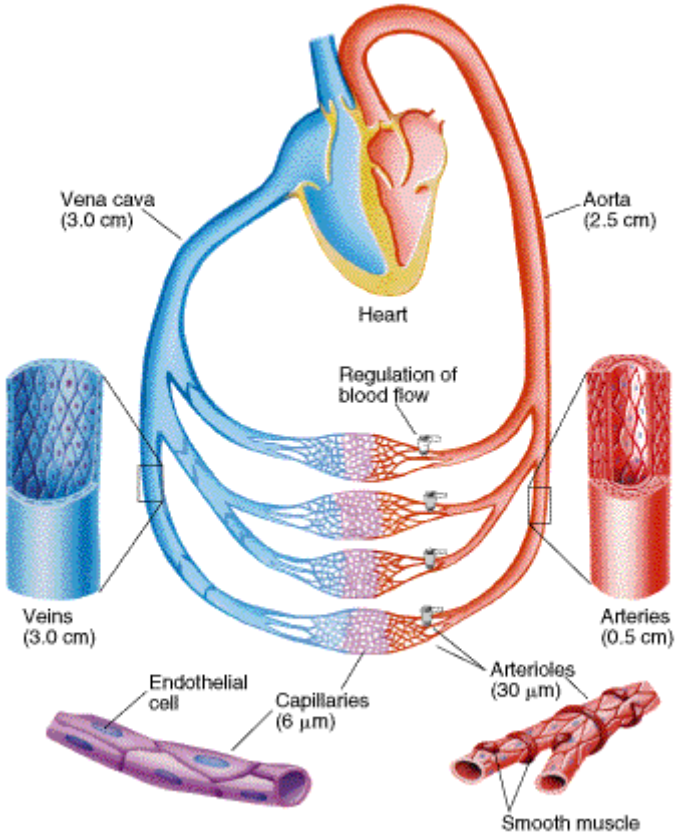
Chapter 12:
Cardiovascular Physiology

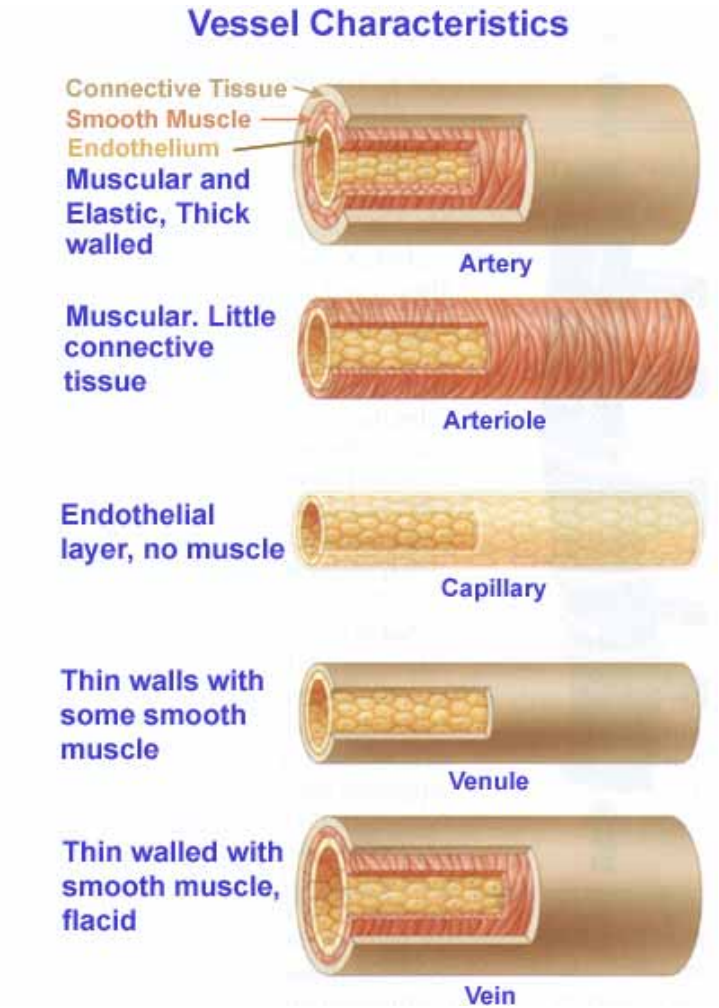
Vascular Physiology



Lecture Outline

- Functional parts of blood vessels
- Hemodynamics
- Arterial blood pressure
- Microcirculation
- Venous pressure and venous return
- The Lymphatic System

Functional parts of blood vessels



- Elastic vessels (Windkessel Vessels)
- Distribution vessels
- Resistance vessels (Precapillary resistance vessels)
- Exchange vessels
- Shunt vessels
- Capacitance vessels

