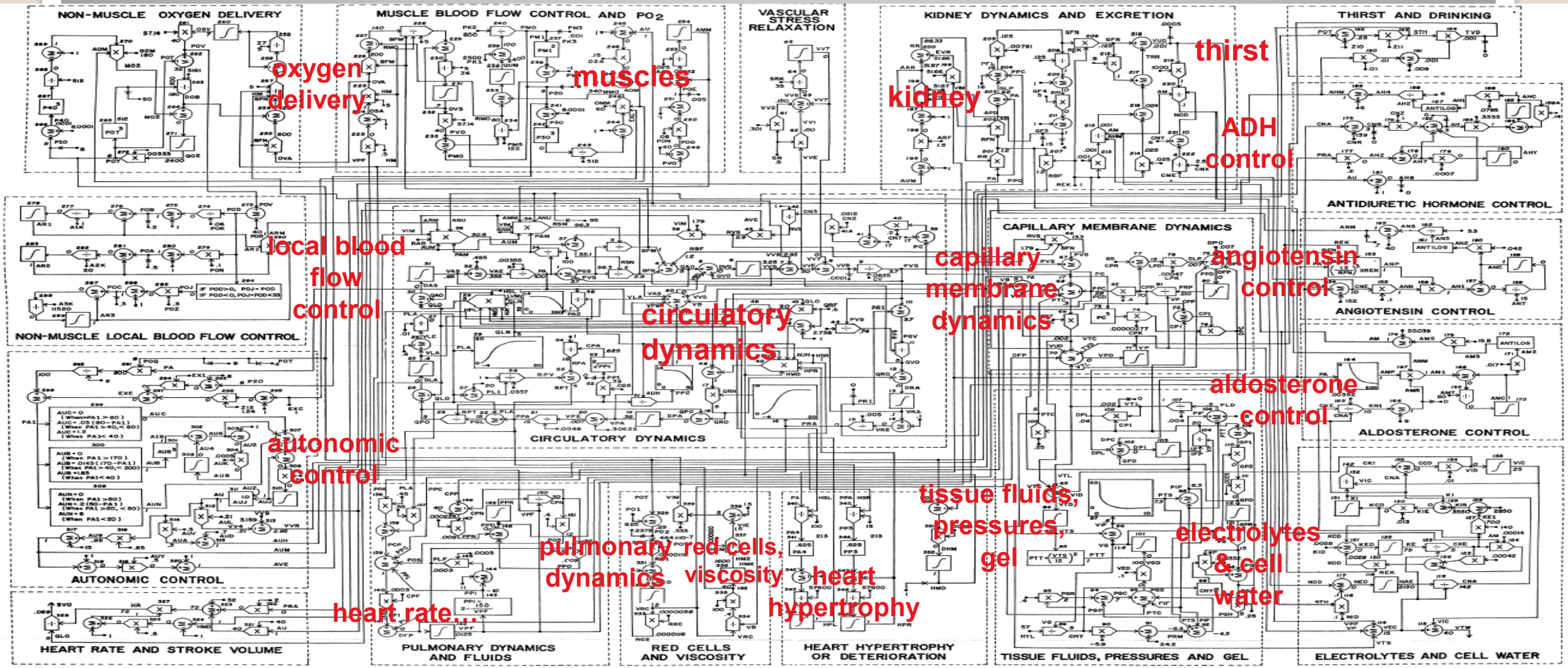
VESSELS PHYSIOLOGY

D.HAMMOUDI.MD

SAPHIR:

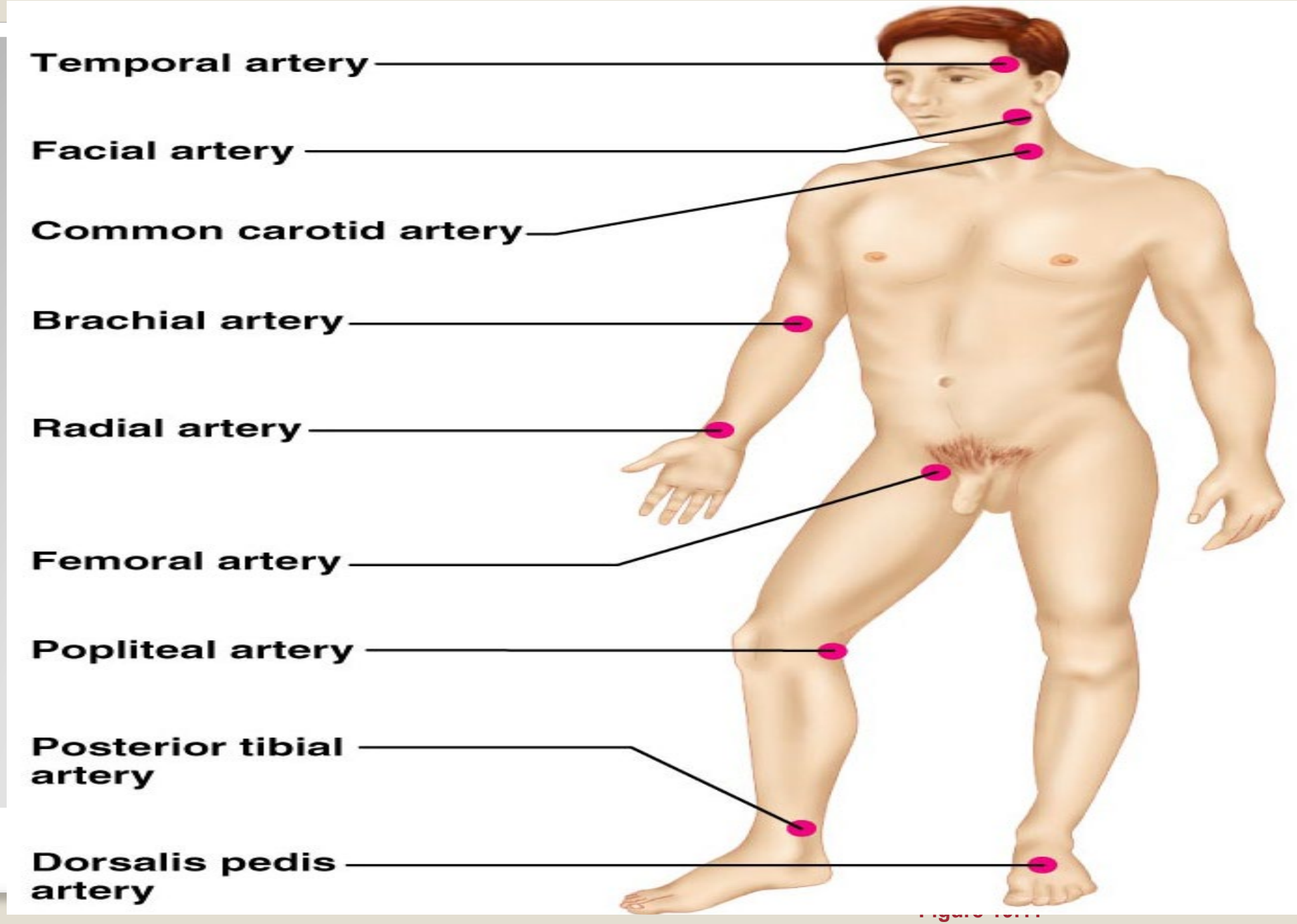
"a Systems Approach for PHysiological Integration of Renal, cardiac, and respiratory functions"

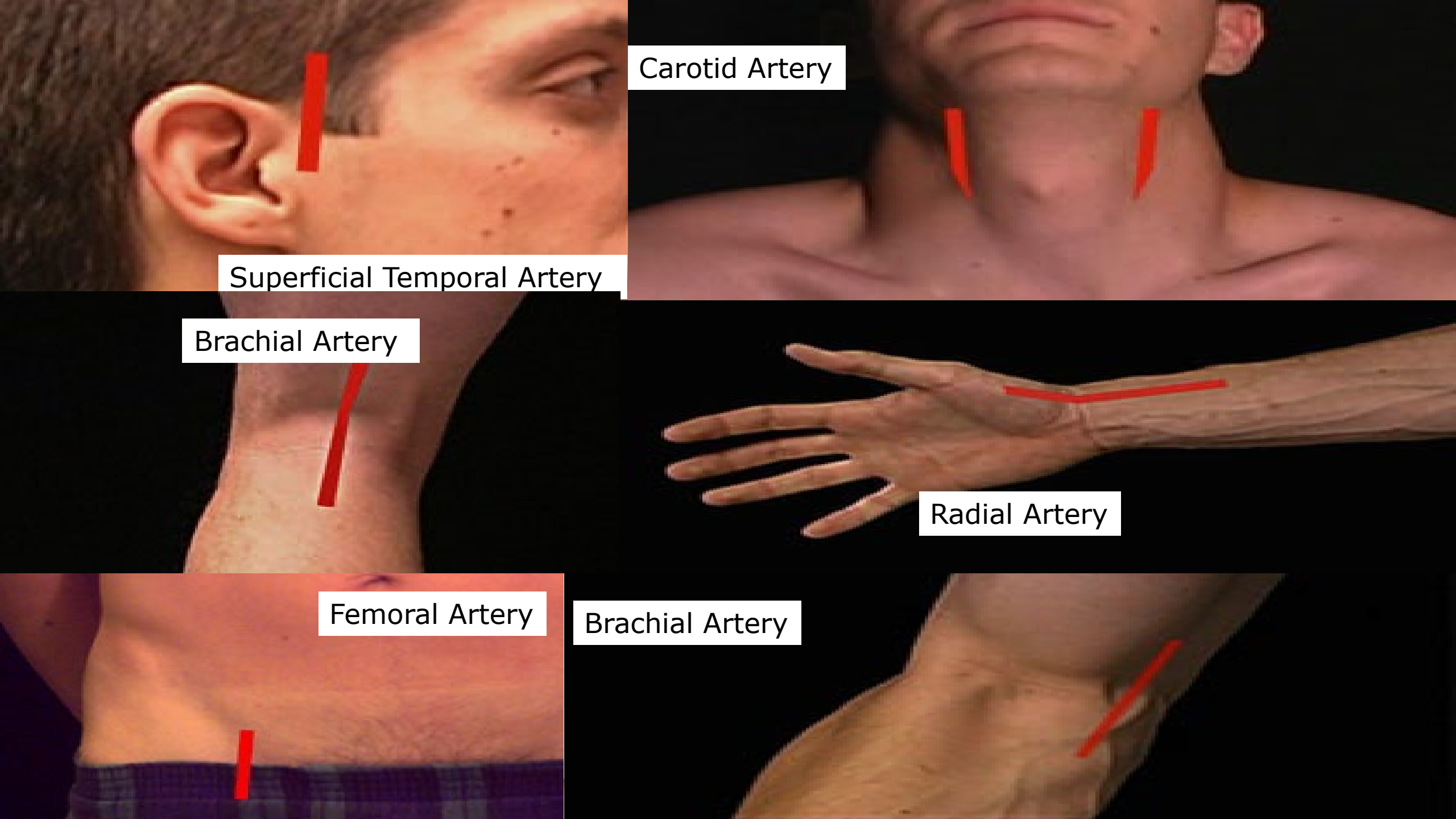


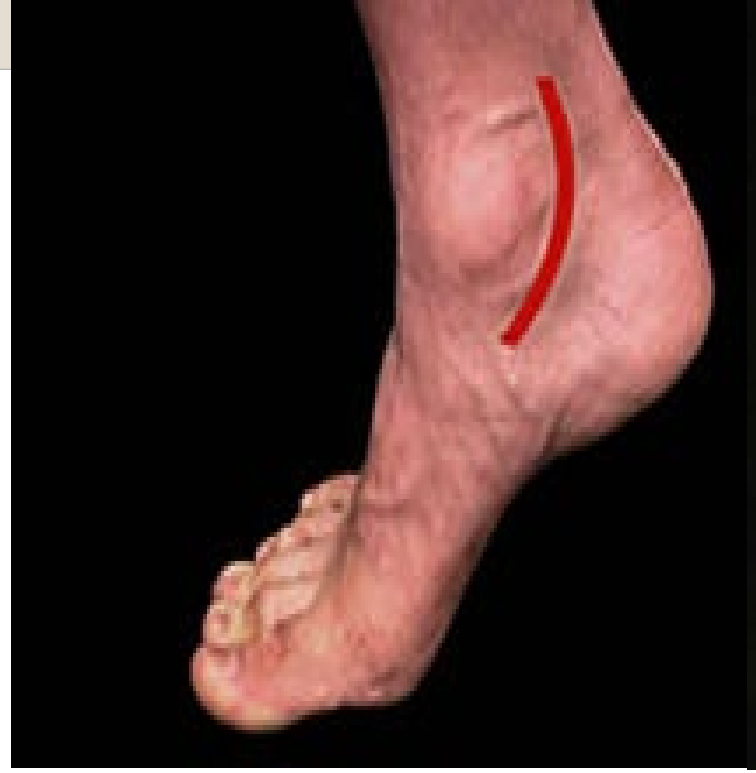
Guyton, Coleman, Granger (1972) *Ann. Rev. Physiol.*

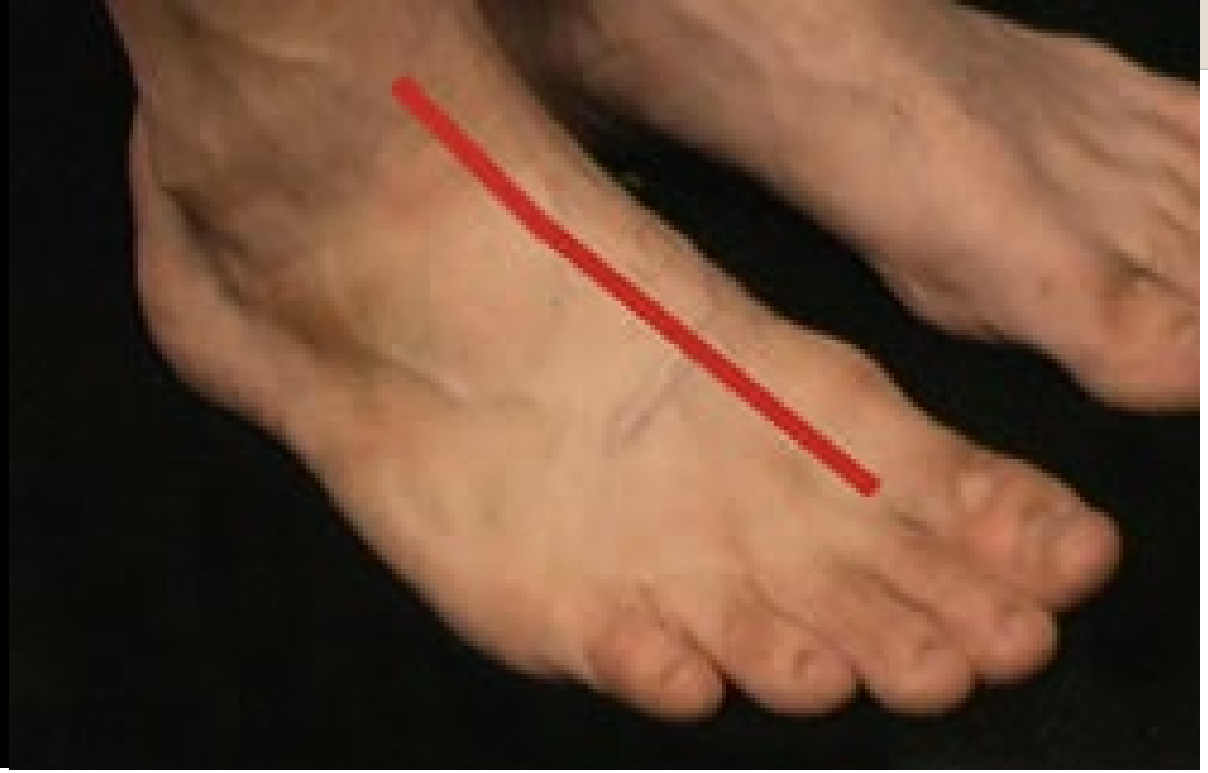
Guyton's modular Systems Model for blood pressure regulation

Palpated Pulse




Carotid Artery
Superficial Temporal Artery
Brachial Artery
Radial Artery
Femoral Artery
Brachial Artery

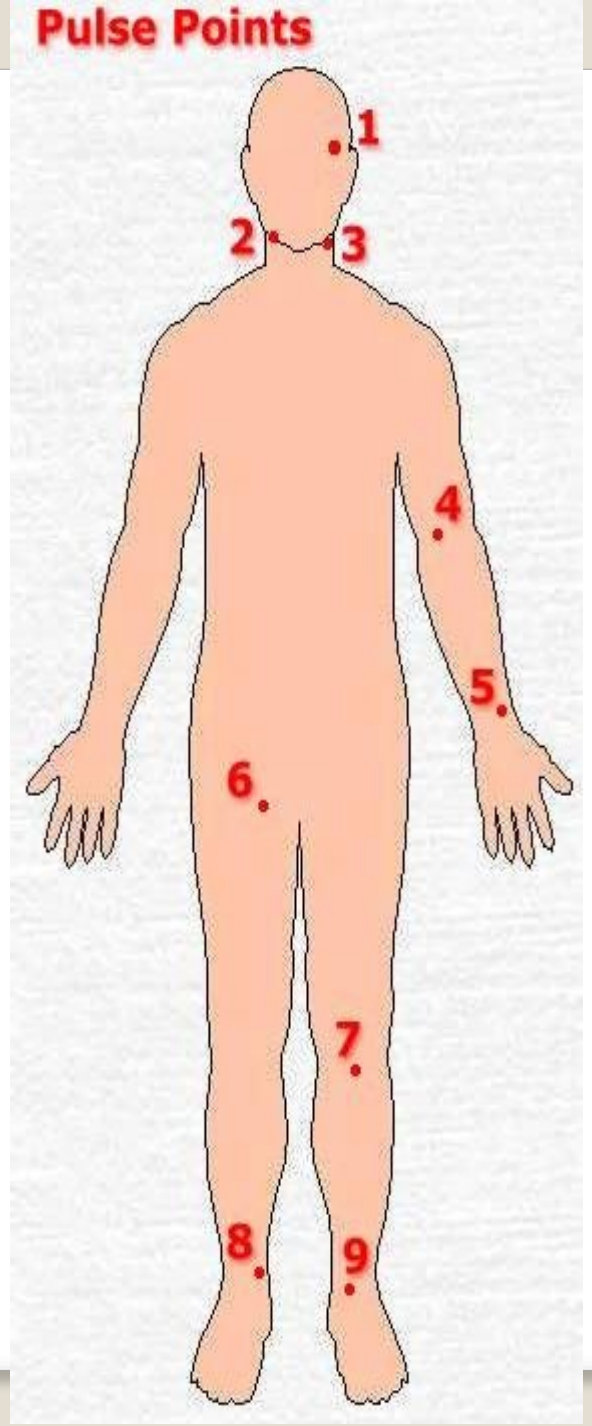




Posterior Tibial Artery

Dorsalis Pedis Artery

http://www.med.umich.edu/lrc/coursepages/M1/anatomy/html/surface/pulses/pulses.html



shows the common sites where the pulse is felt.

1. Temporal artery at the temple above and to the outer side of the eye
2. External maxillary (facial) artery at the point of crossing the mandible (lower jaw)
3. Carotid artery on the side of the neck
4. Brachial artery on the inner side of the biceps
5. Radial artery on the radial bone side of the wrist
6. Femoral artery in the groin
7. Popliteal artery behind the knee
8. Posterior tibial pulse behind the inner ankle
9. Dorsalis pedis artery on the upper front part (anteriosuperior aspect) of the foot

Vascular Endothelium

Vasodilators	Vasoconstrictors
Nitric Oxide Prostacyclin Endothelium-derived hyperpolarizing factor Bradykinin	Endothelin-1 Angiotensin II

Wilson SH, Lerman A.
Heart Physiology and Pathophysiology, Academic Press
(edited by Sperelakis N.) 473-480

- Vasodilator
- Inhibitor of vascular smooth muscle cell proliferation
- Inhibitor of platelet adherence/aggregation
- Inhibitor of leukocyte/endothelial interactions

Nitric Oxide (NO) Function

- Imbalance of endothelium-derived relaxing and contracting factors

Endothelial Dysfunction

Atherosclerotic risk factors

Decreased NO bioavailability
Increased levels of ET-1

Vasodilators

Metabolic

- ↓ O_2
- ↑ CO_2
- ↑ H^+
- ↑ K^+
- Prostaglandins
- Adenosine
- Nitric oxide

Neuronal

- ↓ Sympathetic tone

Hormonal

- Atrial natriuretic peptide

Intrinsic mechanisms (autoregulation)

- Metabolic or myogenic controls
- Distribute blood flow to individual organs and tissues as needed

Extrinsic mechanisms

- Neuronal or hormonal controls
- Maintain mean arterial pressure (MAP)
- Redistribute blood during exercise and thermoregulation

