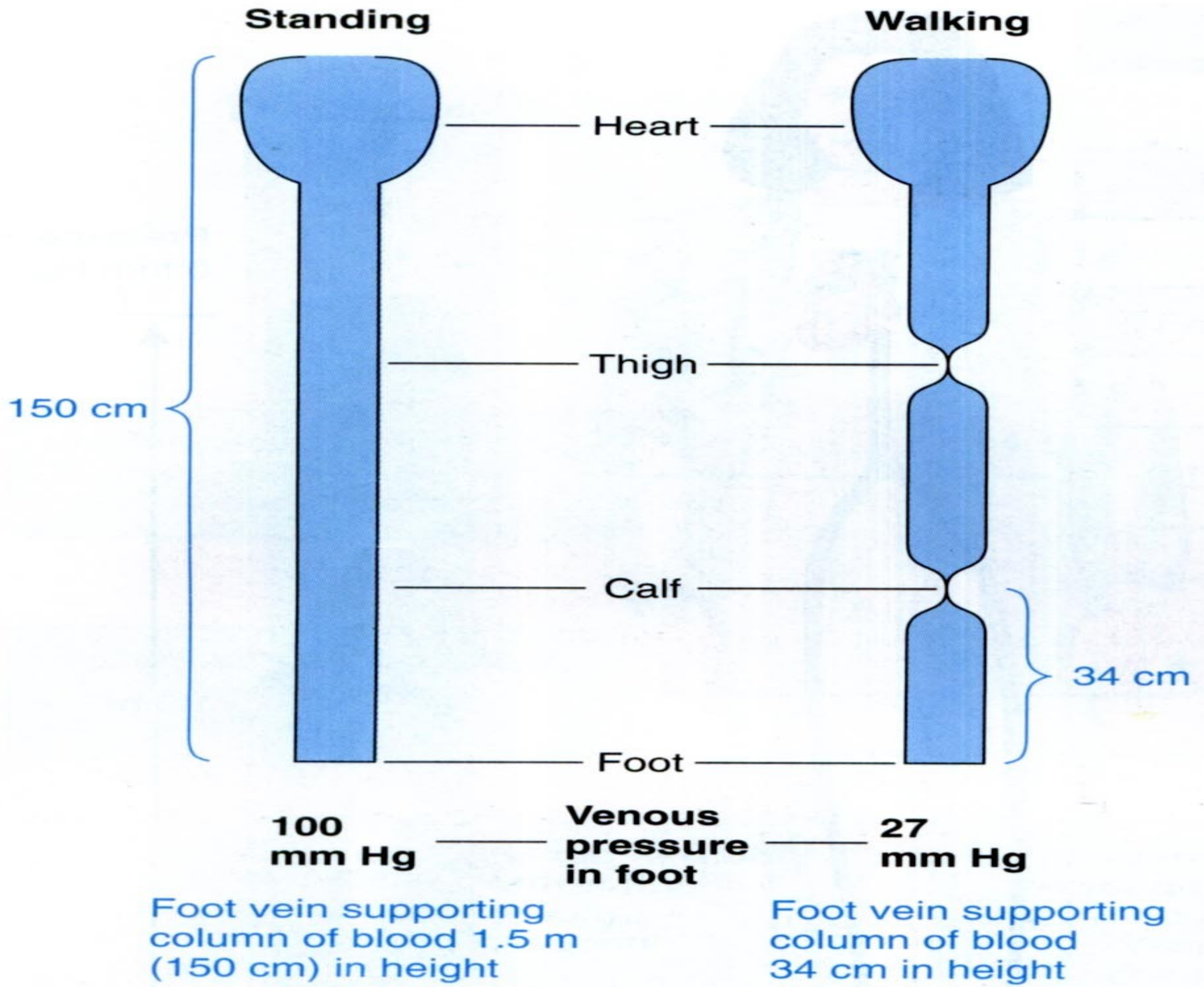
Figure 20.16 Factors that increase cardiac output.

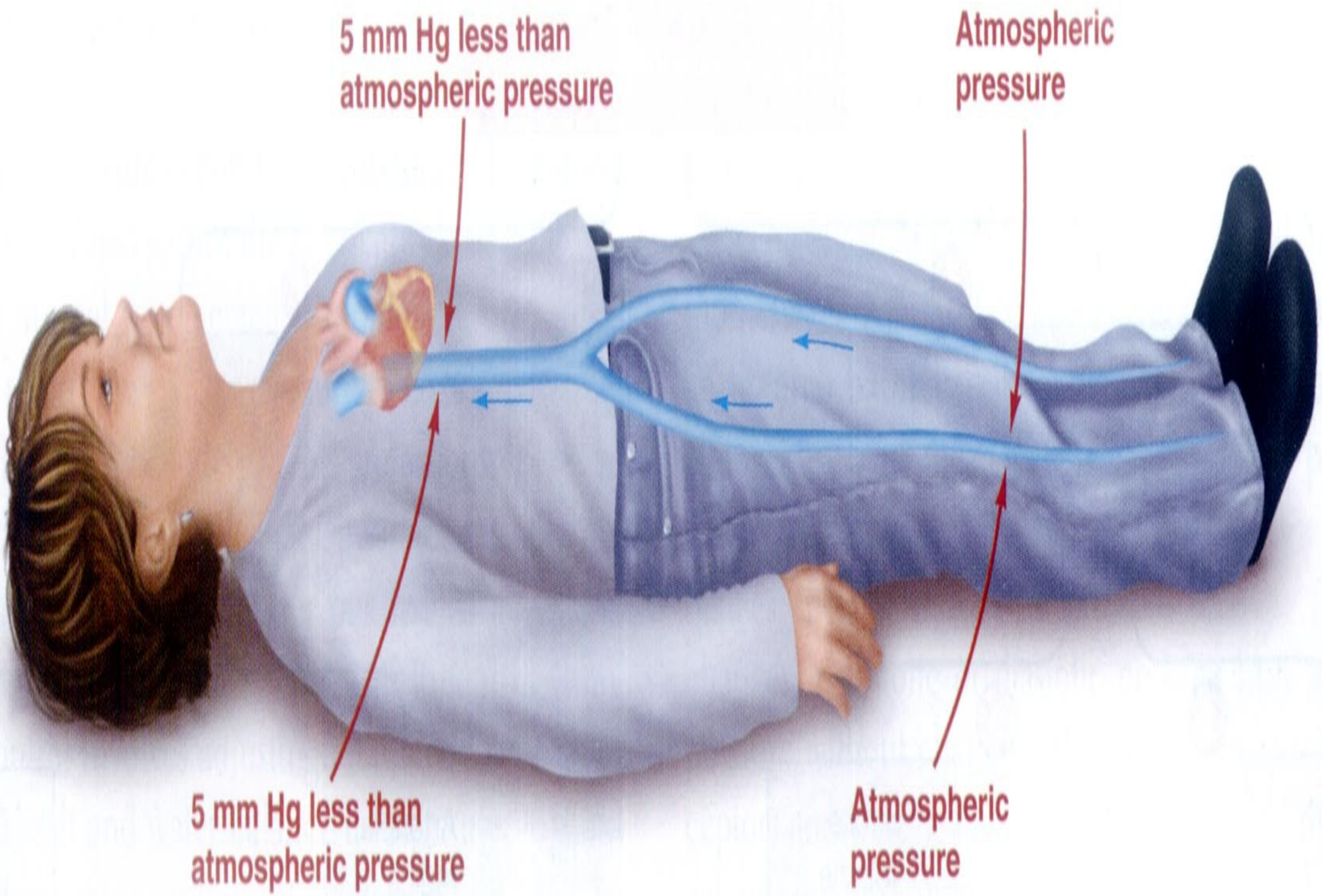
Cardiac output equals stroke volume multiplied by heart rate.



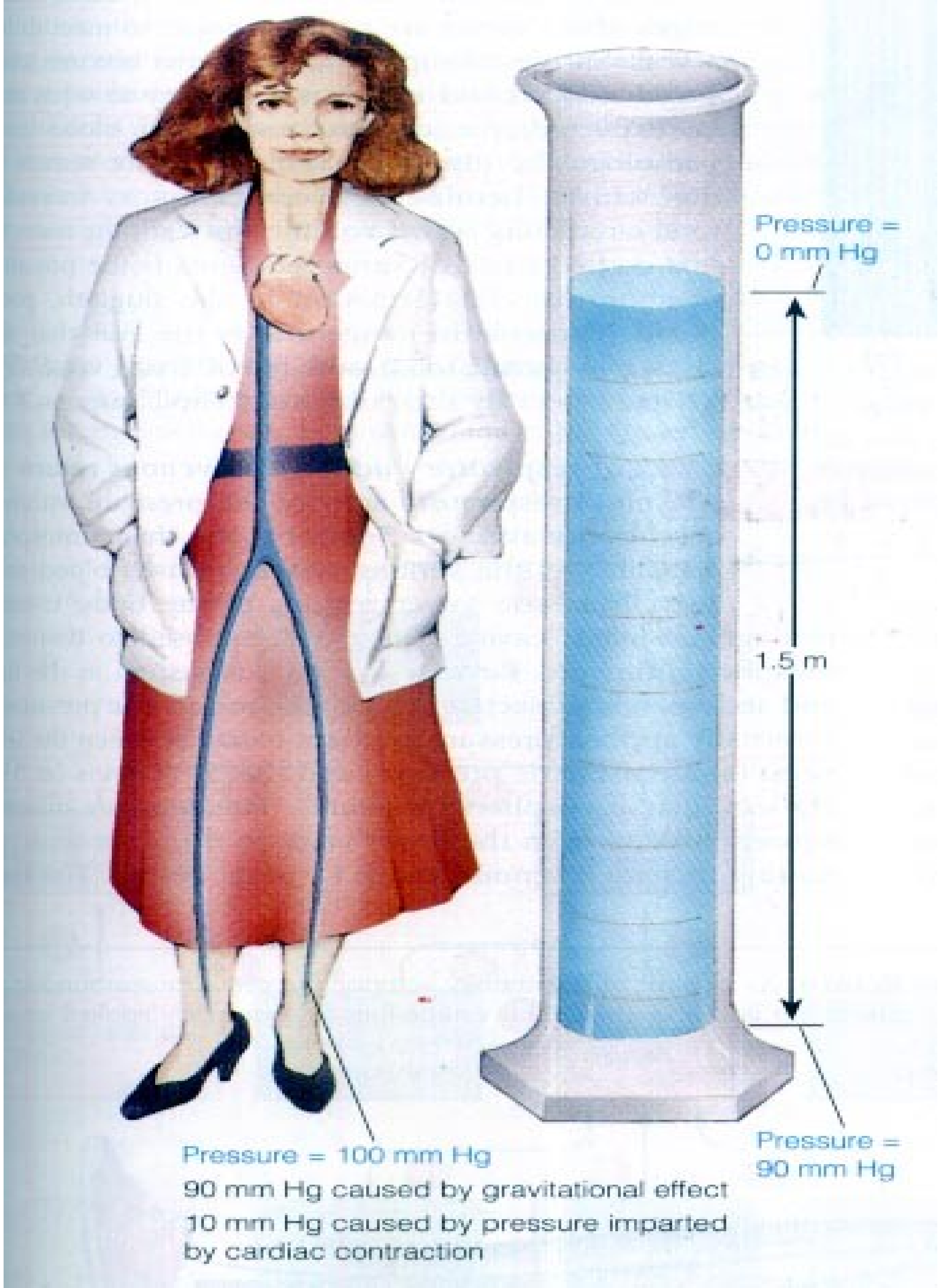
Q When you are exercising, contraction of skeletal muscles helps return blood to the heart more rapidly. Would this effect tend to increase or decrease stroke volume?


Vein
Open venous valve permits flow of blood toward heart
Contracted skeletal muscle
Closed venous valve prevents backflow of blood
(a)
(b)
(c)


Standing
Walking
Heart
Thigh
Calf
Foot
150 cm
34 cm
100
mm Hg
Venous
pressure
in foot
27
mm Hg
Foot vein supporting
column of blood 1.5 m
(150 cm) in height
Foot vein supporting
column of blood
34 cm in height



5 mm Hg less than
atmospheric pressure
Atmospheric
pressure
5 mm Hg less than
atmospheric pressure
Atmospheric
pressure



Pressure =
0 mm Hg
1.5 m
Pressure =
90 mm Hg
Pressure = 100 mm Hg
90 mm Hg caused by gravitational effect
10 mm Hg caused by pressure imparted
by cardiac contraction

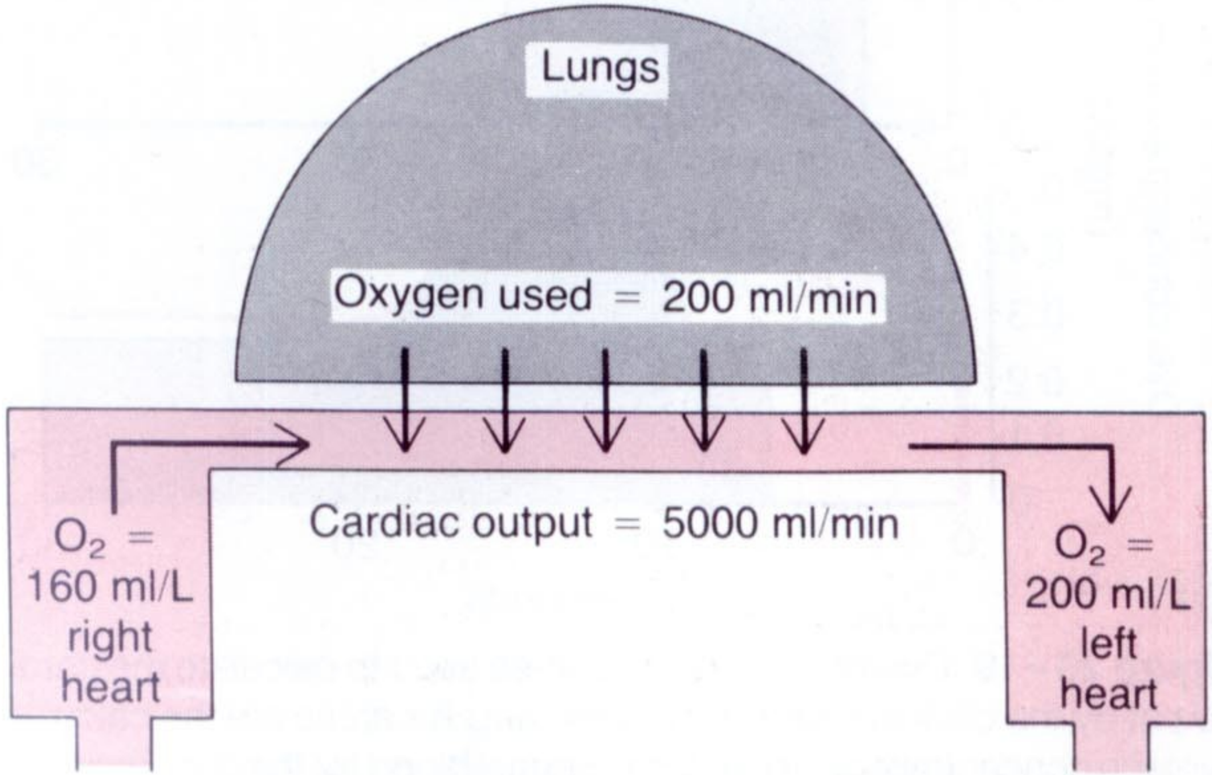


Figure 20–18. The Fick principle for determining cardiac output.

Functions of thecirculation

To serve the needs of the tissues:-

1- Trasport nutrients & remove waste products.

2- Trasport hormones, enzymes, body heat, electrolytes etc.

3-Maintain normal homeostasis for optimal survival &function of cells.

Functional Parts of the circulation

1- **Arteries:-** Has strong muscular walls. Trasport blood rapidly under high pressure to the tissues.

2- **Arterioles:-** Has strong muscular walls that can close the arteriole completely or dilate it several folds i.e they alter blood flow to the capillaries in response to needs.

Arterioles & small arteries are called (Resistance vessels).

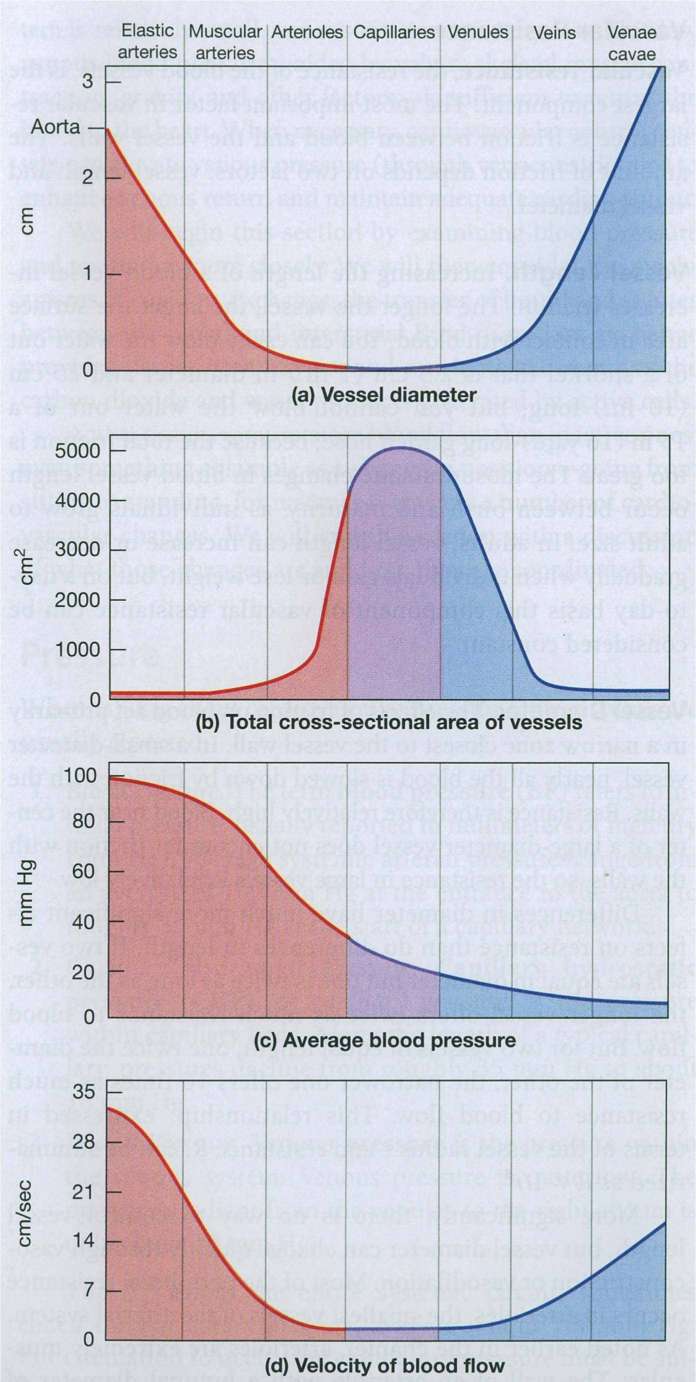
3- **Capillaries:-**

Very thin wall (unicellular layer of endothelial cells). Very small internal diameter. have numerous capillary pores.Very large surface area (**Exchange blood vessels).** For exchange of gases, nutrients, waste products etc.

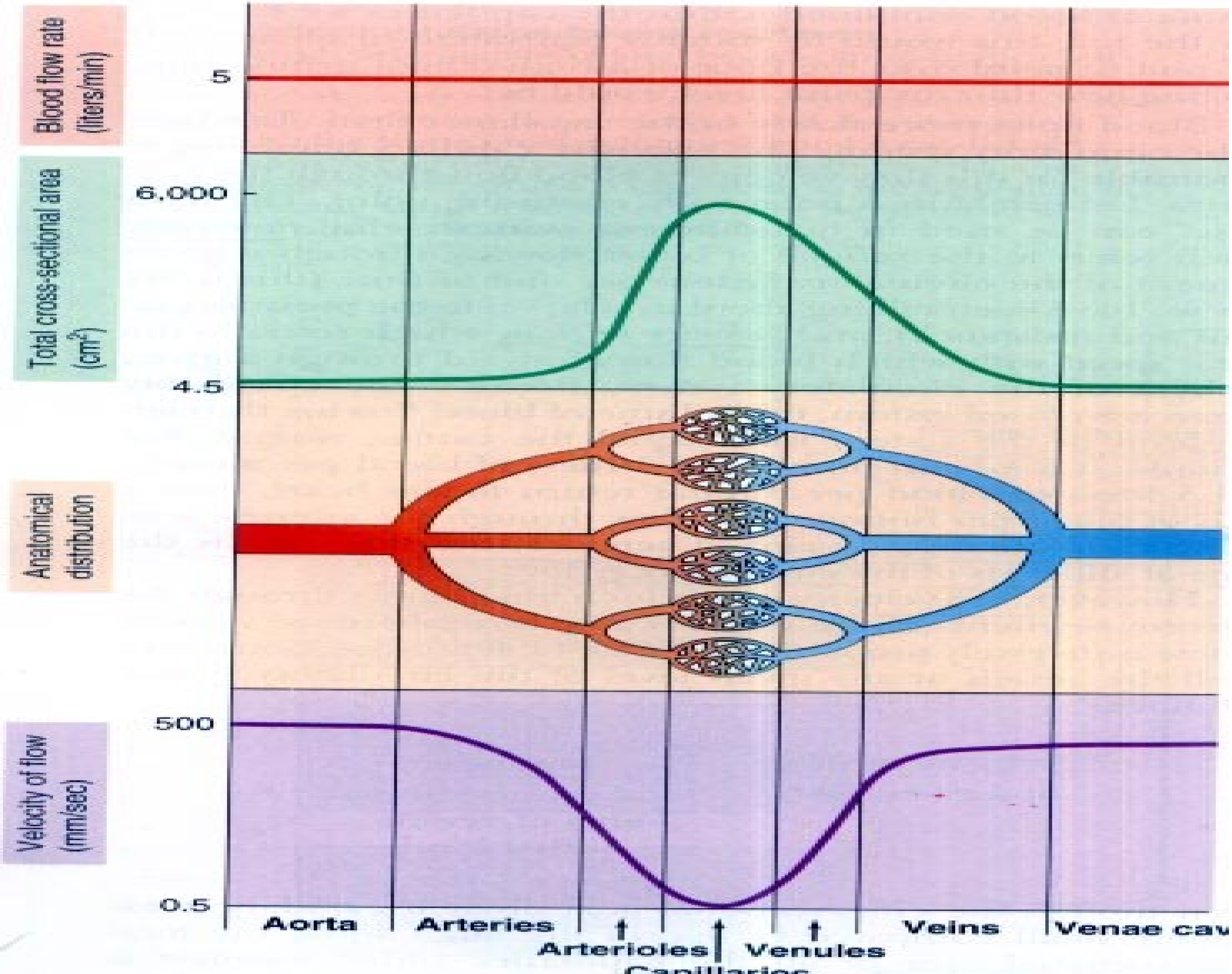
Blood flow is intermittent, turn on and off every few seconds or minutes **(Vasomotion)**,determined by oxygen demand.