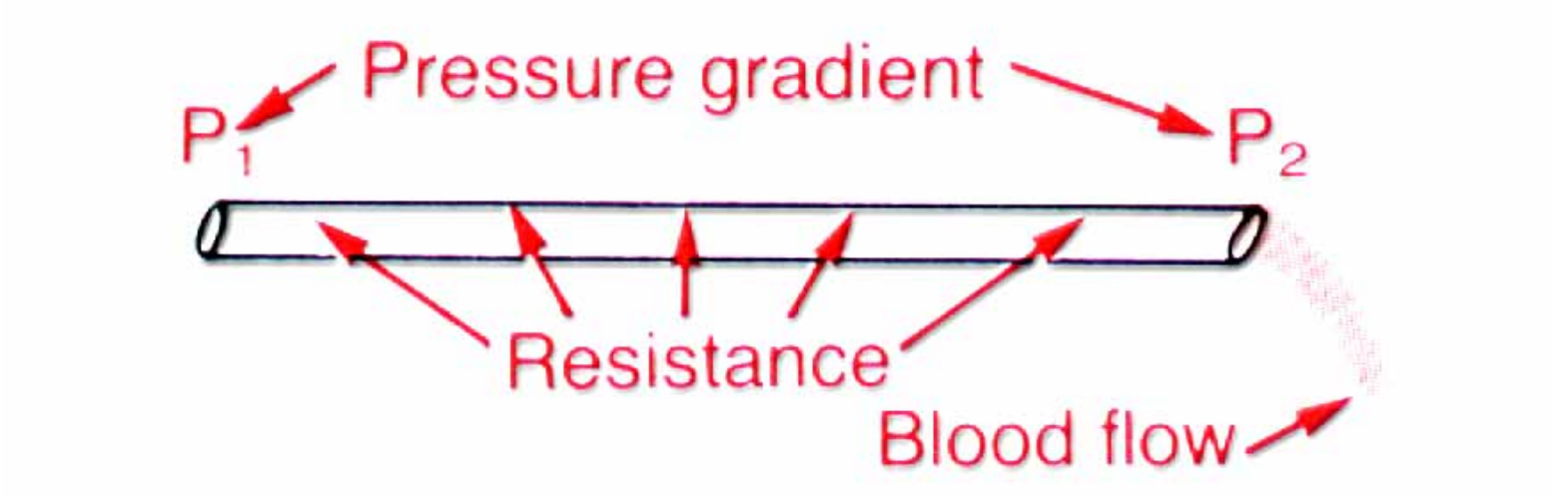
TABLE 12–4 *Functions of Endothelial Cells*

1. Serve as a physical lining that blood cells do not normally adhere to in heart and blood vessels.
2. Serve as a permeability barrier for the exchange of nutrients, metabolic end products, and fluid between plasma and interstitial fluid; regulate transport of macromolecules and other substances.
3. Secrete paracrine agents that act on adjacent vascular smooth muscle cells; including vasodilators—prostacyclin and nitric oxide (endothelium-derived relaxing factor, EDRF)—and vasoconstrictors—notably endothelin-1.
4. Mediate angiogenesis (new capillary growth).
5. Play a central role in vascular remodeling by detecting signals and releasing paracrine agents that act on adjacent cells in the blood vessel wall.
6. Contribute to the formation and maintenance of extracellular matrix.
7. Produce growth factors in response to damage.
8. Secrete substances that regulate platelet clumping, clotting, and anticlotting.
9. Synthesize active hormones from inactive precursors (Chapter 14).
10. Extract or degrade hormones and other mediators (Chapters 11, 13).
11. Secrete cytokines during immune responses (Chapter 18).
12. Influence vascular smooth-muscle proliferation in the disease atherosclerosis.

Hemodynamics

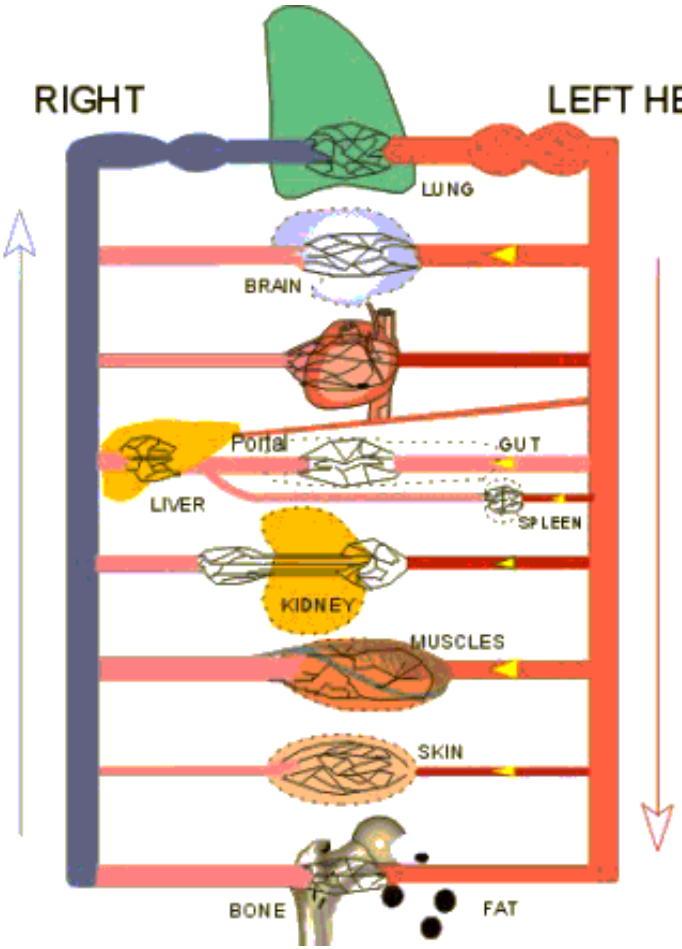
- Blood flow

  $Q = \Delta P/R = (P_1 - P_2)/R$



$Q = P_A/R$

Q: cardiac output, 5 L/min
R: total peripheral resistance
P_A: aortic pressure



Total Peripheral Vascular Resistance (*TPVR*)

Parallel system:
$1/TPVR = 1/R_1 + 1/R_2 \ldots$

Thus R_{total} is always less than any individual resistance

Serial system:
$R_{total} = R_1 + R_2 \ldots$

Thus R_{total} is always larger than any individual resistance

Cross sectional area (A) of all open capillaries (Eq. 8-1):
$A = (10^{-4})/(10^{-3}) = 0.1\ m^2$.