Vasoconstrictors

Myogenic

- Stretch

Metabolic

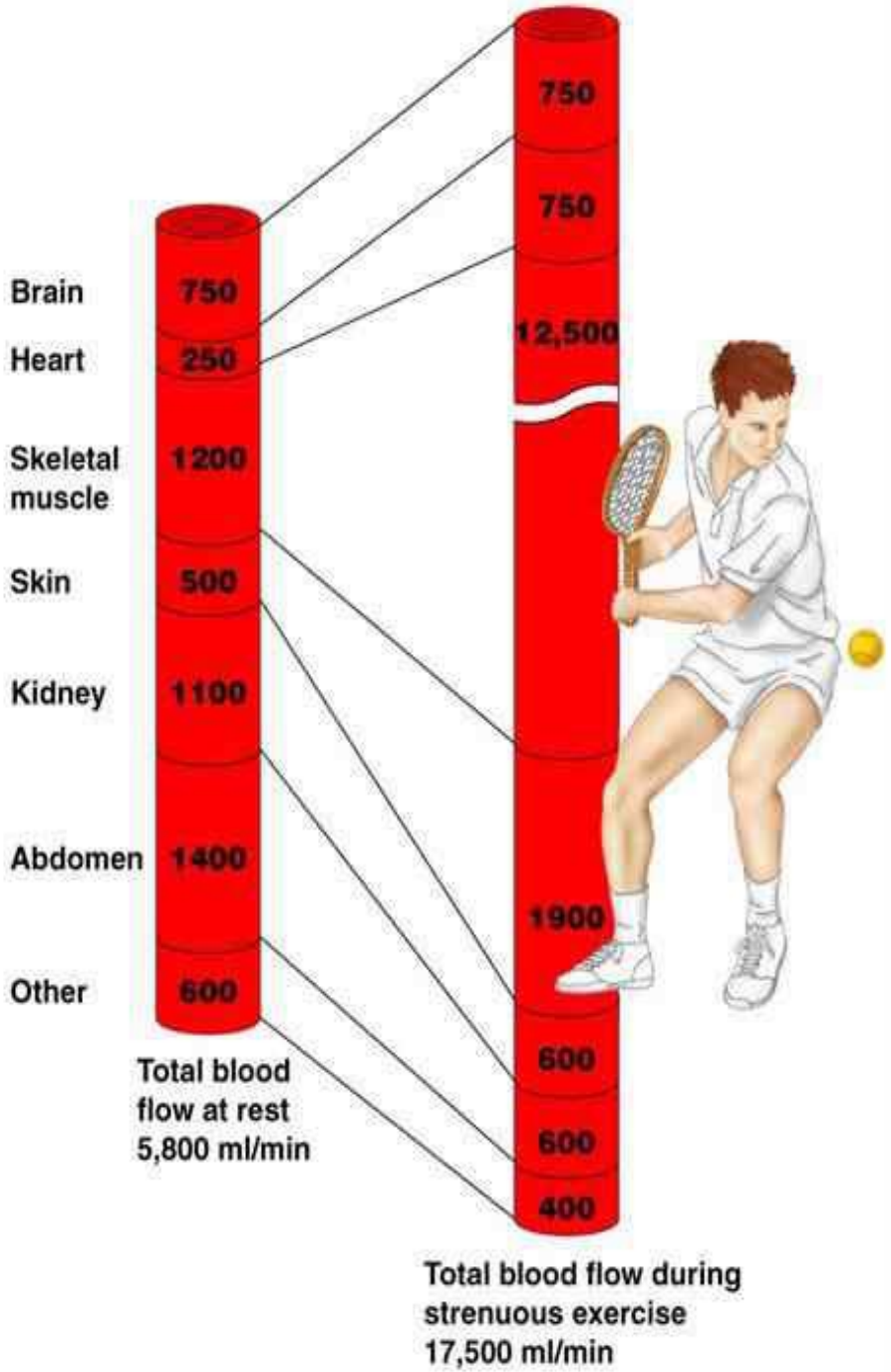
- Endothelins

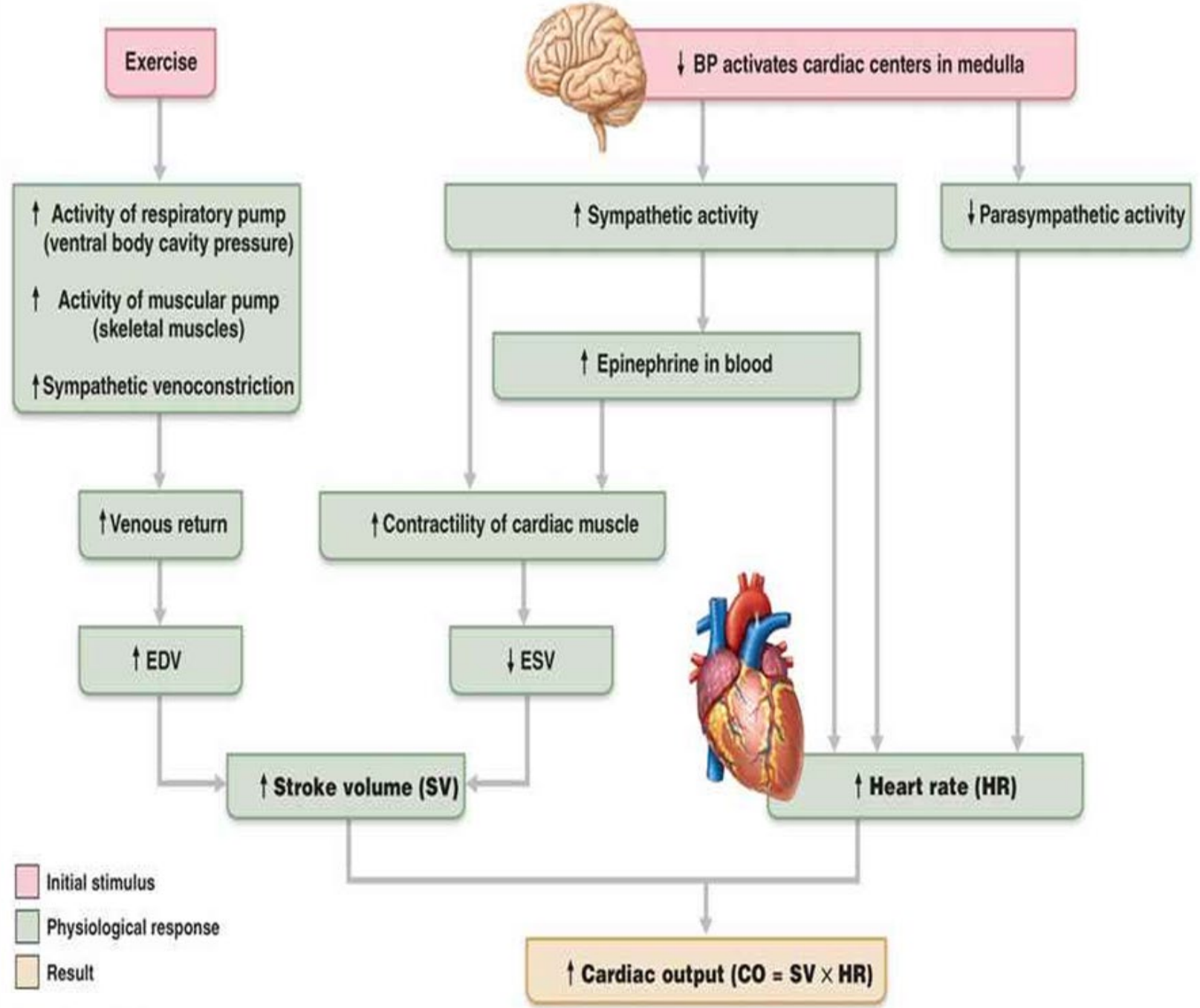
Neuronal

- ↑ Sympathetic tone

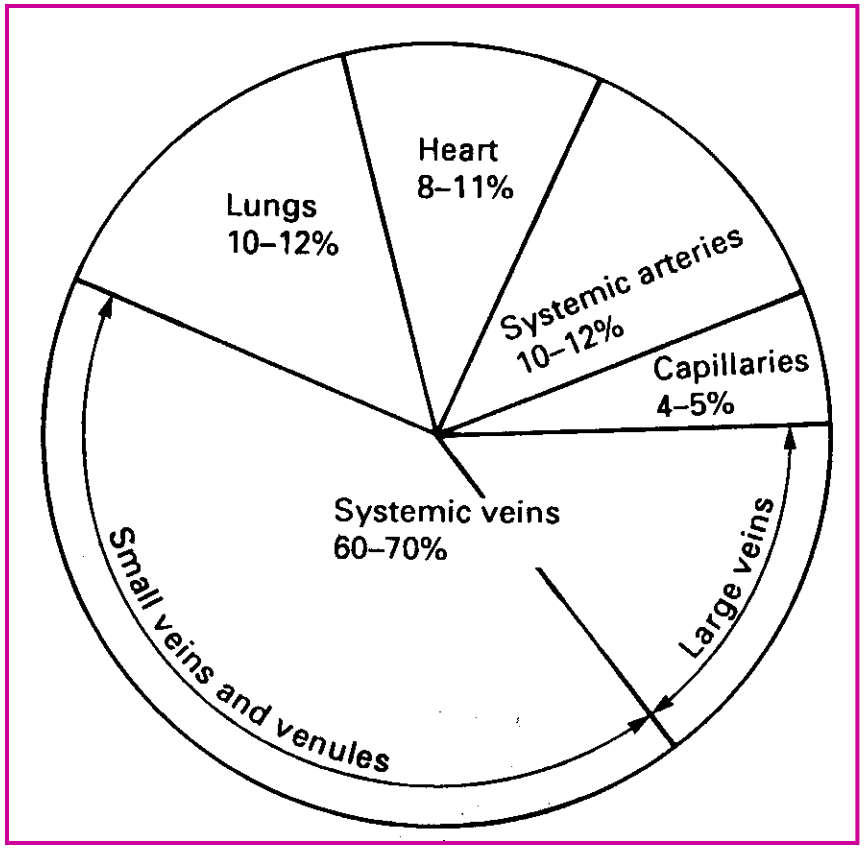
Hormonal

- Angiotensin II
- Antidiuretic hormone


Brain
Heart
Skeletal muscle
Skin
Kidney
Abdomen
Other
750
250
1200
500
1100
1400
600
Total blood flow at rest 5,800 ml/min
750
750
12,500
1900
600
600
400
Total blood flow during strenuous exercise 17,500 ml/min


Exercise
↓ BP activates cardiac centers in medulla
↑ Activity of respiratory pump (ventral body cavity pressure)
↑ Activity of muscular pump (skeletal muscles)
↑ Sympathetic venoconstriction
↑ Sympathetic activity
↓ Parasympathetic activity
↑ Epinephrine in blood
↑ Venous return
↑ Contractility of cardiac muscle
↑ EDV
↓ ESV
↑ Stroke volume (SV)
↑ Heart rate (HR)
↑ Cardiac output (CO = SV × HR)
Initial stimulus
Physiological response
Result
© 2013 Pearson Education, Inc.

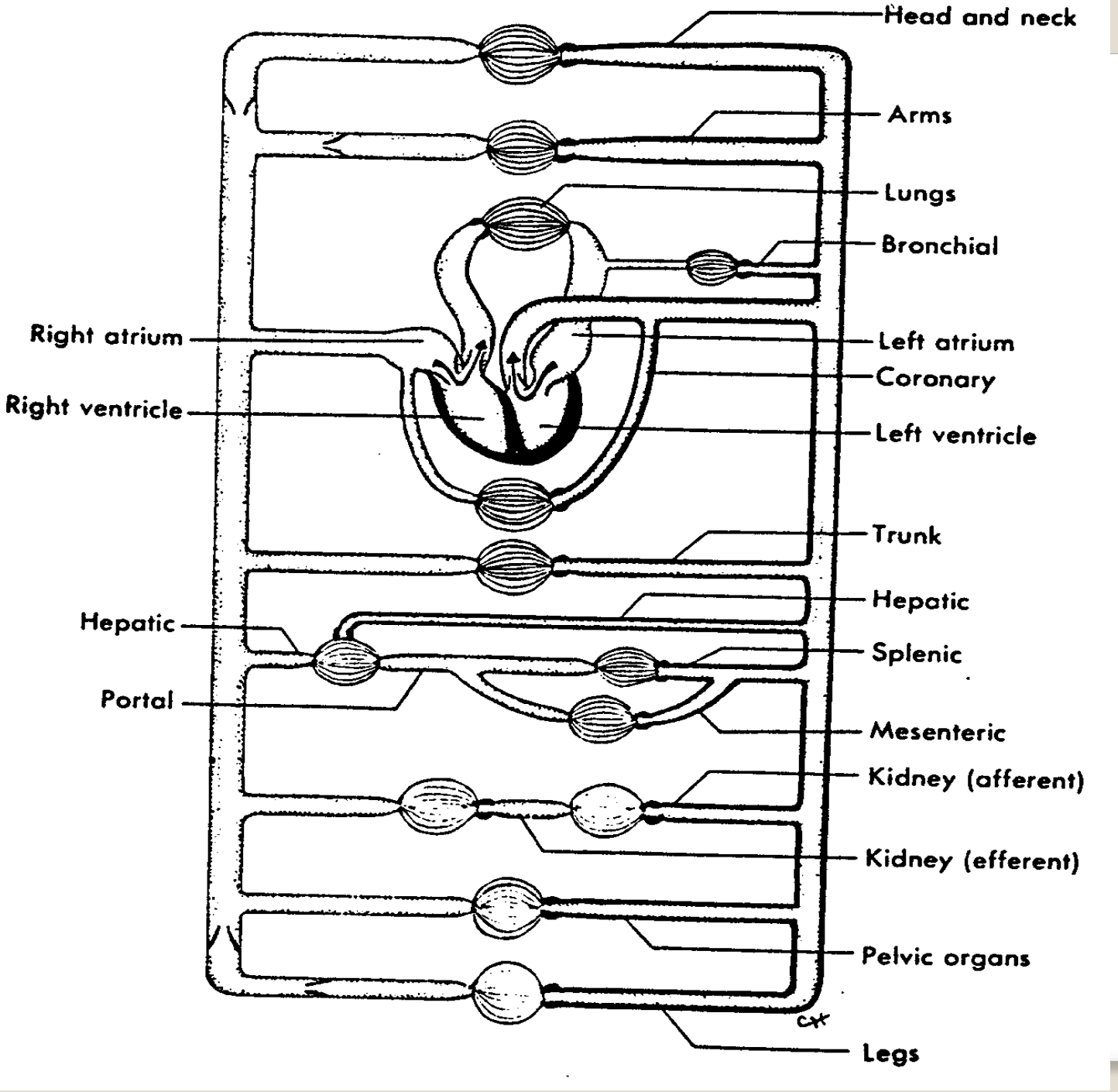
Distribution of blood volume in a resting man (5.5 litres)



Folkow B, Neil E. 1971,
Oxford University Press, London

Blood flow in kidneys and other organs

Organ	**Approx. blood flow (mg/min/g of tissue)**	**A-V O_2 difference (ml/L)**
Kidney	4.00	12-15 (depends on reabsorption of Na^{+})
Heart	0.80	96
Brain	0.50	48
Skeletal muscle (rest)	0.05	-
Skeletal muscle (max. exercise)	1.00	-



PULMONARY CIRCULATION

1. LOW RESISTANCE
2. LOW PRESSURE (25/10 mmHg)

SYSTEMIC CIRCULATION

1. HIGH RESISTANCE
2. HIGH PRESSURE (120/80 mmHg)

PARALLEL SUBCIRCUITS

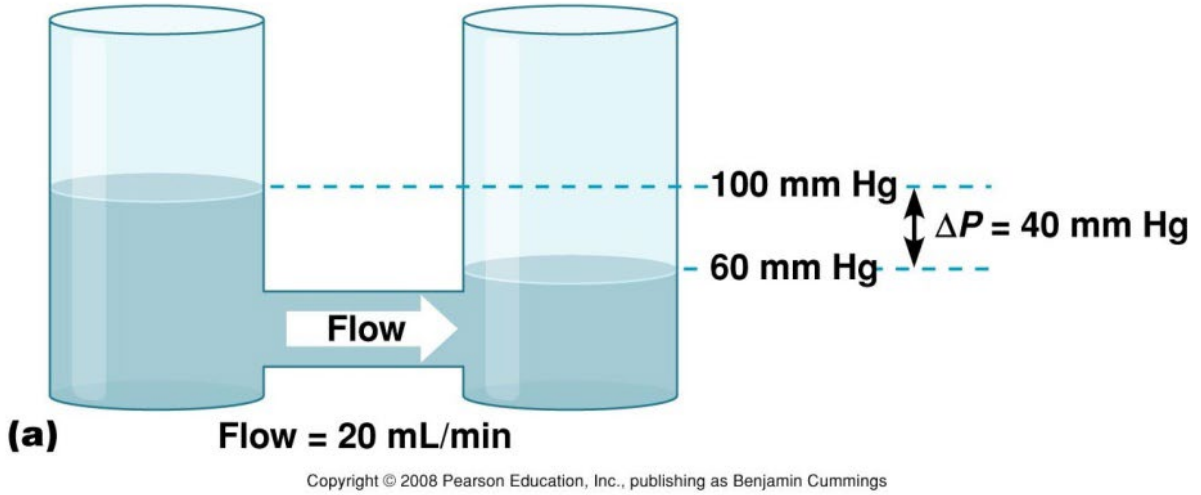
UNIDIRECTIONAL FLOW

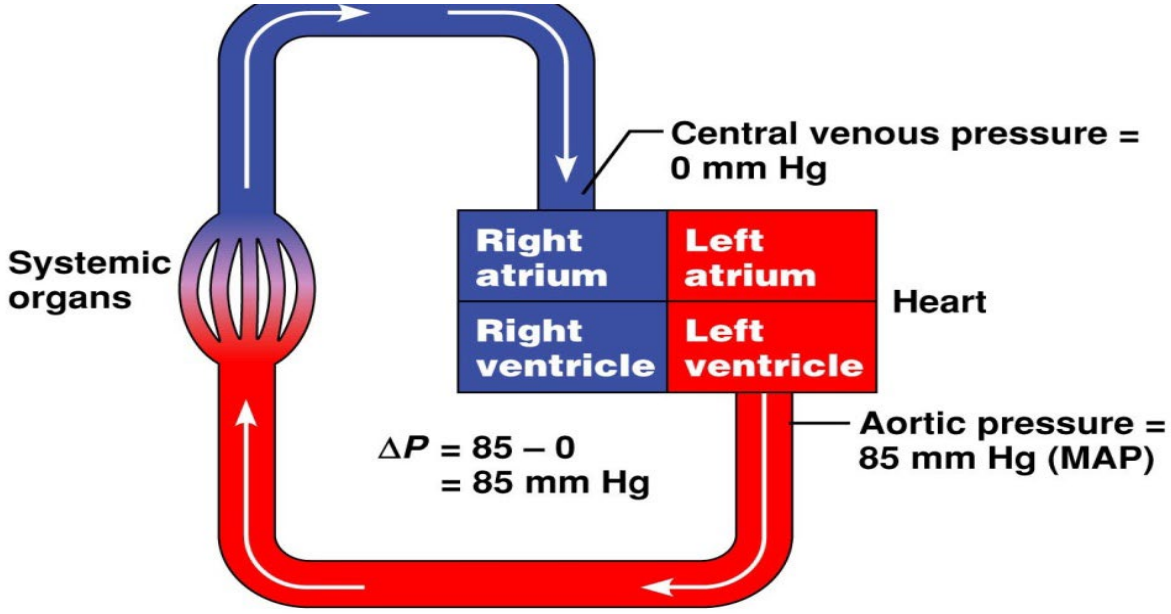
Physical laws governing blood flow and blood pressure

- Flow of blood through out body = pressure gradient within vessels X resistance to flow

  - Pressure gradient: aortic pressure – central venous pressure

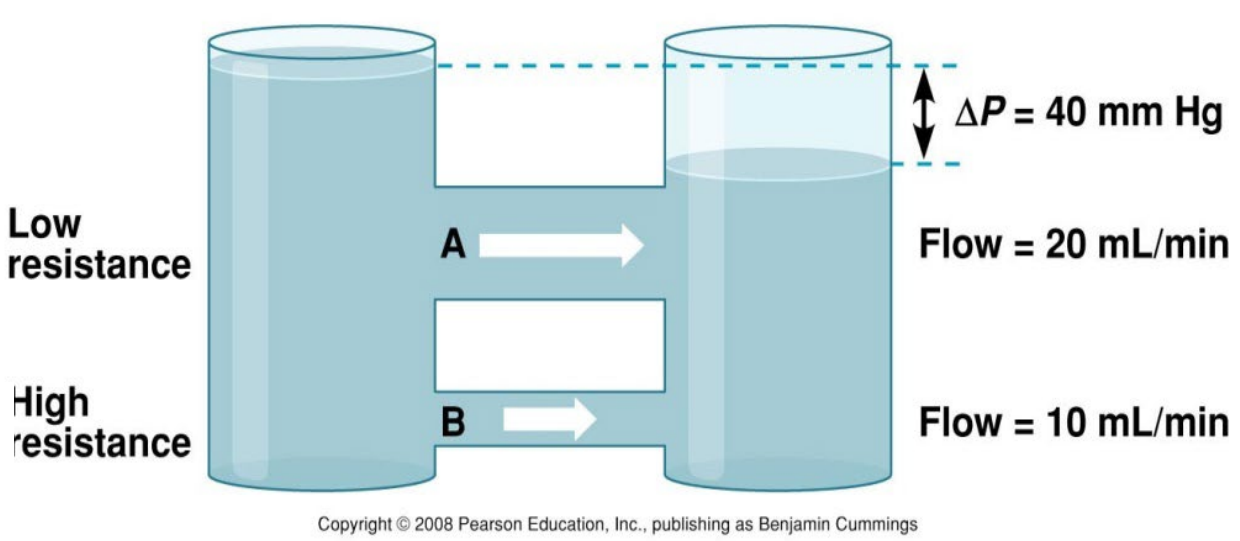
- **Resistance:**
  - -- vessel radius
  - -- vessel length
  - -- blood viscosity





Factors promoting total peripheral resistance (TPR)

- Total peripheral resistance = TPR
  - **-- combined resistance of all vessels**
  - **-- vasodilation → resistance decreases**
  - **-- vasoconstriction → resistance increases**

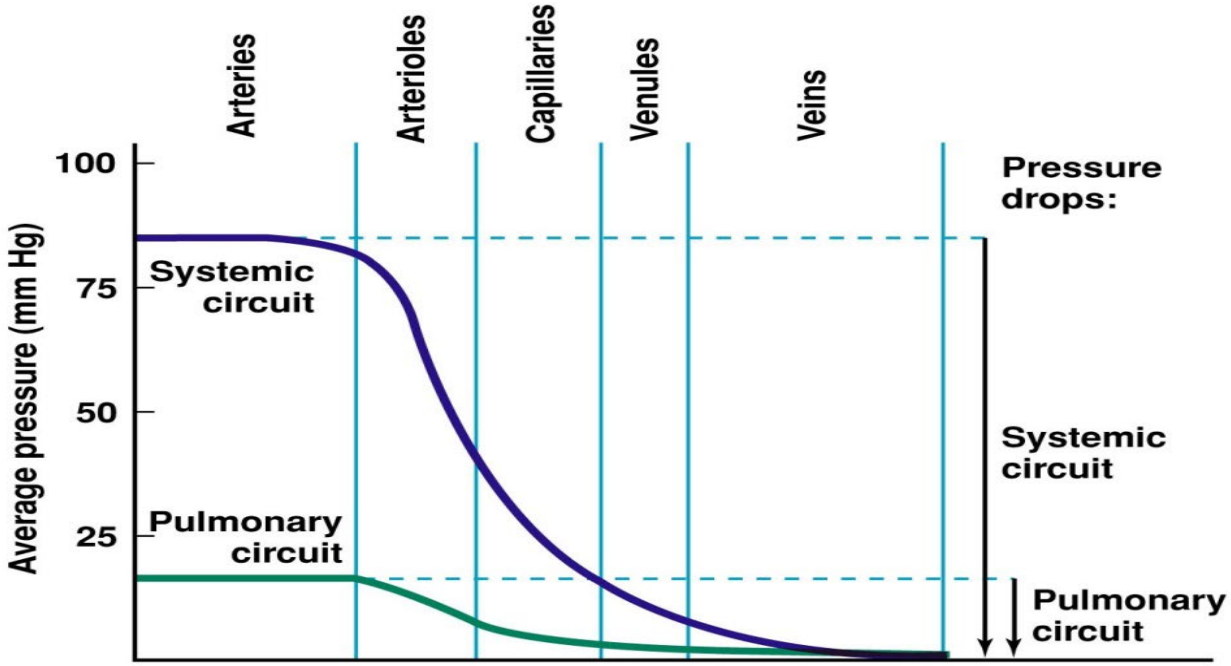


•Blood viscosity: The thickness of the blood can affect how easily it flows through blood vessels. Higher blood viscosity can increase total peripheral resistance.

•Blood vessel length: Longer blood vessels have more resistance to blood flow than shorter ones.

•Blood vessel radius: The radius of blood vessels has a significant impact on blood flow. Narrower blood vessels have higher resistance to blood flow than wider ones.

•Blood vessel elasticity: The elasticity of blood vessels can affect how easily blood flows through them. Less elastic blood vessels can increase total peripheral resistance.