4- **Venules & Veins:-**

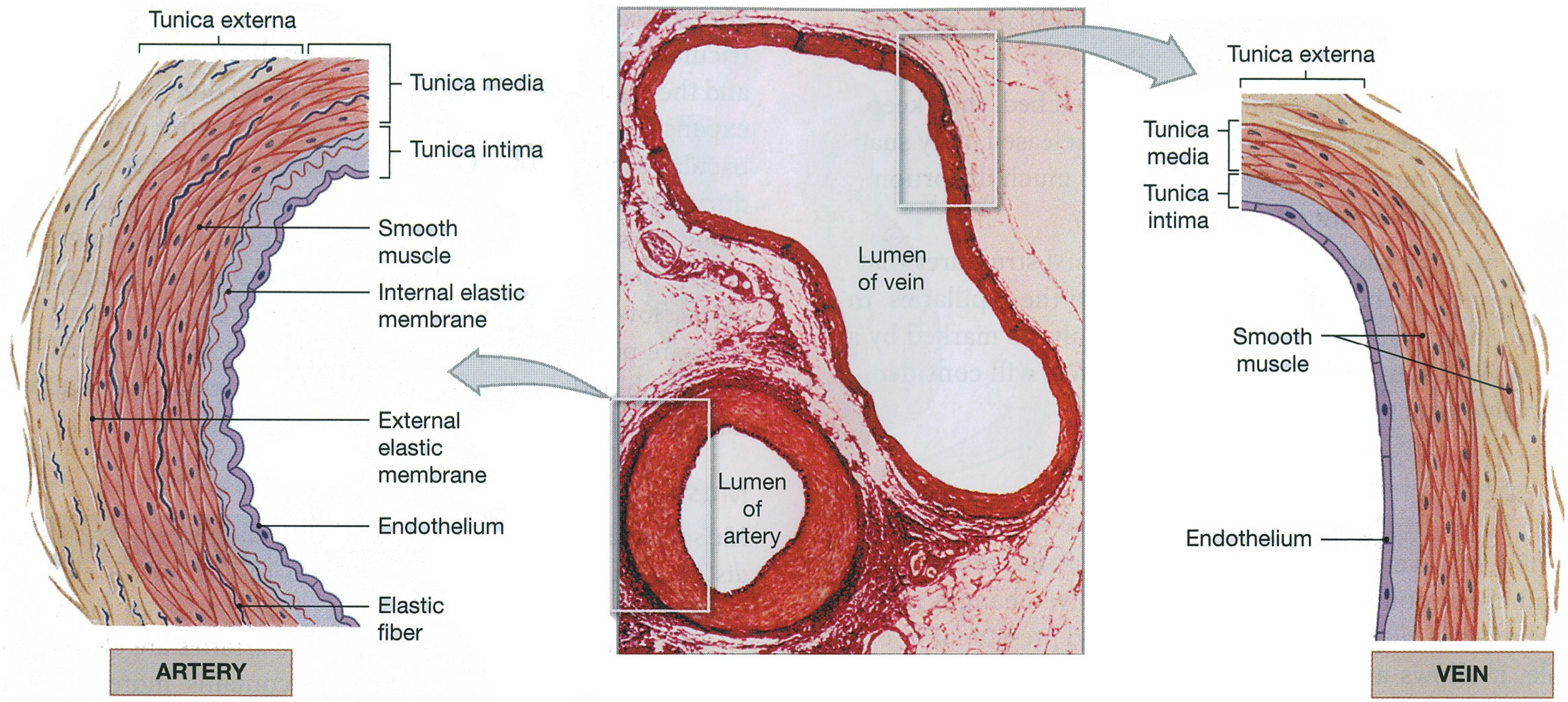
At rest more than ⅔rds. Of total blood volume is found withen the venous system.More than half of it is within venules **(Capacitance vessels).**



Relationships among Vessel Diameter, Cross-Sectional Area, Blood Pressure, and Blood Velocity.

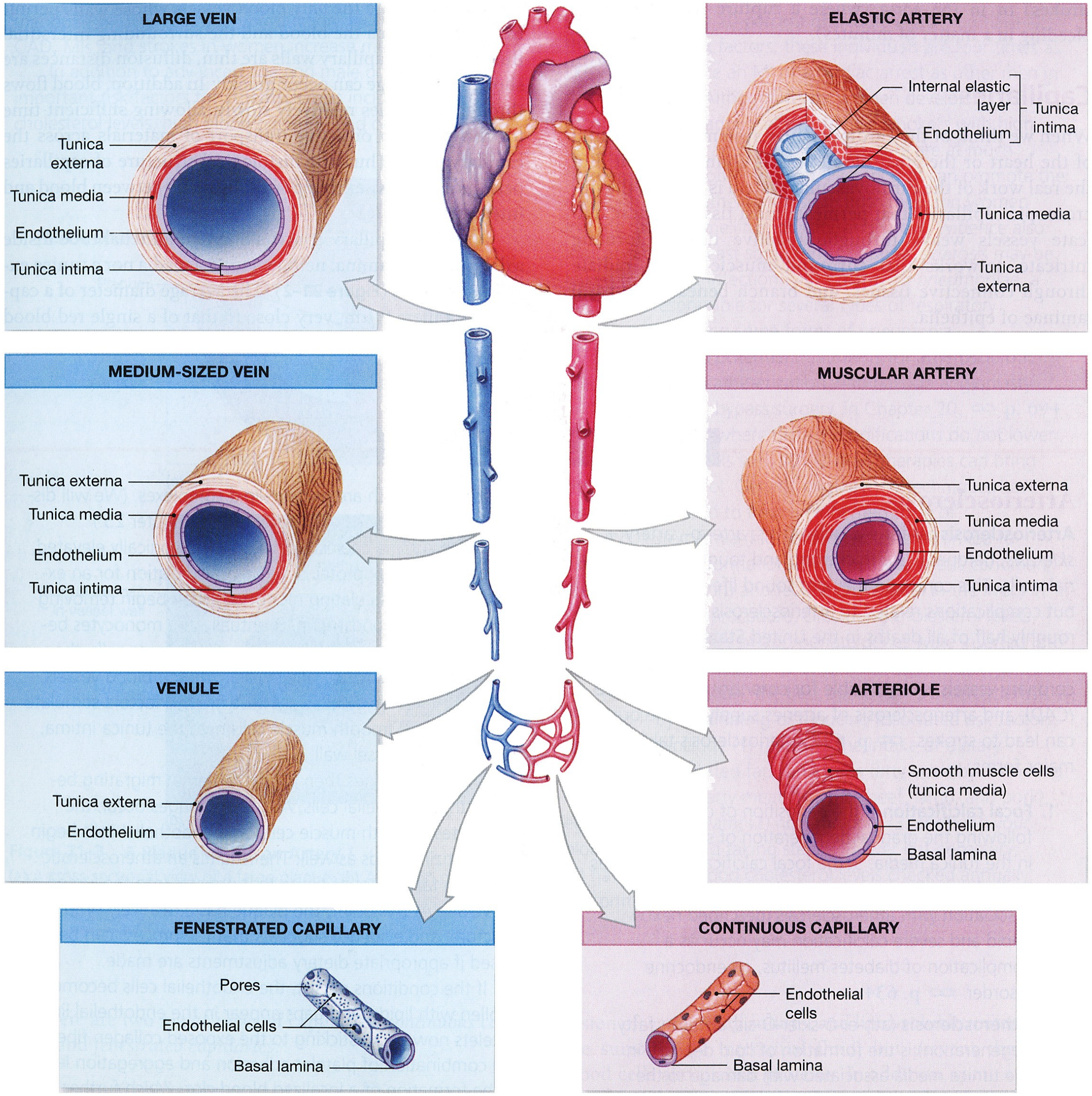

Blood flow rate (liters/min)
5
Total cross-sectional area (cm^2)
6,000
4.5
Anatomical distribution
Velocity of flow (mm/sec)
500
0.5
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Venae cav

■ FIGURE 10-17

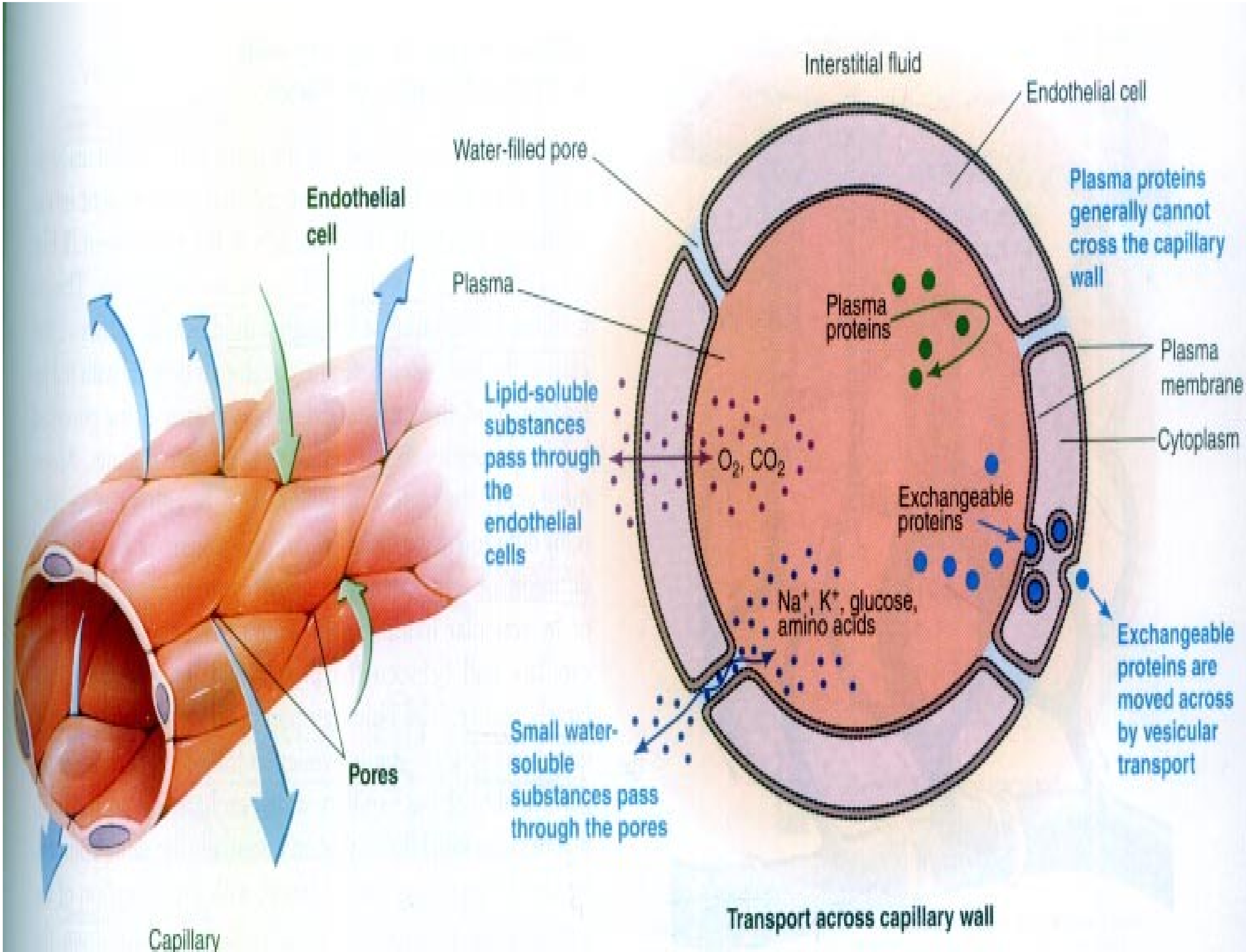


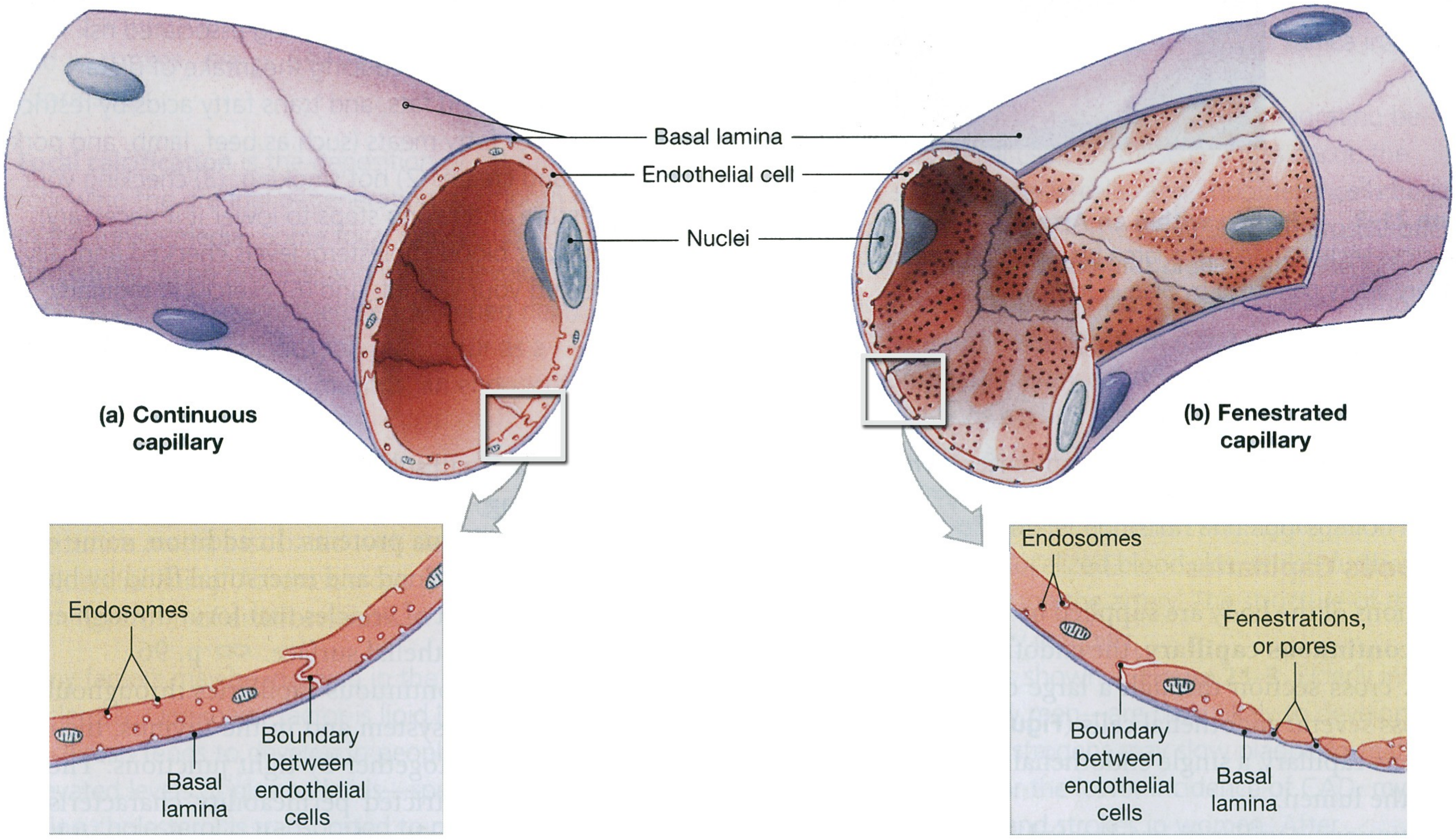
Feature	Typical Artery	Typical Vein
GENERAL APPEARANCE IN SECTIONAL VIEW	Usually round, with relatively thick wall	Usually flattened or collapsed, with relatively thin wall
TUNICA INTIMA		
Endothelium	Usually rippled, due to vessel constriction	Often smooth
Internal elastic membrane	Present	Absent
TUNICA MEDIA	Thick, dominated by smooth muscle cells and elastic fibers	Thin, dominated by smooth muscle cells and collagen fibers
External elastic membrane	Present	Absent
TUNICA EXTERNA	Collagen and elastic fibers	Collagen and elastic fibers and smooth muscle cells

Comparison of a Typical Artery and a Typical Vein.

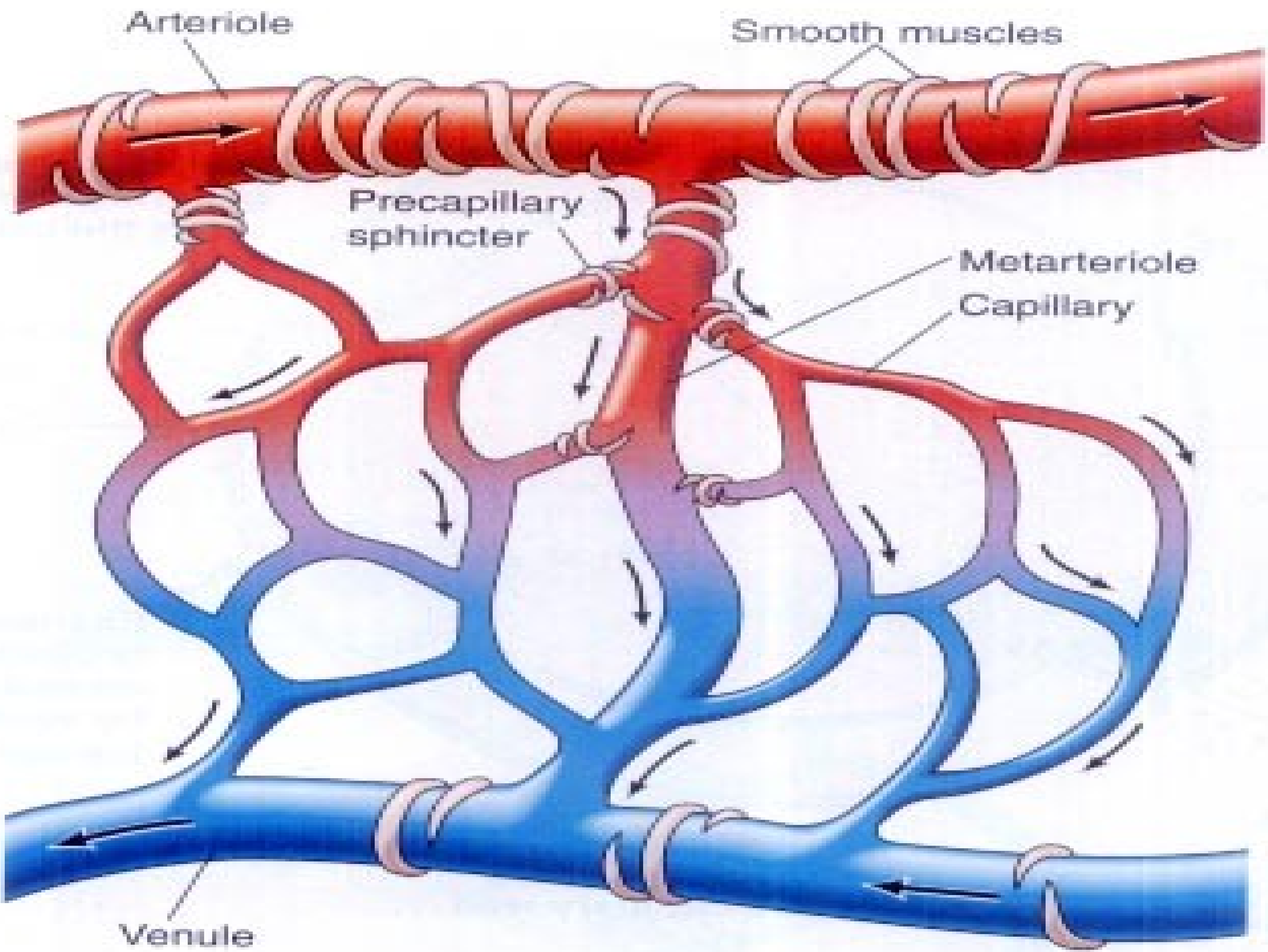


Histological Structure of Blood Vessels. Representative diagrammatic cross-sectional views of the walls of arteries, capillaries, and veins. Notice the relative sizes of the layers in these vessels.