Resistance of blood flow

Poiseuille Law: $Q=\pi\Delta Pr^4/8\eta L$

η: viscosity

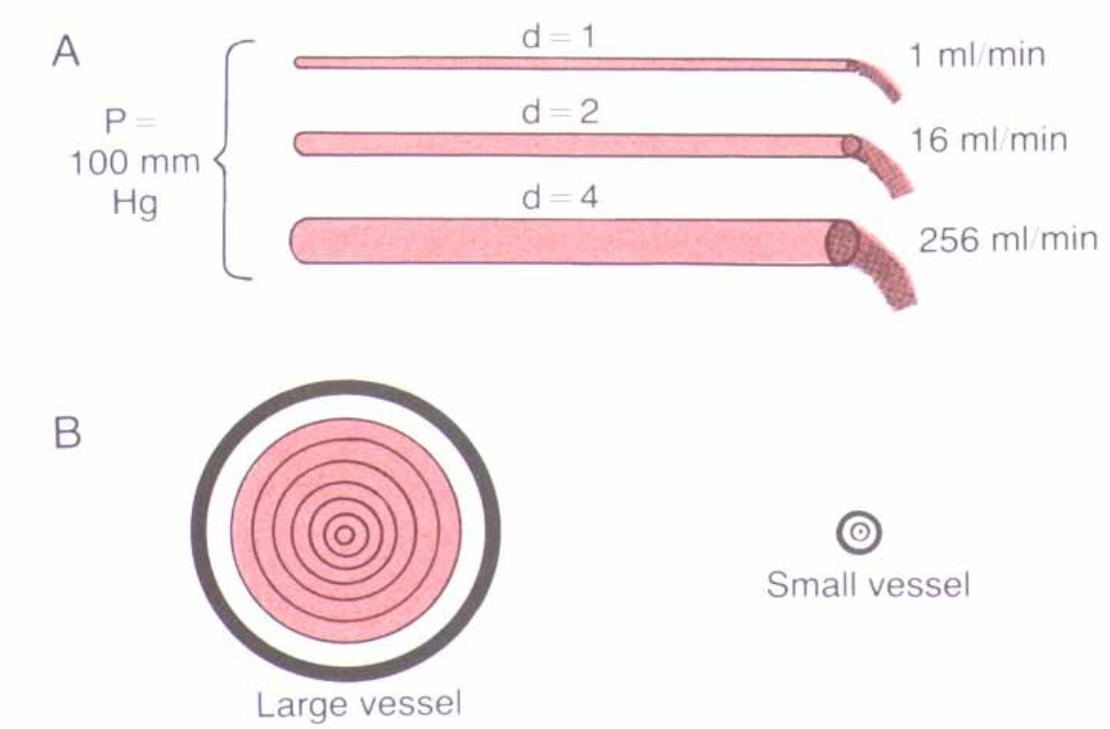
r: radius of the vessel

L: length of the vessel

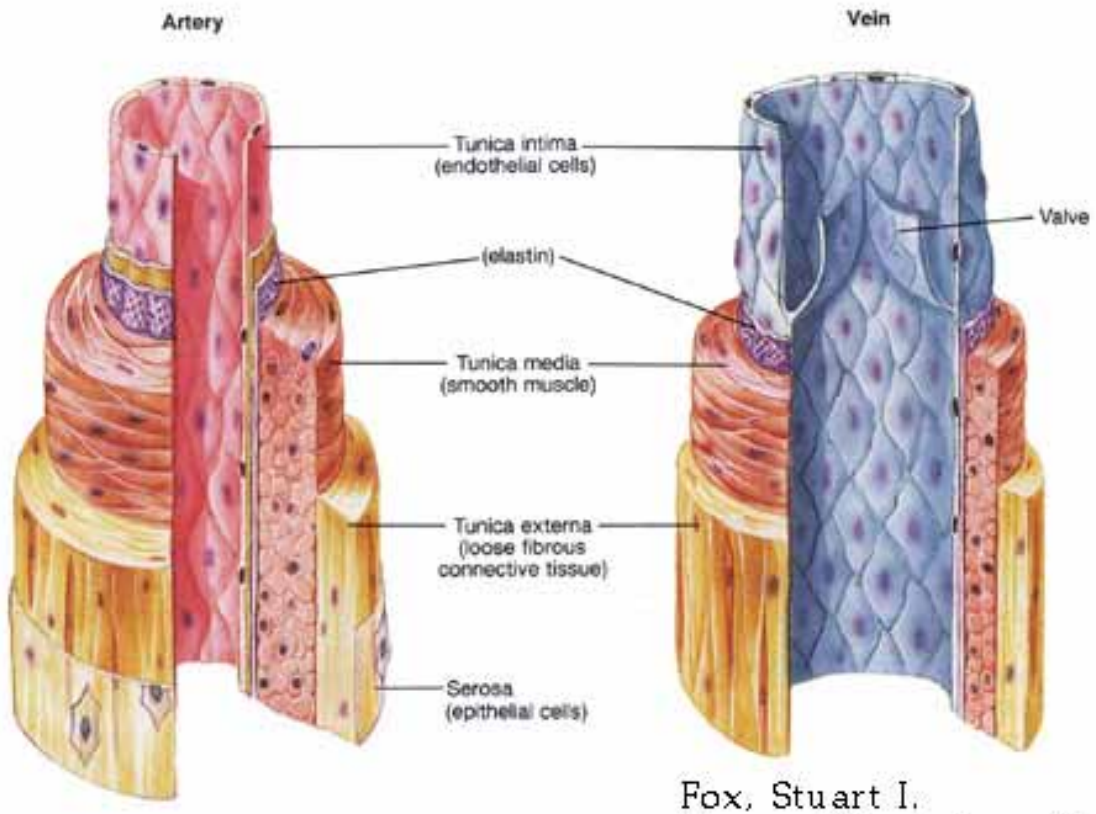
$R= 8\eta L/\pi r^4$

$Q= \Delta P/R$