Determinants of Peripheral Vascular Resistance

- Diameter of blood vessels
- Vasoconstriction → increased afterload = high TPR
- Vasodilation → decreased afterload = low TPR

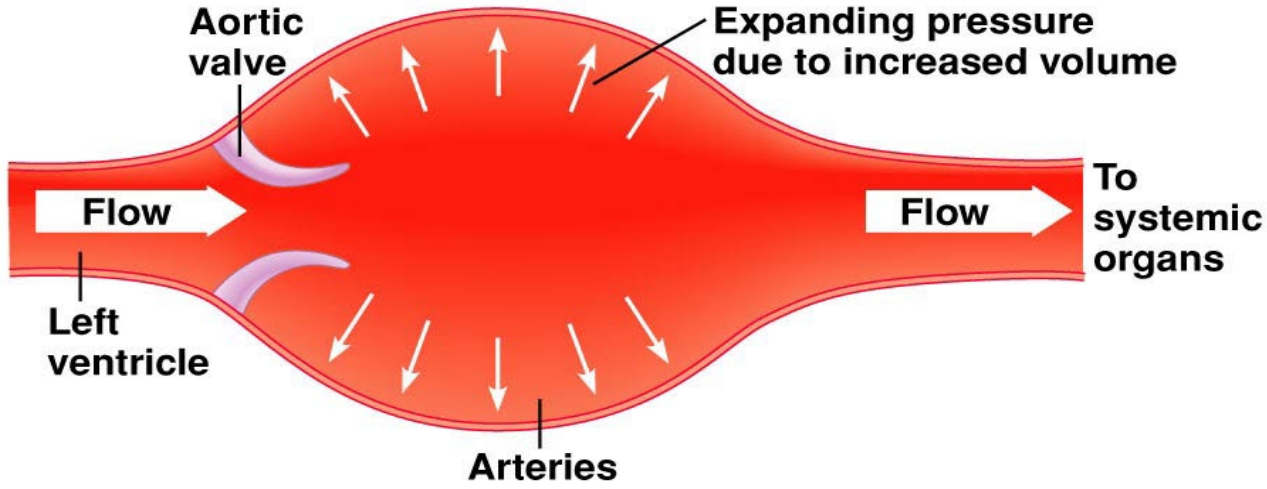
Normal cross-section | Vasoconstriction | Vasodilation

BLOOD FLOW THROUGH BLOOD VESSELS

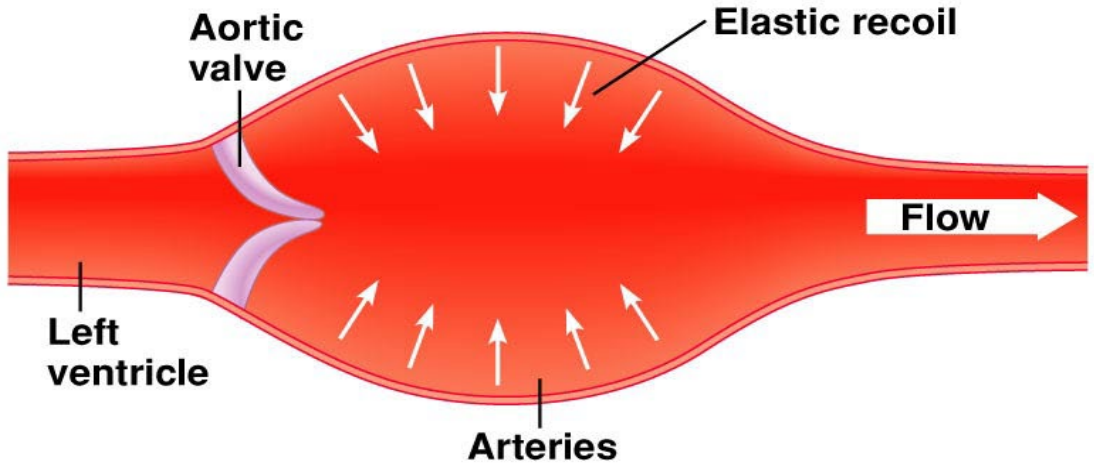
- **From areas of higher pressure to areas of lower pressure**
  - greater the pressure difference the greater the blood flow
- **Contractions of the ventricles generate blood pressure (BP)**
- **Blood pressure is the measure of pressure exerted by blood on the walls of a blood vessel**
  - highest in the aorta and large systemic arteries

Arteries and blood pressure

- Pressure reservoir
- Arterial walls are able to expand and recoil because of the pressure of elastic fibers in the arterial wall
- Systolic pressure: maximum pressure occurring during systole
- Diastolic pressure: pressure during diastole



(a) Systole



(b) Diastole

Arterial blood pressure

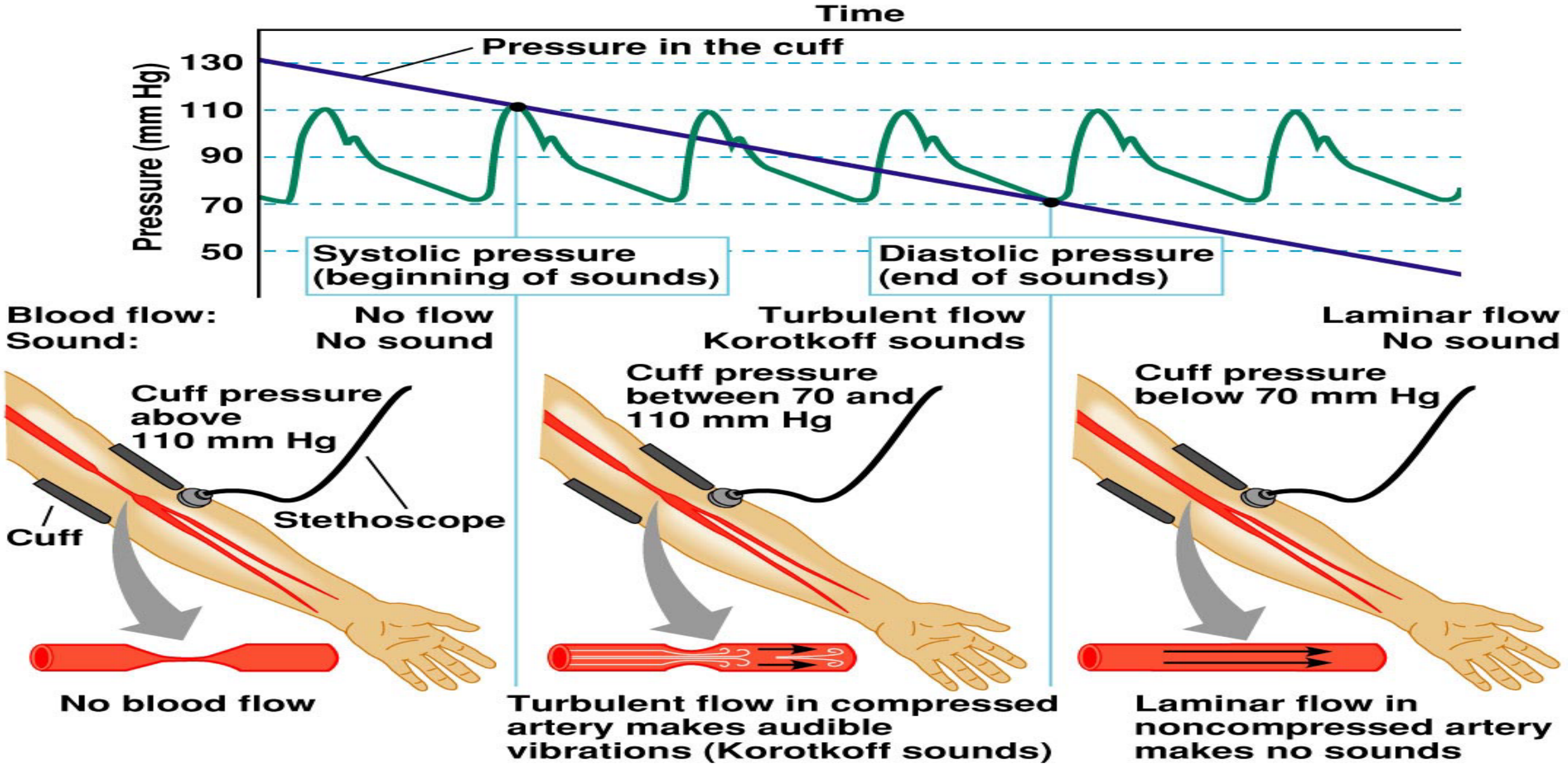


Figure 14.8

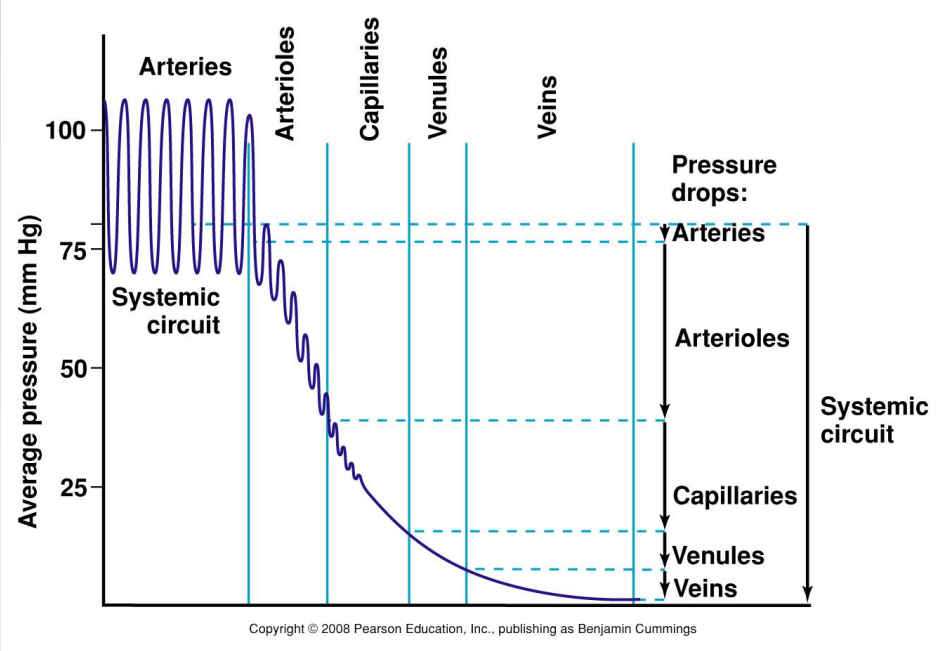
Blood pressure values: what do they mean?

- Pulse pressure:
  PP = SP-DP

- Mean arterial blood pressure = MABP

- $MABP = \frac{SBP + (2XDBP)}{3}$

$CO = \frac{MABP}{TPR} = SV \times HR$

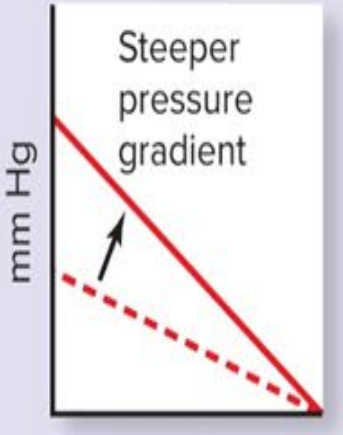


$$\text{Total blood flow} \propto \frac{\textbf{Pressure gradient} \text{ (established by the heart)}}{\textbf{Resistance} \text{ (experienced by blood as it moves through the vessels)}}$$

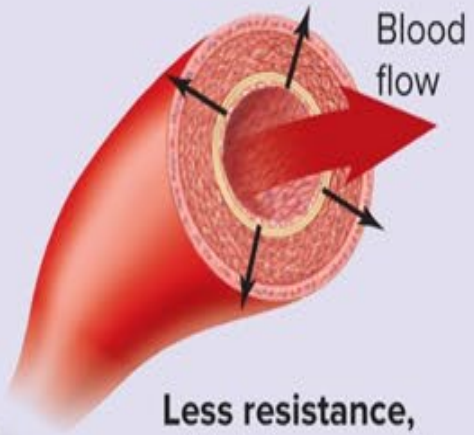
Factors that increase total blood flow

Cardiac output

An **increase in cardiac output** causes a steeper (larger) pressure gradient



Vasodilation

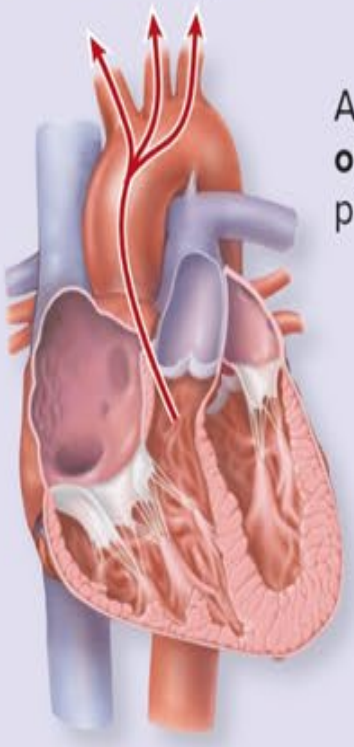


Less resistance, which is caused by vasodilation, reduction in vessel length, or decrease in blood viscosity

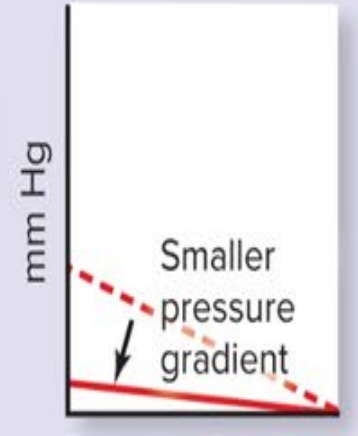
(a)

Factors that decrease total blood flow

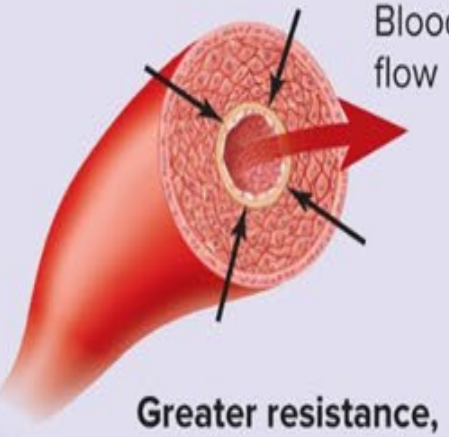
Cardiac output



A **decrease in cardiac output** causes a smaller pressure gradient



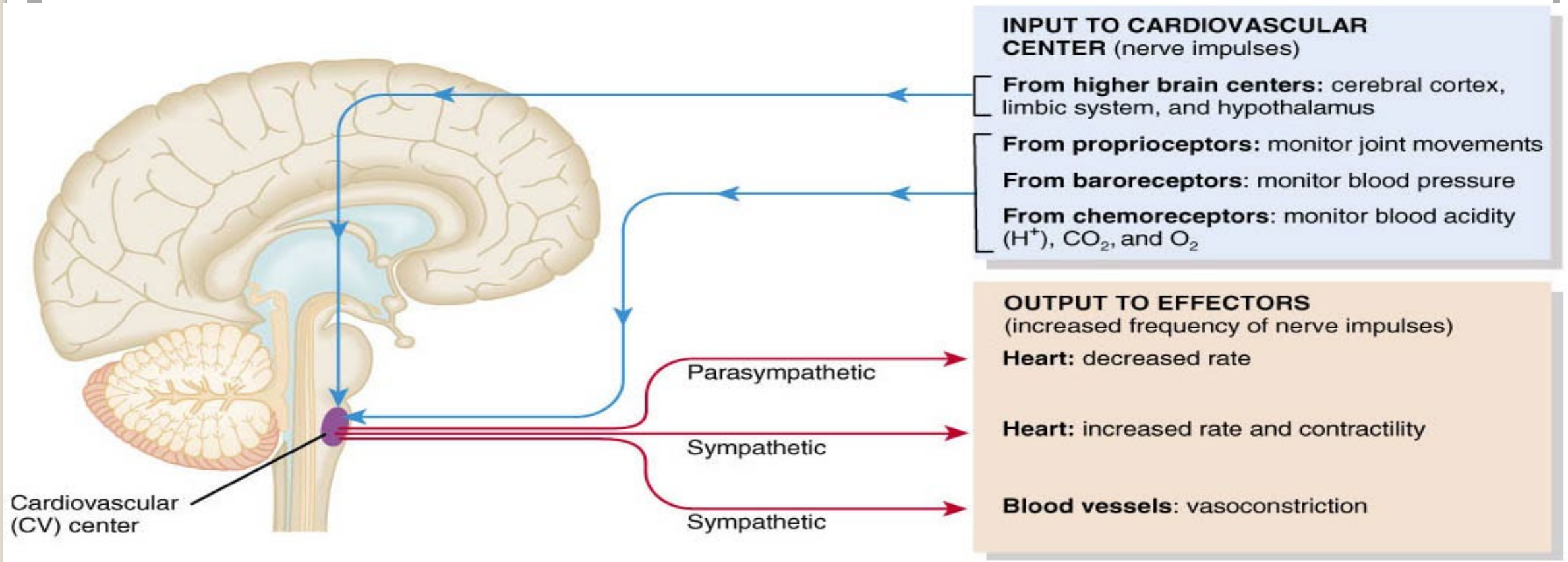
Vasoconstriction



Greater resistance, which is caused by vasoconstriction, increase in vessel length, or increase in blood viscosity

(b)

- ***Role of the Cardiovascular Center***
  - Cardiovascular Center (CV) in the medulla oblongata regulates heart rate and stroke volume



Regulation of Blood Pressure and Blood Flow

Pulse rate

- Your pulse is the rate at which your heart beats.
- Your pulse is usually called your heart rate, which is the number of times your heart beats each minute (bpm).

•Example :
•Given the following data:
Mean Blood Pressure = 100 mmHg
Diastolic Blood Pressure = 90 mmHg
Pulse rate [PR] = 25 pulses/15seconds

PR = (25 pulses /15 seconds) x (60seconds / 1 minute) = 100 pulses / minute
HR = pulse rate = 100 b/min

Mean Blood Pressure

- At normal resting heart rates *MAP* can be approximated using the more easily measured systolic and diastolic pressures, *SP* and *DP:*

$$MAP \simeq DP + \frac{1}{3}(SP - DP)$$

- or equivalently

$$MAP \simeq \frac{(2 \times DP) + SP}{3}$$

- or equivalently

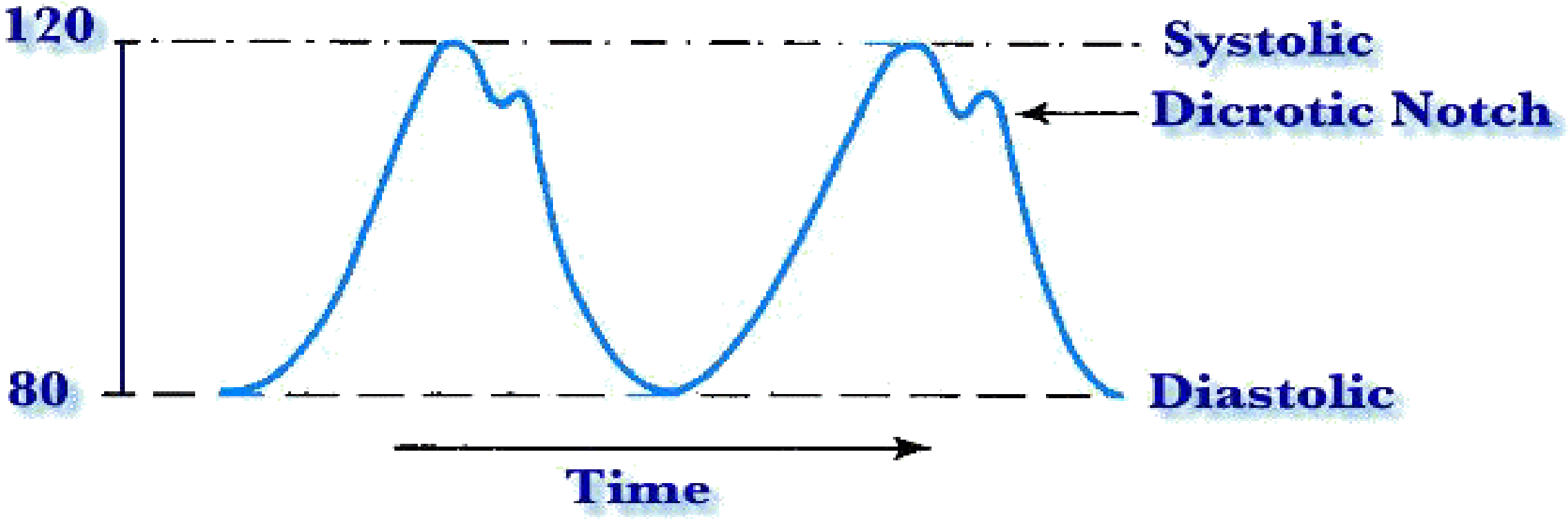
$$MAP \simeq DP + \frac{1}{3}PP$$

- where *PP* is the pulse pressure, *SP* – *DP*

- **Blood Pressure = Cardiac Output x Total Peripheral Resistance**

or

- **BP = CO x TPR**



- **The main factors influencing blood pressure are:**
  - ***Cardiac output (CO)***
  - ***Peripheral resistance (PR)***
  - ***Blood volume***

- **Blood pressure** = CO x PR
- Blood pressure varies directly with CO, PR, and blood volume

Maintaining Blood Pressure

Factors affecting arterial pressure

(1) stoke volume

(2) heart rate

(3) peripheral resistance

(4) aorta large artery

(5)circulatory blood flow

- **Stroke Volume (SV)** = EDV – ESV
- **Ejection Fraction (EF)** = (SV / EDV) × 100%
- **Cardiac Output (Q)** = SV × HR
- **Cardiac Index (CI)** = Q / Body Surface Area (BSA) = SV × HR/BSA
- HR is Heart Rate, expressed as BPM (Beats Per Minute) BSA is Body Surface Area in square metres.

Normal coronary blood flow:

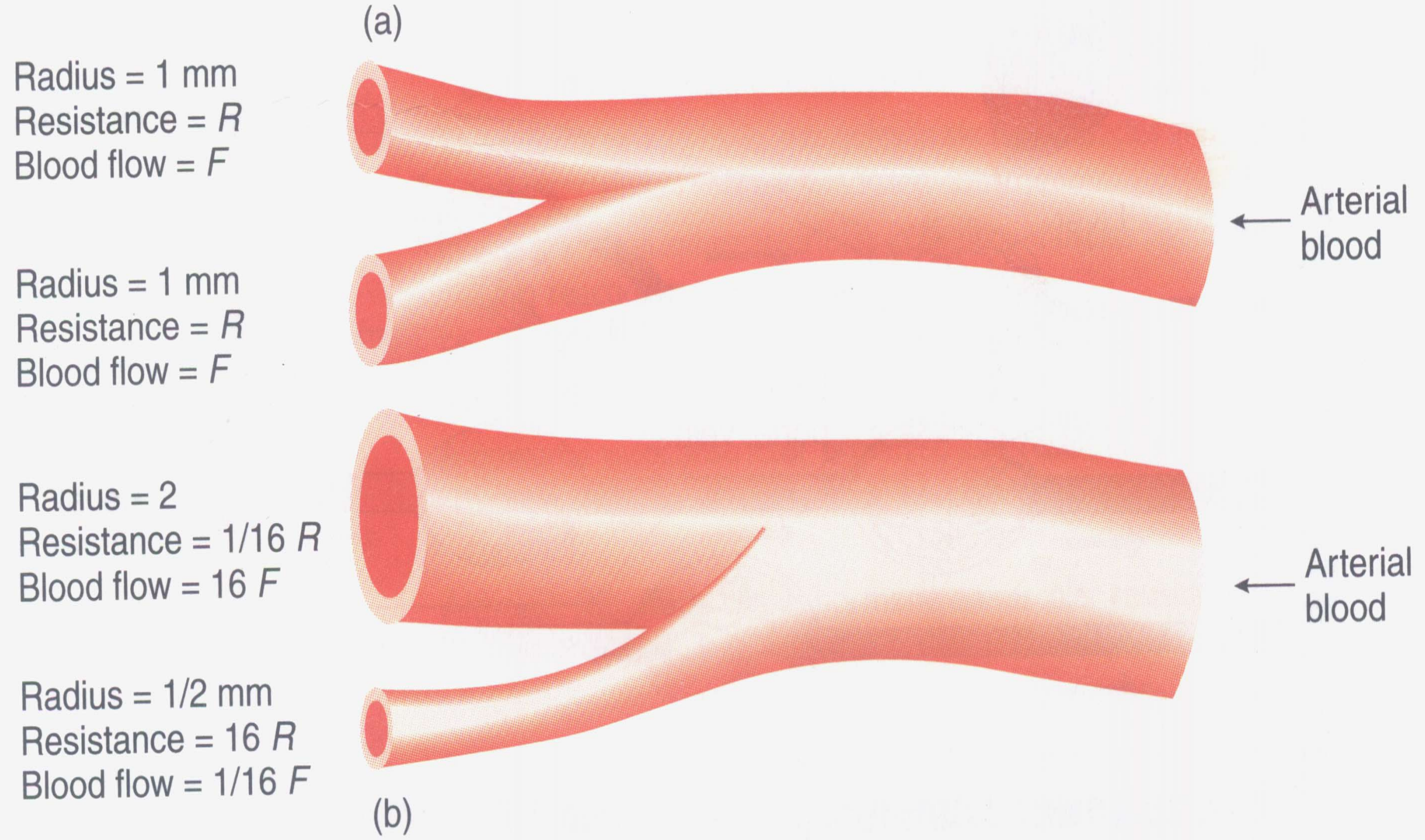
The resting coronary blood flow in human being averages about 225 ml /min, which is about **4 to 5 percent** of the total cardiac output.

- Flow = Pressure/Resistance
- **Q [co]= (MAP – RAP)/TPR**

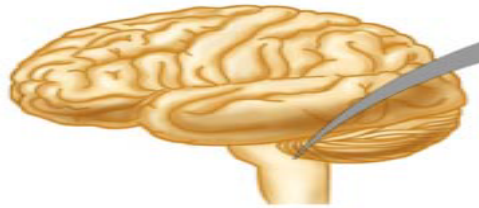
Where MAP = Mean Aortic (or Arterial) Blood Pressure in mmHg,

- RAP = Mean Right Atrial Pressure in mmHg
- TPR = Total Peripheral Resistance in dynes-sec-cm-5.