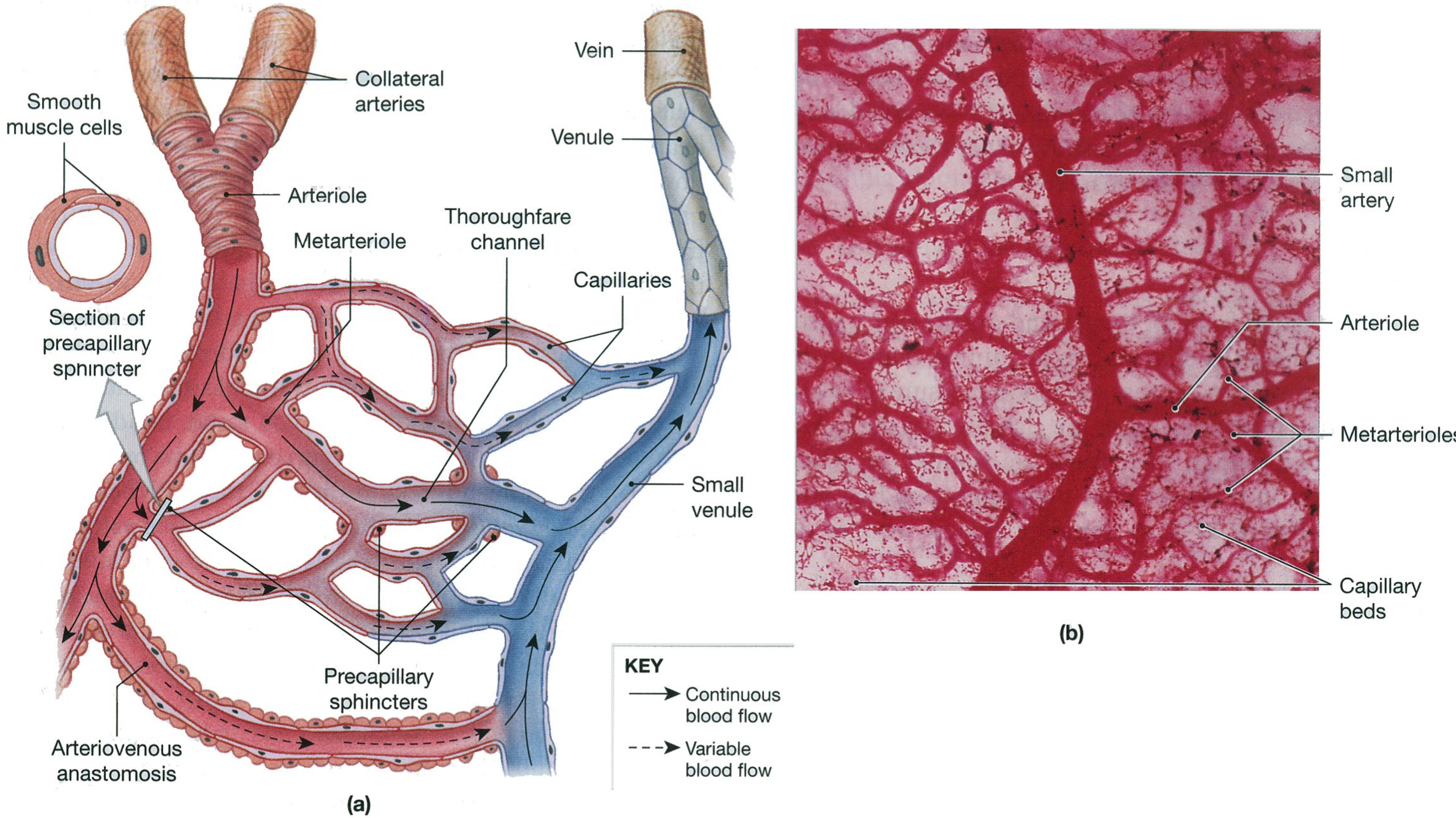

Endothelial cell
Pores
Capillary
Interstitial fluid
Endothelial cell
Water-filled pore
Plasma
Plasma proteins generally cannot cross the capillary wall
Plasma proteins
Plasma membrane
Cytoplasm
Lipid-soluble substances pass through the endothelial cells
O2, CO2
Exchangeable proteins
Na+, K+, glucose, amino acids
Exchangeable proteins are moved across by vesicular transport
Small water-soluble substances pass through the pores
Transport across capillary wall



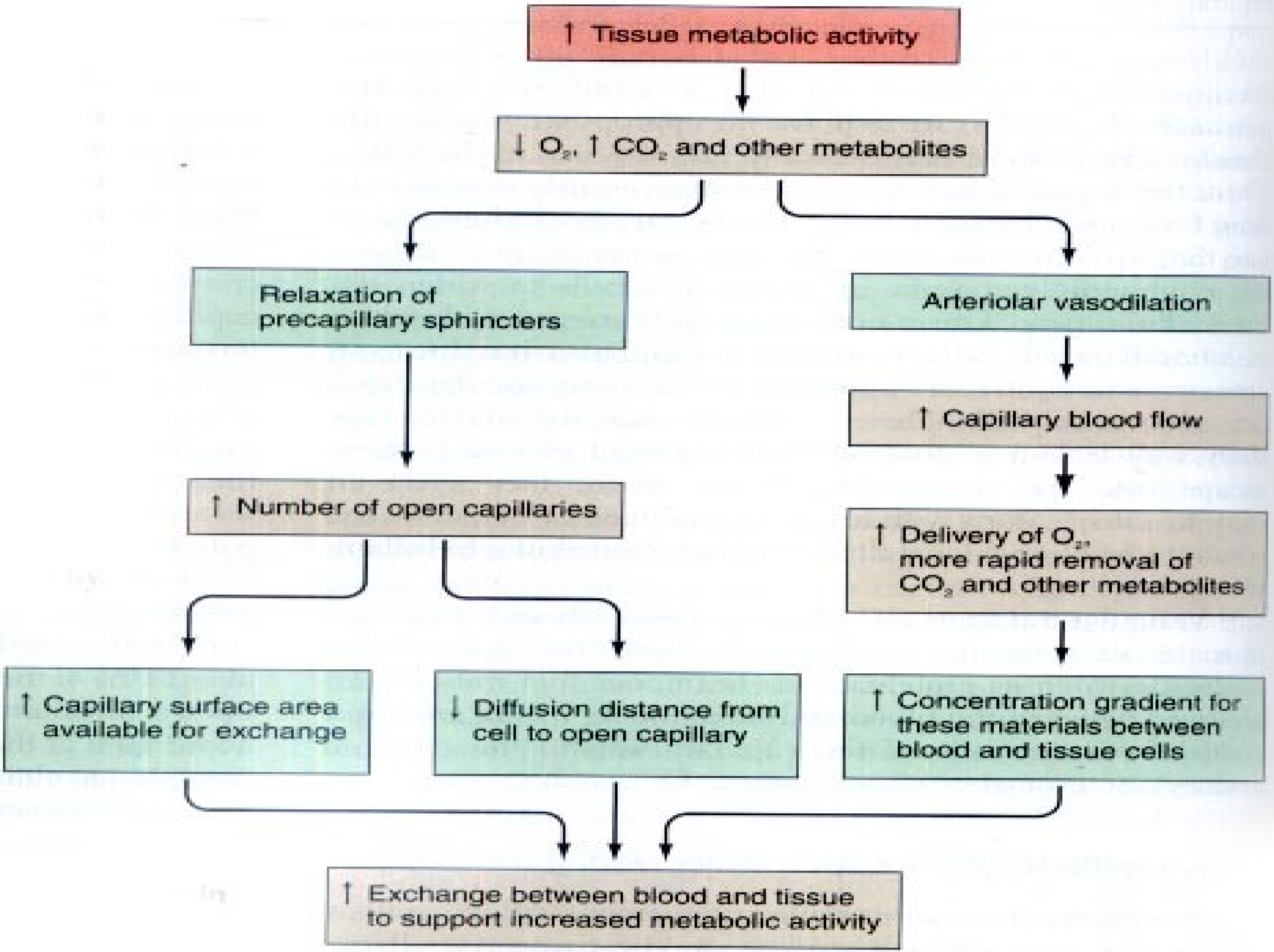
Capillary Structure. (a) A continuous capillary. The enlargement shows routes for the diffusion of water and solutes. (b) A fenestrated capillary. Note the pores, which facilitate diffusion across the endothelial lining.



Arteriole
Smooth muscles
Precapillary
sphincter
Metarteriole
Capillary
Venule



The Organization of a Capillary Bed. (a) A typical capillary bed. Solid arrows indicate consistent blood flow; dashed arrows indicate variable or pulsating blood flow. (b) A micrograph of a number of capillary beds.


↑ Tissue metabolic activity
↓ O_2, ↑ CO_2 and other metabolites
Relaxation of precapillary sphincters
Arteriolar vasodilation
↑ Capillary blood flow
↑ Number of open capillaries
↑ Delivery of O_2, more rapid removal of CO_2 and other metabolites
↑ Capillary surface area available for exchange
↓ Diffusion distance from cell to open capillary
↑ Concentration gradient for these materials between blood and tissue cells
↑ Exchange between blood and tissue to support increased metabolic activity

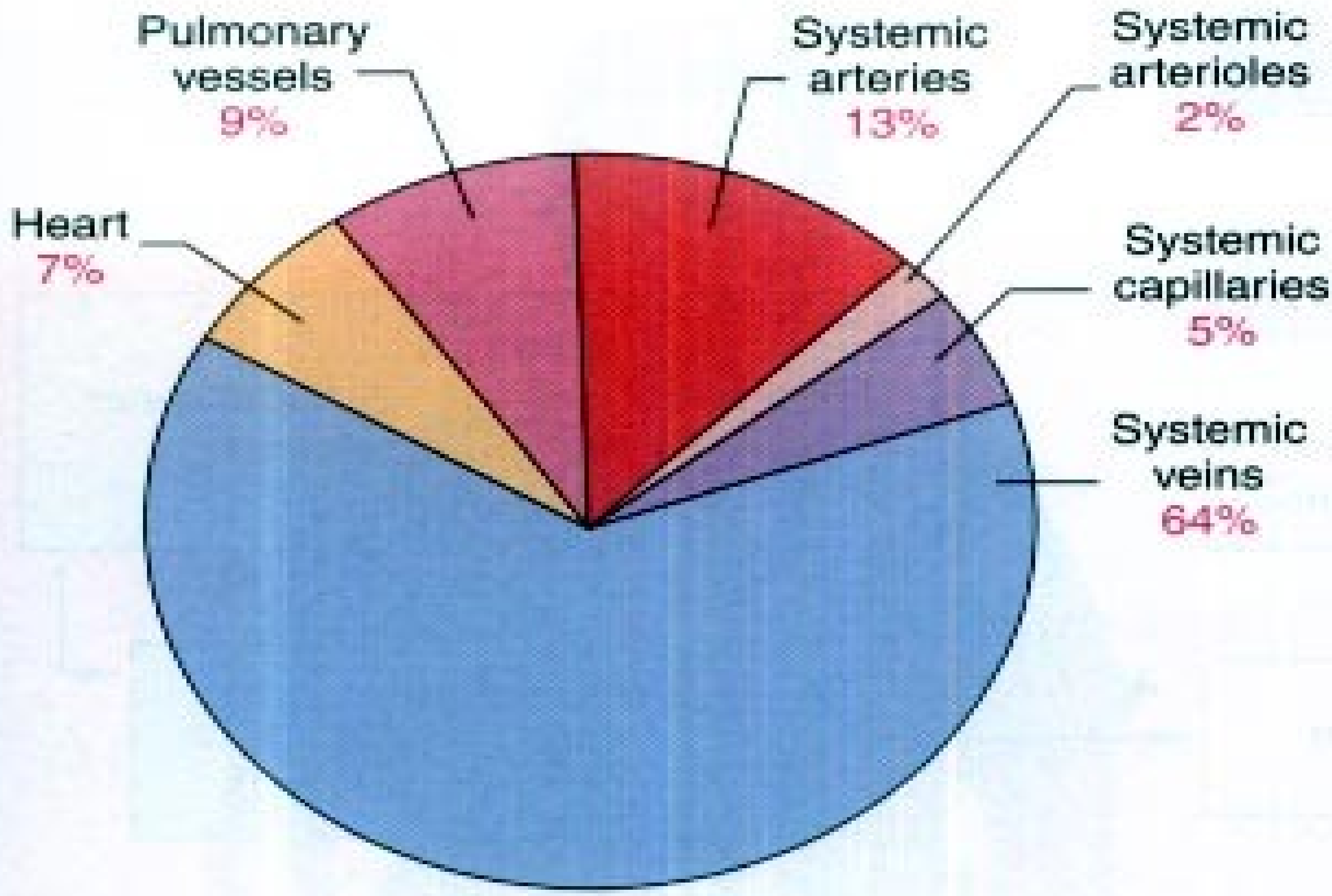
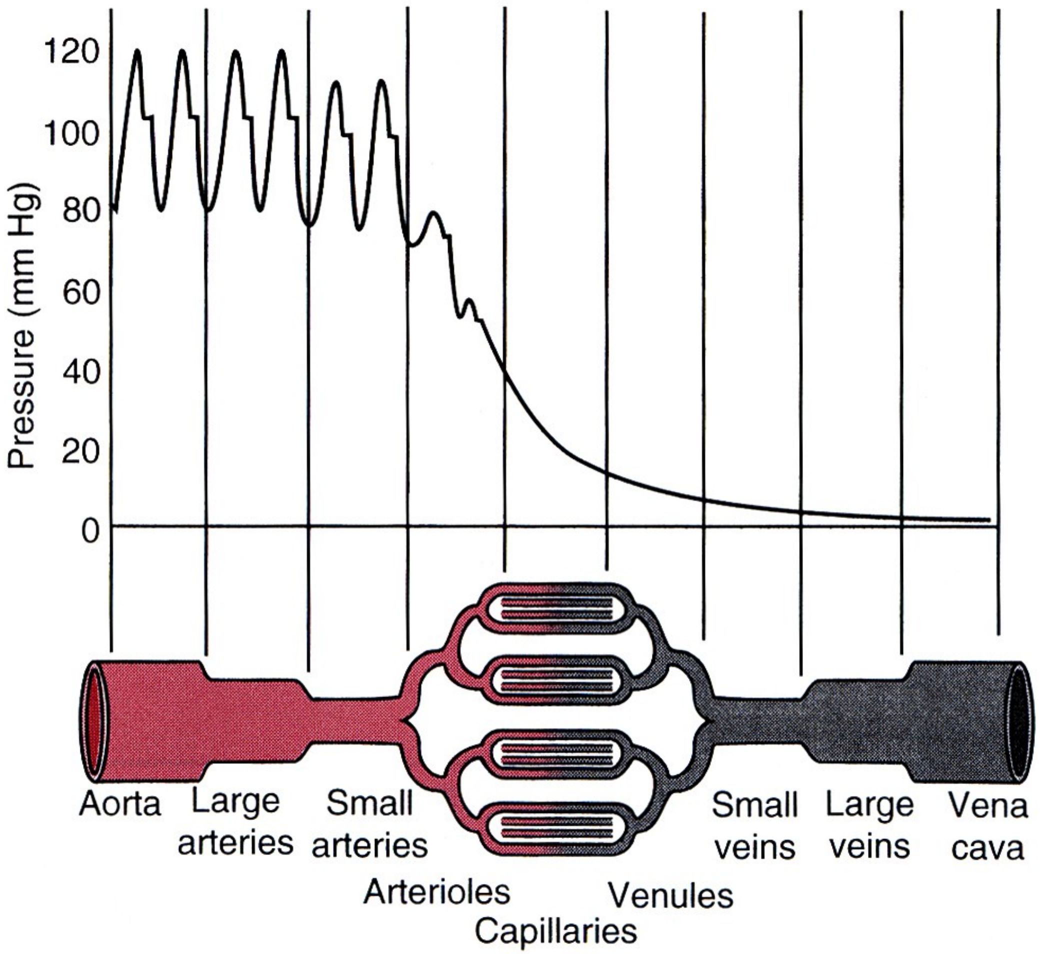

Pulmonary vessels 9%
Systemic arteries 13%
Systemic arterioles 2%
Heart 7%
Systemic capillaries 5%
Systemic veins 64%

FIGURE 10-29



Pressures in different vessels of the systemic circulation. Pulse pressure is greatest in the aorta and large arteries. The greatest drop in pressure occurs in the arteries.

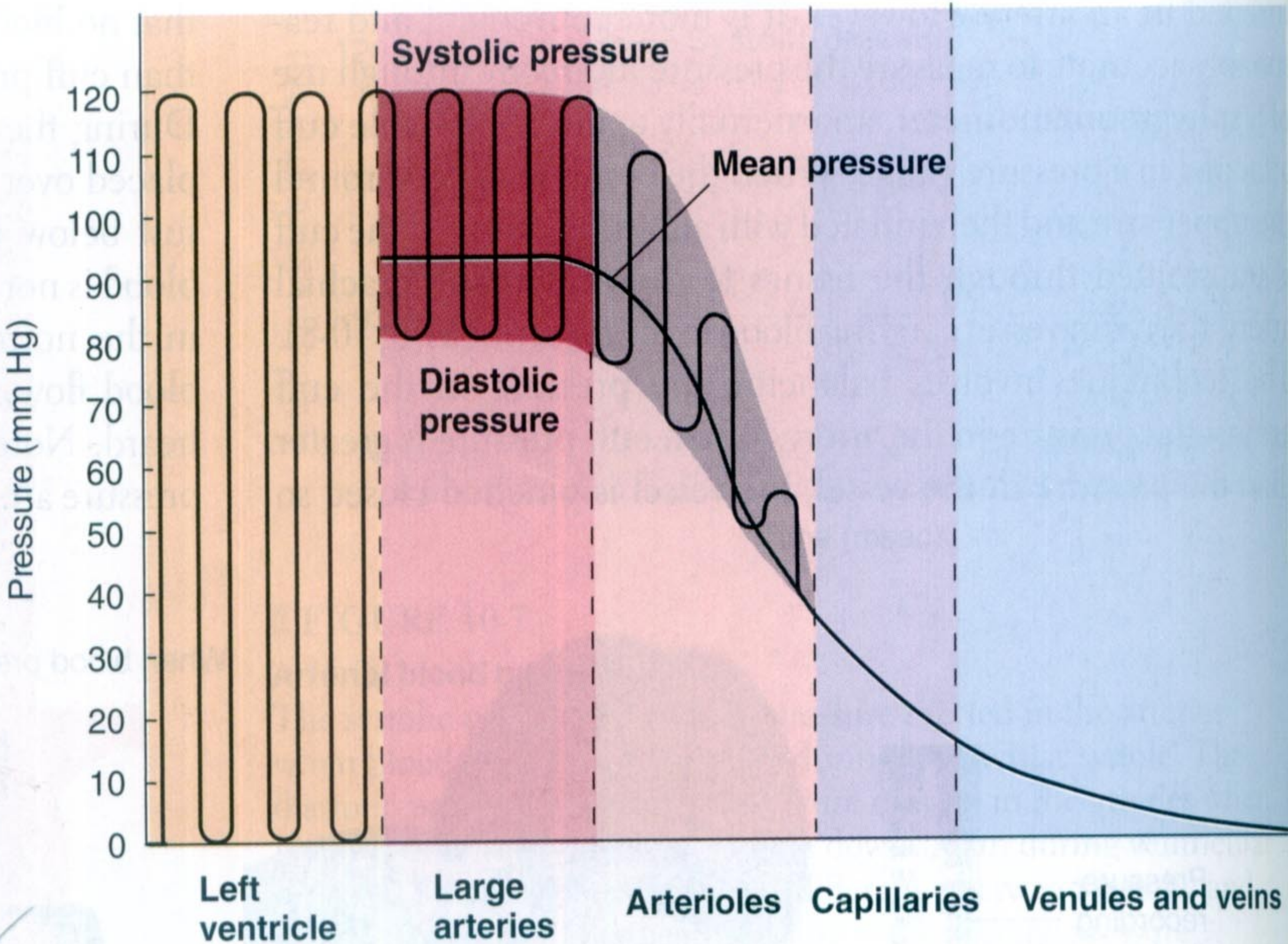


FIGURE 10-9

Pressures throughout the systemic circulation

▲ TABLE 10-1

Features of Blood Vessels

Feature	Vessel Type: Aorta	Large arterial branches	Arterioles	Capillaries	Large veins	Venae cavae
Number	One	Several hundred	Half a million	Ten billion	Several hundred	Two
Wall Thickness	2 mm (2,000 μm)	1 mm (1,000 μm)	20 μm	1 μm	0.5 mm (500 μm)	1.5 mm (1,500 μm)
Internal Radius	1.25 cm (12,500 μm)	0.2 cm (2,000 μm)	30 μm	3.5 μm	0.5 cm (5,000 μm)	3 cm (30,000 μm)
Total Cross-Sectional Area	4.5 cm^2	20 cm^2	400 cm^2	6,000 cm^2	40 cm^2	18 cm^2
Special Features	Thick, highly elastic, walls; large radii		Highly muscular, well-innervated walls; small radii	Thin walled; large total cross-sectional area	Thin walled; highly distensible; large radii	
Functions	Passageway from the heart to the tissues; serve as a pressure reservoir		Primary resistance vessels; determine the distribution of cardiac output	Site of exchange; determine the distribution of extracellular fluid between the plasma and interstitial fluid	Passageway to the heart from the tissues; serve as a blood reservoir	

Haemodynamics

Is the branch of physiology concerned with the physical principles governing:-

Pressure, Flow, Resistance, Volume, and Compliance as they relate to the CVS.

Resistance to blood flow results from the inner friction & viscosity of blood.

Pressure flow and resistance are related by (Ohm's Law).

$$Q = \Delta P/R.$$

Q = blood flow.

ΔP = the pressure difference between the two ends of the vessel.

R = Resistance.

Resistance depends on the <u>radius</u> & length of the blood vessel & the viscosity of blood (Poiseuilles law).

R = V x L / r4

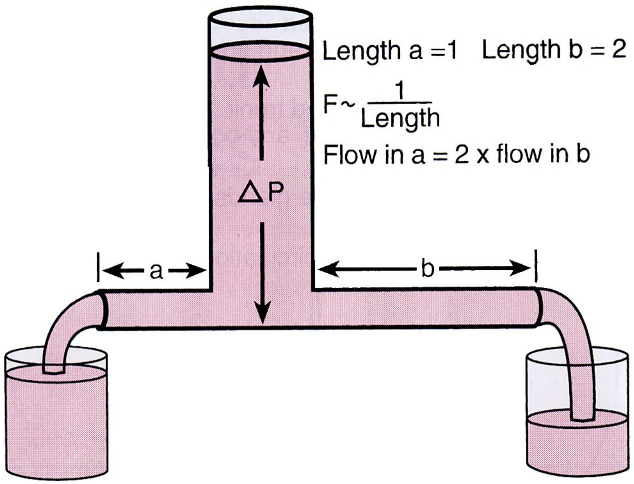
Q = ΔP x r4 / V x L .

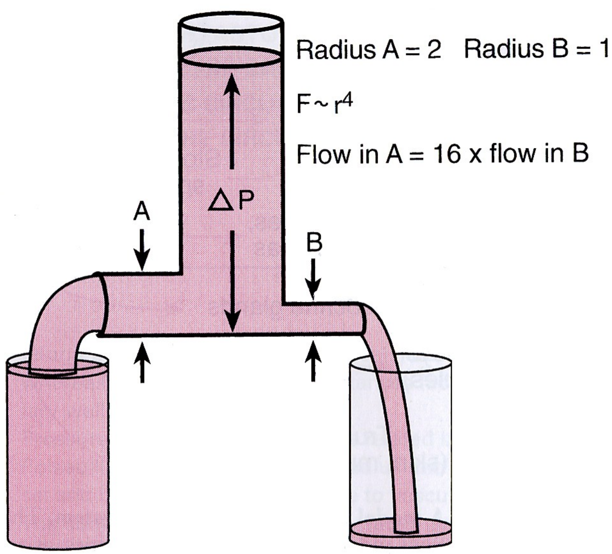
Length does not change, and viscosity rarely changes enough to have a significant effect on resistance.