r: main determinant of blood flow



Arterial blood pressure

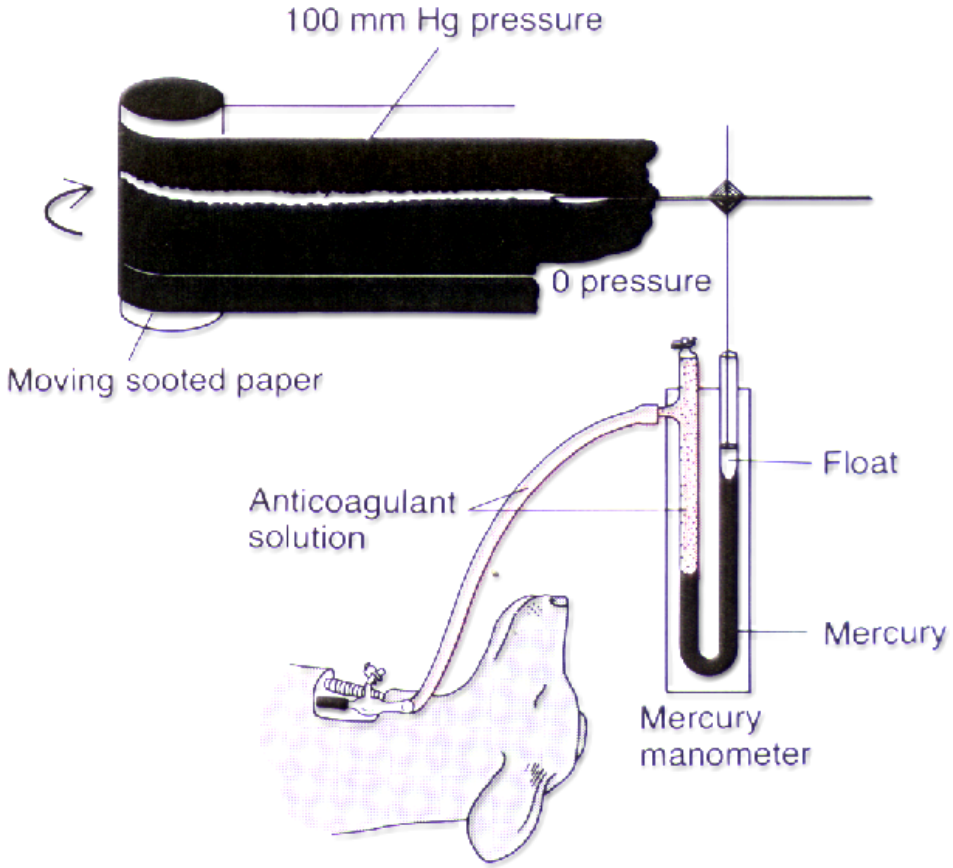


Fox, Stuart I.
Human Physiology 4th
Brown Publishers

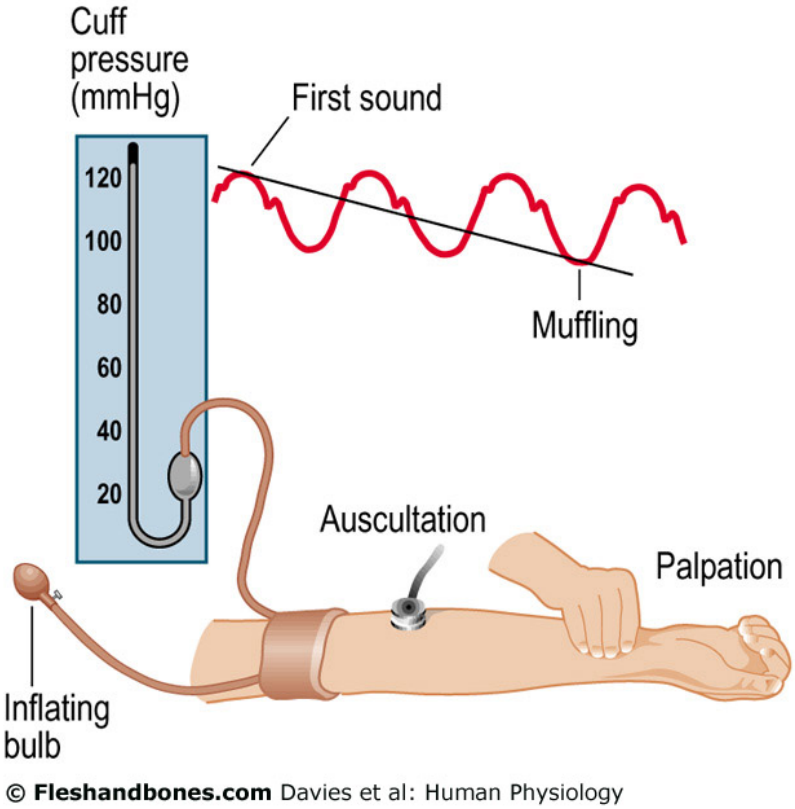
Arteries

Blood pressure measurement

1. Direct (invasive) measurement technique