- **Q ≈ (HR x SV) ≈ MAP / TPR**


(a)
Radius = 1 mm
Resistance = R
Blood flow = F
Radius = 1 mm
Resistance = R
Blood flow = F
Arterial blood
Radius = 2
Resistance = 1/16 R
Blood flow = 16 F
Radius = 1/2 mm
Resistance = 16 R
Blood flow = 1/16 F
Arterial blood
(b)

Cardiac Output (CO)



BP activates cardiac centers in medulla

Parasympathetic activity

Sympathetic activity

Activity of respiratory pump (ventral body cavity pressure)
Activity of muscular pump (skeletal muscles)
Sympathetic venoconstriction

Epinephrine in blood

Venous return

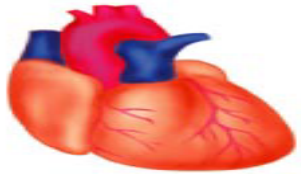
Contractility of cardiac muscle

EDV

ESV

Stroke volume (SV)

Heart rate (HR)



Cardiac output (CO = SV x HR)

Key:

Increased

Decreased

Initial stimulus

Physiological response

Result

Blood Flow

- Actual volume of **blood flowing through a vessel**, an organ, or the entire circulation in a given period:
  - Is measured in ml per min.
  - Is **equivalent to cardiac output (CO), considering the entire vascular system**
  - Is relatively constant when at rest
  - Varies widely through individual organs

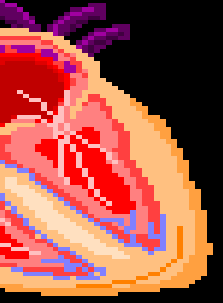
- **Blood flow (F) is directly proportional to the difference in blood pressure (ΔP) between two points in the circulation**
  - If ΔP increases, blood flow speeds up; if ΔP decreases, blood flow declines
- **Blood flow is inversely proportional to resistance (R)**
  - If R increases, blood flow decreases
- **R is more important than ΔP in influencing local blood pressure**

Blood Flow, Blood Pressure, and Resistance

Flow = Difference in pressure/resistance

Flow rate through blood vessels

- directly proportional to the pressure gradient
- inversely proportional to vascular resistance



Blood Flow

$$F = \frac{\Delta P}{R}$$

Blood flow (F) depends on:

① Pressure Gradient (ΔP) - *heart*

② Resistance (R) - *blood vessels*

- viscosity
- vessel length
- vessel diameter

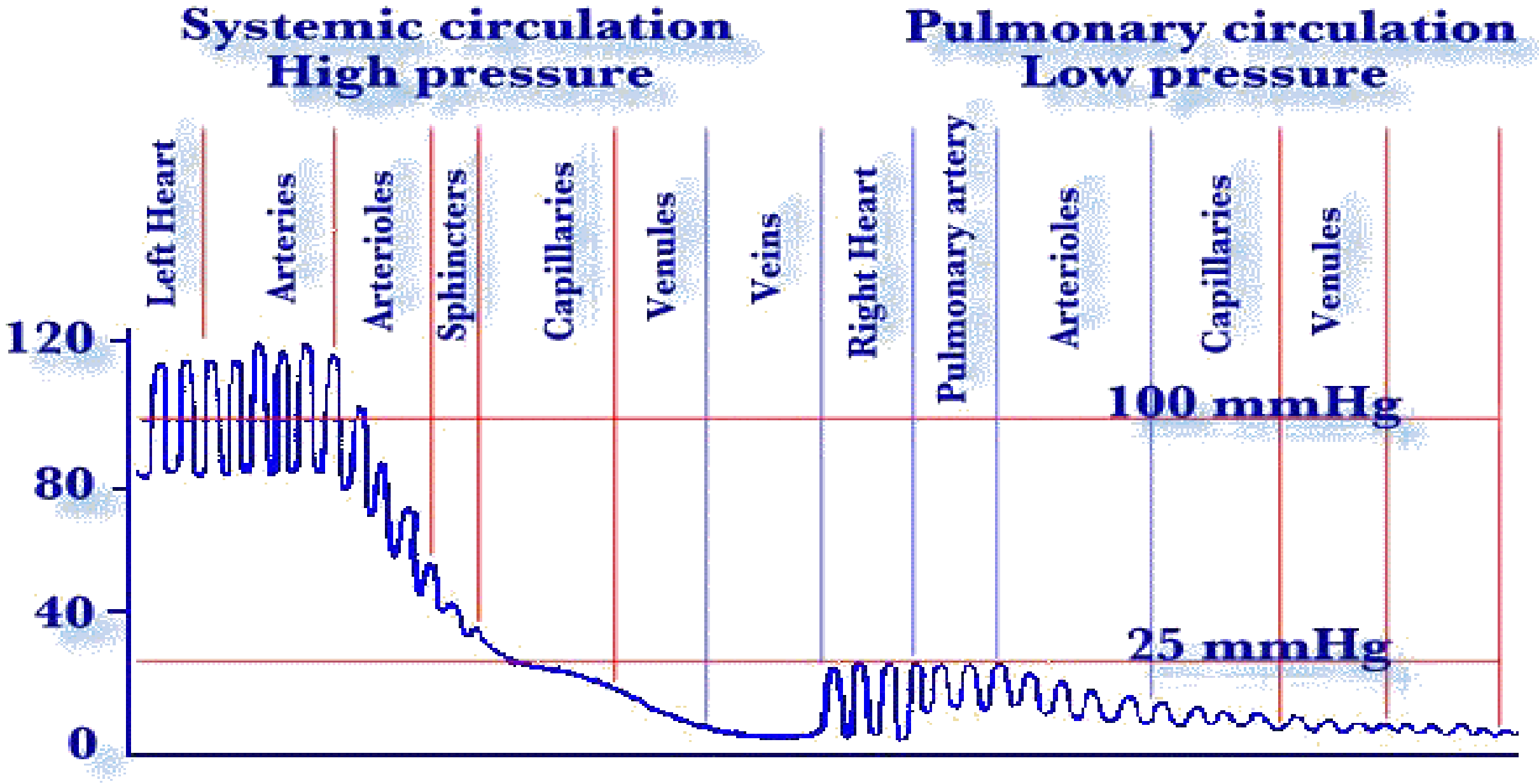
Vessel diameter is the main determinant of vascular resistance.

- Resistance factors that remain relatively constant are:
  - **Blood viscosity** – "stickiness" of the blood
  - **Blood vessel length** – the longer the vessel, the greater the resistance encountered

Resistance Factors: Viscosity and Vessel Length

Blood Pressure (BP)

- Force per unit area exerted on the wall of a blood vessel by its contained blood
  - Expressed in millimeters of mercury (mm Hg)
  - **Measured in reference to systemic arterial BP in large arteries near the heart**
- **The differences in BP within the vascular system provide the driving force that keeps blood moving from higher to lower pressure areas**


Systemic circulation
High pressure
Pulmonary circulation
Low pressure
Left Heart
Arteries
Arterioles
Sphincters
Capillaries
Venules
Veins
Right Heart
Pulmonary artery
Arterioles
Capillaries
Venules
120
80
40
0
100 mmHg
25 mmHg

Normal blood pressures are said to range from 100/60 mmHg to 150/90 mmHg.

Table 1. Some 'average' blood pressures relating to age

Age (years)	Systolic pressure (mmHg)	Diastolic pressure (mmHg)
New-born	80	46
10	103	70
20	120	80
40	126	84
60	135	89

Category	Systolic (mmHg)		Diastolic (mmHg)
Optimal	<120	and	<80
Normal	120–129	and/or	80–84
High normal	130–139	and/or	85–89
Grade 1 hypertension	140–159	and/or	90–99
Grade 2 hypertension	160–179	and/or	100–109
Grade 3 hypertension	≥180	and/or	≥110
Isolated systolic hypertension[b]	≥140	and	<90

BP = blood pressure; SBP = systolic blood pressure.

[a]BP category is defined according to seated clinic BP and by the highest level of BP, whether systolic or diastolic.

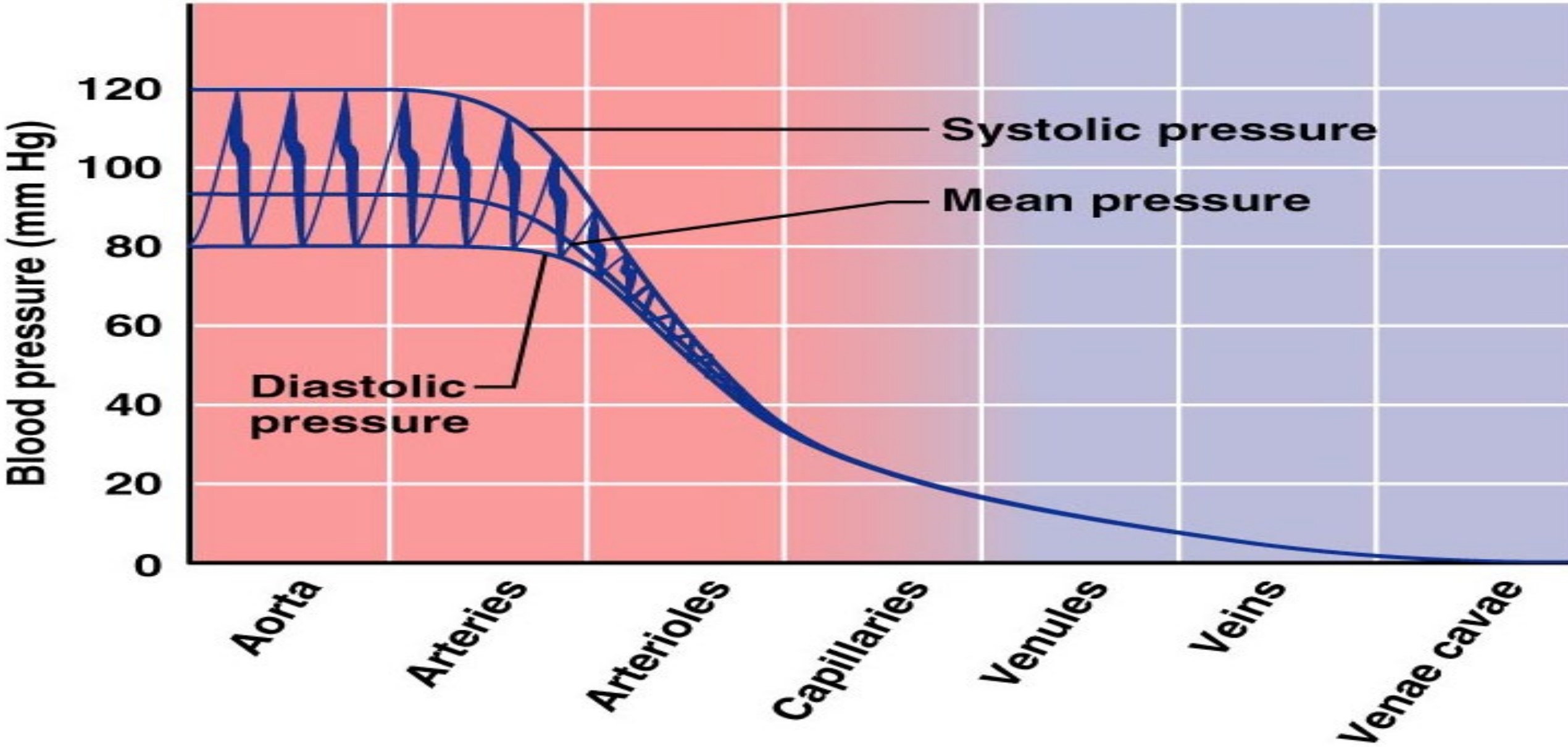
[b]Isolated systolic hypertension is graded 1, 2, or 3 according to SBP values in the ranges indicated.

The same classification is used for all ages from 16 years.

Hypertension Classification	BP ACC/AHA	BP ESC/ESH	Management
Normal	<120/80	120-129/ 80-84	
Elevated/ High Normal	120-129/ <80	130-139/ 85-89	Lifestyle and Diet measures + Monitoring BP
Stage 1/ Grade 1	130-139/ 80-89	140-159/ 90-99	Lifestyle and Diet measures + BP lowering drugs + Monitoring BP
Stage 2/ Grade 2	≥140/90	160-179/ 100-109	
Crisis/ Grade 3	≥180/120	≥180/110	Emergency management with BP lowering drugs

- **Systemic pressure:**
  - Is highest in the aorta
  - Declines throughout the length of the pathway
  - **Is 0 mm Hg in the right atrium**
- **The steepest change in blood pressure occurs in the arterioles**

Systemic Blood Pressure



Systemic Blood Pressure

Figure 19.5

- Systolic pressure – pressure exerted on arterial walls during ventricular contraction
-
- Diastolic pressure – lowest level of arterial pressure during a ventricular cycle
- Pulse pressure – the difference between systolic and diastolic pressure
- Mean arterial pressure (MAP) – pressure that propels the blood to the tissues
- **MAP = diastolic pressure + 1/3 pulse pressure[systolic]**

Arterial Blood Pressure

Capillary Blood Pressure

- **Capillary BP ranges from 20 to 40 mm Hg**
- Low capillary pressure is desirable because high BP would rupture fragile, thin-walled capillaries
- Low BP is sufficient to force filtrate out into interstitial space and distribute nutrients, gases, and hormones between blood and tissues

- Venous BP is steady and changes little during the cardiac cycle
- **The pressure gradient in the venous system is only about 20 mm Hg**
- A cut vein has even blood flow; a lacerated artery flows in spurts

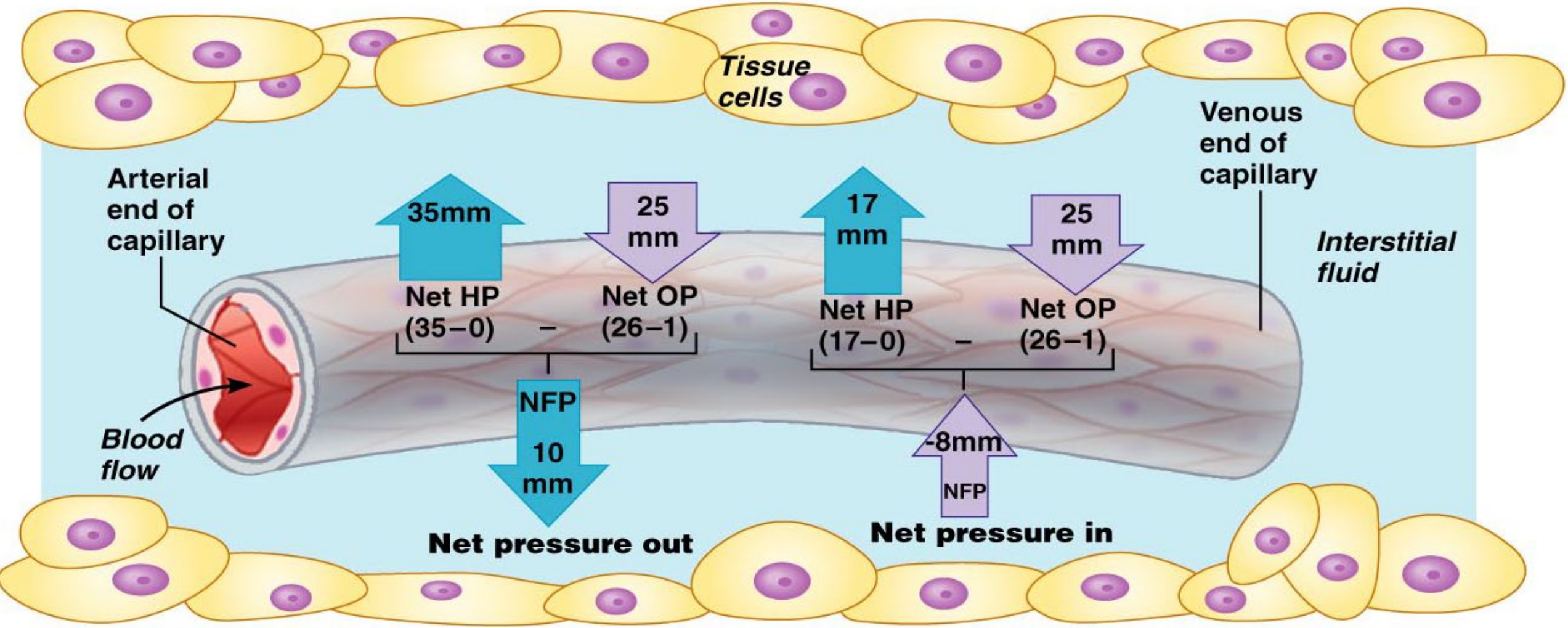
Venous Blood Pressure

Capillary Exchange: Fluid Movements

- Direction and amount of fluid flow depends upon the difference between:
  - Capillary hydrostatic pressure (HP_c)
  - Capillary colloid osmotic pressure (OP_c)
- HP_c – pressure of blood against the capillary walls:
  - Tends to force fluids through the capillary walls
  - Is greater at the arterial end of a bed than at the venule end
- OP_c– created by nondiffusible plasma proteins, which draw water toward themselves

Net Filtration Pressure (NFP)

- NFP – all the forces acting on a capillary bed
  - **$NFP = (HP_c - HP_{if}) - (OP_c - OP_{if})$**
- At the arterial end of a bed, hydrostatic forces dominate (fluids flow out)



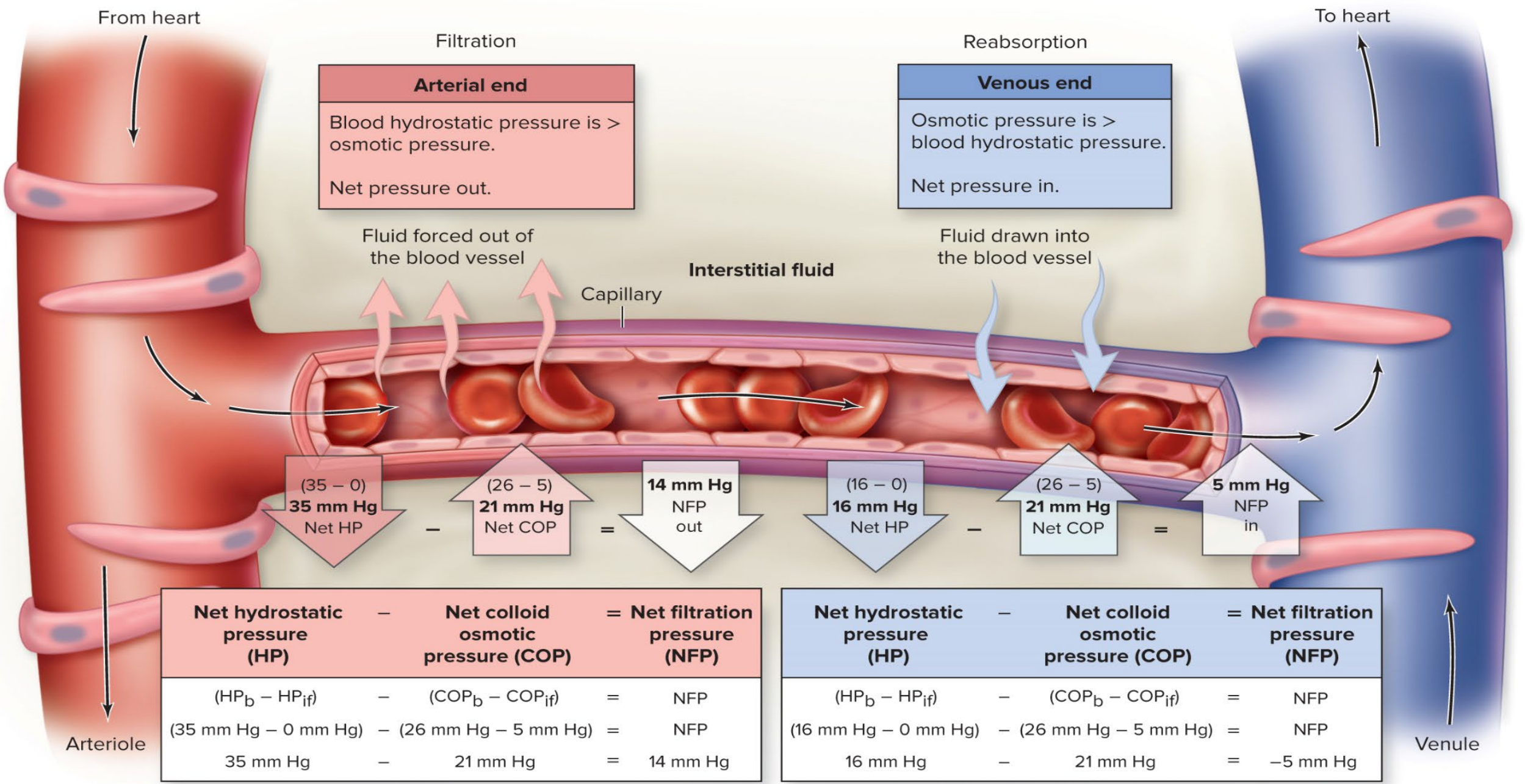
Key to pressure values:

HP_c at arterial end = 35 mm Hg HP_{if} = 0 mm Hg OP_{if} = 1 mm Hg

HP_c at venous end = 17 mm Hg OP_c = 26 mm Hg

Net Filtration Pressure (NFP)

Figure 19.16

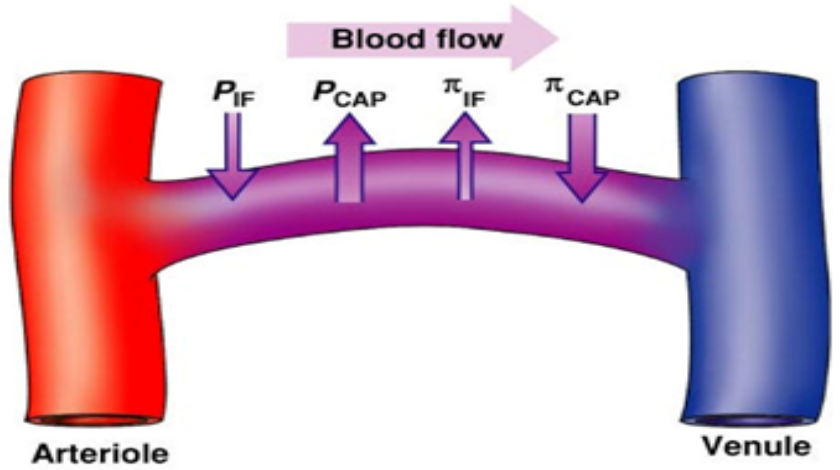


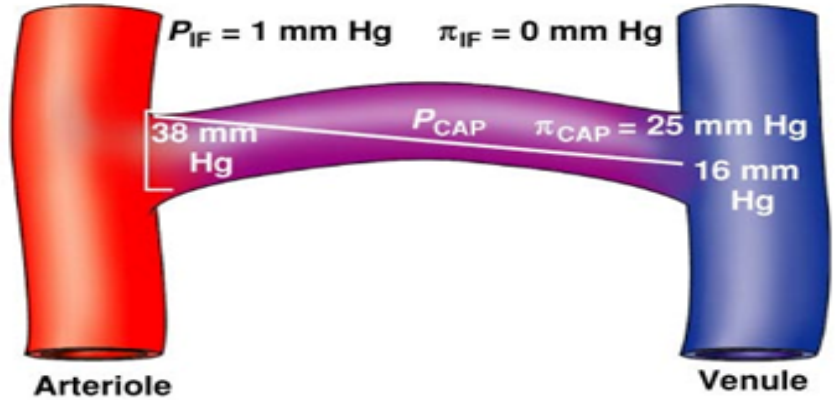
Net hydrostatic pressure (HP)	–	Net colloid osmotic pressure (COP)	=	Net filtration pressure (NFP)
$(HP_b - HP_{if})$	–	$(COP_b - COP_{if})$	=	NFP
(35 mm Hg – 0 mm Hg)	–	(26 mm Hg – 5 mm Hg)	=	NFP
35 mm Hg	–	21 mm Hg	=	14 mm Hg

Net hydrostatic pressure (HP)	–	Net colloid osmotic pressure (COP)	=	Net filtration pressure (NFP)
$(HP_b - HP_{if})$	–	$(COP_b - COP_{if})$	=	NFP
(16 mm Hg – 0 mm Hg)	–	(26 mm Hg – 5 mm Hg)	=	NFP
16 mm Hg	–	21 mm Hg	=	–5 mm Hg

- **Arterial side of the capillary:**
  - High capillary hydrostatic pressure (BHP), lower capillary osmotic pressure (BOP, due to proteins and other molecules in the blood) → Net filtration pressure pushes fluid from the blood toward the tissue (but the proteins remain in the capillary
- **Venous side of the capillary:**

  - Lower hydrostatic pressure (due to resistance) and higher capillary osmotic pressure → Net filtration pressure moves fluid back toward the capillary
- **Interstitial fluid hydrostatic (IFHP) and osmotic pressures (IFOP) remain overall identical**





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

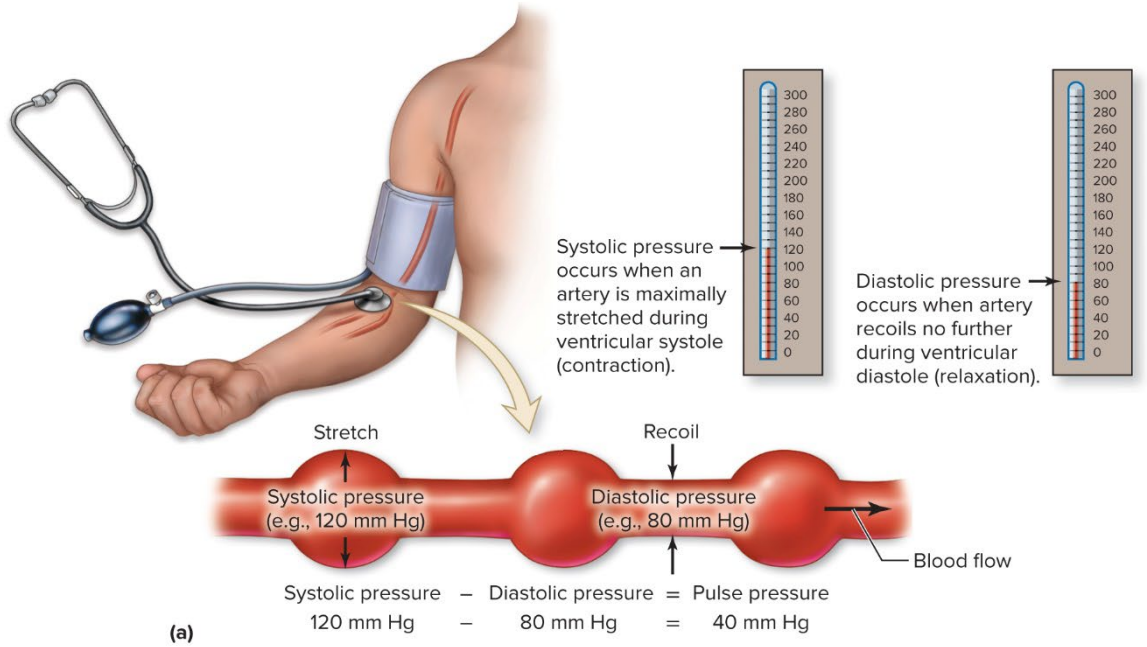
Filtration pressure:		Absorption pressure:	
P_{CAP}	16 mm Hg	π_{CAP}	25 mm Hg
π_{IF}	0 mm Hg	P_{IF}	1 mm Hg
	16 mm Hg		26 mm Hg