There for small changes in arteriolar radius can cause large changes in blood flow.

Q ~ r4

R ~ 1/ r4





The influence of tube length and radius on flow. Because flow is determined by the fourth power of the radius, small changes in radius have a much greater effect than small changes in length. Furthermore, changes in blood vessel length do not occur over short periods of time and are not involved in the physiological control of blood flow. The pressure difference (Δ P) driving flow is the result of the height of the column of fluid above the openings of tubes A and B.

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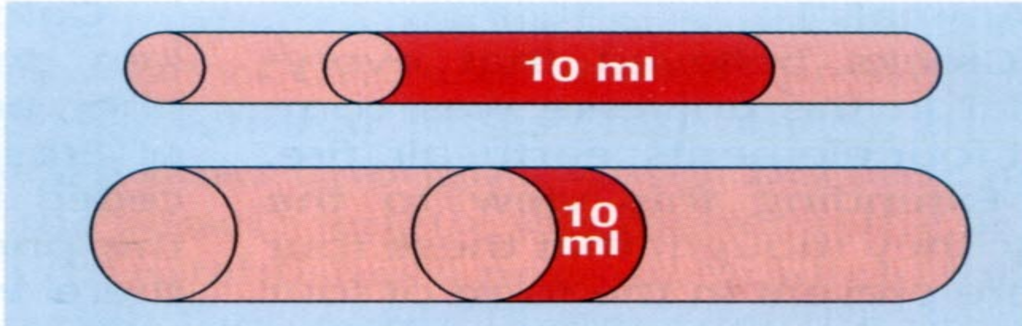
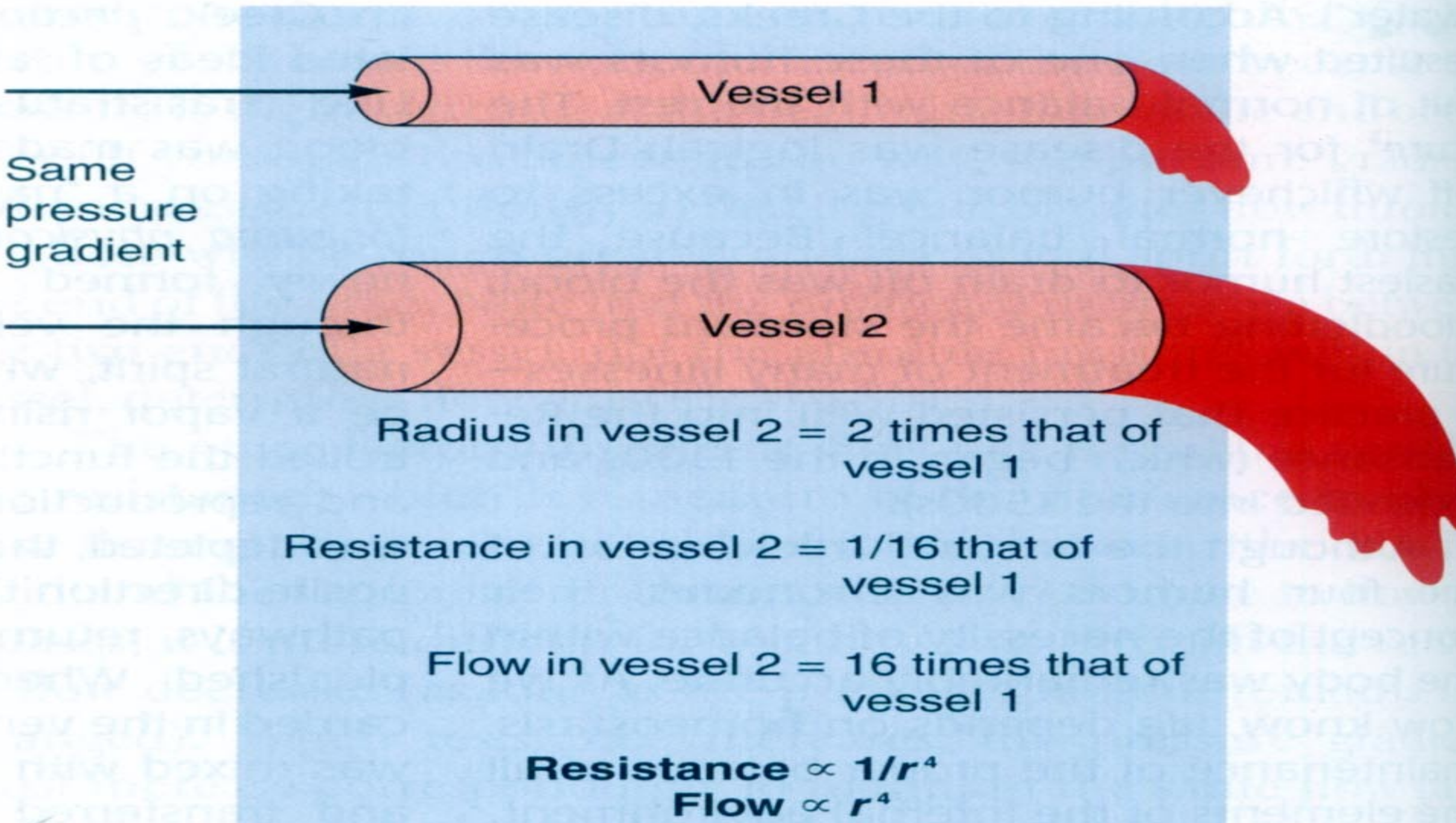


(a)



(b)

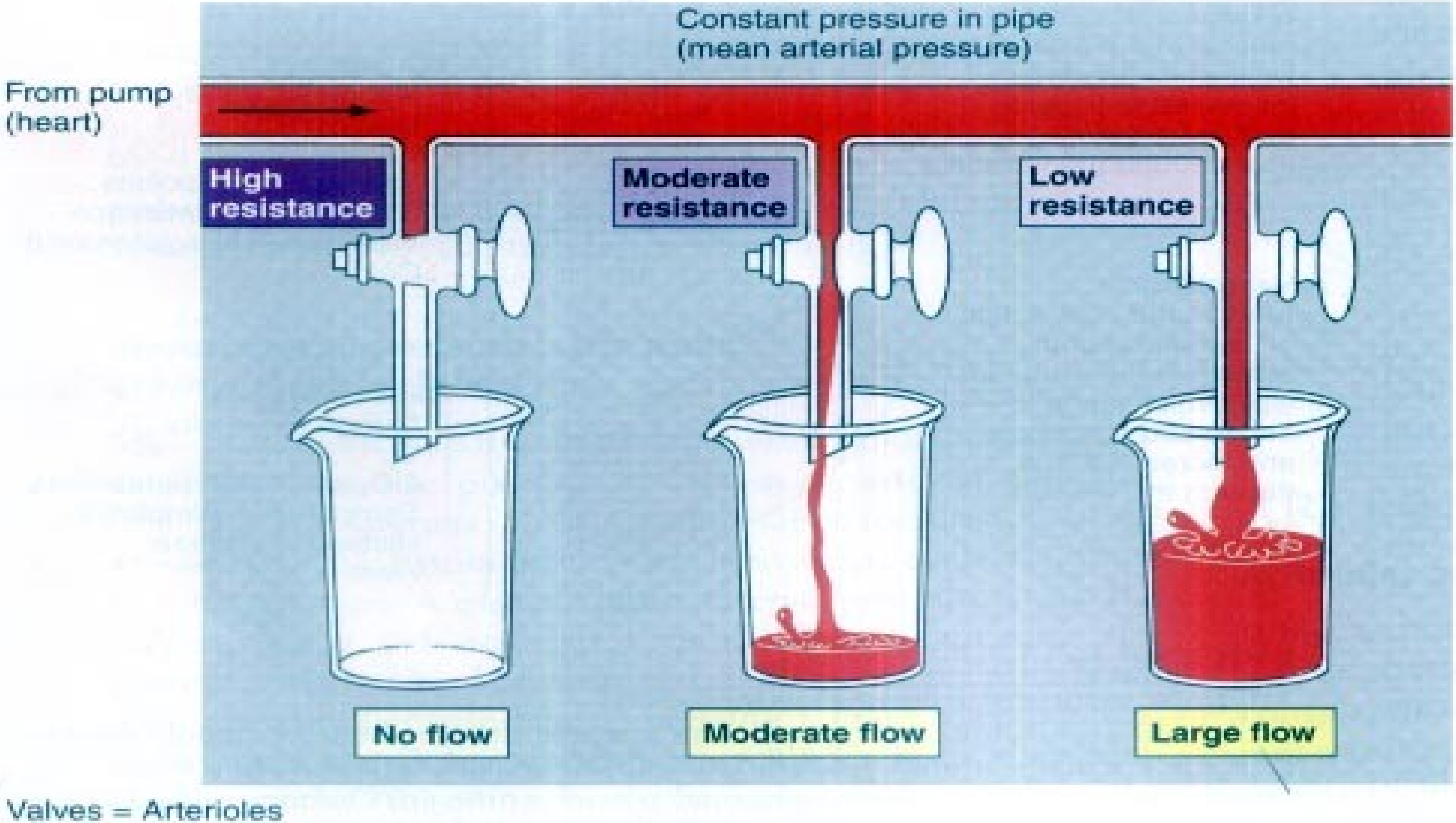
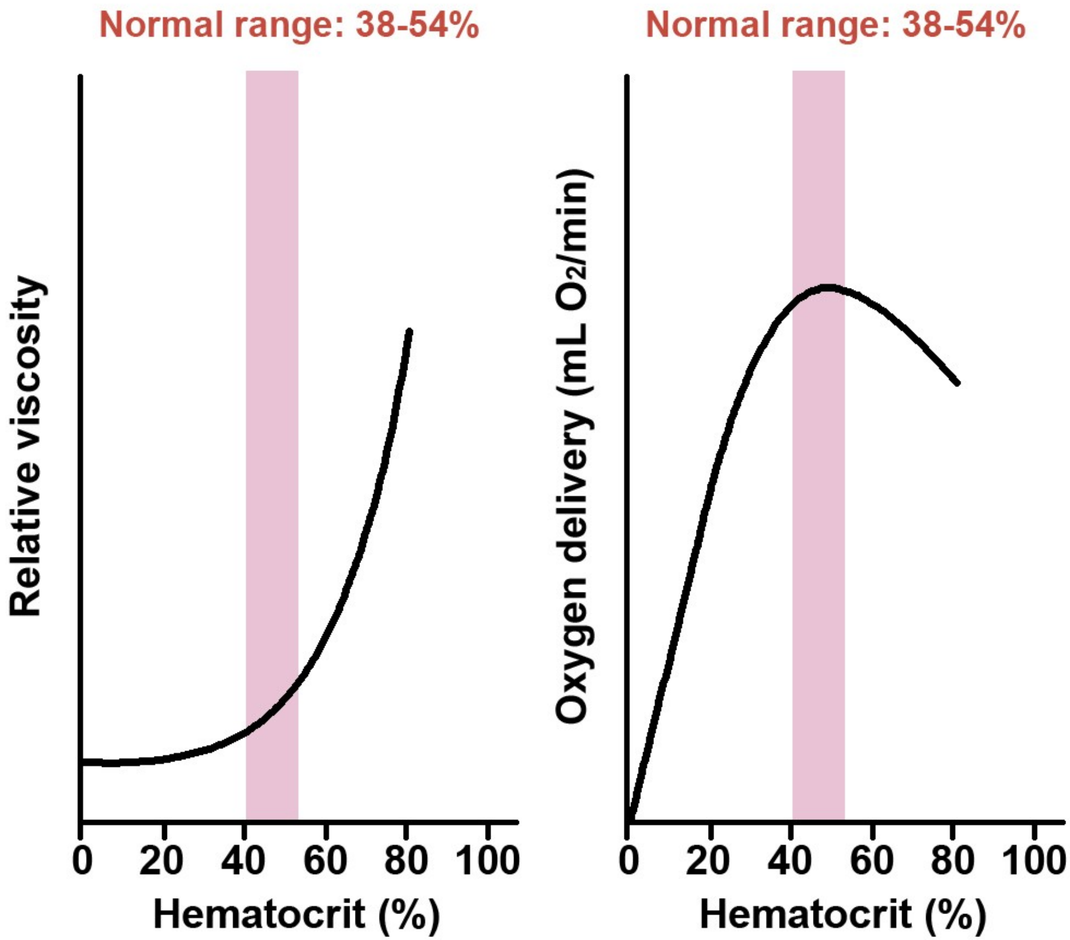


FIGURE 10-11

Flow rate as a function of resistance



Effect of hematocrit on blood viscosity. Above-normal hematocrits produce a sharp increase in viscosity. Because increased viscosity raises vascular resistance, hemoglobin and oxygen delivery may fall when the hematocrit rises above the normal range.

Local control of blood flow by the tissues & humoral regulation

Local vasodilator substances :-

↓ tissue oxygen, or ↑ carbon dioxide levels.

Nitric oxide (NO) relsead from endothelial cells.

Lactic acid or other acids rleased by tissues.

↑ potassium or Hydrogen ions.

↑ local temperature.

Histamine & NO rleased during inflammton.

Adenosine is the most important of the local vasdilators.

Local vasoconstrictors :-

Prostaglandins & thromboxanes rleased by activated platelets & WBS & endothelins by damaged endothelial cells.

Humoral (vasoconstrictor) factors :-

Norepinephrine → strong vascostrictor.

Epinephrine → less powerful.

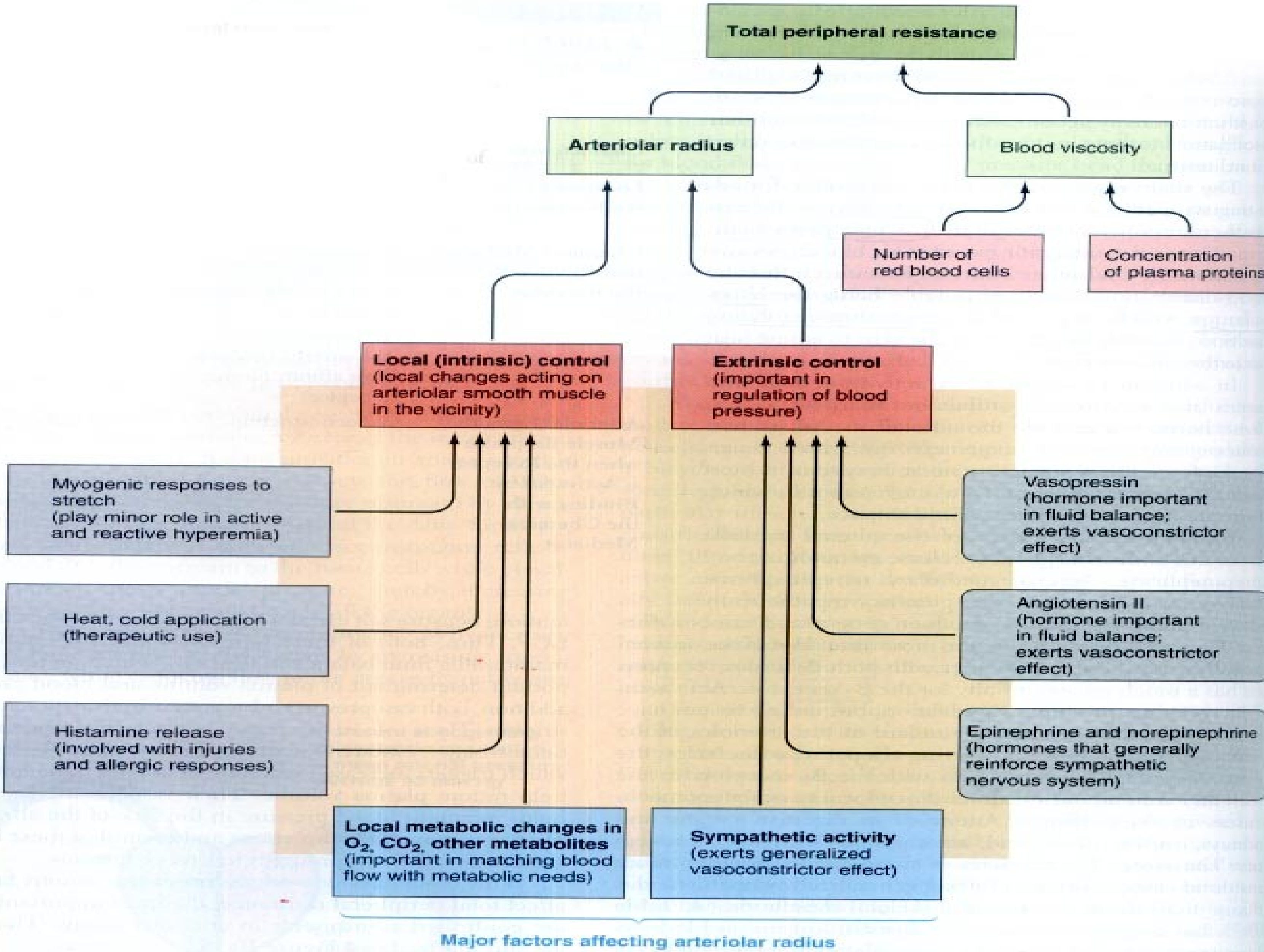
Angiotensin II.

Vasopressin (ADH).

Vasodilator agents :-

Bradykinin.

Histamine.



Total peripheral resistance
Arteriolar radius
Blood viscosity
Number of red blood cells
Concentration of plasma proteins
Local (intrinsic) control (local changes acting on arteriolar smooth muscle in the vicinity)
Extrinsic control (important in regulation of blood pressure)
Myogenic responses to stretch (play minor role in active and reactive hyperemia)
Heat, cold application (therapeutic use)
Histamine release (involved with injuries and allergic responses)
Local metabolic changes in O_2, CO_2, other metabolites (important in matching blood flow with metabolic needs)
Sympathetic activity (exerts generalized vasoconstrictor effect)
Vasopressin (hormone important in fluid balance; exerts vasoconstrictor effect)
Angiotensin II (hormone important in fluid balance; exerts vasoconstrictor effect)
Epinephrine and norepinephrine (hormones that generally reinforce sympathetic nervous system)
Major factors affecting arteriolar radius

Types of blood flow

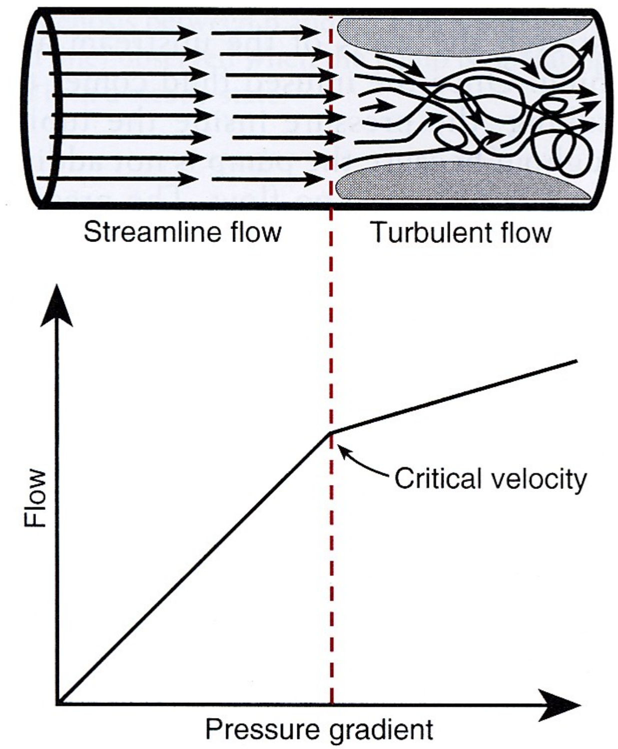
Laminar (Streamline) flow :-

Smooth flow at a steady rate. The central portion of blood stays in the center of the vesel → Less friction.

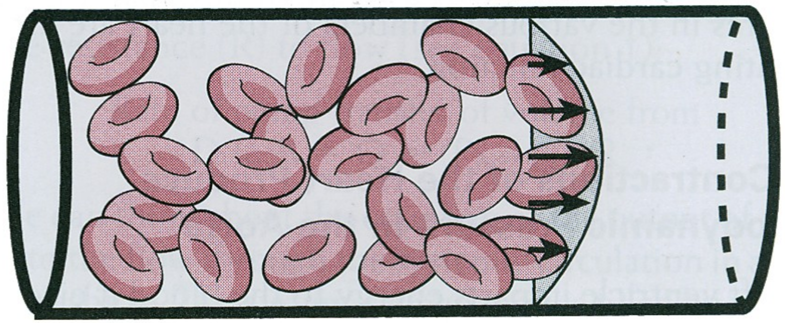
Turbulent flow :-

High flow rate in all directions (Mixing) → increase resistance & slow flow rate.

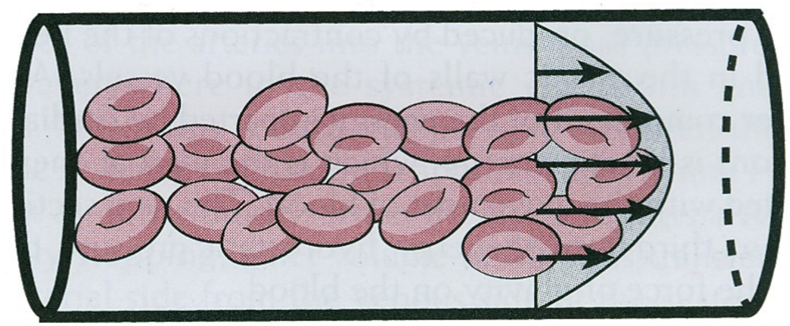
In restricted blood flow or valvular lesions bruits or murmurs can be heard.



Streamline and turbulent blood flow. Blood flow is streamlined until a critical flow velocity is reached. When flow is streamlined, concentric layers of fluid slip past each other with the slowest layers at the interface between blood and vessel wall. The fastest layers are in the center of the blood vessel. When the critical velocity is reached, turbulent flow results. In the presence of turbulent flow, flow does not increase as much for a given rise in pressure because energy is lost in the turbulence. The Reynolds number defines critical velocity.