2. Indirect (non-invasive) measurement technique



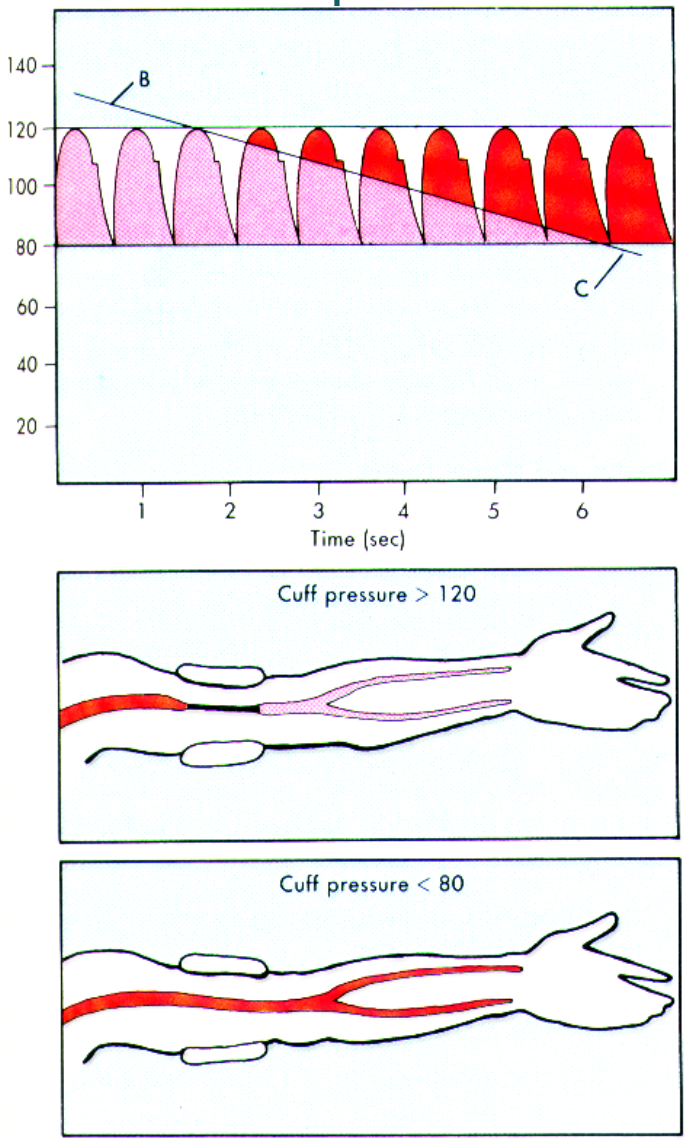


Figure 12-31

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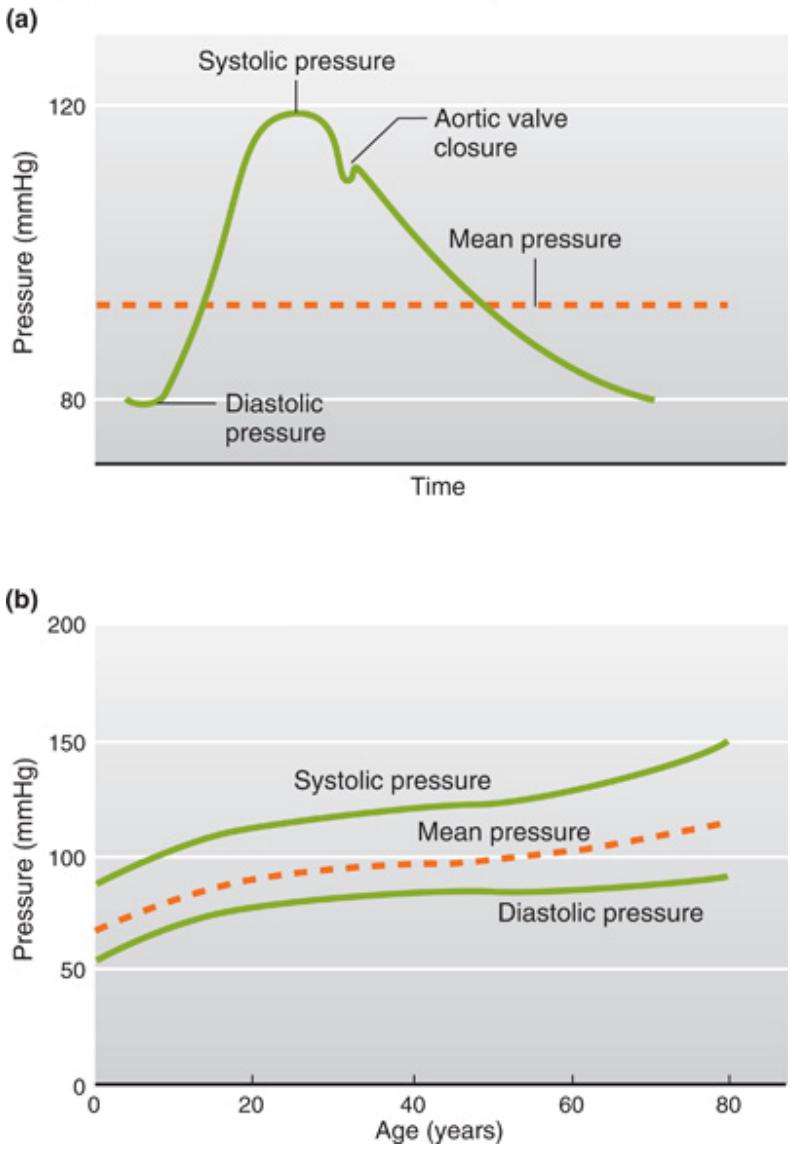
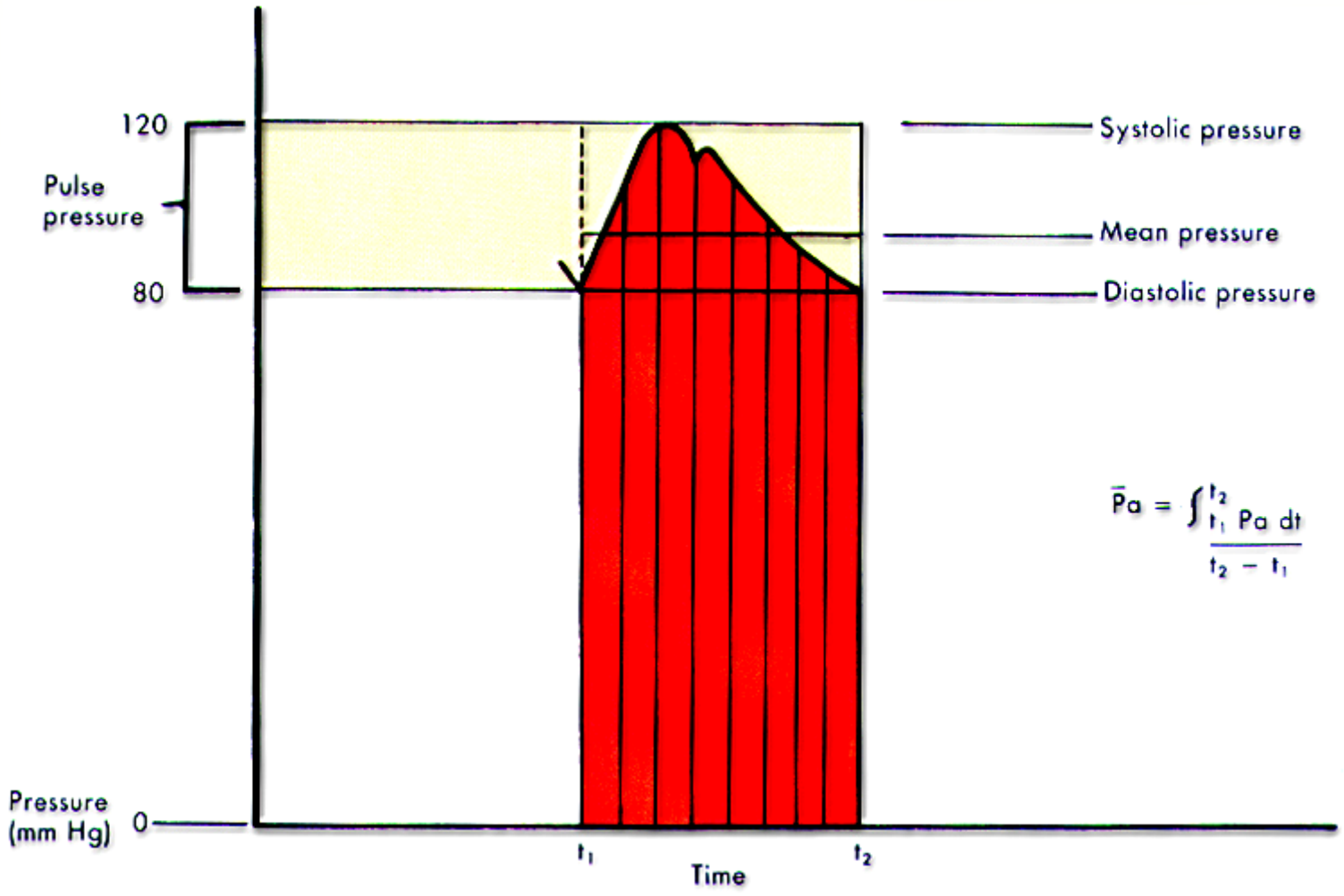