NFP = Filtration pressure – Absorption pressure

= 16 mm Hg – 26 mm Hg = –10 mm Hg

(b)

Figure 20.11



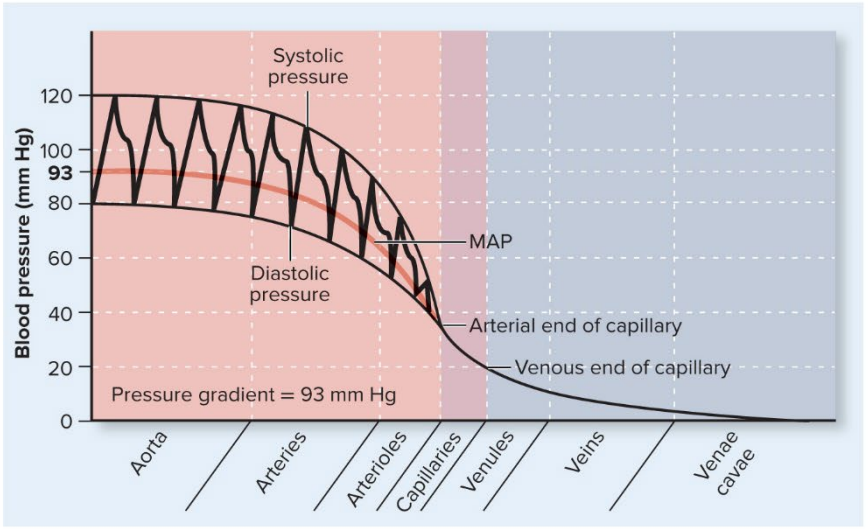
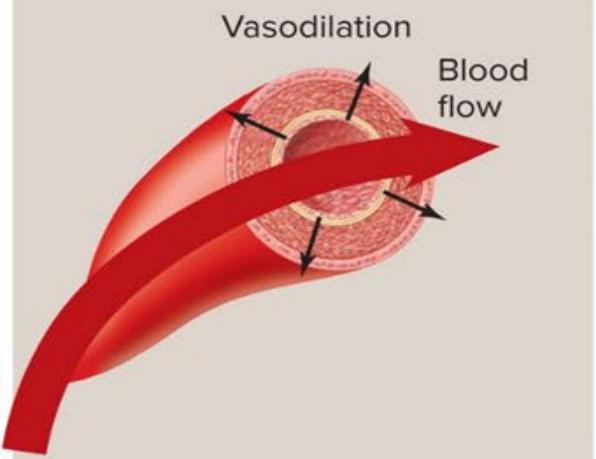
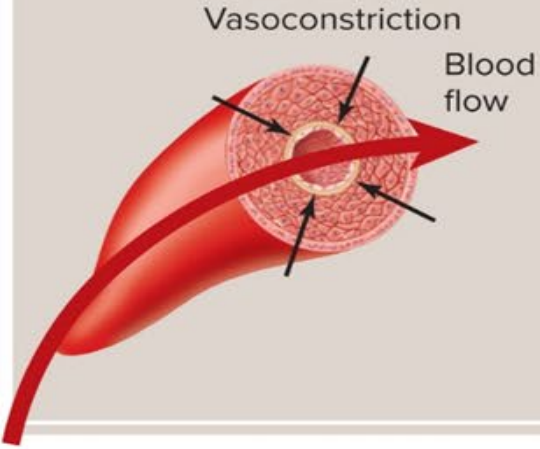


Table 20.3 Substances and Systems That Affect Blood Pressure and Flow

Effect	Local Substances	Hormones and Neurotransmitters
Vasodilators  	Decreased oxygen levels Decreased nutrient levels Increased CO_2, H^+, K^+, lactate levels Histamine Bradykinin Nitric oxide	Atrial natriuretic peptide (ANP) Epinephrine (bound to β_2 receptors within coronary and skeletal muscle blood vessels)
Vasoconstrictors  	Increased oxygen levels Increased nutrient levels Decreased CO_2, H^+, K^+, lactate levels Endothelins Prostaglandins Thromboxanes	Angiotensin II Aldosterone Antidiuretic hormone (ADH) Norepinephrine and to a lesser extent epinephrine (bound to α_1 receptors of most blood vessels, including the skin and abdominal organs)[1]

1. A *decrease* in sympathetic stimulation will result in a decrease in the listed effect, much like taking the foot off the gas pedal will slow down a car.

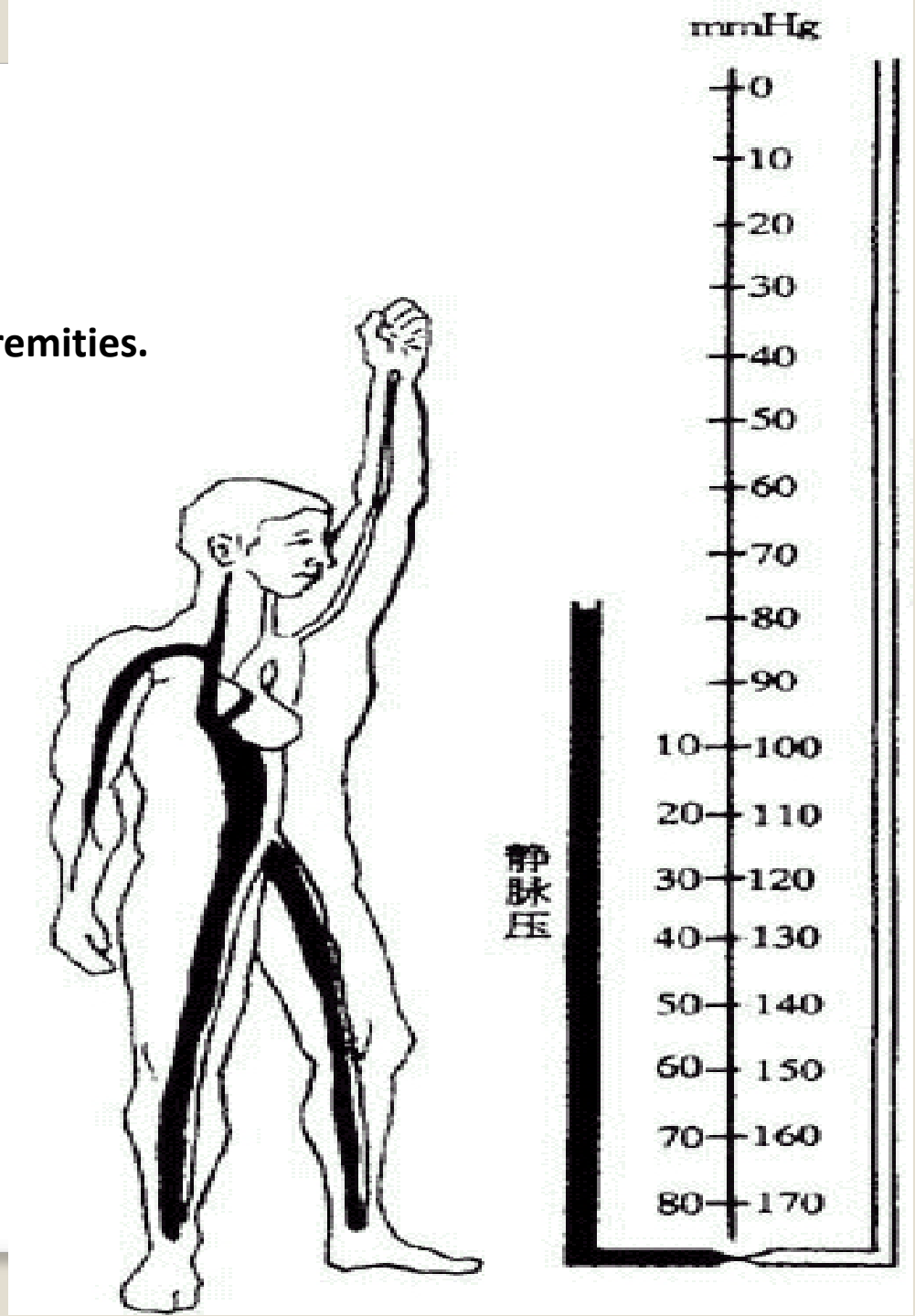
- Small vessel coronary circulation is influenced by:
  - Aortic pressure
  - The pumping activity of the ventricles
- During ventricular systole:
  - Coronary vessels compress
  - Myocardial blood flow ceases
  - Stored myoglobin supplies sufficient oxygen
- During ventricular diastole, oxygen and nutrients are carried to the heart

Blood Flow: Heart

Effect of gravity on venous pressure

Gravity significantly affects venous pressure, particularly in the lower extremities.

- baroreceptor reflexes
- **Veinous compliance**
- systemic vascular resistance
- **Stroke volume**



Orthostatic hypotension

- condition where a person's blood pressure drops significantly when they stand up from a sitting or lying down position.
- This sudden drop in blood pressure can cause dizziness, lightheadedness, and even fainting.
- **Symptoms**

Effect of gravity on venous pressure

- When a person is standing upright, the hydrostatic pressure exerted by the column of blood from the heart to the feet increases venous pressure in the lower limbs.
- This increased pressure causes blood to pool in the veins, reducing venous return to the heart.

Key effects of gravity on venous pressure:

•**Increased venous pressure in lower extremities:** This can lead to edema (swelling) and varicose veins over time.

•**Decreased venous return:** Less blood returns to the heart, which can reduce cardiac output and blood pressure.

•**Compensatory mechanisms:** The body activates mechanisms like the skeletal muscle pump and the respiratory pump to counteract the effects of gravity on venous pressure.

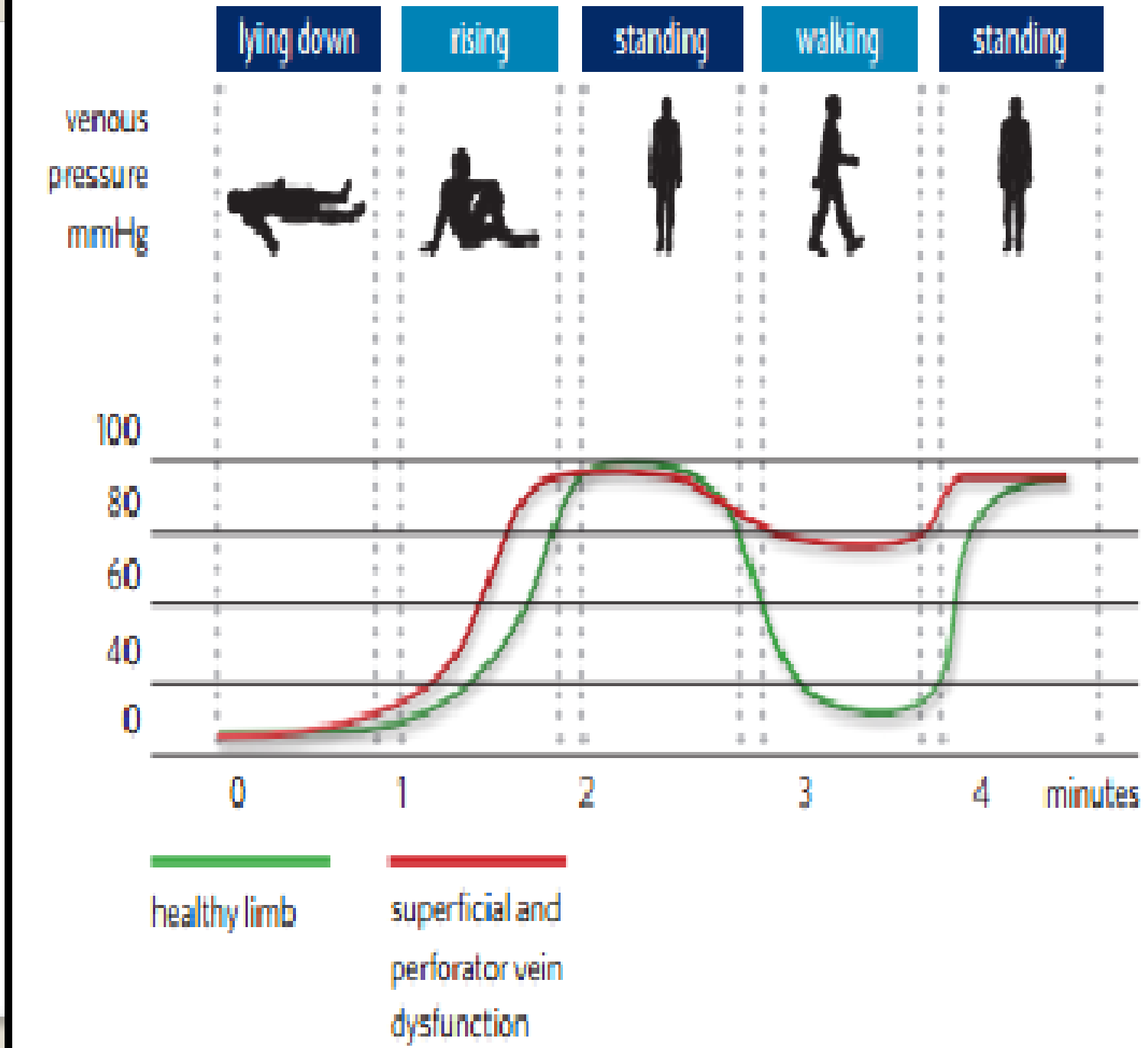
•**Orthostatic hypotension:** A rapid drop in blood pressure upon standing can occur due to the pooling of blood in the lower extremities.

Factors mitigating the effects of gravity:

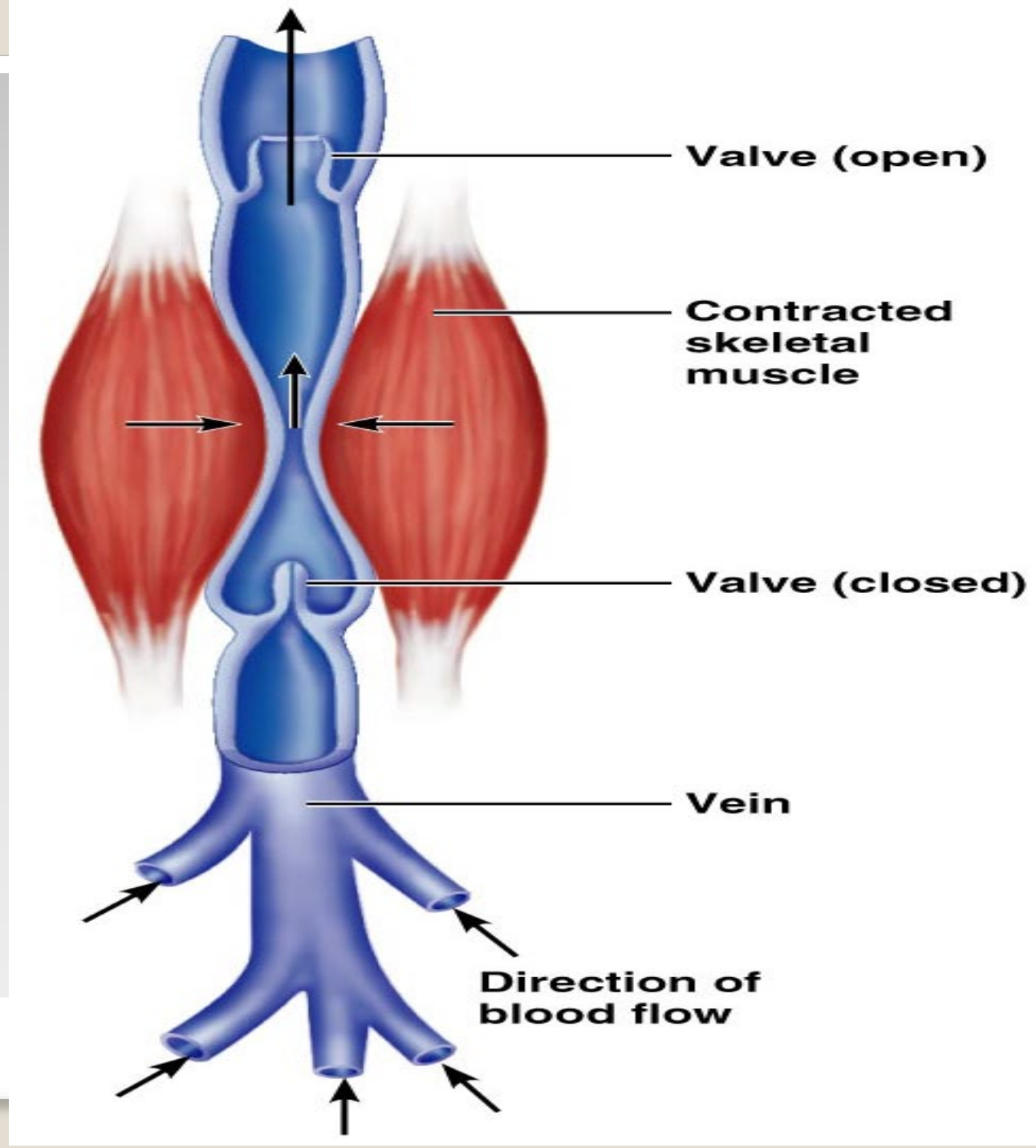
- **Venous valves:** These prevent the backflow of blood and aid in venous return.

- **Skeletal muscle pump:** Contraction of leg muscles helps to propel blood back to the heart.

- **Respiratory pump:** Changes in thoracic and abdominal pressure during breathing assist venous return.

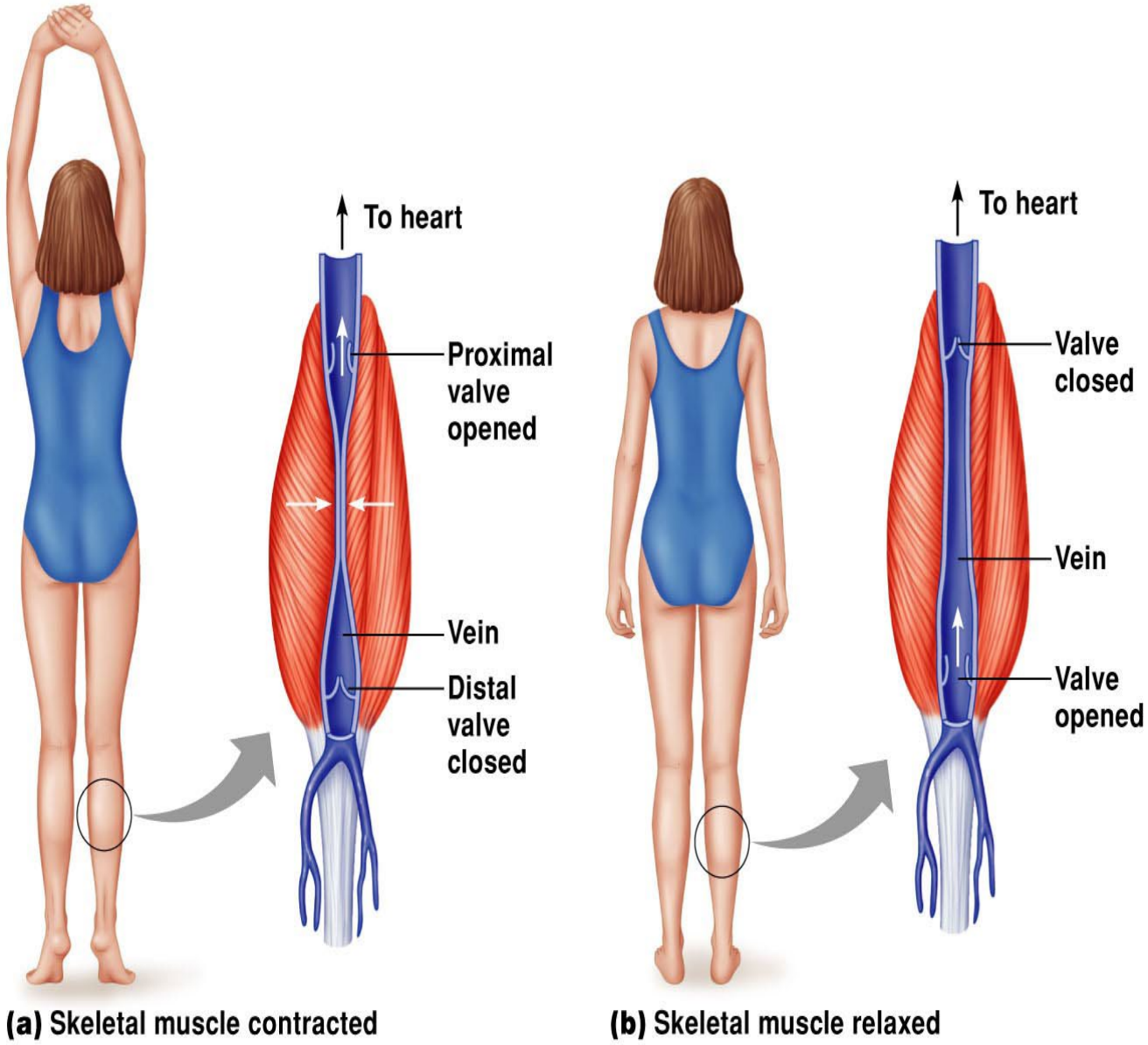


Factors Aiding Venous Return



Factors influencing venous return

- 1- Skeletal muscle pump and valves
- 2- Respiratory pump
- 3- Blood volume and cardiac output
- 4. venous pressure
- 5- Venomotor tone and compliance
- 6-gravity



Factors Affecting Venous Return

1.Blood Volume:

1. An increase in blood volume directly increases venous return, as there is more blood to be returned.
2. A decrease in blood volume (e.g., hemorrhage) reduces venous return.

2.Venous Pressure:

1. **Right Atrial Pressure:** A lower right atrial pressure facilitates venous return, as it creates a pressure gradient.
2. **Venous Tone:** Increased venous tone (contraction of venous smooth muscle) increases venous pressure and promotes venous return.
3. **Skeletal Muscle Pump:** Contraction of skeletal muscles compresses veins, increasing venous pressure and aiding return.

3.Venous Compliance:

1. High venous compliance (ability of veins to stretch) decreases venous pressure and hinders venous return.
2. Low venous compliance (increased venous tone) increases venous pressure and improves venous return.