Slow flow



Fast flow

Axial streamline and flow velocity. The distribution of red blood cells in blood vessel depends on flow velocity. As flow velocity increases, red blood cells move toward the center of the blood vessel (axial streaming), where velocity is highest. Axial streaming of red blood cells lowers the apparent viscosity of blood

Arterial blood pressure

B.P. is the force exerted by blood against a vessel wall.

It maintains blood flow through capillaries.

It depends on blood volume & compliance (distensibility) of blood vessels.

Arterial B.P. is not constant, it rises during ventricular systole & falls during ventricular diastole.

Systolic B.P. :-

Is the peak B.P. measured during ventricular systole = 120 mmHg, in a young person at rest.

Diastolic B.P. :-

Is the minimum B.P. at the end of ventricular diastole = 80 mmHg, in a young person at rest.

Pulse pressure :-

Is the difference between systolic and diastolic B.P.

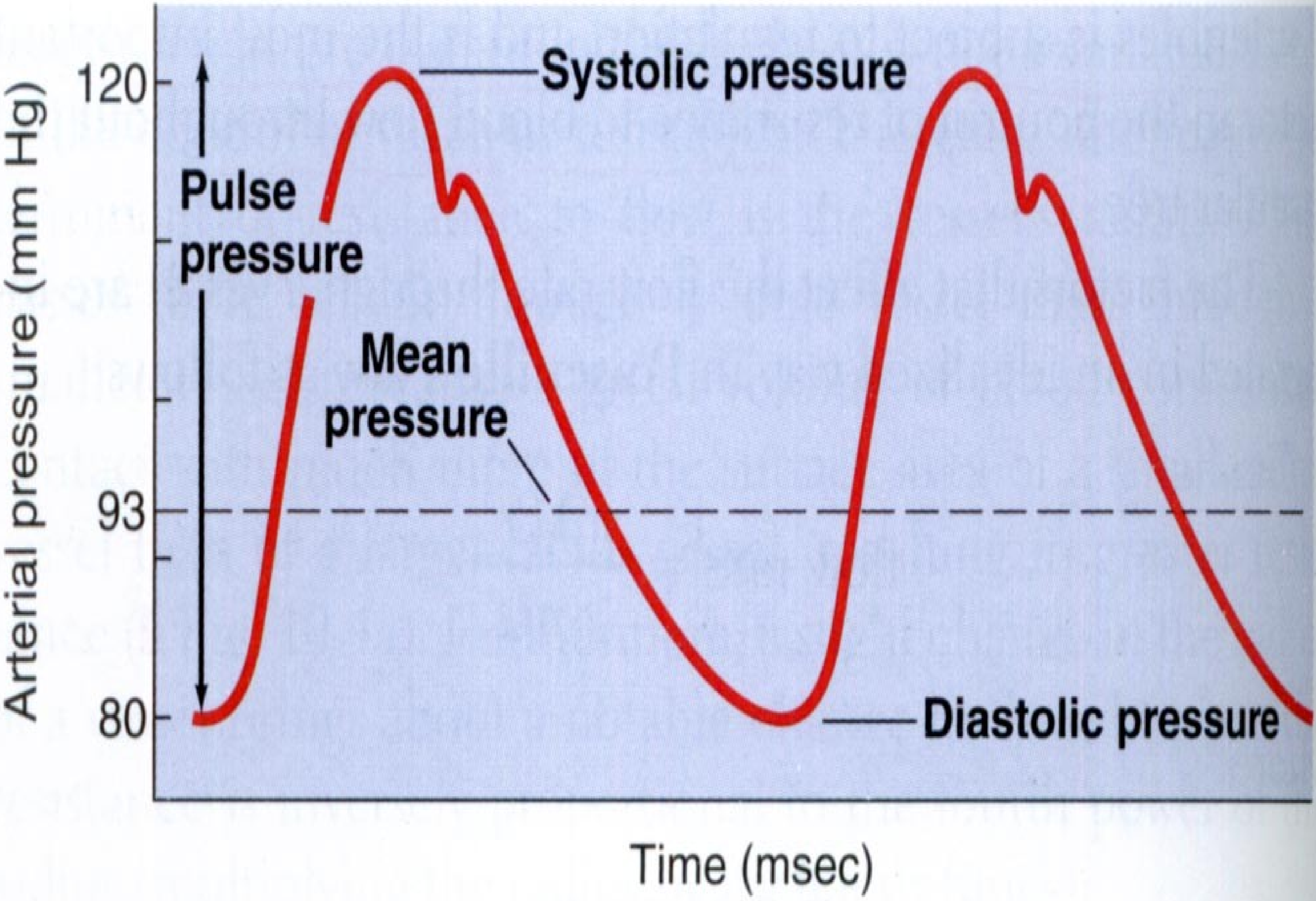


FIGURE 10-7

Arterial blood pressure

Mean B.P. :-

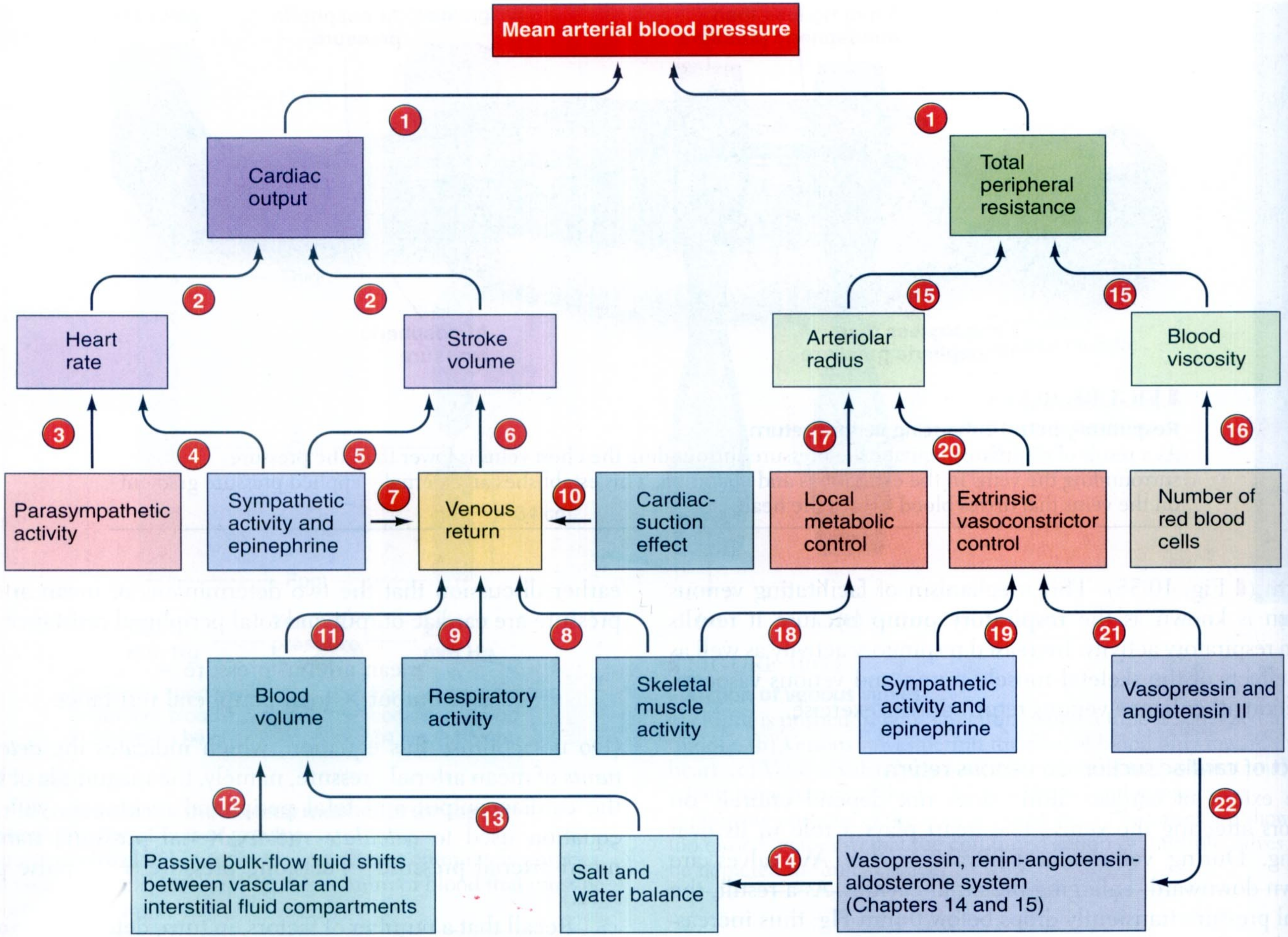
Calculated by adding one-third of the pulse pressure to the diastolic B.P.

If B.P. = 120/90 mmHg.

$$\textbf{The mean B.P.} = 90 + \frac{120 - 90}{3}$$

$$= 90 + 10 = 100 \text{ mmHg.}$$

Mean arterial B.P. = C.O. x total peripheral resistance.


Mean arterial blood pressure
1
1
Cardiac output
Total peripheral resistance
2
2
15
15
Heart rate
Stroke volume
Arteriolar radius
Blood viscosity
3
4
5
6
17
20
16
Parasympathetic activity
Sympathetic activity and epinephrine
7
Venous return
10
Cardiac-suction effect
Local metabolic control
Extrinsic vasoconstrictor control
Number of red blood cells
11
9
8
18
19
21
Blood volume
Respiratory activity
Skeletal muscle activity
Sympathetic activity and epinephrine
Vasopressin and angiotensin II
12
13
22
14
Passive bulk-flow fluid shifts between vascular and interstitial fluid compartments
Salt and water balance
Vasopressin, renin-angiotensin-aldosterone system (Chapters 14 and 15)

Hypertension in adults is a B.P. greater than 140/90.

B.P. at or below 120/80 is normal.

Values between 121/81 and 139/89 indicate a state of pre-hypertension.

Hypertension increases the work load of the heart → enlargement of the left ventricle → ↑ muscle mass → ↑ oxygen demand.

Insufficient coronary circulation → symptoms of ischemic heart disease.

↑ arterial B.P. → strokes, heart attacks & heart failure.

Elastic rebound

During **systole** the arterial walls expand to accommodate the exta amount of blood pumped by the ventricles.

During **diastole** the B.P. falls, the arteries recoil to their original dimentions **(Elastic rebound)** → Maintains blood flow in the arteries when the ventricle is in diastole.

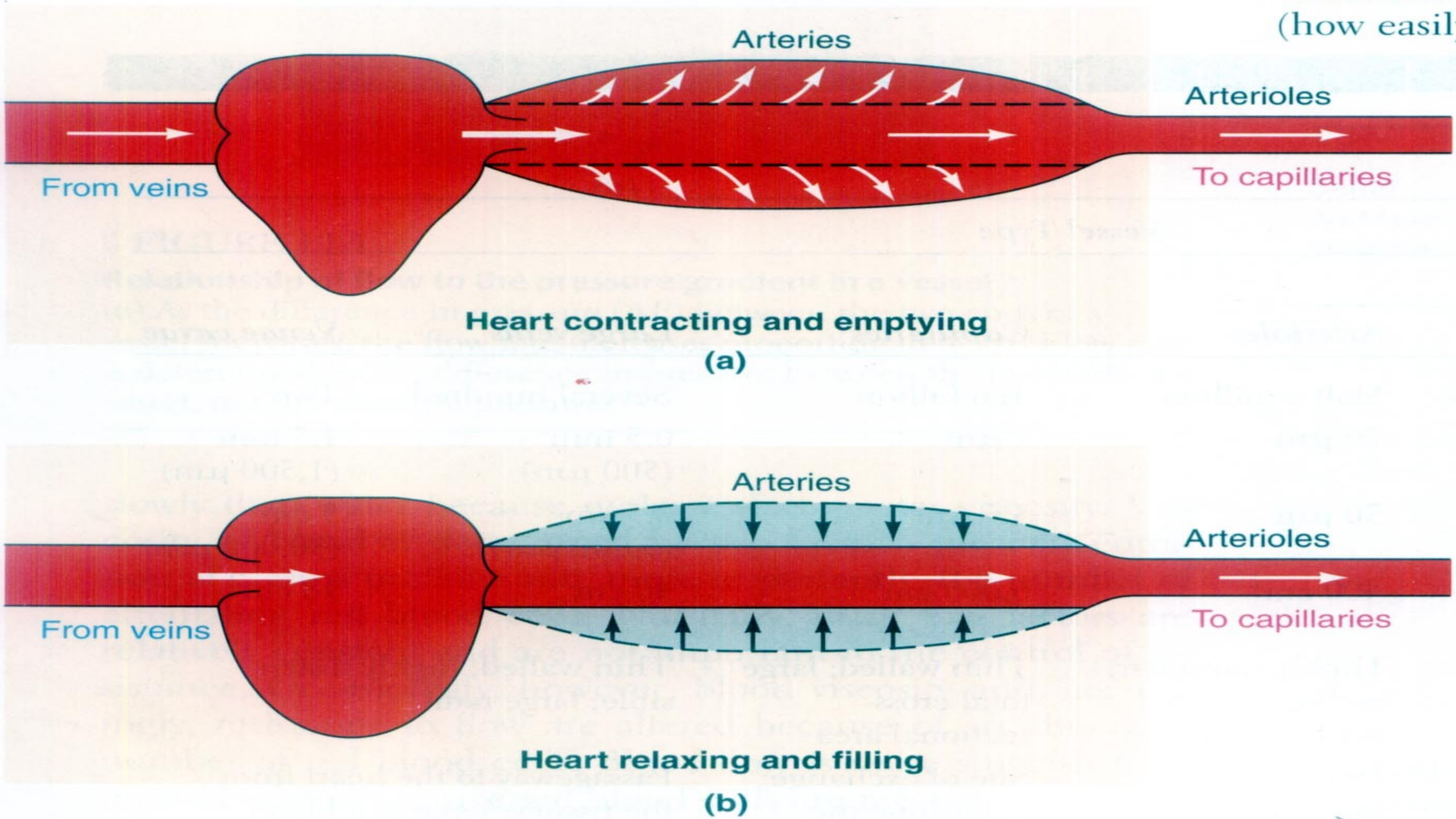


FIGURE 10-6

Arteries as a pressure reservoir

Because of their elasticity, arteries act as a pressure reservoir. (a) The elastic arteries distend during cardiac systole as more blood is ejected into them than drains off into the narrow, high-resistance arterioles downstream. (b) The elastic recoil of arteries during cardiac diastole continues driving the blood forward when the heart is not pumping.

Blood pressure, wall, depends o vessel and the **co** (how easily they

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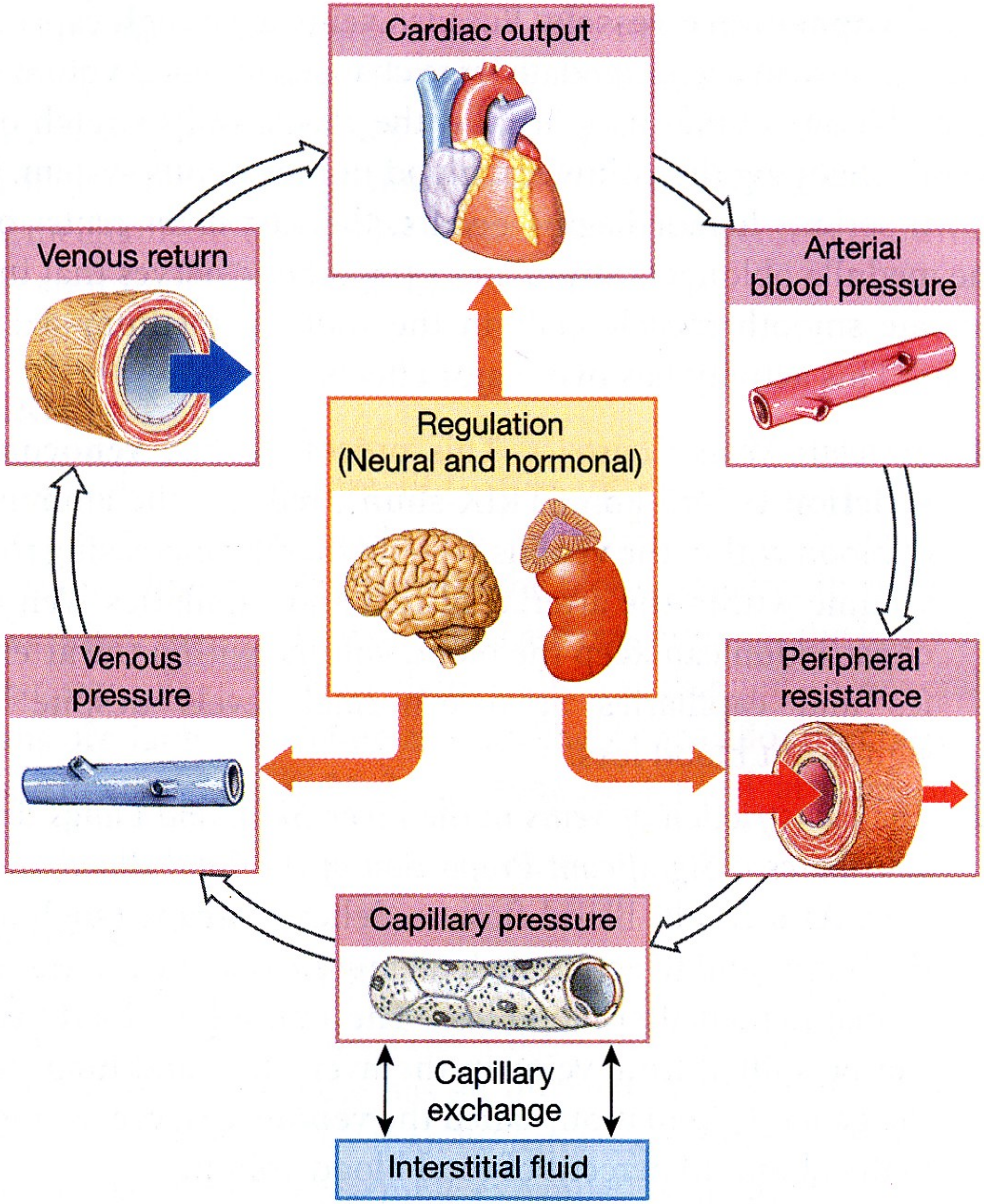
Cardiovascular regulatory mechanisms

It involve autoregulation, neural mechanisms, and endocrine responses.



An Overview of Cardiovascular Physiology. Neural and hormonal activities influence cardiac output, peripheral resistance, and venous pressure (through venoconstriction). Capillary pressure is the primary drive for exchange between blood and interstitial fluid.

Neural control mechanisms

Two centers are responsible :-

1- The cardiac centers :-

A- Cardioacceleratory → ↑ H.R.& C.O.

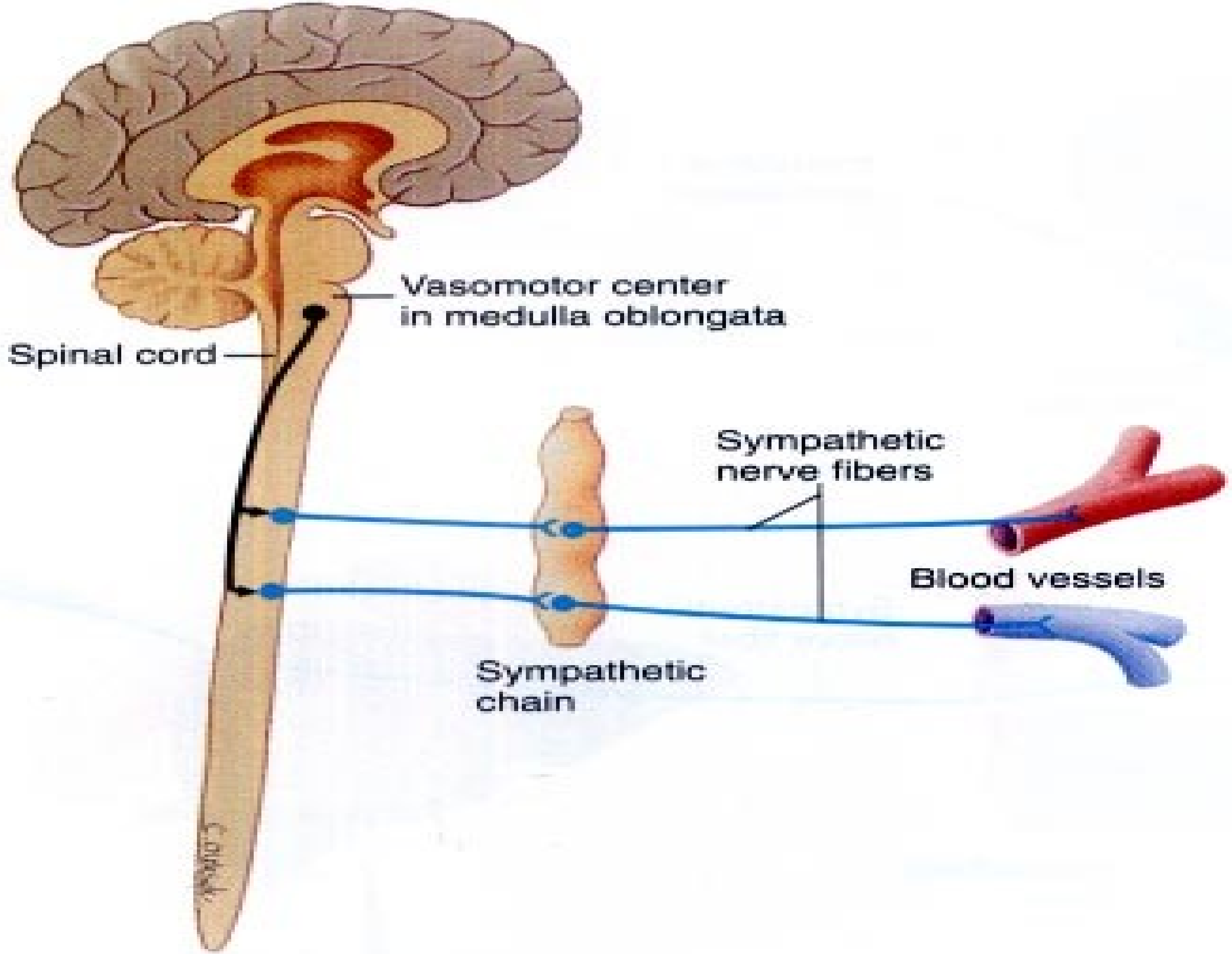
B- Cardioinhibitory → ↓ H.R.& C.O.