Systolic pressure (SP): the maximum arterial pressure reached during peak ventricular ejection

Diastolic pressure (DP): the minimum arterial pressure just before ventricular ejection begins

Pulse pressure (PP): the difference between SP and DP

Mean arterial pressure (MAP): the average pressure in the cardiac cycle (=DP+1/3PP)



Mean arterial pressure (MAP)

Figure 12-32

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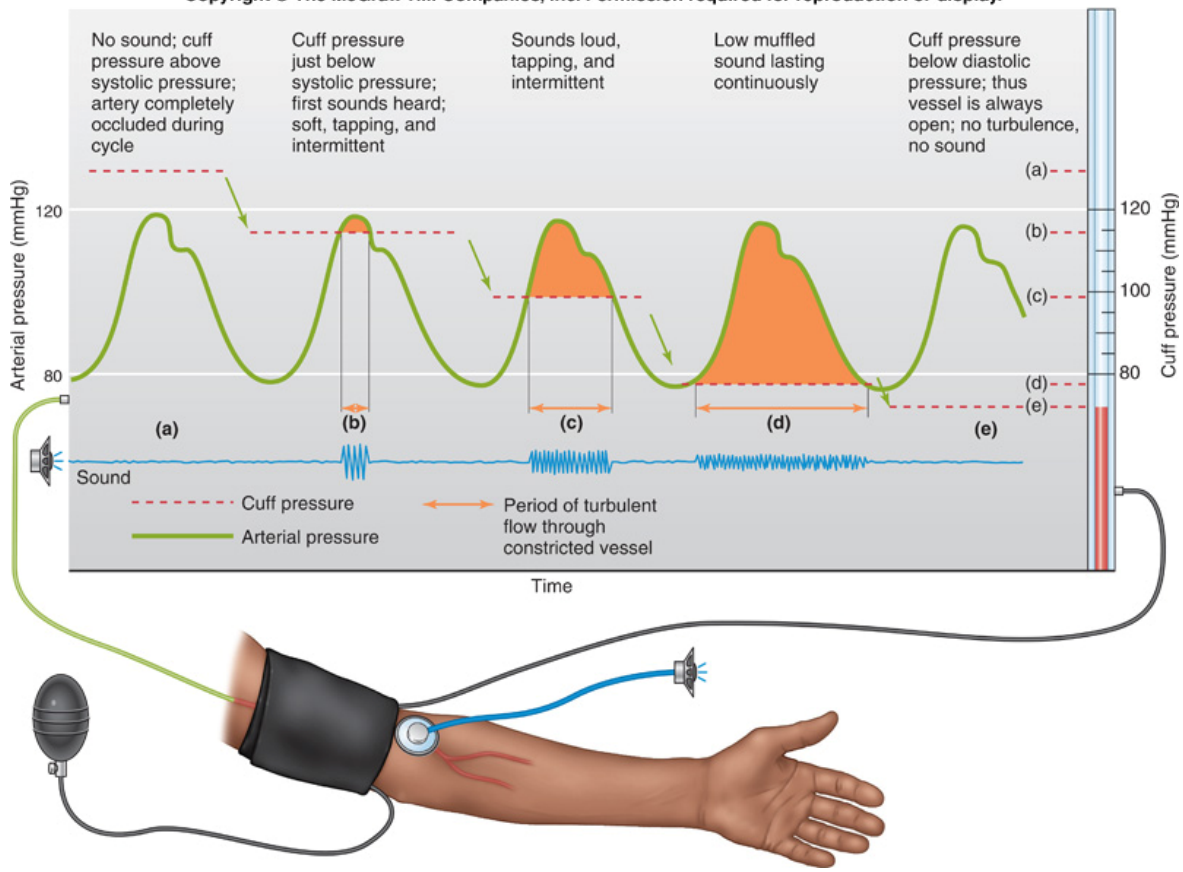