•Gravity:

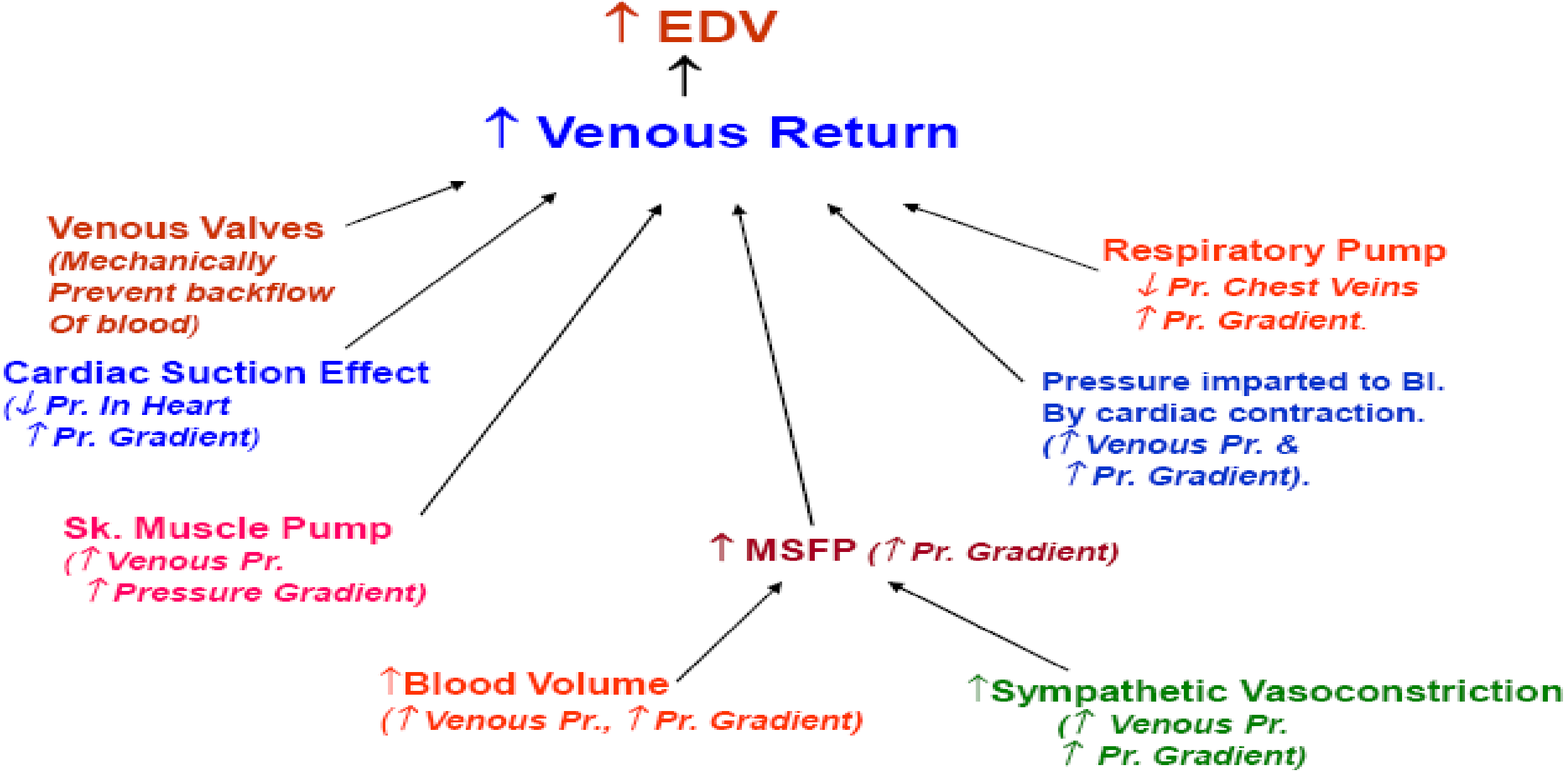
•Standing upright increases hydrostatic pressure in lower limb veins, hindering venous return.
•Lying down reduces hydrostatic pressure, improving venous return.

•Respiratory Pump:

•Inspiration decreases thoracic pressure and increases abdominal pressure, aiding venous return to the heart.
•Expiration has the opposite effect.

•Cardiac Output:

•Although it might seem counterintuitive, a higher cardiac output can indirectly increase venous return by increasing tissue perfusion and capillary filtration, leading to increased blood volume in the veins.



(Regulation of Venous Return)

- Inadequate blood perfusion or excessively high arterial pressure:
  - Are autoregulatory
  - Provoke myogenic responses – stimulation of vascular smooth muscle
- Vascular muscle responds directly to:
  - Increased vascular pressure with increased tone, which causes vasoconstriction
  - Reduced stretch with vasodilation, which promotes increased blood flow to the tissue

Myogenic Controls

- **Sympathetic activity causes:**
  - Vasoconstriction and a rise in BP if increased
  - BP to decline to basal levels if decreased

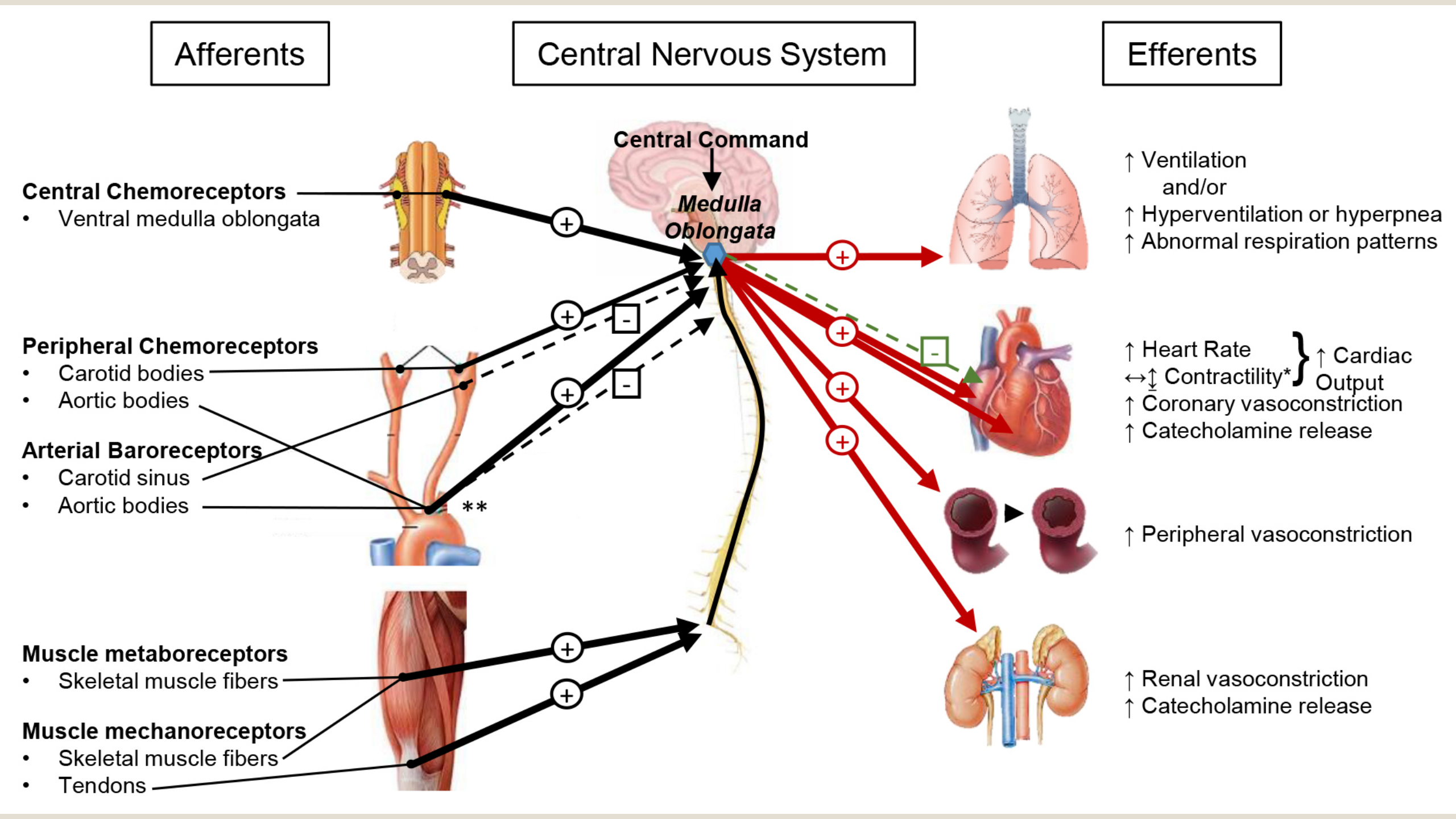
- **Vasomotor activity is modified by:**
  - Baroreceptors (pressure-sensitive),
  - chemoreceptors (O_2, CO_2, and H^+ sensitive),
  - higher brain centers,
  - bloodborne chemicals,
  - hormones

Short-Term Mechanisms: Vasomotor Activity

Cardiovascular reflex

Cardiovascular reflexes are rapid, automatic responses that help maintain blood pressure and heart rate within a normal range.

- **(1) Arterial baroreflexes:**
  - **Carotid sinus baroreflex**
  - **Aortic baroreflex**
- **(2) Cardiopulmonary reflex**
- **(3) Chemoreceptor reflex**


Afferents
Central Nervous System
Efferents
Central Command
Medulla Oblongata
Central Chemoreceptors
• Ventral medulla oblongata
Peripheral Chemoreceptors
• Carotid bodies
• Aortic bodies
Arterial Baroreceptors
• Carotid sinus
• Aortic bodies
**
Muscle metaboreceptors
• Skeletal muscle fibers
Muscle mechanoreceptors
• Skeletal muscle fibers
• Tendons
↑ Ventilation
and/or
↑ Hyperventilation or hyperpnea
↑ Abnormal respiration patterns
↑ Heart Rate
↔↕ Contractility*
↑ Cardiac Output
↑ Coronary vasoconstriction
↑ Catecholamine release
↑ Peripheral vasoconstriction
↑ Renal vasoconstriction
↑ Catecholamine release

Neural regulation

Innervation of the heart dual innervation

(1) cardiac sympathetic nerve

(2) cardiac parasympathetic nerve

- **Adrenal medulla hormones** – norepinephrine and epinephrine increase blood pressure
- **Antidiuretic hormone (ADH)** – causes intense vasoconstriction in cases of extremely low BP
- **Angiotensin II** – kidney release of renin generates angiotensin II, which causes vasoconstriction
- **Endothelium-derived factors** – endothelin and prostaglandin-derived growth factor (PDGF) are both vasoconstrictors

Chemicals that Increase Blood Pressure

- **Atrial natriuretic peptide (ANP)** – causes blood volume and pressure to decline
- **Nitric oxide (NO)** – is a brief but potent vasodilator
- **Inflammatory chemicals** – histamine, prostacyclin, and kinins are potent vasodilators
- **Alcohol** – causes BP to drop by inhibiting ADH

Chemicals that Decrease Blood Pressure

- Long-term mechanisms control BP by altering blood volume

- **Baroreceptors adapt to chronic high or low BP**
  - Increased BP stimulates the kidneys to eliminate water, thus reducing BP
  - Decreased BP stimulates the kidneys to increase blood volume and BP

Long-Term Mechanisms: Renal Regulation

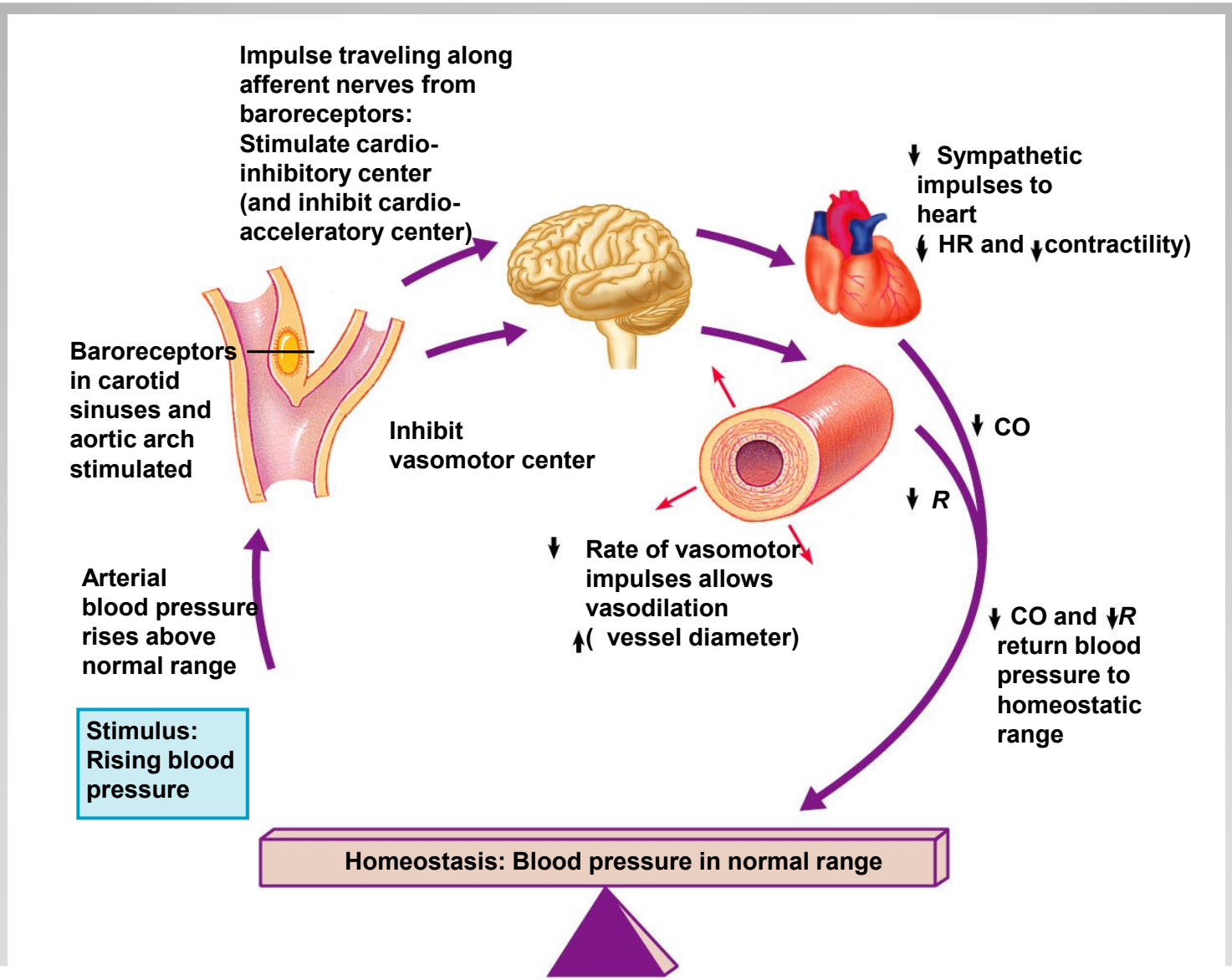

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio-inhibitory center (and inhibit cardio-acceleratory center)
↓ Sympathetic impulses to heart
↓ HR and ↓contractility)
Baroreceptors in carotid sinuses and aortic arch stimulated
Inhibit vasomotor center
↓ CO
↓ R
↓ Rate of vasomotor impulses allows vasodilation
↑(vessel diameter)
Arterial blood pressure rises above normal range
↓ CO and ↓R return blood pressure to homeostatic range
Stimulus: Rising blood pressure
Homeostasis: Blood pressure in normal range

Figure 19.8

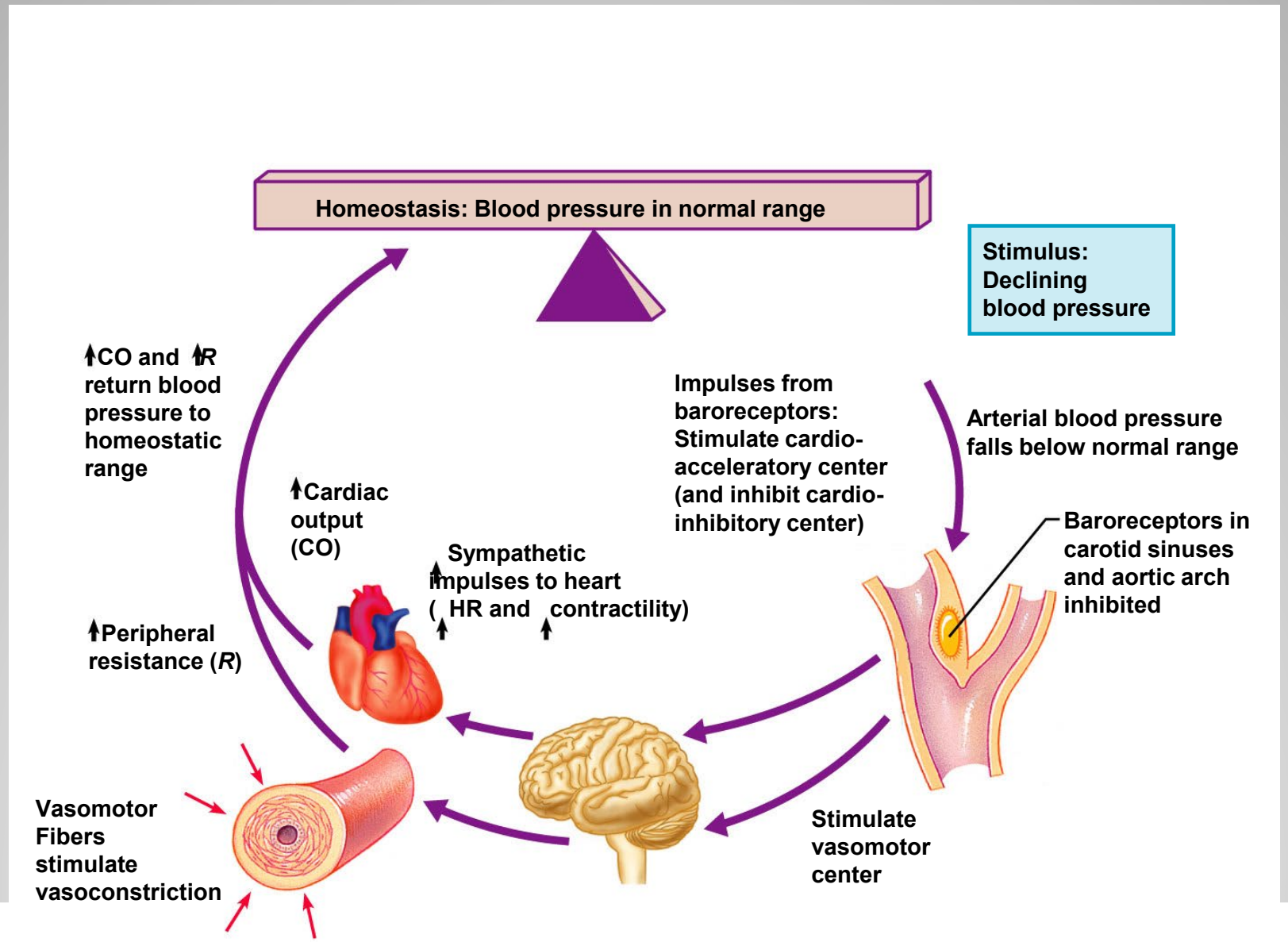
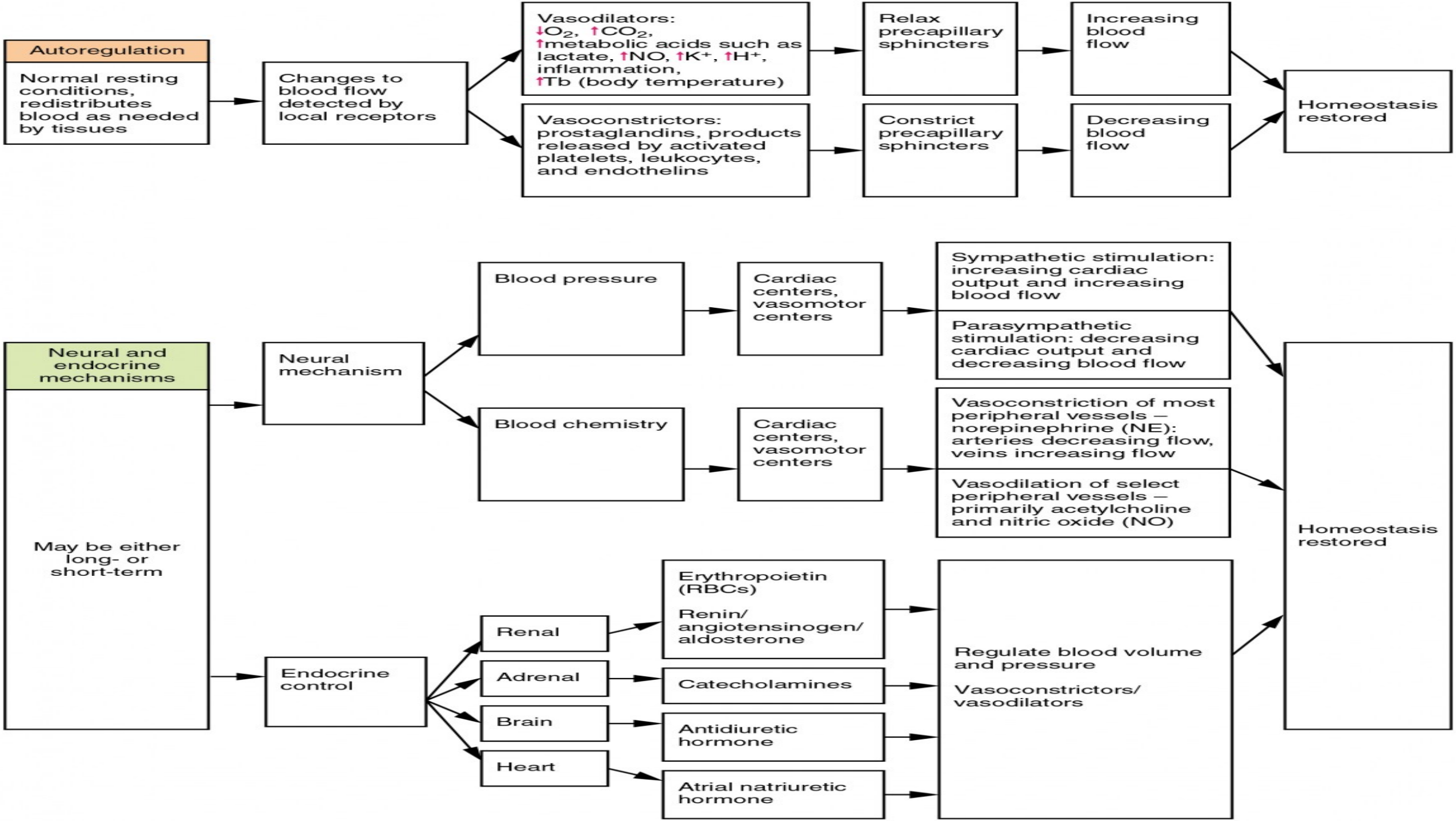
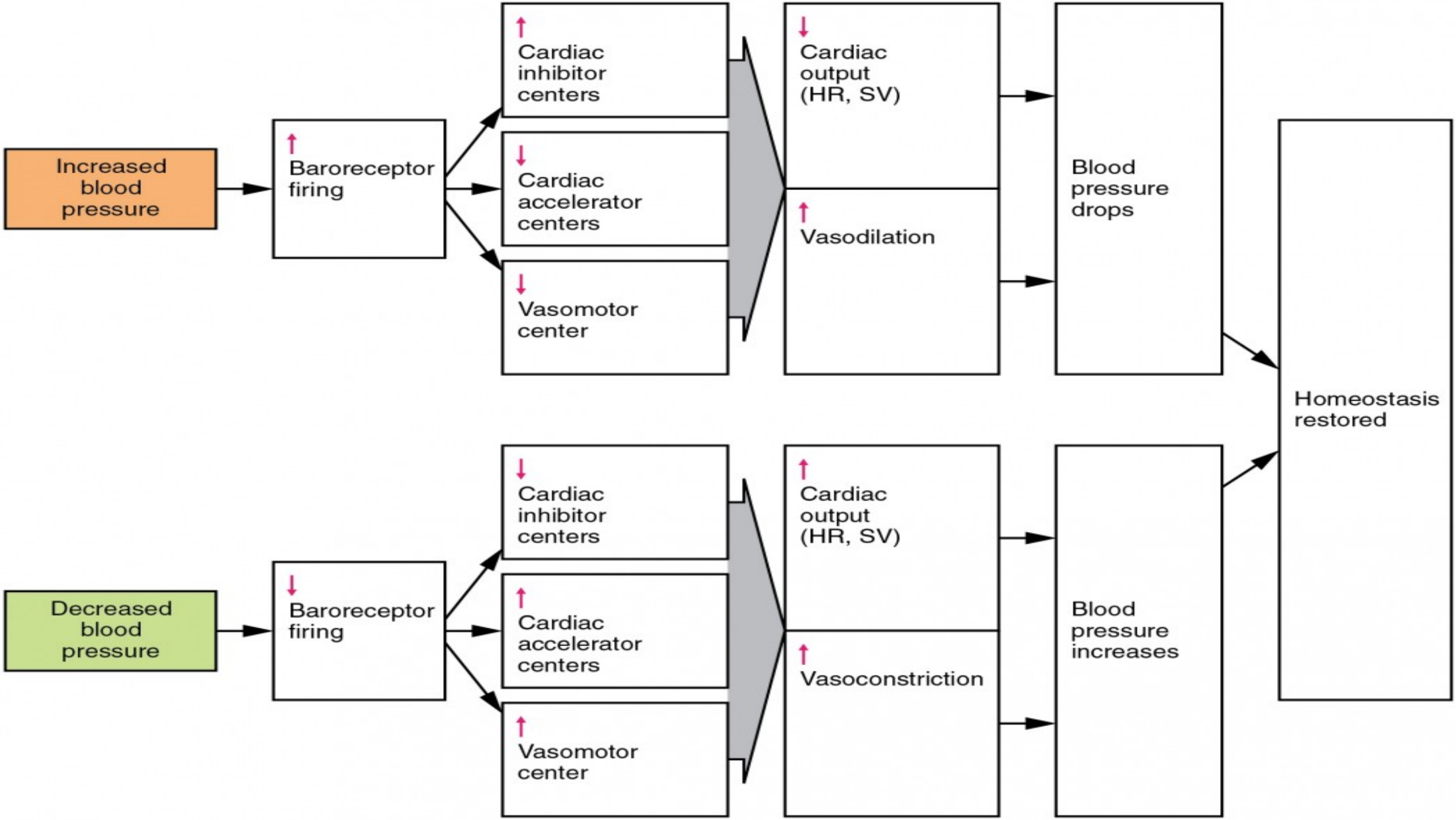
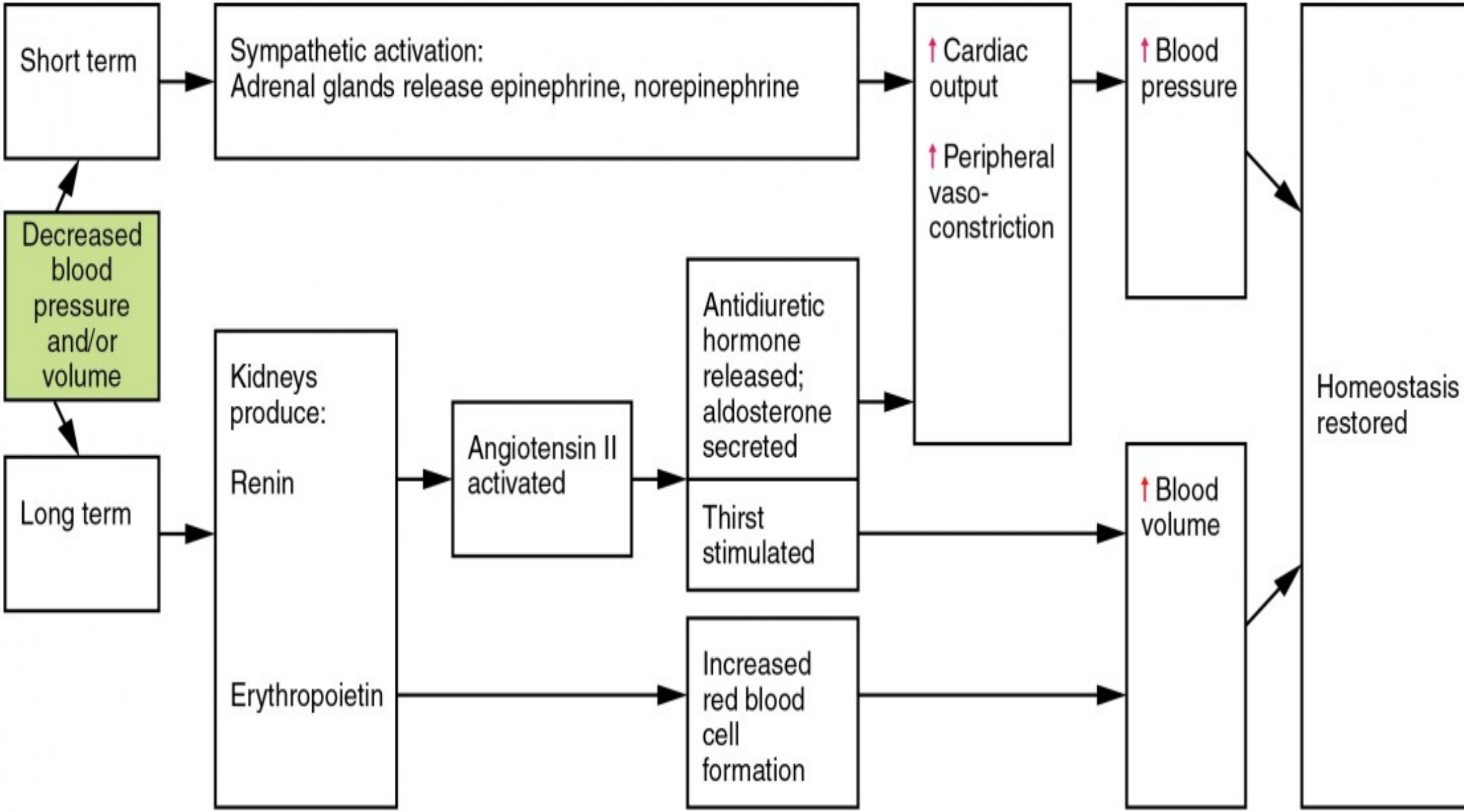
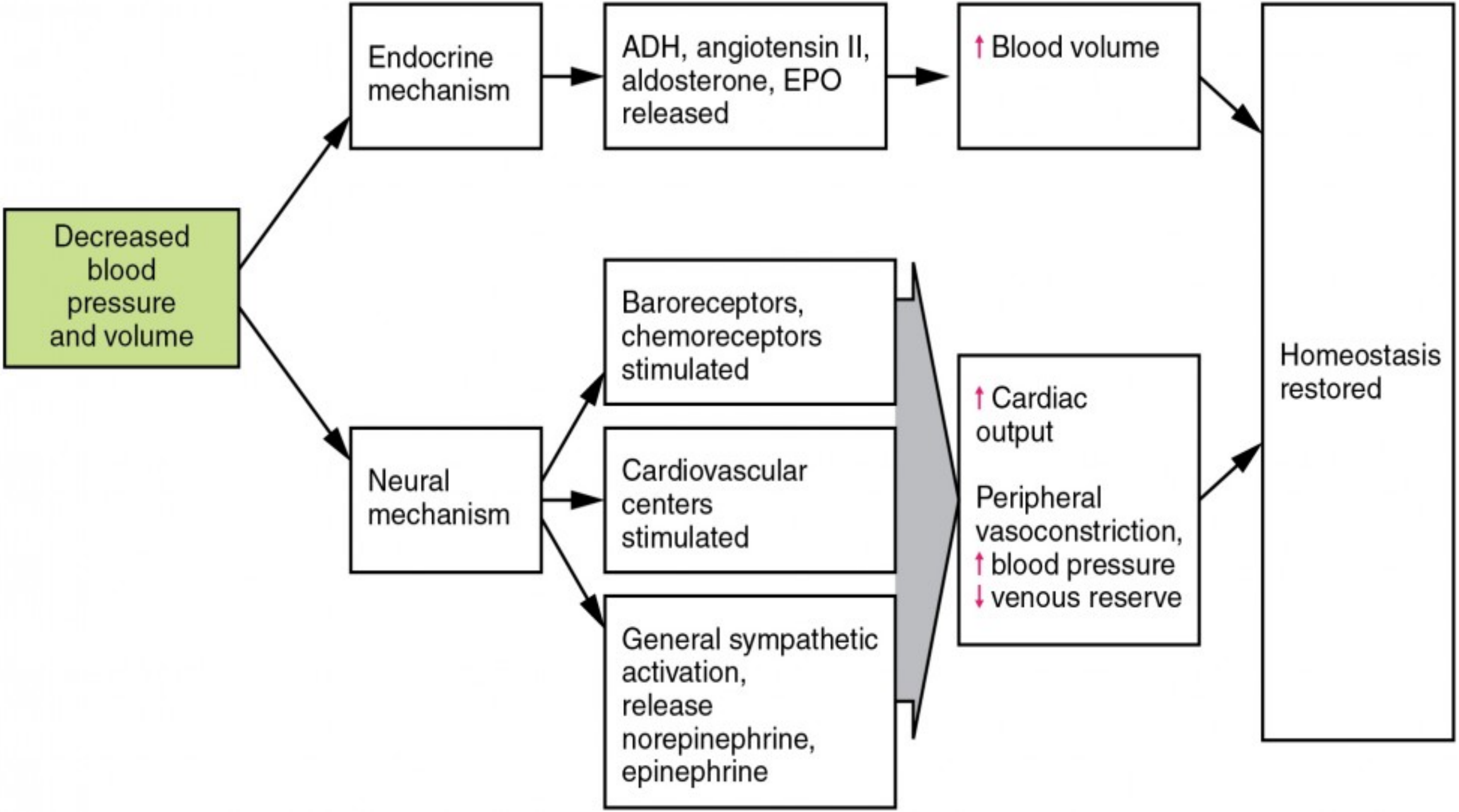