2- The vasomotor center :-

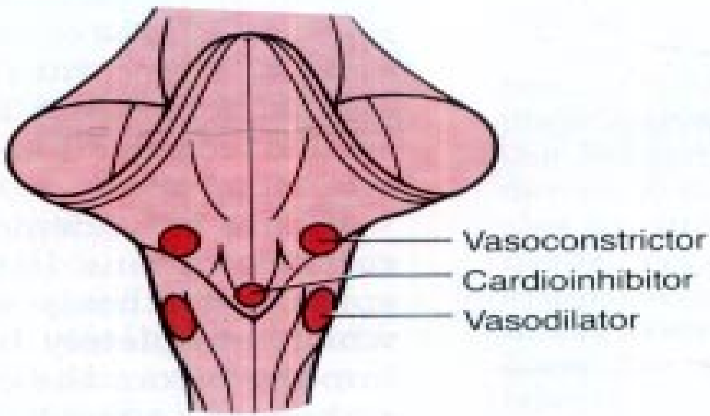
A- Large group of vasocostrictor neurons.

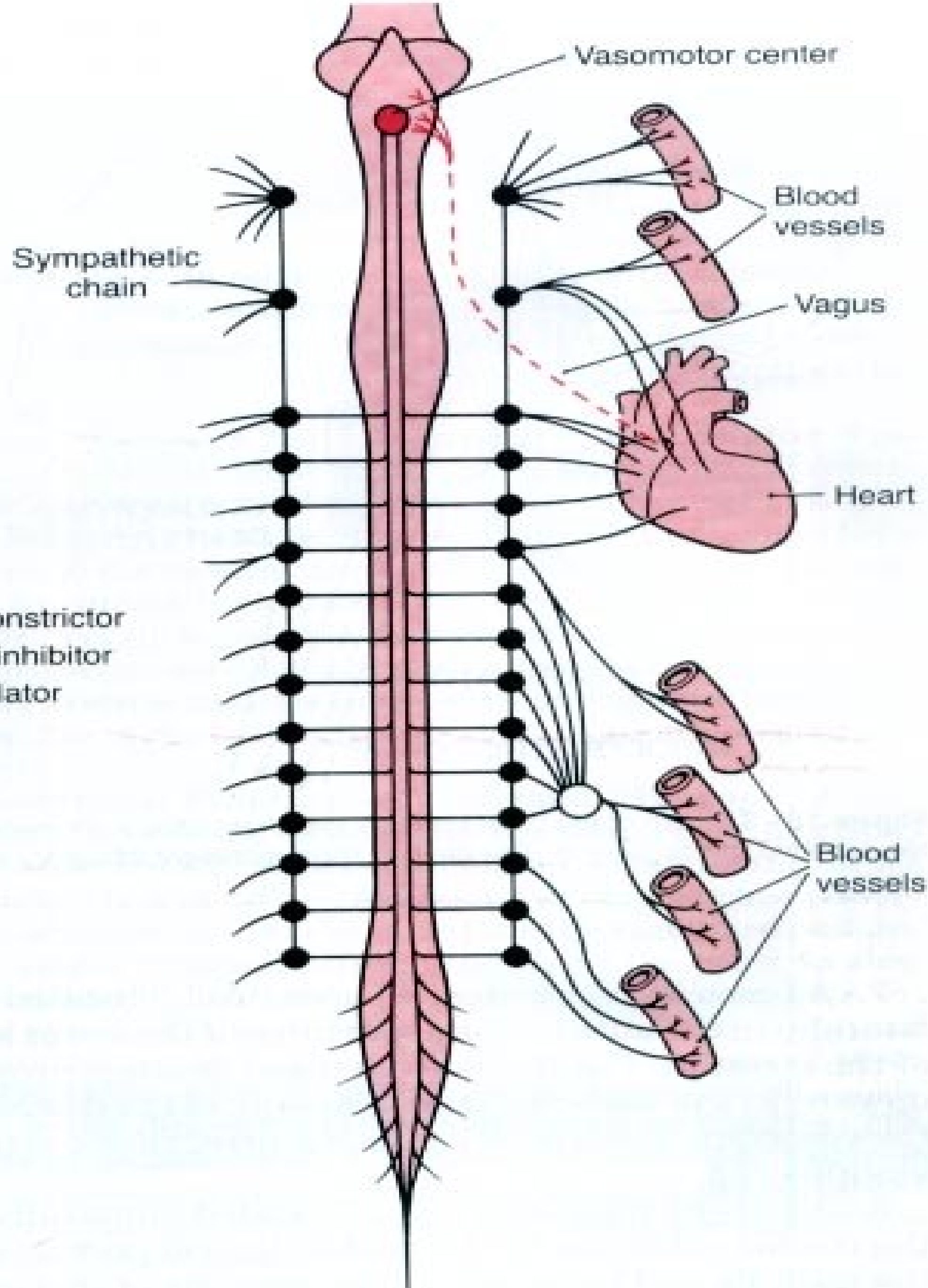
B- Small group of vasodilator neurons.

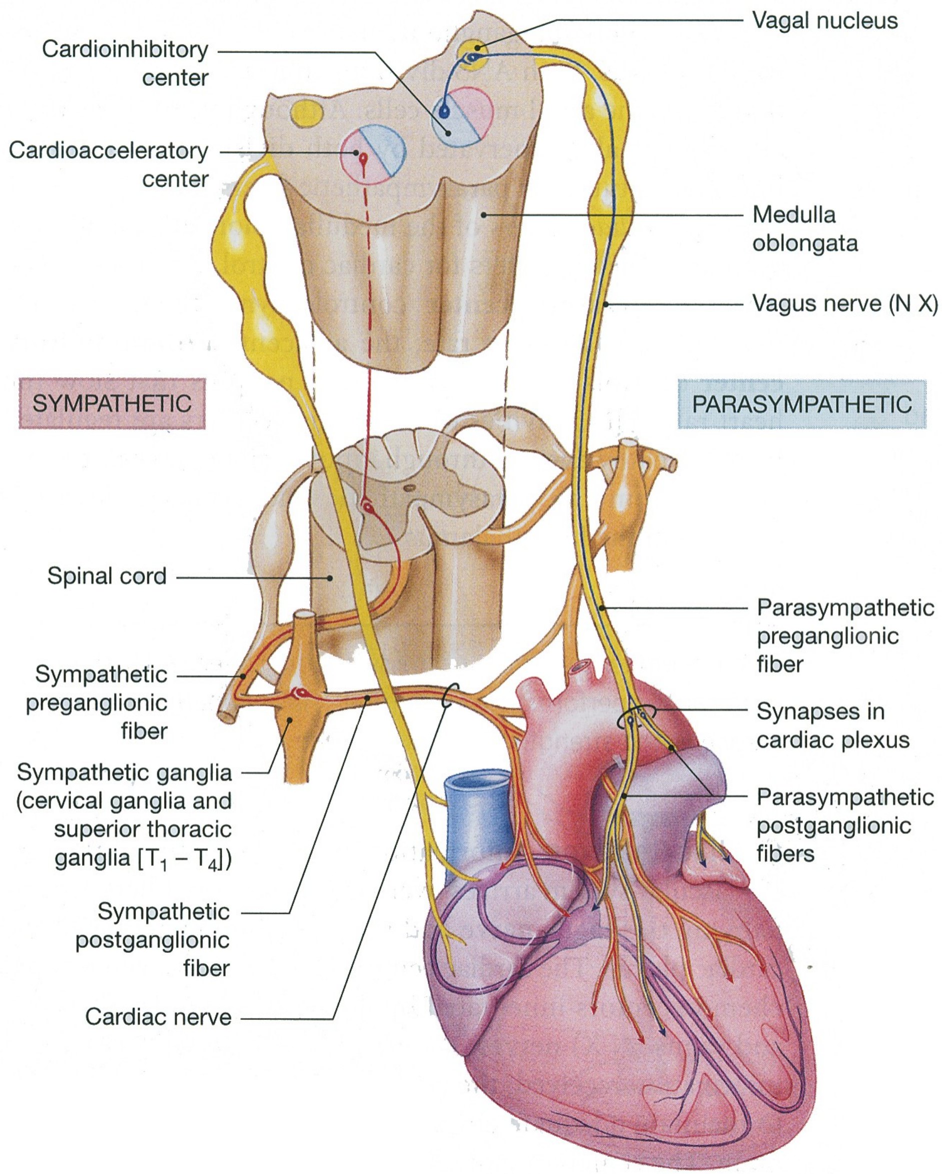
Through control of sympathetic motor neurons, which are chronically active (vasomotor tone).

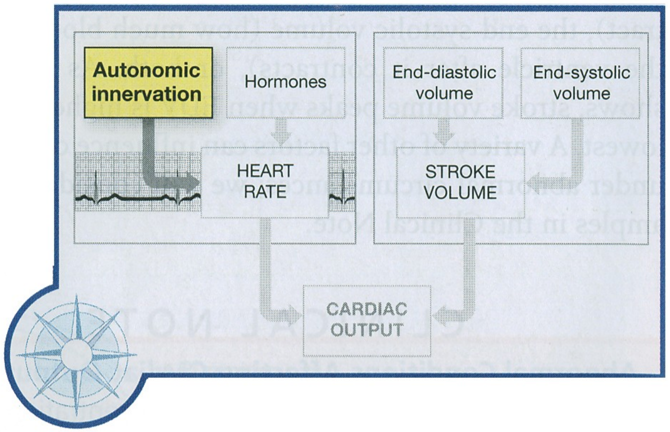


Blood Vessel Innervation by Sympathetic Nerve Fibers
Figure 21.38


Vasoconstrictor
Cardioinhibitor
Vasodilator


Vasomotor center
Blood
vessels
Sympathetic
chain
Vagus
Heart
Blood
vessels





Autonomic innervation of the Heart. The Navigator icon in the shadow box highlights the topic we will consider in this section.

Reflex control of cardiovascular function

The CV center detect changes in tissue demands by monitoring :-

Arterial B.P., PH, and conc. of dissolved gases.

1- The baroreceptors (Pressure receptors):-

Respond to changes in B.P.

2- The chemoreceptors :-

Monitor changes of oxygen, carbon dioxide, and hydrogen ions.

Baroreceptor reflexes

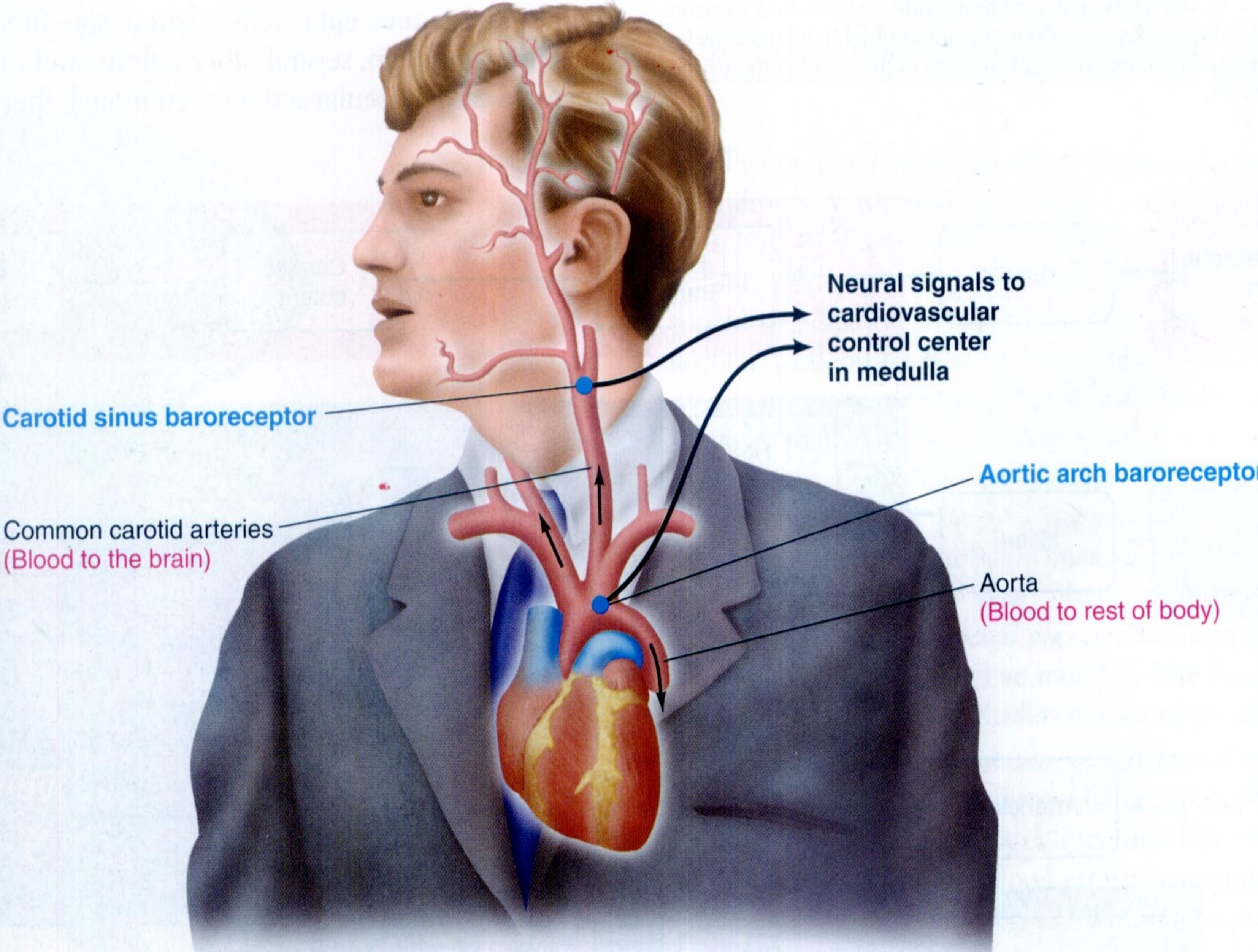
Monitor the degree of stretch of expansable organs.

Located in the :-

1- Carotid sinuses.

2- Aortic sinuses.

3- The wall of the right atrium.

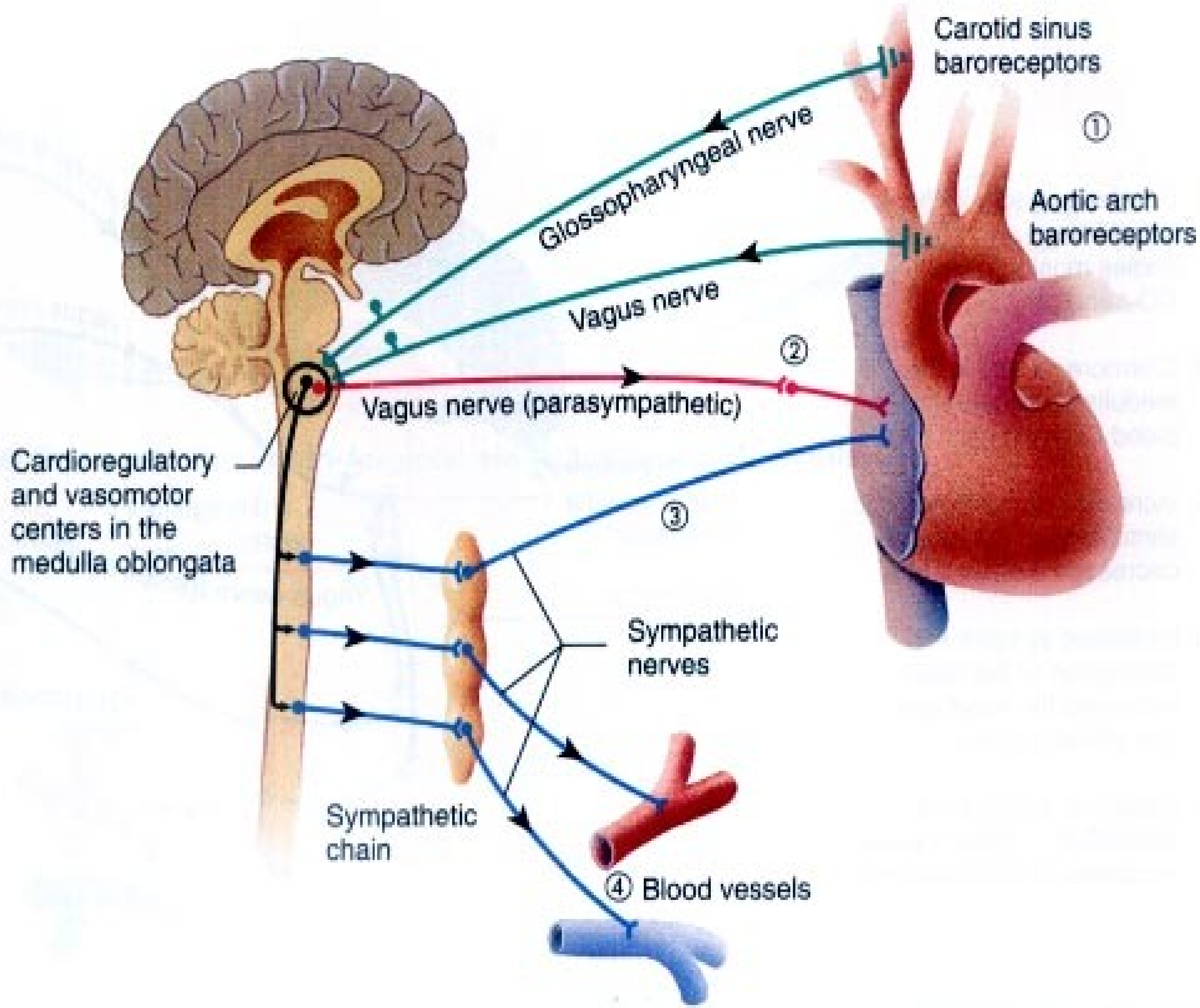

Neural signals to
cardiovascular
control center
in medulla
Carotid sinus baroreceptor
Aortic arch baroreceptor
Common carotid arteries
(Blood to the brain)
Aorta
(Blood to rest of body)

1. Baroreceptors in the carotid sinus and aortic arch monitor blood pressure.

2. Increased parasympathetic stimulation of the heart decreases the heart rate.

3. Increased sympathetic stimulation of the heart increases the heart rate and stroke volume.

4. Increased sympathetic stimulation of blood vessels increases vasoconstriction.



Baroreceptor Reflex Control of Blood Pressure
Figure 21.39

Sudden increase in B.P. → ↑ activity of the baroreceptors which produces :-

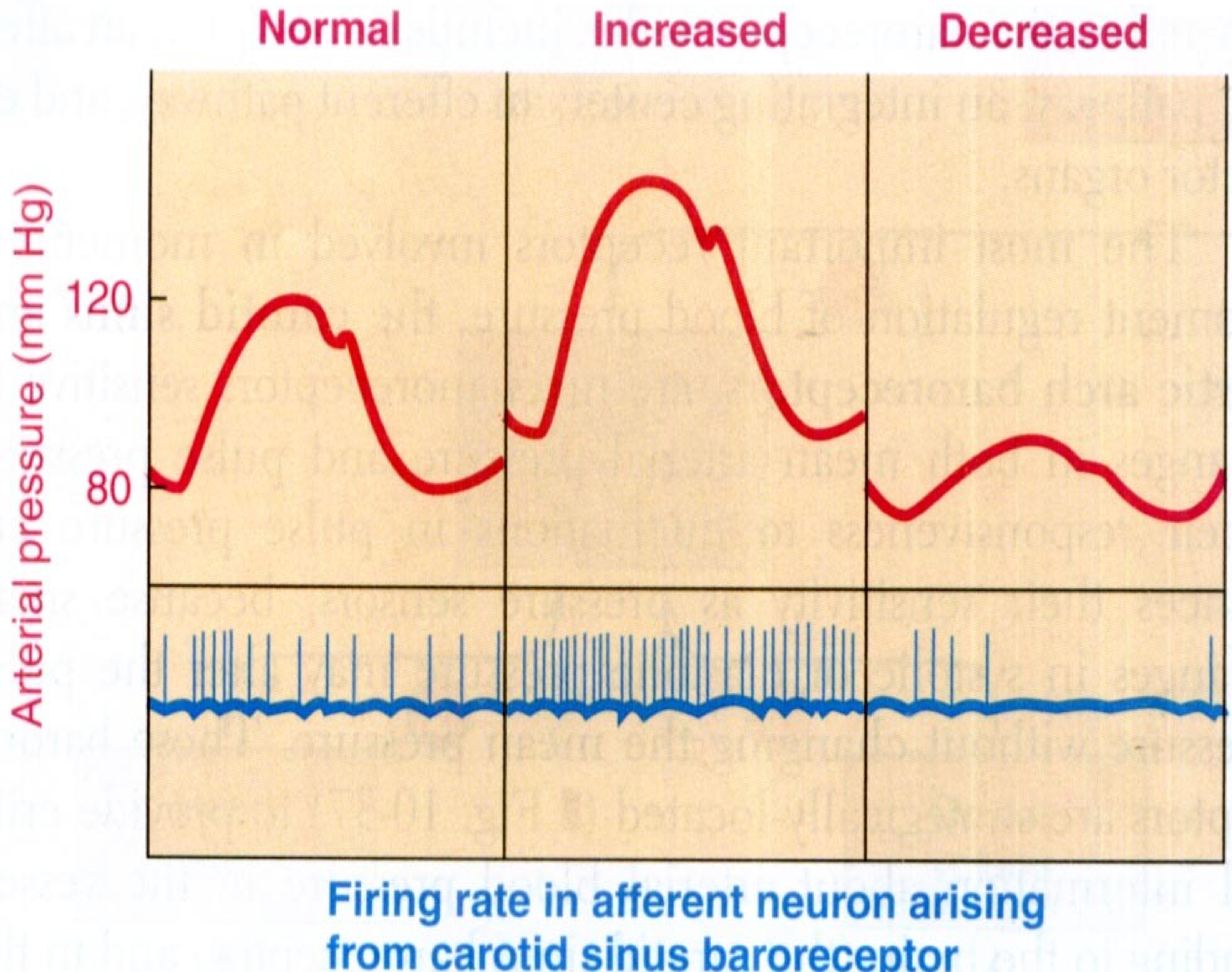
1- ↓ H.R. & ↓ C.O. due to ↓ sympathetic & ↑ parasympathetic activity.