To estimate systolic and diastolic pressures, pressure is released from an inflatable cuff on the upper arm while listening as blood flow returns to the lower arm.

Click here to play the Sphygmomanometry Flash Animation

Classification of blood pressure for adults age 18 years and older

Blood Pressure Classification Chart		
Category	Systolic (mm Hg)	Diastolic (mm Hg)
Normal	Lower than 120	Lower than 80
Prehypertension	120 - 139	80 - 89
Hypertension		
Stage 1	140-159	90-99
Stage 2	160 or higher	100 or higher

Adapted from The Seventh Report on the joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 7), NIH Publication No. 03-5233, May 2003

The classification chart is based on adults, aged 18 and older, who are not taking high blood pressure medicines and who are not acutely ill. If systolic and diastolic measurements fall into different categories, the higher category should be used to classify the person's blood pressure status.

Factors affecting arterial blood pressure

- Stroke volume
- Heart rate

} Ventricular ejection

- Peripheral resistance
- Elastic vessels
- Blood volume

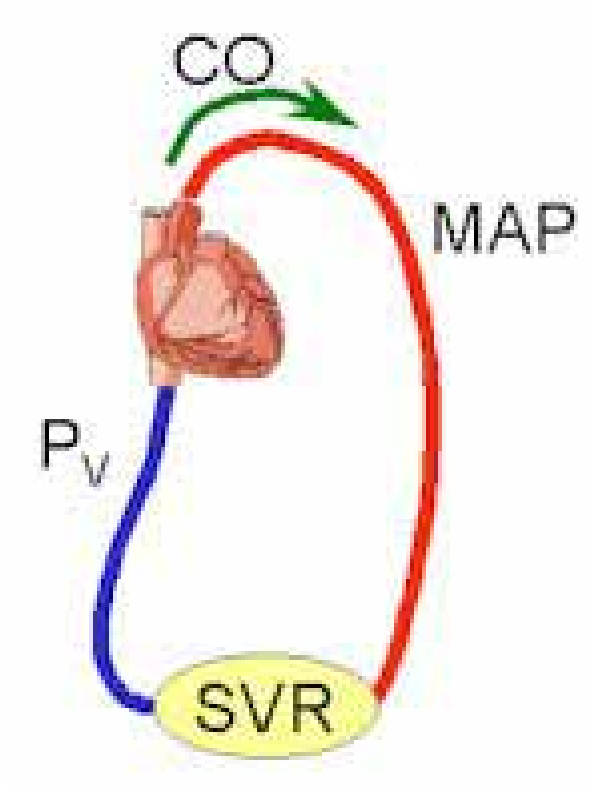
$$Q = P_A / R$$

Q: cardiac output (CO)

R: total peripheral resistance (SVR)

P_A: aortic pressure (MAP)