Homeostasis: Blood pressure in normal range
Stimulus: Declining blood pressure
↑CO and ↑R return blood pressure to homeostatic range
↑Cardiac output (CO)
↑Peripheral resistance (R)
Sympathetic impulses to heart (↑HR and ↑contractility)
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Baroreceptors in carotid sinuses and aortic arch inhibited
Stimulate vasomotor center
Vasomotor Fibers stimulate vasoconstriction

Figure 19.8


Autoregulation
Normal resting conditions, redistributes blood as needed by tissues
Changes to blood flow detected by local receptors
Vasodilators: ↓O_2, ↑CO_2, ↑metabolic acids such as lactate, ↑NO, ↑K^+, ↑H^+, inflammation, ↑Tb (body temperature)
Vasoconstrictors: prostaglandins, products released by activated platelets, leukocytes, and endothelins
Relax precapillary sphincters
Constrict precapillary sphincters
Increasing blood flow
Decreasing blood flow
Homeostasis restored
Neural and endocrine mechanisms
May be either long- or short-term
Neural mechanism
Blood pressure
Blood chemistry
Cardiac centers, vasomotor centers
Cardiac centers, vasomotor centers
Sympathetic stimulation: increasing cardiac output and increasing blood flow
Parasympathetic stimulation: decreasing cardiac output and decreasing blood flow
Vasoconstriction of most peripheral vessels — norepinephrine (NE): arteries decreasing flow, veins increasing flow
Vasodilation of select peripheral vessels — primarily acetylcholine and nitric oxide (NO)
Endocrine control
Renal
Adrenal
Brain
Heart
Erythropoietin (RBCs)
Renin/ angiotensinogen/ aldosterone
Catecholamines
Antidiuretic hormone
Atrial natriuretic hormone
Regulate blood volume and pressure
Vasoconstrictors/ vasodilators
Homeostasis restored


Increased blood pressure
Baroreceptor firing
Cardiac inhibitor centers
Cardiac accelerator centers
Vasomotor center
Cardiac output (HR, SV)
Vasodilation
Blood pressure drops
Homeostasis restored
Decreased blood pressure
Baroreceptor firing
Cardiac inhibitor centers
Cardiac accelerator centers
Vasomotor center
Cardiac output (HR, SV)
Vasoconstriction
Blood pressure increases


Short term
Sympathetic activation:
Adrenal glands release epinephrine, norepinephrine
↑ Cardiac output
↑ Peripheral vaso-constriction
↑ Blood pressure
Decreased blood pressure and/or volume
Long term
Kidneys produce:
Renin
Erythropoietin
Angiotensin II activated
Antidiuretic hormone released; aldosterone secreted
Thirst stimulated
Increased red blood cell formation
↑ Blood volume
Homeostasis restored


Decreased blood pressure and volume
Endocrine mechanism
ADH, angiotensin II, aldosterone, EPO released
↑ Blood volume
Neural mechanism
Baroreceptors, chemoreceptors stimulated
Cardiovascular centers stimulated
General sympathetic activation, release norepinephrine, epinephrine
↑ Cardiac output
Peripheral vasoconstriction, ↑ blood pressure
↓ venous reserve
Homeostasis restored

Summary of Mechanisms Regulating Arteriole Smooth Muscle and Veins

Control	Factor	Vasoconstriction	Vasodilation
Neural	**Sympathetic Stiumulation**	**Arterioles within integument, abdominal viscera, and mucosa membrane; skeletal muscle (at high levels); varied in veins and venules**	**Arterioles within heart; skeletal muscles at low to moderate levels**
	Parasympathetics	No known innervation for most	Arterioles in external genitalia, no known innervation for most other arterioles or veins
	Epinephrine	Similar to sympathetic stimulation for extended fight-or-flight responses; at high levels, binds to specialized alpha (α) receptors	Similar to sympathetic stimulation for extended fight-or-flight responses; at low to moderate levels, binds to specialized beta (β) receptors
	Norepinephrine	Similar to epinephrine	Similar to epinephrine
Endocrine	Angiotensin II	Powerful generalized vasoconstrictor; also stimulates release of aldosterone and ADH	n/a
	ANH (peptide)	n/a	Powerful generalized vasodilator; also promotes loss of fluid volume from kidneys, hence reducing blood volume, pressure, and flow
	ADH	Moderately strong generalized vasoconstrictor; also causes body to retain more fluid via kidneys, increasing blood volume and pressure	n/a

Decreasing levels of oxygen	n/a	Vasodilation, also opens precapillary sphincters
Decreasing pH	n/a	Vasodilation, also opens precapillary sphincters
Increasing levels of carbon dioxide	n/a	Vasodilation, also opens precapillary sphincters
Increasing levels of potassium ion	n/a	Vasodilation, also opens precapillary sphincters
Increasing levels of prostaglandins	Vasoconstriction, closes precapillary sphincters for many	Vasodilation, opens precapillary sphincters for many
Increasing levels of adenosine	n/a	Vasodilation
Increasing levels of NO	n/a	Vasodilation, also opens precapillary sphincters
Increasing levels of lactic acid and other metabolites	n/a	Vasodilation, also opens precapillary sphincters
Increasing levels of endothelins	Vasoconstriction	n/a
Increasing levels of platelet secretions	Vasoconstriction	n/a
Increasing hyperthermia	n/a	Vasodilation
Stretching of vascular wall (myogenic)	Vasoconstriction	n/a
Increasing levels of histamines from basophils and mast cells	n/a	Vasodilation

Kidney Action and Blood Pressure

How Kidneys Help Regulate Blood Pressure

•**Fluid Balance:** Kidneys play a crucial role in maintaining the body's fluid balance. They filter blood, removing waste products and excess water. By adjusting the amount of water excreted in urine, kidneys help regulate blood volume, which directly impacts blood pressure.

•**Electrolyte Balance:** Kidneys regulate levels of sodium, potassium, and other electrolytes in the blood. These electrolytes are essential for maintaining blood pressure.

•**Hormone Production:**

- **Renin-Angiotensin-Aldosterone System (RAAS):** Kidneys produce an enzyme called renin, which initiates a cascade that ultimately leads to the production of aldosterone. Aldosterone helps to retain sodium and water, increasing blood volume and blood pressure.
- **Atrial Natriuretic Peptide (ANP):** In response to increased blood volume and blood pressure, the heart releases ANP. This hormone promotes sodium and water excretion by the kidneys, helping to lower blood pressure.

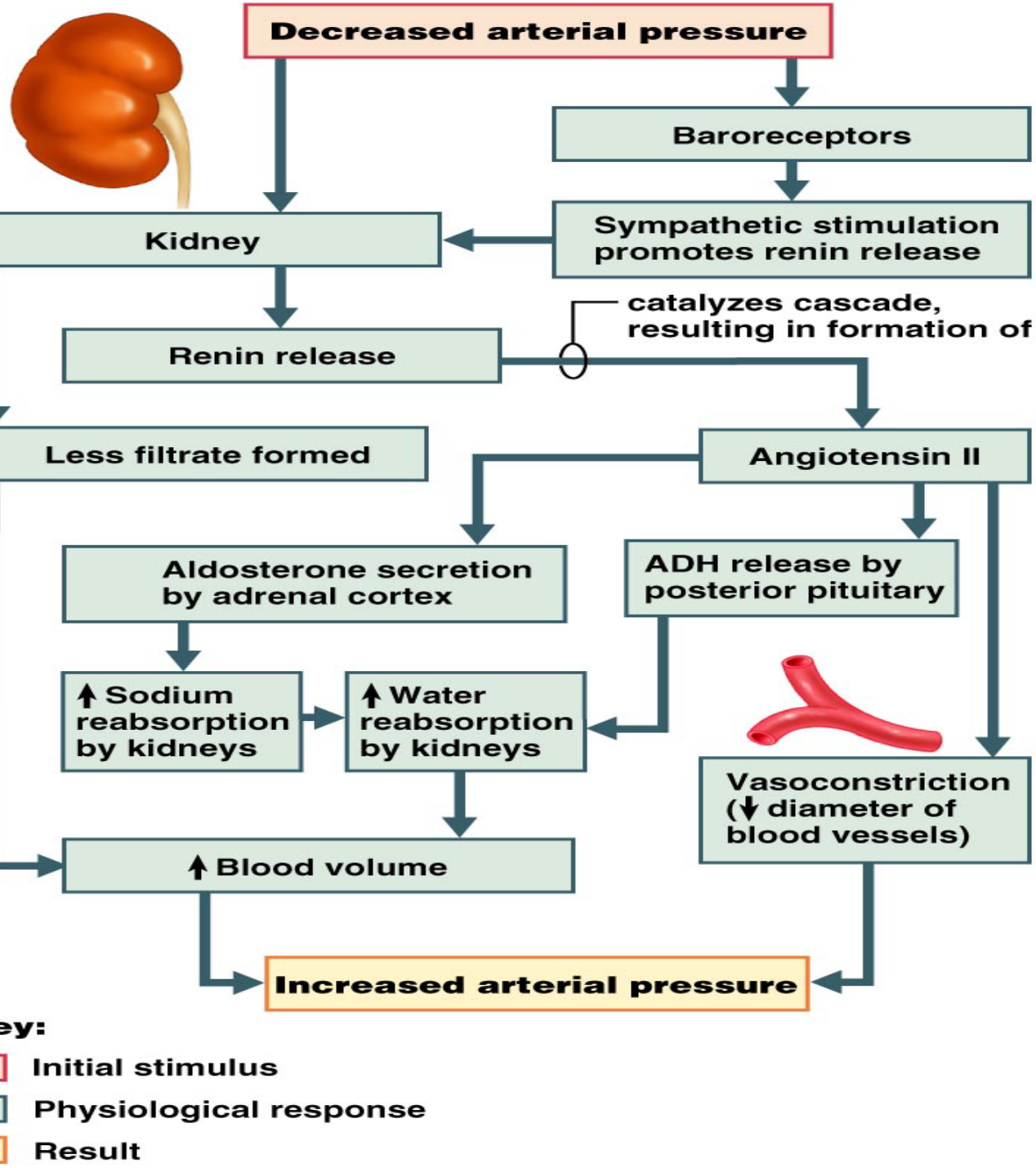
- High blood pressure can damage the kidneys in several ways:
- **Reduced Blood Flow:** High blood pressure can damage the tiny blood vessels in the kidneys, reducing blood flow and impairing their ability to filter waste.
- **Glomerular Damage:** The glomeruli, the filtering units in the kidneys, can be damaged by high blood pressure, leading to proteinuria (protein in the urine) and other signs of kidney damage.
- **Progression of Kidney Disease:** Chronic high blood pressure is a major cause of chronic kidney disease (CKD) and can eventually lead to kidney failure.
- **In essence, kidneys and blood pressure are interdependent. Healthy kidneys help maintain normal blood pressure, while normal blood pressure is essential for kidney health.**

How Blood Pressure Affects Kidneys

Kidney Action and Blood Pressure

Table 138. Clinical Evaluation of Patients at Increased Risk of Chronic Kidney Disease

All Patients
Measurement of blood pressure
Serum creatinine to estimate GFR
Protein-to-creatinine ratio or albumin-to-creatinine ratio in a first-morning or random untimed "spot" urine specimen
Examination of the urine sediment or dipstick for red blood cells and white blood cells
Selected Patients, Depending on Risk Factors
Utrasound imaging (for example, in patients with symptoms of urinary tract obstruction, infection or stone, or family history of polycystic kidney disease)
Serum electrolytes (sodium, potassium, chloride and bicarbonate)
Urinary concentration or dilution (specific gravity or osmolality)
Urinary acidification (pH)



Blood Flow: Skin

- Blood flow to **venous plexuses** below **the skin surface**:

  Venous plexuses are networks of interconnected veins.

  - Varies from 50 ml/min to 2500 ml/min, depending on body temperature
  - **Is controlled by sympathetic nervous system reflexes initiated by temperature receptors and the central nervous system**

- As temperature rises (e.g., heat exposure, fever, vigorous exercise):
  - Hypothalamic signals reduce vasomotor stimulation of the skin vessels
  - Heat radiates from the skin
- Sweat also causes vasodilation via bradykinin in perspiration
  - Bradykinin stimulates the release of NO
- As temperature decreases, blood is shunted to deeper, more vital organs

Temperature Regulation

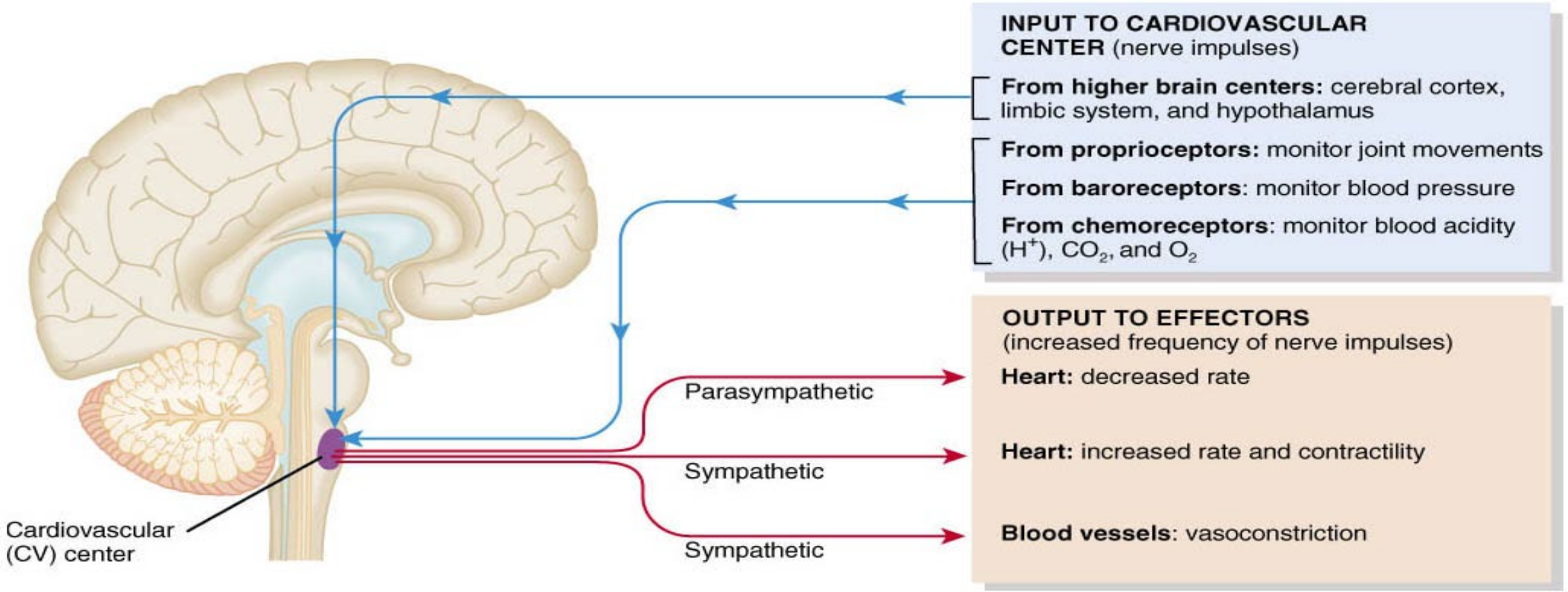
Blood Flow: Lungs

- Blood flow in the pulmonary circulation is unusual in that:
  - The pathway is short
  - Arteries/arterioles are more like veins/venules (thin-walled, with large lumens)
  - They have a much lower arterial pressure (24/8 mm Hg versus 120/80 mm Hg)

- **Three types include:**
  - Hypovolemic shock – results from large-scale blood loss
  - Vascular shock= Distributive Shock– poor circulation resulting from extreme vasodilation (several type)(septic, anaphylactic,neurogenic)
  - Cardiogenic shock – the heart cannot sustain adequate circulation