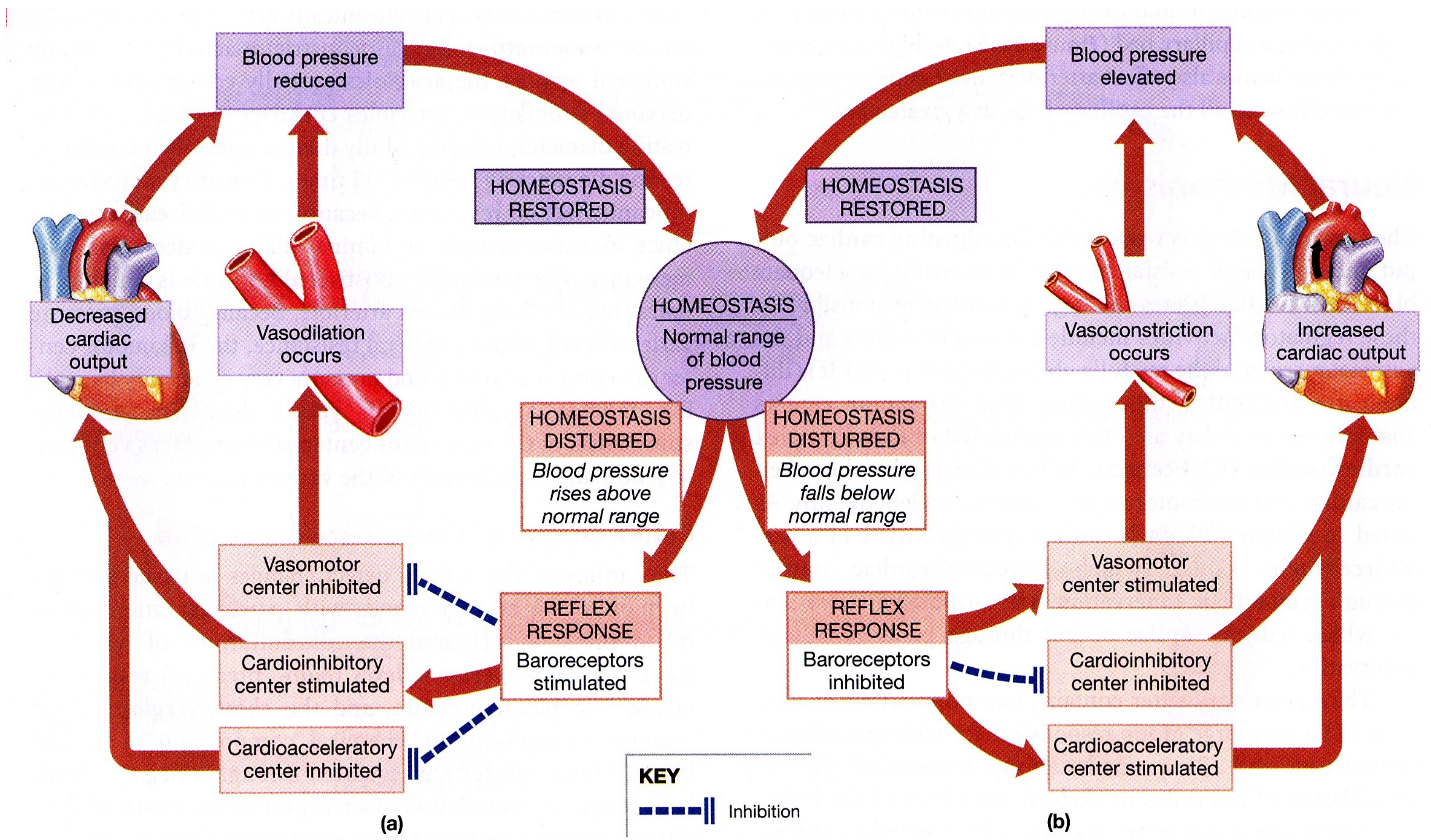
2- Widespread peripheral vasodilation due to inhibition of the vasomotor center.

Sudden decrease in B.P. → ↓ activity of the baroreceptors which produces :-

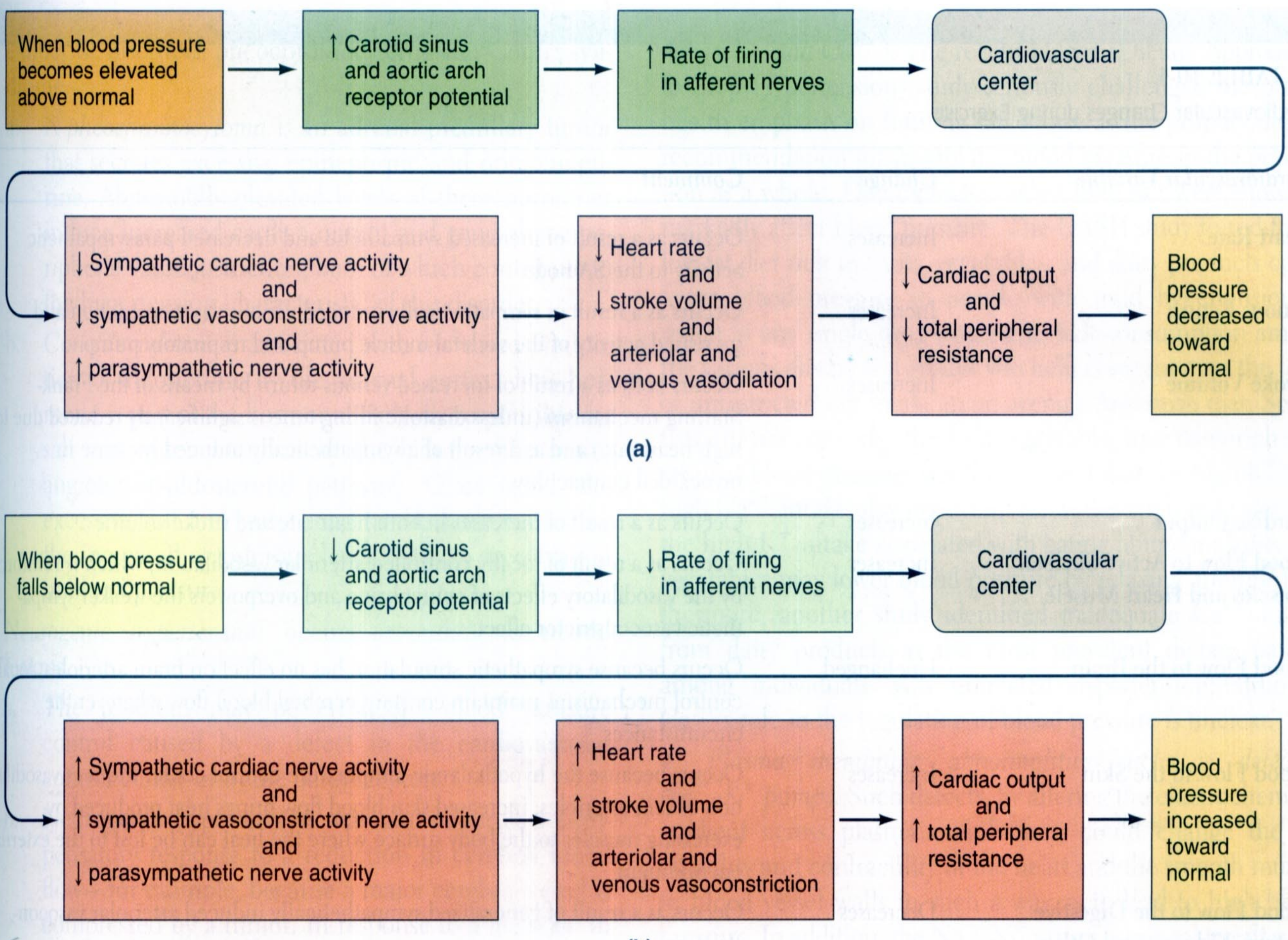
1- ↑ H.R. & ↑ C.O. due to ↑ sympathetic & ↓ parasympathetic activity.

2- Widespread peripheral vasocostriction due to stimulation of the vasomotor center.


Normal
Increased
Decreased
Arterial pressure (mm Hg)
120
80
Firing rate in afferent neuron arising from carotid sinus baroreceptor



Baroreceptor Reflexes of the Carotid and Aortic Sinuses.

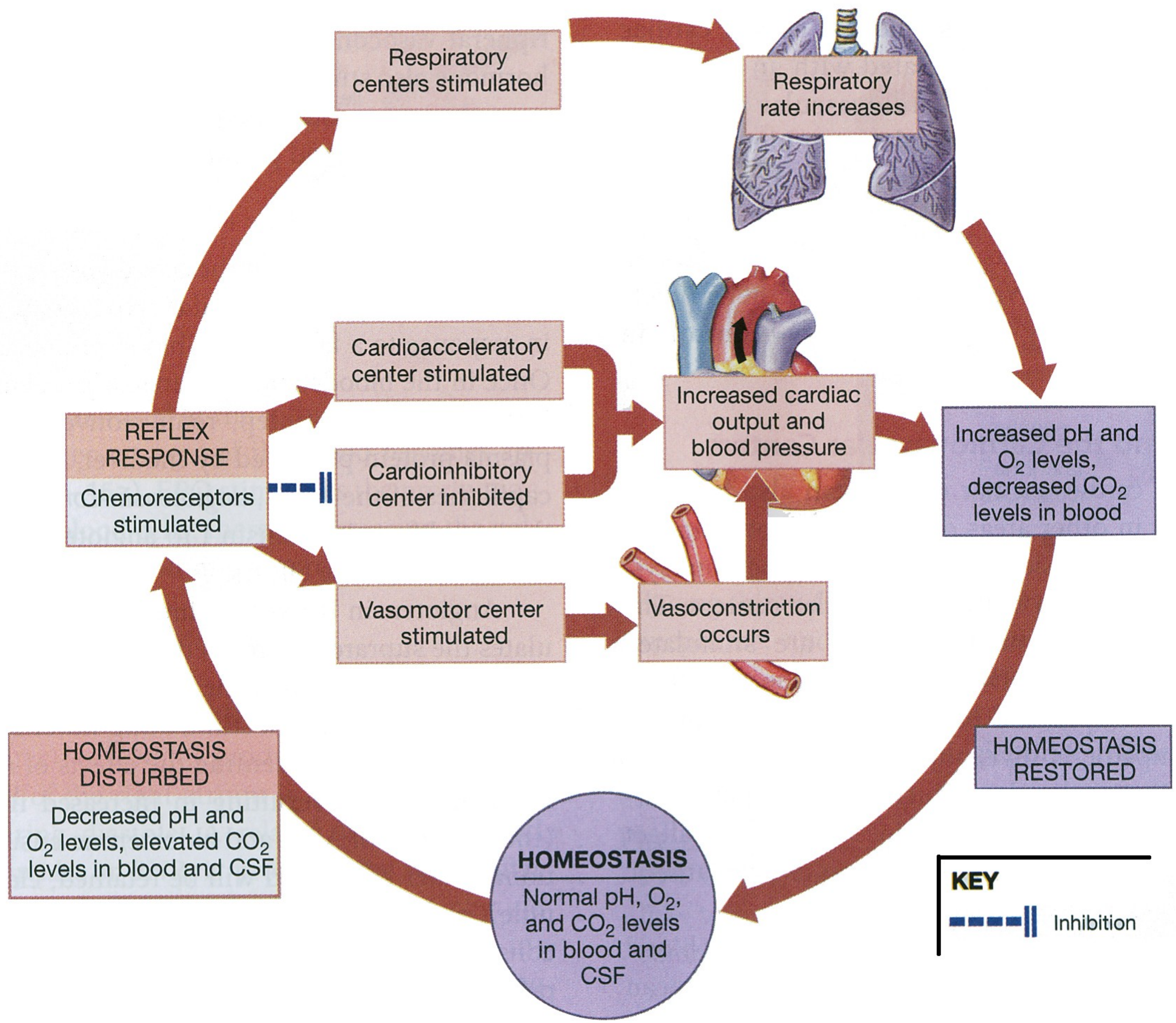

When blood pressure becomes elevated above normal
↑ Carotid sinus and aortic arch receptor potential
↑ Rate of firing in afferent nerves
Cardiovascular center
↓ Sympathetic cardiac nerve activity and ↓ sympathetic vasoconstrictor nerve activity and ↑ parasympathetic nerve activity
↓ Heart rate and ↓ stroke volume and arteriolar and venous vasodilation
↓ Cardiac output and ↓ total peripheral resistance
Blood pressure decreased toward normal
(a)
When blood pressure falls below normal
↓ Carotid sinus and aortic arch receptor potential
↓ Rate of firing in afferent nerves
Cardiovascular center
↑ Sympathetic cardiac nerve activity and ↑ sympathetic vasoconstrictor nerve activity and ↓ parasympathetic nerve activity
↑ Heart rate and ↑ stroke volume and arteriolar and venous vasoconstriction
↑ Cardiac output and ↑ total peripheral resistance
Blood pressure increased toward normal
(b)

Atrial baroreceptors (low pressure receptors)

Respond to stretch of the wall of the right atrium.

↑ **atrial pressure** → stimulate C.V. centre → ↑ H.R.& ↑ C.O (**Bainbridge reflex)** → prevent damming of blood in veins, atria & pulmonary Circulation.

Atrial stretch also → dilate afferent arterioles → ↑ GFR → ↑ ADH & ↑ ANP hormone secretion → ↑ urine output. → ↓ B.P.



The Chemoreceptor Reflexes.

Hormonal regulation of CVS

The endocrine system provides both **short-term** and **long-term** regulation of CVS.

E. and NE. stimulate C.O. and vasocostriction.

Other hormones for long-term regulation include:-

1- Antidiuretic hormone (ADH).

2- Angiotensin II.

3- Erythropoietin.

4- Natriuretic peptides (ANP and BNP).

Rapid control of arterial B.P.

Sudden fall in arterial B.P. leads to :-

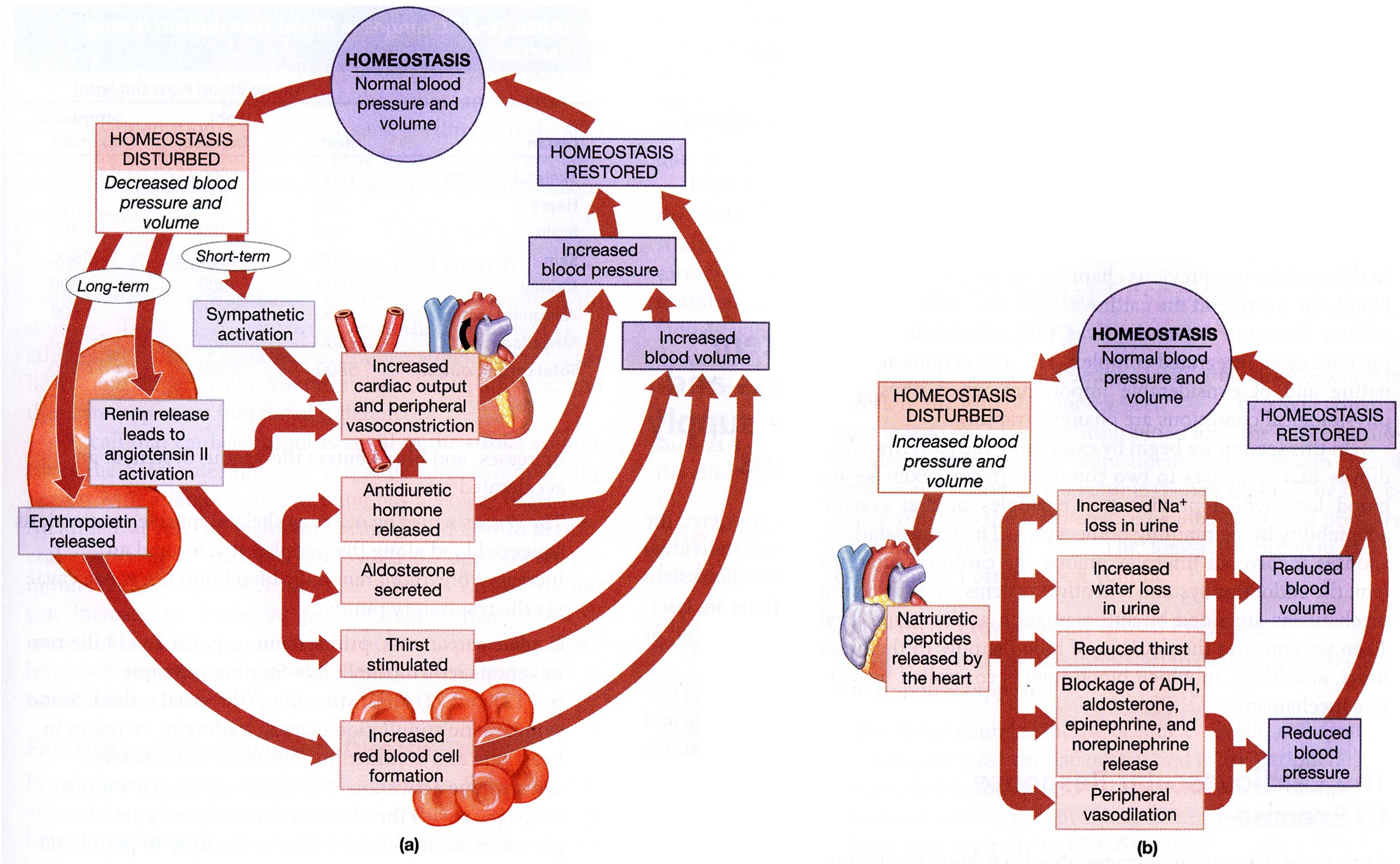
1- CNS effects :-

a- ↑ sympathetic stimulation.

b- ↓ parasympath. Stimulation.

2- Baroreceptor reflexes.

3- Chemoreceptor reflexes.



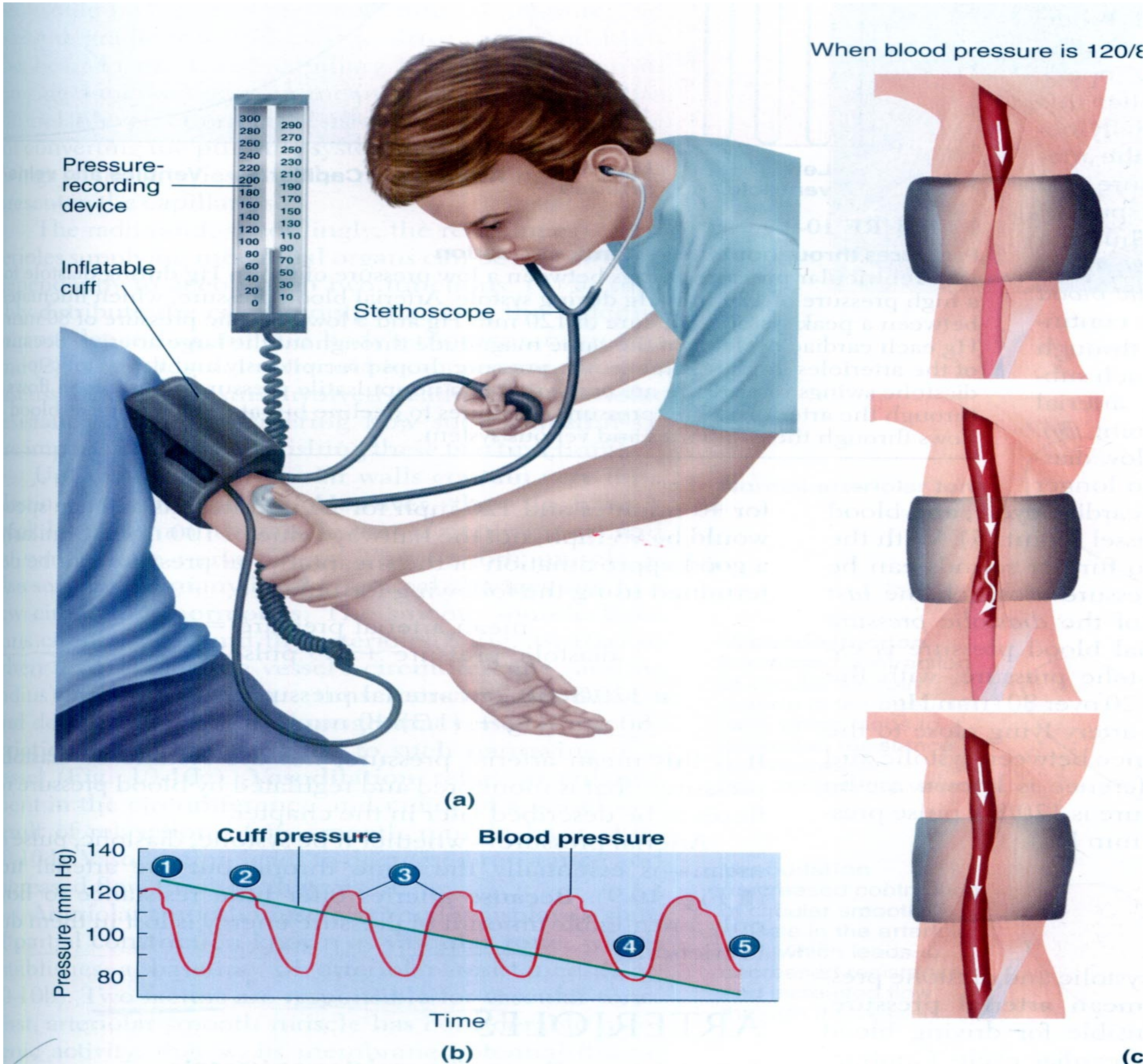
The Hormonal Regulation of Blood Pressure and Blood Volume. Shown are factors that compensate for (a) decreased blood pressure and volume and for (b) increased blood pressure and volume.

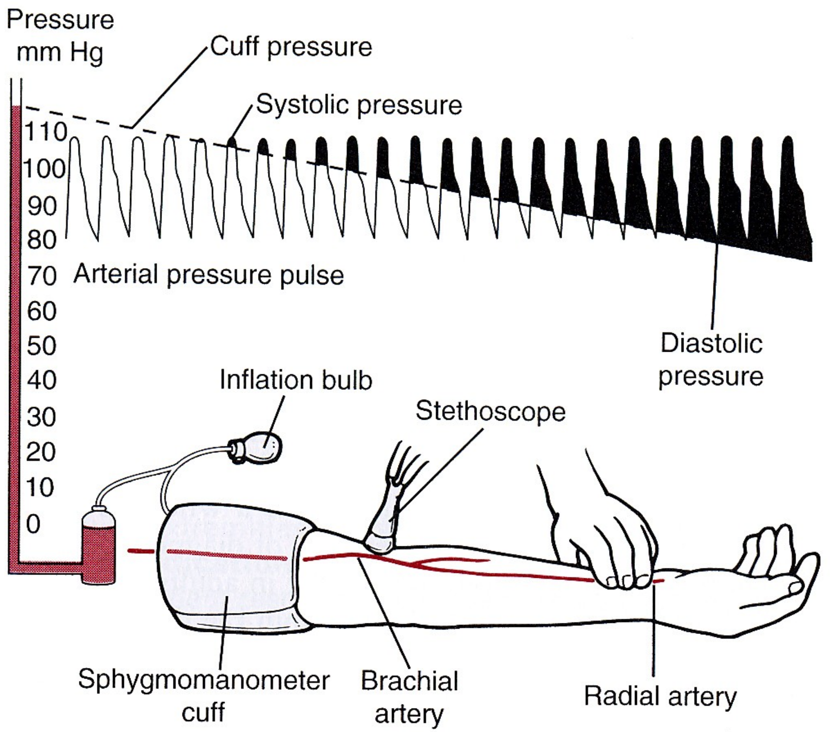
The mean Circulatory Filling Pressure

It is the pressure required to fill the blood vessels when the heart stops completely = 7 mmHg.

It is equal every where in the systemic circulation.

Measurement of B.P.





The relationship between true arterial pressure and blood pressure as measured with a sphygmomanometer. When cuff pressure falls just below systolic pressure, turbulence blood squirting through the partially occluded artery under the cuff produces the first Korotkoff sound, which can be heard via a stethoscope bell placed over the brachial artery (auscultatory method). Systolic pressure can also be estimated by palpating the radial artery and noting the cuff pressure at which the pressure falls just below diastolic pressure, the artery stays open, flow is no longer turbulent, and the sounds cease. The arterial pressure tracing is simplified in that systolic, diastolic, and mean arterial pressures vary around average values from moment-to-moment. For this reason, the production of sounds may vary from heartbeat to heartbeat.

Shock

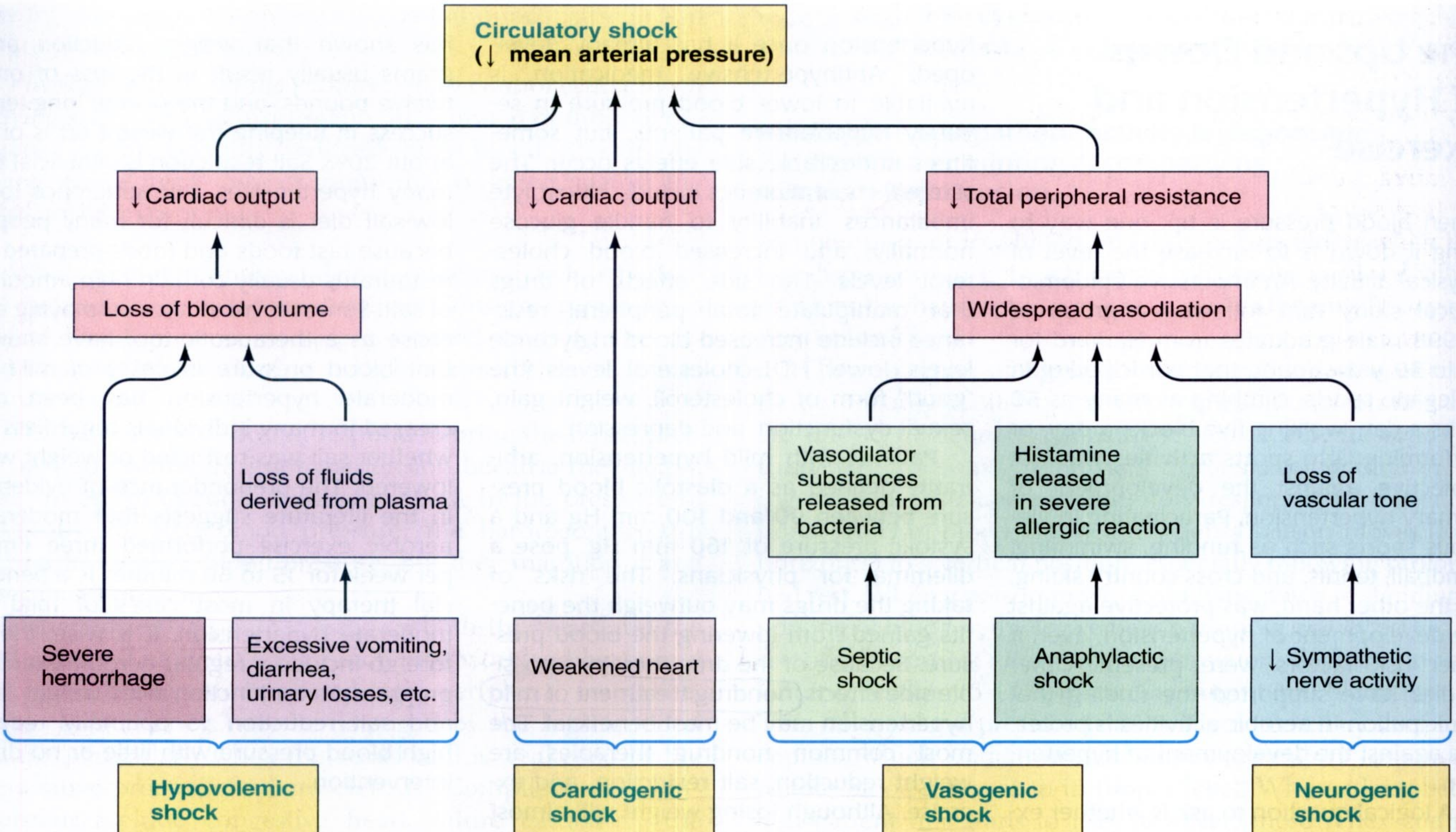
It is a sudden drop in B.P. leading to decrease tissue perfusion.

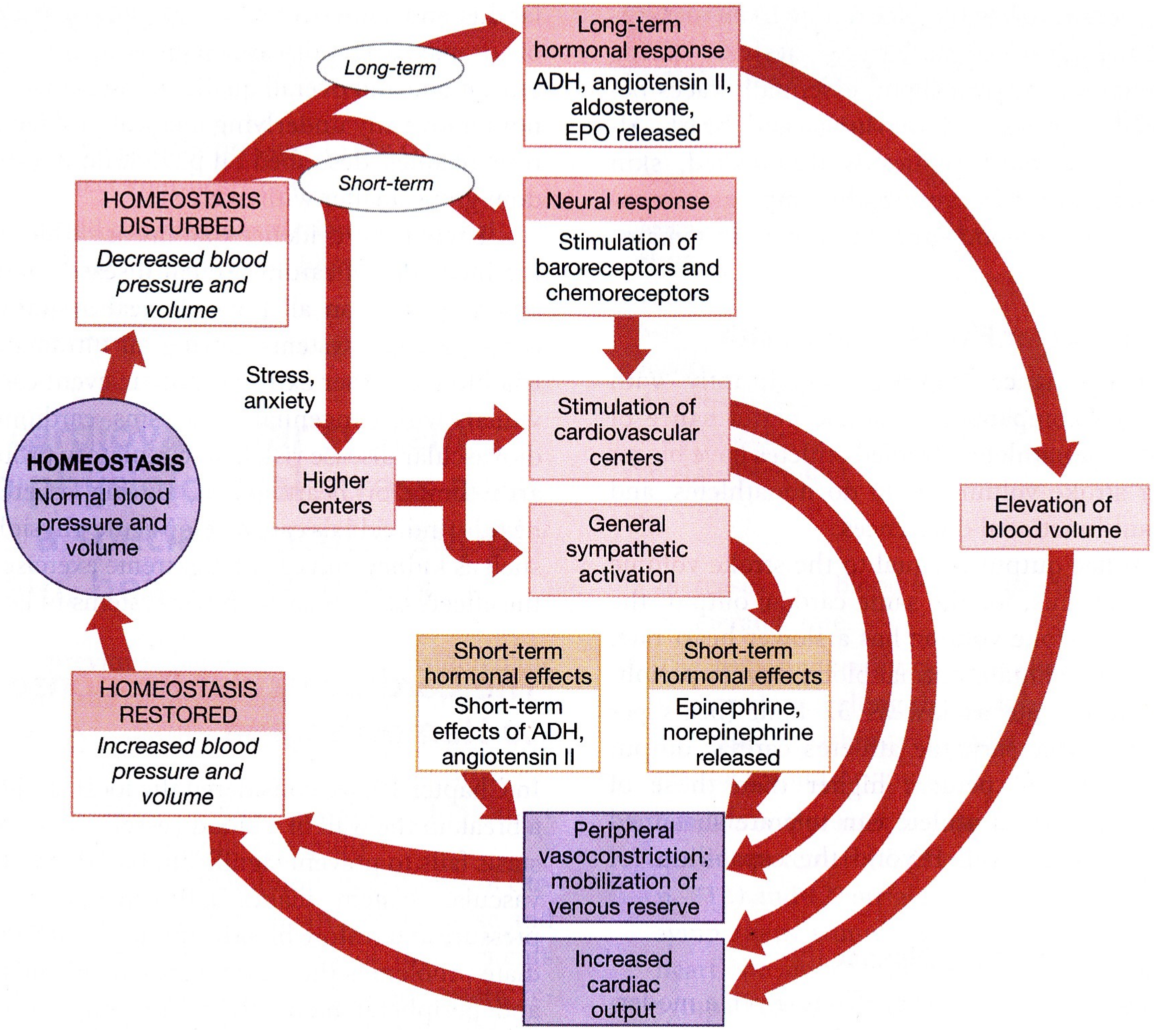
Symptoms and signs :-

Patient may or may not be conscious with :-

↑ H.R., (Thready pulse), ↓ B.P., cold & moist skin, pallor, oliguria, thirst, weakness, ↑ respiratory rate, cyanosis.

Causes of shock





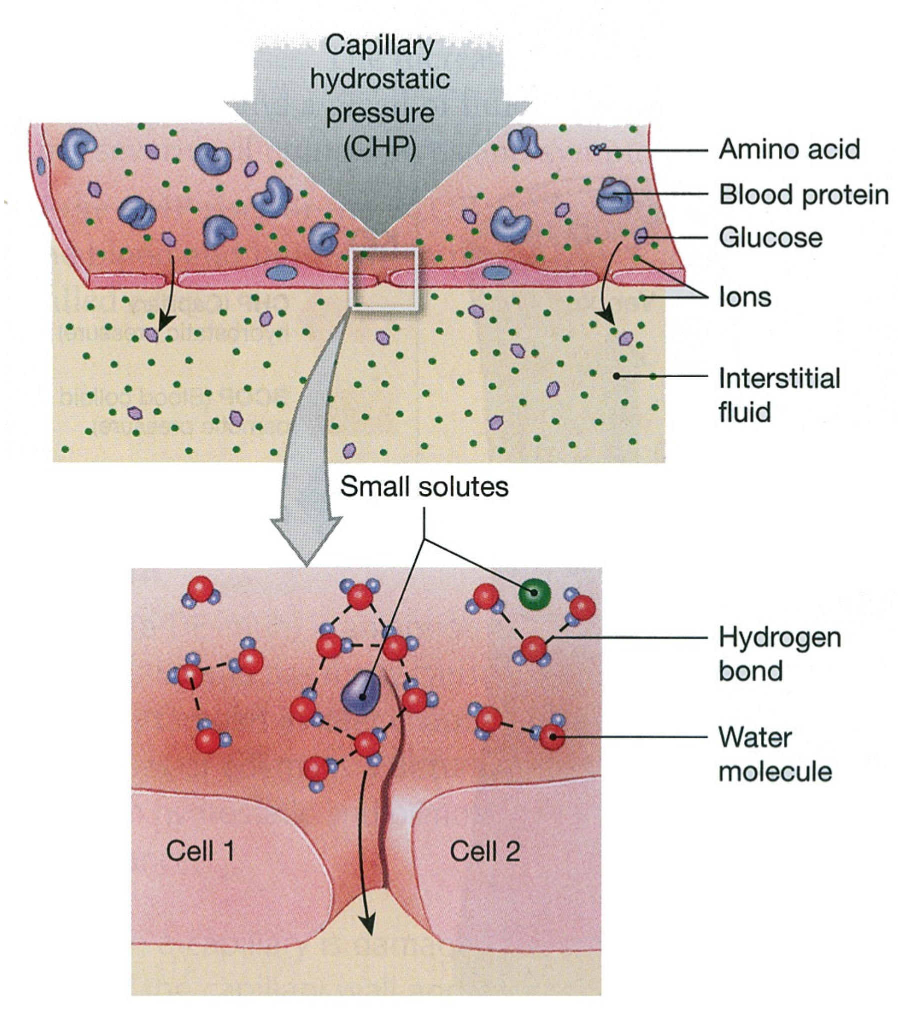
Cardiovascular Responses to Hemorrhaging and Blood Loss. These mechanisms can cope with blood losses equivalent to approximately 30 percent of total blood volume.

Capillary pressures and capillary exchange

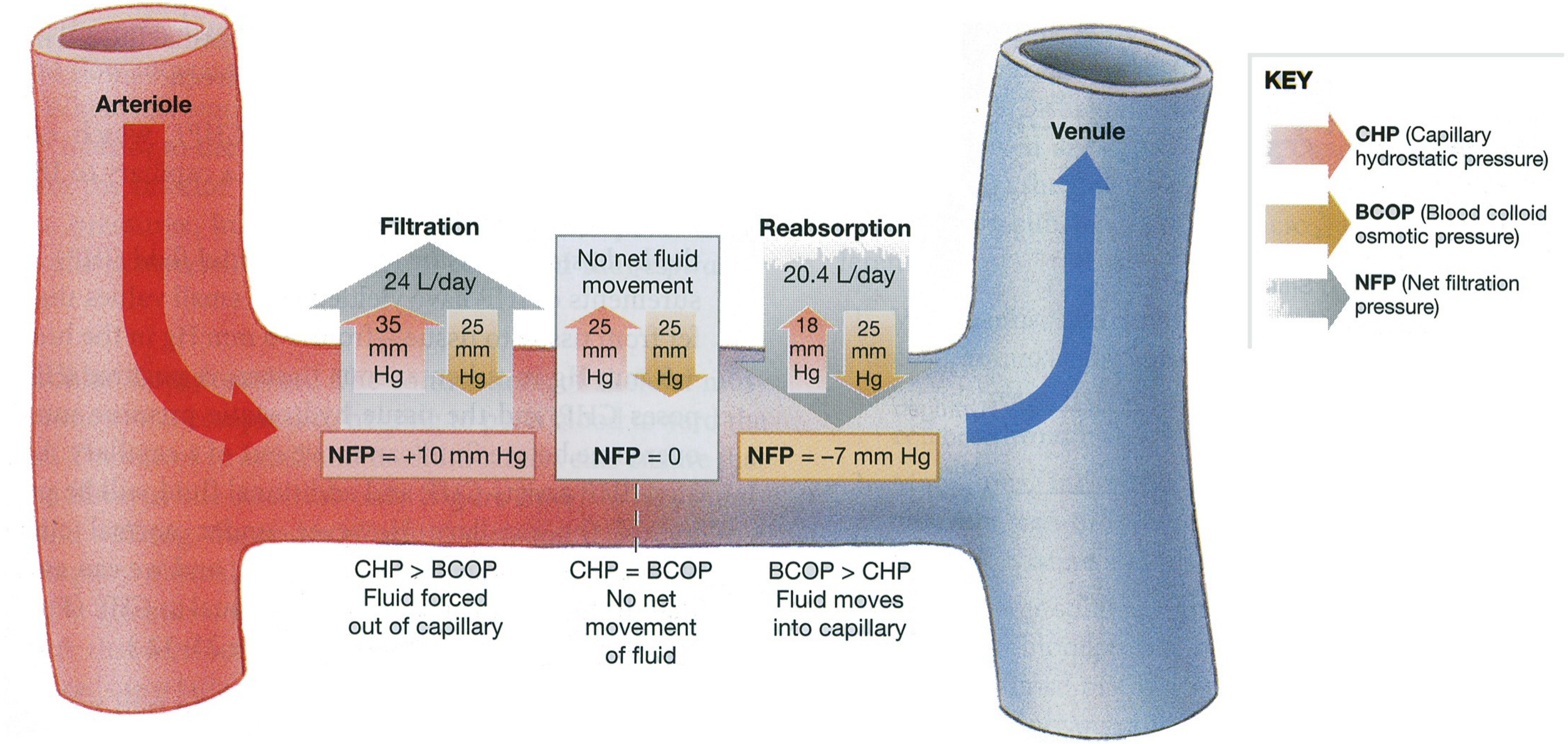
Capillary exchange plays important role in homeostasis.

The important processes that move materials across capillary walls are :-

Diffusion, Filteration, and Reabsorbtion



Capillary Filtration. Capillary hydrostatic pressure (CHP) forces water and solutes through the gaps between adjacent endothelial cells in continuous capillaries. The sizes of solutes that move across the capillary wall are determined primarily by the dimensions of the gaps.



Forces Acting across Capillary Walls. At the arterial end of the capillary, capillary hydrostatic pressure (CHP) is greater than blood colloid osmotic pressure (BCOP), so fluid moves out of the capillary (filtration). Near the venule, CHP is lower than BCOP, so fluid moves into the capillary (reabsorption). In this model, interstitial fluid colloid osmotic pressure (ICOP) and interstitial fluid hydrostatic pressure (IHP) are assumed to be 0 mmHg and so are not shown.

More filteration than reabsorbtion occurs along the capillary.

The extra amount of fluid in the interstitial spaces is carried by the lymphatic Vessels → venous circulation. :-**This will help in :-**

1- Costant exchange of fluid.

2- **Accelerate distribution of substances.**

3- **Transport insoluble lipids & tissue proteins.**

4- **Carry bacterial toxins to lymphoid tissues → provide immunity**.

Oedema

It is an excessive amount of fluid in the interstitial spaces. Caused by :-

1- ↑ Capillary hydrostatic pressure e.g. heart failure, local venous block, etc.

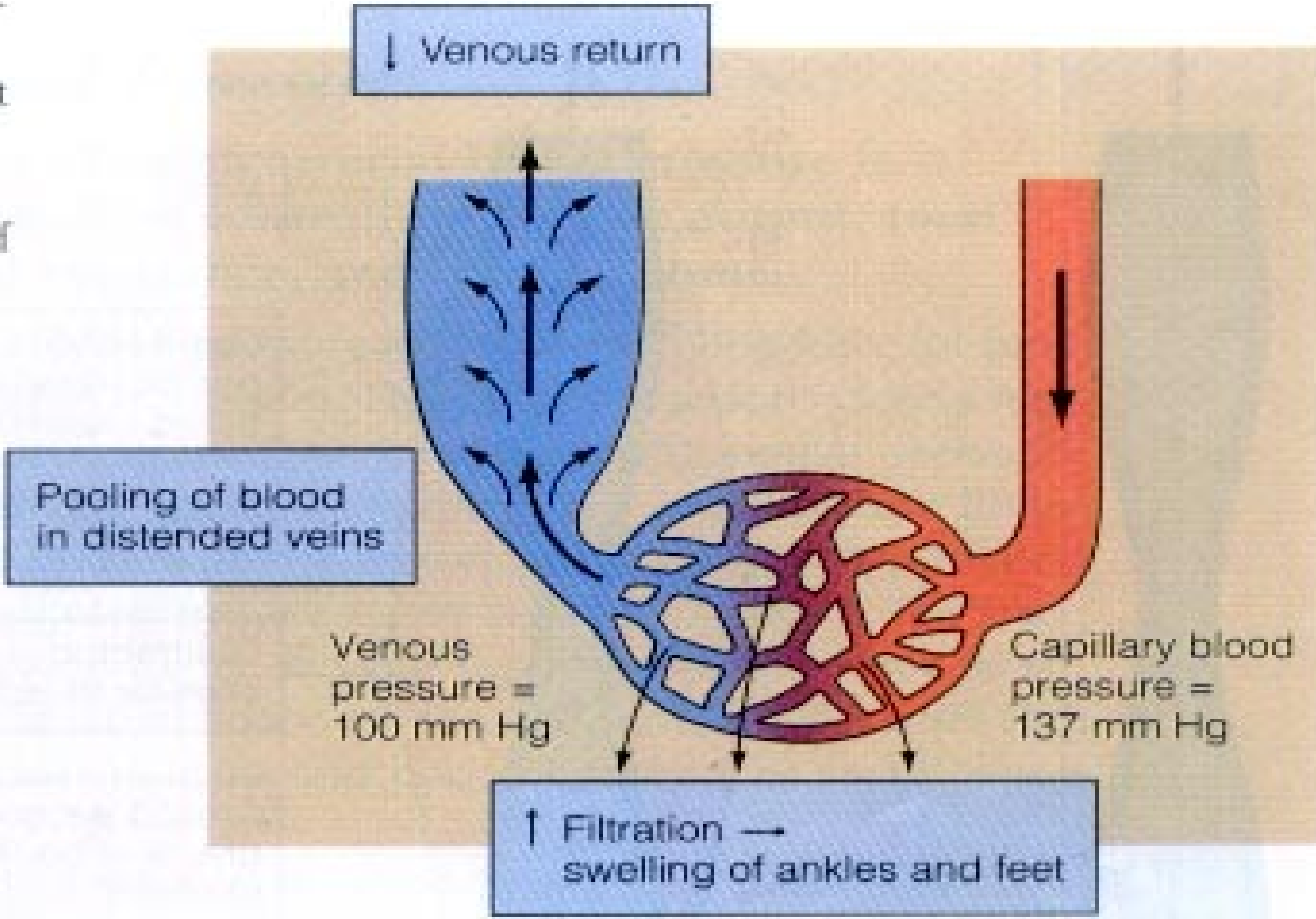
2- ↓ Plasma proteins e.g. in :-

A- Nephrosis. B- Burns & wounds.

C- Liver disease D- Malnutrition.

3- ↑ Capillary permeability e.g. in allergic reactions & burns.

4- Blockage of lymph return by, e.g. infection or cancer.


↓ Venous return
Pooling of blood
in distended veins
Venous
pressure =
100 mm Hg
Capillary blood
pressure =
137 mm Hg
↑ Filtration →
swelling of ankles and feet

(b)