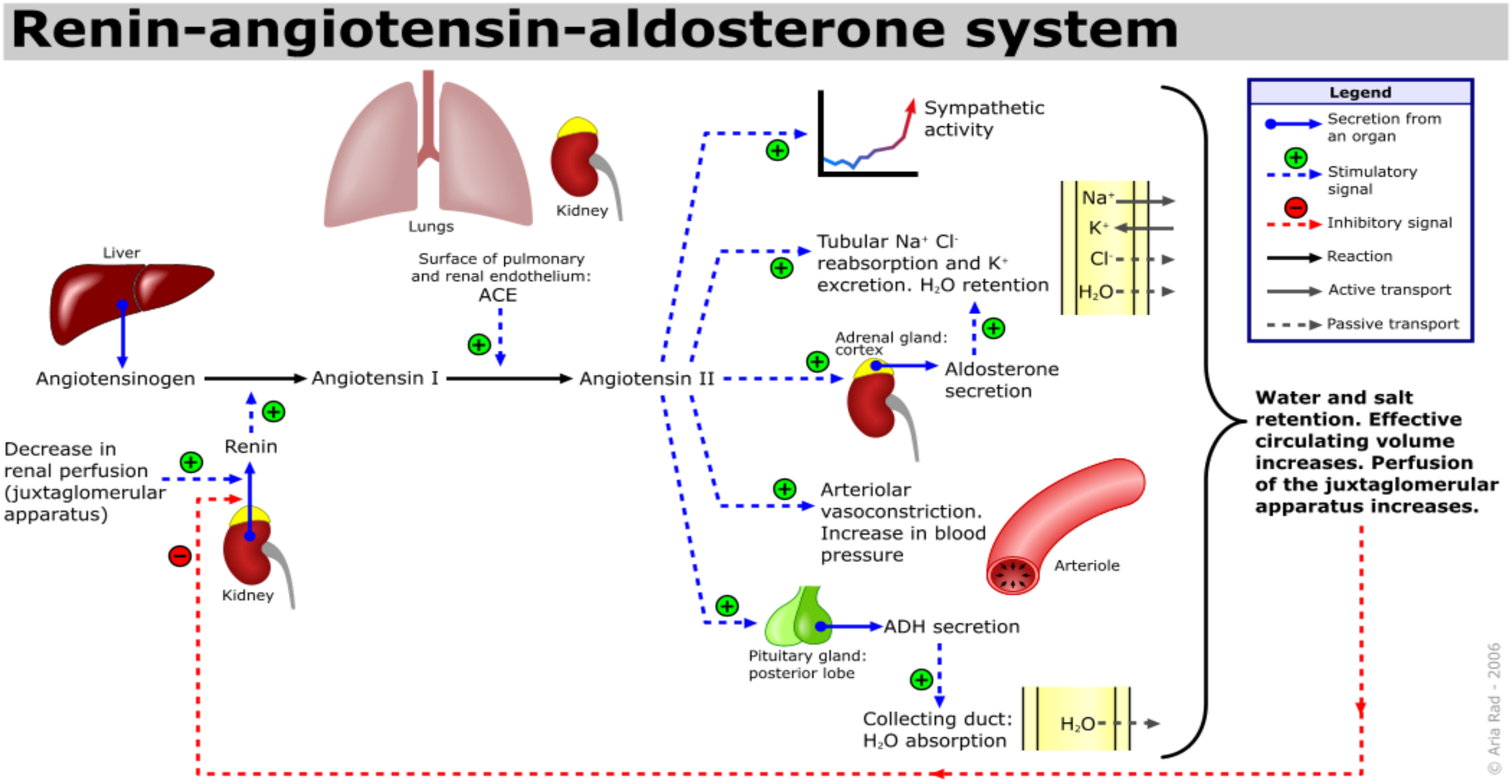
Circulatory Shock

- ***Role of the Cardiovascular Center***
  - Cardiovascular Center (CV) in the medulla oblongata regulates heart rate and stroke volume



Regulation of Blood Pressure and Blood Flow

- (RAA system):


Renin-angiotensin-aldosterone system
Lungs
Kidney
Liver
Surface of pulmonary and renal endothelium:
ACE
Angiotensinogen
Angiotensin I
Angiotensin II
Renin
Decrease in renal perfusion (juxtaglomerular apparatus)
Kidney
Sympathetic activity
Tubular Na⁺ Cl⁻ reabsorption and K⁺ excretion. H₂O retention
Na⁺
K⁺
Cl⁻
H₂O
Adrenal gland: cortex
Aldosterone secretion
Arteriolar vasoconstriction. Increase in blood pressure
Arteriole
Pituitary gland: posterior lobe
ADH secretion
Collecting duct: H₂O absorption
H₂O
Water and salt retention. Effective circulating volume increases. Perfusion of the juxtaglomerular apparatus increases.
Legend
Secretion from an organ
Stimulatory signal
Inhibitory signal
Reaction
Active transport
Passive transport
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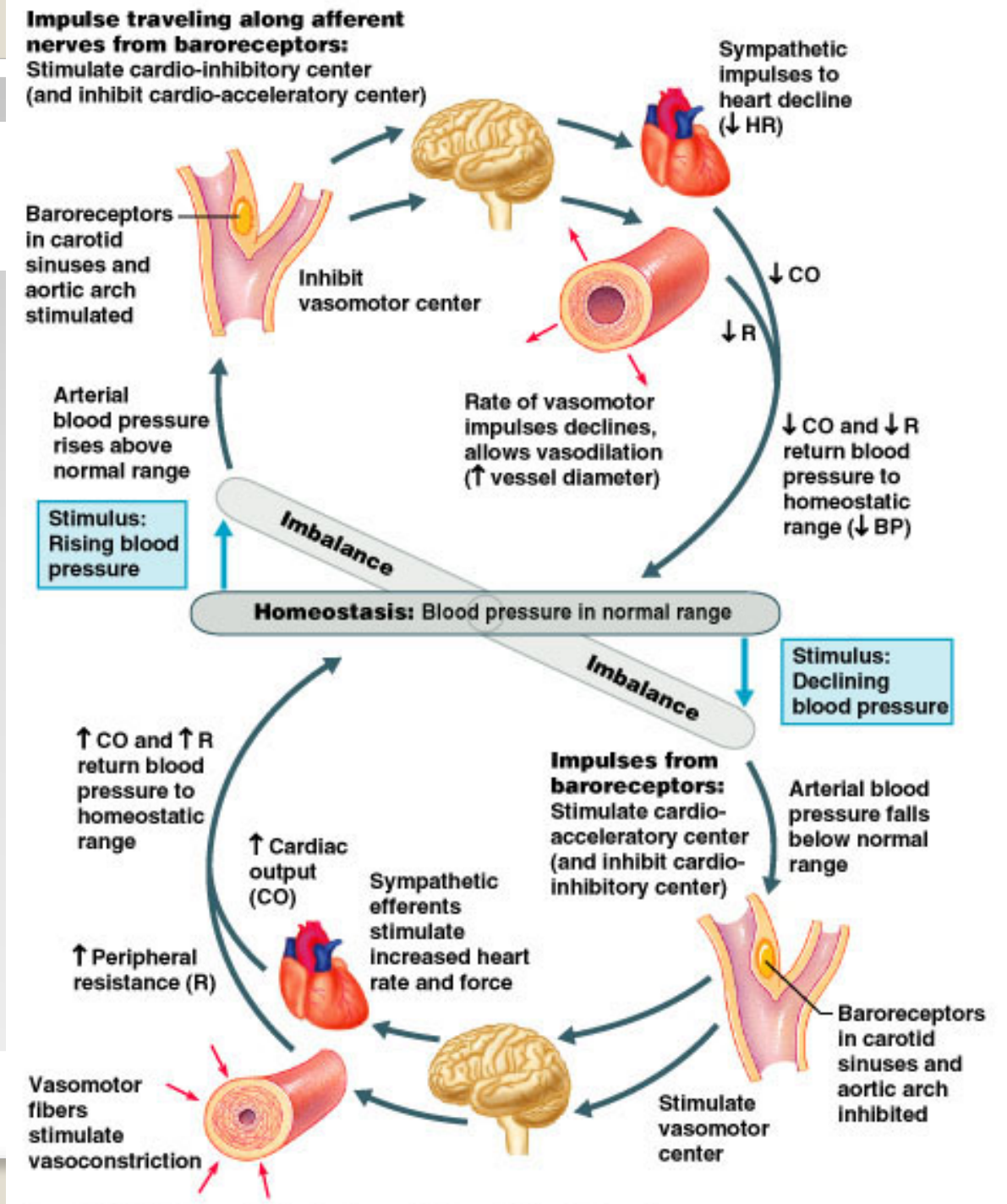
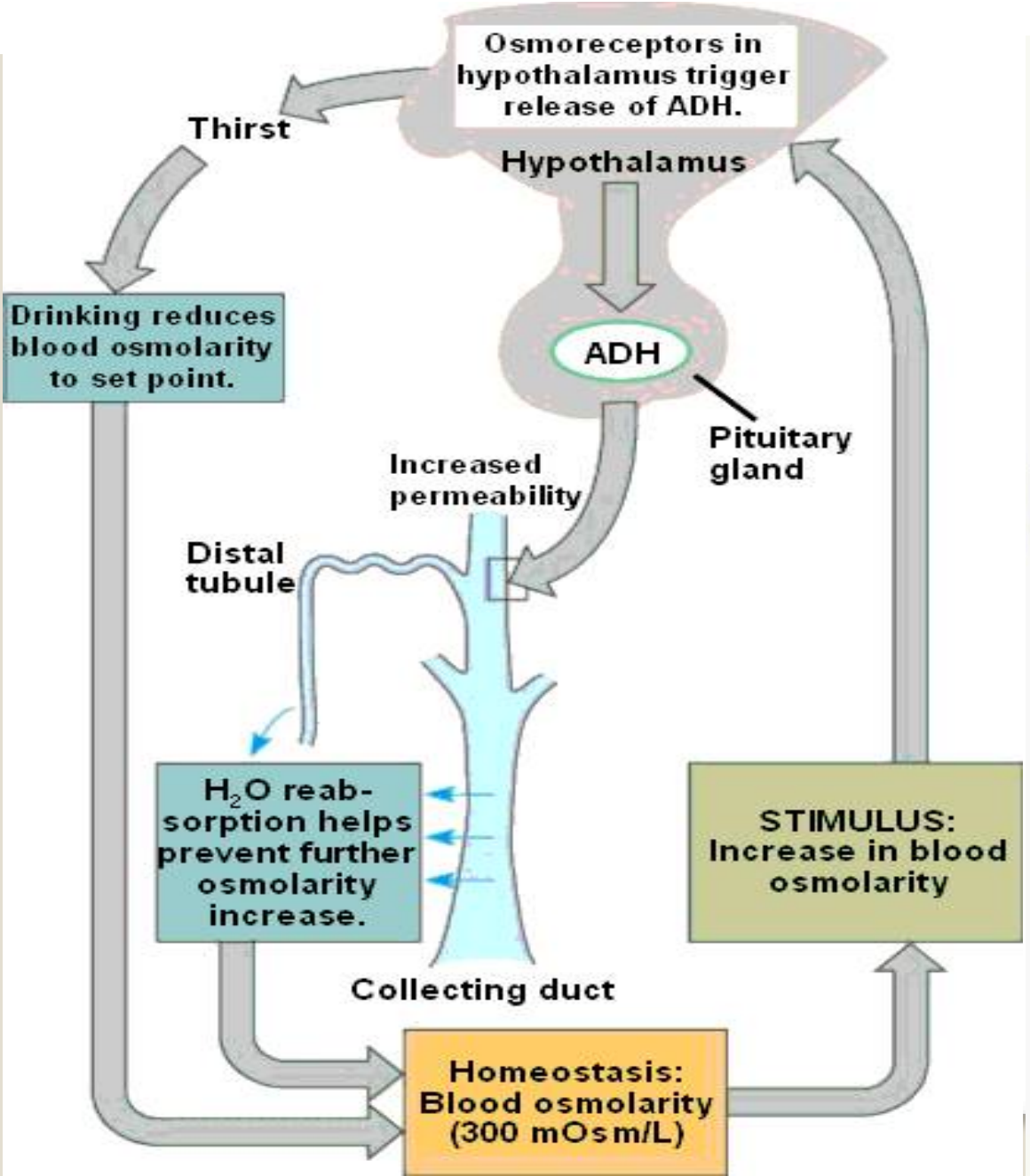
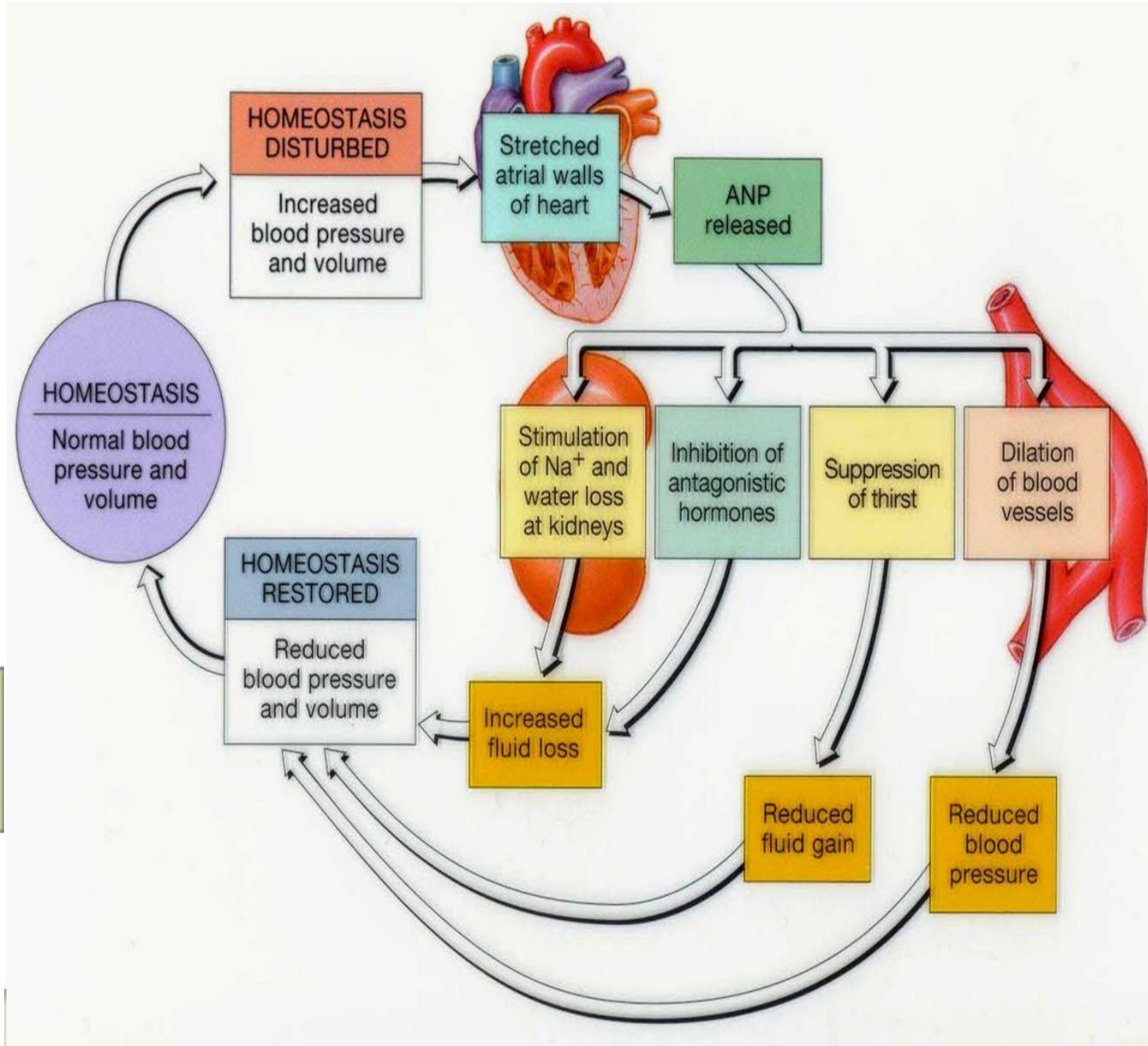
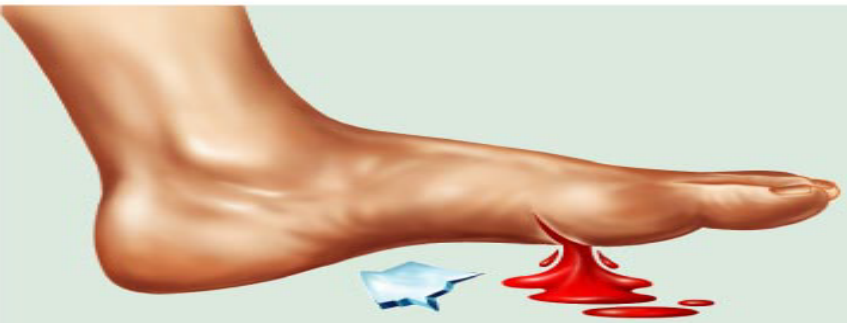
- Epinephrine and norepinephrine



- Antidiuretic hormone (ADH)
- Atrial natriuretic peptide (ANP)





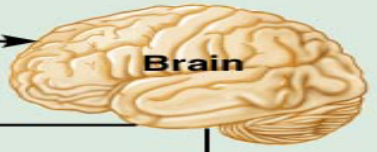


Acute bleeding (or other events leading to blood volume loss)

leads to

① Inadequate tissue perfusion → ↓ O_2 and nutrients to cells
② Cells begin to metabolize anaerobically (without O_2) → lactic acid accumulates
③ Interstitial fluid moves into blood → tissues dehydrate

Compensatory mechanisms activated

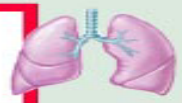


Chemoreceptors activated (by ↓ in blood pH)

major effect

Activation of respiratory centers

↑ Rate and depth of breathing



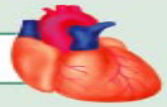
CO_2 blown off; blood pH rises

minor effect

Cardioacceleratory and vasomotor centers activated

Sympathetic nervous system activated

↑ Heart rate



Tachycardia, weak, thready pulse

Skin becomes cold, clammy, and cyanotic

Baroreceptor firing reduced (by ↓ in blood volume and blood pressure)

Intense vasoconstriction (only heart and brain spared)

↓ Renal blood flow

Renin released

Angiotensin II produced in the blood

Adrenal cortex

Aldosterone released

Kidneys retain salt and water

↓ Urine output

Hypothalamus activated (by ↓ pH and ↓ blood volume)

Thirst

Blood pressure maintained*

ADH released

targets

Water retention

↓ Urine output

↑ Blood volume

Neurons depressed by ↓ pH

Restlessness (early sign)

Central nervous system depressed

Coma (late sign)

*If fluid volume continues to decrease, blood pressure ultimately drops. ↓ Blood pressure is a late sign.

A 56-year-old man suffers from the rupture of his abdominal aorta. He undergoes an emergent graft-based repair surgery during which the surgeon must clamp all arterial blood flow to the lower limbs for 90 minutes. The surgeon would like to remove the clamp, but he knows that when he does he must closely watch the patient's blood pressure.

What two things are going on when the surgeon removes the clamp?

This is a classic question in the operating suite. Because the lower limbs have been deprived of O2, the tissues have begun to use anaerobic metabolism to support themselves.
With that there is a buildup of metabolic by-products (lactic acid, adenosine, cytokines etc), these are potent vasodilators.
When the clamp is removed the pressure will go down both because there is a new parallel large-volume vascular circuit added, and the release of these metabolic byproducts into circulation leads to more vasodilation systemically.

A 57-year-old man comes in complaining of new onset chest pain. Twenty minutes later his descending abdominal aorta ruptures leading to massive blood loss. Sympathetic outflow leads to mobilization of what immediately available blood reserve?

The venous reserve; the unstressed volume can be quickly mobilized to compensate for acute hemorrhage. Remember: the arterial vessels carry only about 15% to 20% of total blood volume under normal resting state; the balance can be quickly recruited for use.

What happens to the stressed volume in older patients compared to younger ones?

It decreases since the capacitance of the arteries decreases with age.

A patient has a mean arterial pressure (MAP) of 70 mm Hg, a right atrial pressure (P_{RA}) of 10 mm Hg, and total peripheral resistance (TPR) is determined to be 10 mm Hg min/L.

What is the cardiac output (CO)?

$$CO = \frac{(MAP - P_{RA})}{TPR}$$

Substituting in the numbers given:

$$CO = \frac{70 \text{ mm Hg} - 10 \text{ mm Hg}}{10 \text{ mm Hg min/L}} = 6 \text{L/min}$$

A patient is given an experimental drug, which the manufacturer claims to be a cardioselective ACh-analog. What type of effects will this drug have on the patient's heart rate and conduction velocities?

The drug will mimic parasympathetic stimulation and result in decreased heart rate, slower AV conduction, and increased PR interval

•**Which of the following vessels carries oxygen-rich blood from the heart to the tissues of the body?** a) Veins
b) Arteries
c) Capillaries
d) Venules
e) Lymphatic vessels
•**The primary site of nutrient and gas exchange between blood and tissues occurs in which type of blood vessel?** a) Arteries
b) Arterioles
c) Capillaries
d) Veins
e) Venules
•**Which layer of the blood vessel wall is responsible for vasoconstriction and vasodilation?** a) Tunica intima
b) Tunica media
c) Tunica externa
d) Endothelium
e) Adventitia

•**What is the primary function of the endothelium in blood vessels?** a) Structural support
b) Regulating blood pressure
c) Facilitating nutrient exchange
d) Preventing blood clotting
e) Producing red blood cells
•**Which blood vessels have the thickest walls and the highest pressure?** a) Capillaries
b) Venules
c) Veins
d) Arteries
e) Arterioles
•**What mechanism assists venous return to the heart?** a) Smooth muscle contraction in veins
b) High arterial pressure
c) Skeletal muscle pump
d) Capillary action
e) Active transport

•**Which blood vessels are known as resistance vessels because they play a major role in regulating blood flow and pressure?** a) Arteries
b) Capillaries
c) Veins
d) Arterioles
e) Venules
•**Which of the following factors does NOT influence blood flow resistance in blood vessels?** a) Blood vessel length
b) Blood viscosity
c) Blood vessel diameter
d) Cardiac output
e) Presence of plaques
•**Which vessel type is primarily involved in the exchange of gases, nutrients, and wastes with the tissues?** a) Arteries
b) Veins
c) Capillaries
d) Arterioles
e) Venules
•**Which vessel contains valves to prevent the backflow of blood?** a) Arteries
b) Capillaries
c) Arterioles
d) Veins
e) Lymphatic vessels

Answer Key

1.b) Arteries
2.c) Capillaries
3.b) Tunica media
4.c) Facilitating nutrient exchange
5.d) Arteries
6.c) Skeletal muscle pump
7.d) Arterioles
8.d) Cardiac output
9.c) Capillaries
10.d) Veins

There are several recognized forms of shock:

•**Hypovolemic shock** in adults is typically caused by hemorrhage, although in children it may be caused by fluid losses related to severe vomiting or diarrhea. Other causes for hypovolemic shock include extensive burns, exposure to some toxins, and excessive urine loss related to diabetes insipidus or ketoacidosis. Typically, patients present with a rapid, almost tachycardic heart rate; a weak pulse often described as “thread;” cool, clammy skin, particularly in the extremities, due to restricted peripheral blood flow; rapid, shallow breathing; hypothermia; thirst; and dry mouth. Treatments generally involve providing intravenous fluids to restore the patient to normal function and various drugs such as dopamine, epinephrine, and norepinephrine to raise blood pressure.

•**Cardiogenic shock** results from the inability of the heart to maintain cardiac output. Most often, it results from a myocardial infarction (heart attack), but it may also be caused by arrhythmias, valve disorders, cardiomyopathies, cardiac failure, or simply insufficient flow of blood through the cardiac vessels. Treatment involves repairing the damage to the heart or its vessels to resolve the underlying cause, rather than treating cardiogenic shock directly.

•**Vascular shock** occurs when arterioles lose their normal muscular tone and dilate dramatically. It may arise from a variety of causes, and treatments almost always involve fluid replacement and medications, called inotropic or pressor agents, which restore tone to the muscles of the vessels. In addition, eliminating or at least alleviating the underlying cause of the condition is required. This might include antibiotics and antihistamines, or select steroids, which may aid in the repair of nerve damage. A common cause is **sepsis** (or septicemia), also called “blood poisoning,” which is a widespread bacterial infection that results in an organismal-level inflammatory response known as **septic shock**. **Neurogenic shock** is a form of vascular shock that occurs with cranial or spinal injuries that damage the cardiovascular centers in the medulla oblongata or the nervous fibers originating from this region. **Anaphylactic shock** is a severe allergic response that causes the widespread release of histamines, triggering vasodilation throughout the body.

•**Obstructive shock**, as the name would suggest, occurs when a significant portion of the vascular system is blocked. It is not always recognized as a distinct condition and may be grouped with cardiogenic shock, including pulmonary embolism and cardiac tamponade. Treatments depend upon the underlying cause and, in addition to administering fluids intravenously, often include the administration of anticoagulants, removal of fluid from the pericardial cavity, or air from the thoracic cavity, and surgery as required. The most common cause is a pulmonary embolism, a clot that lodges in the pulmonary vessels and interrupts blood flow. Other causes include stenosis of the aortic valve; cardiac tamponade, in which excess fluid in the pericardial cavity interferes with the ability of the heart to fully relax and fill with blood (resulting in decreased preload); and a pneumothorax, in which an excessive amount of air is present in the thoracic cavity, outside of the lungs, which interferes with venous return, pulmonary function, and delivery of oxygen to the tissues.