$$MAP = CO \times SVR$$



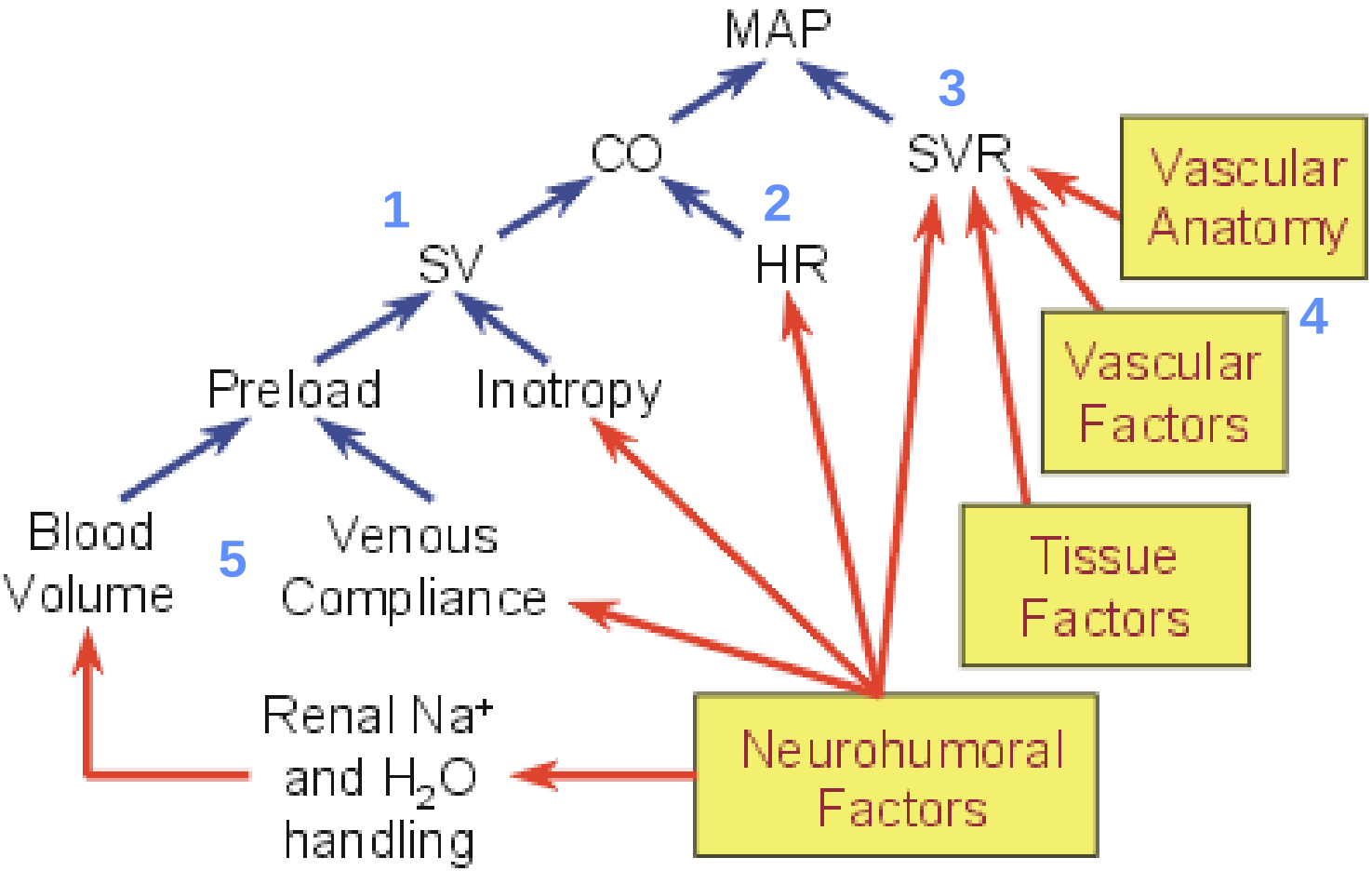
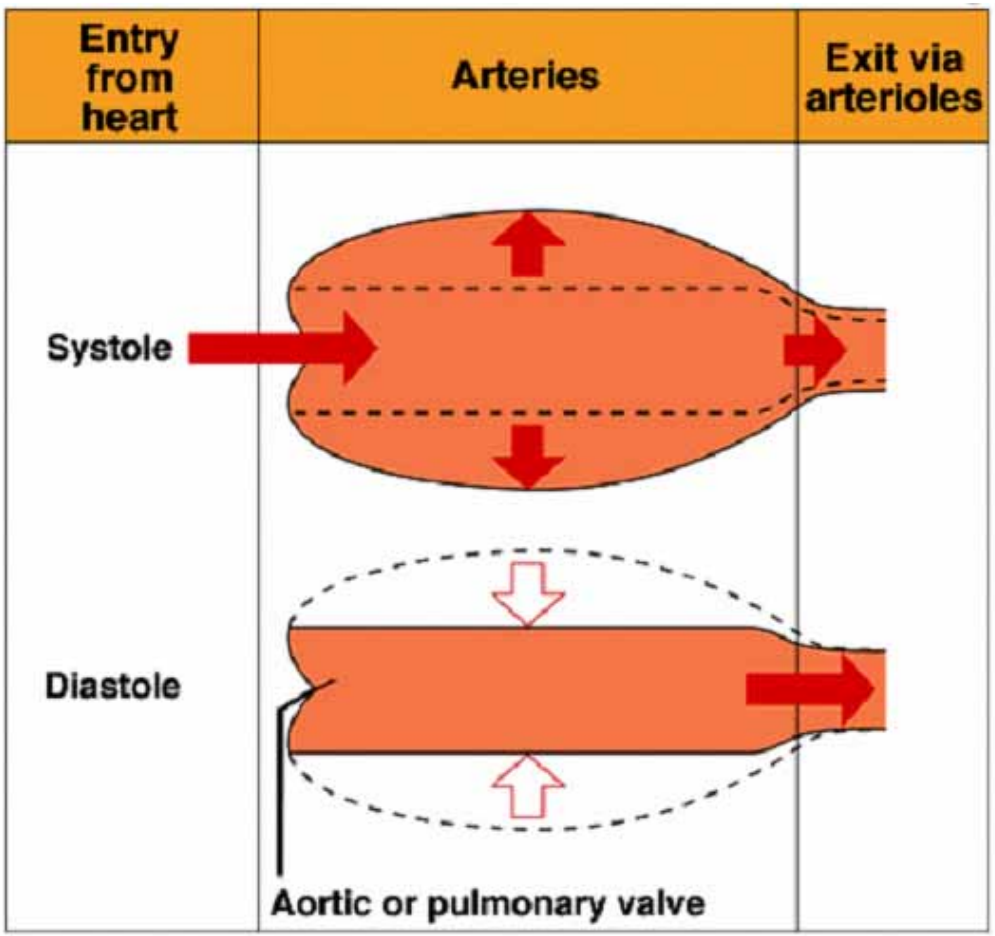
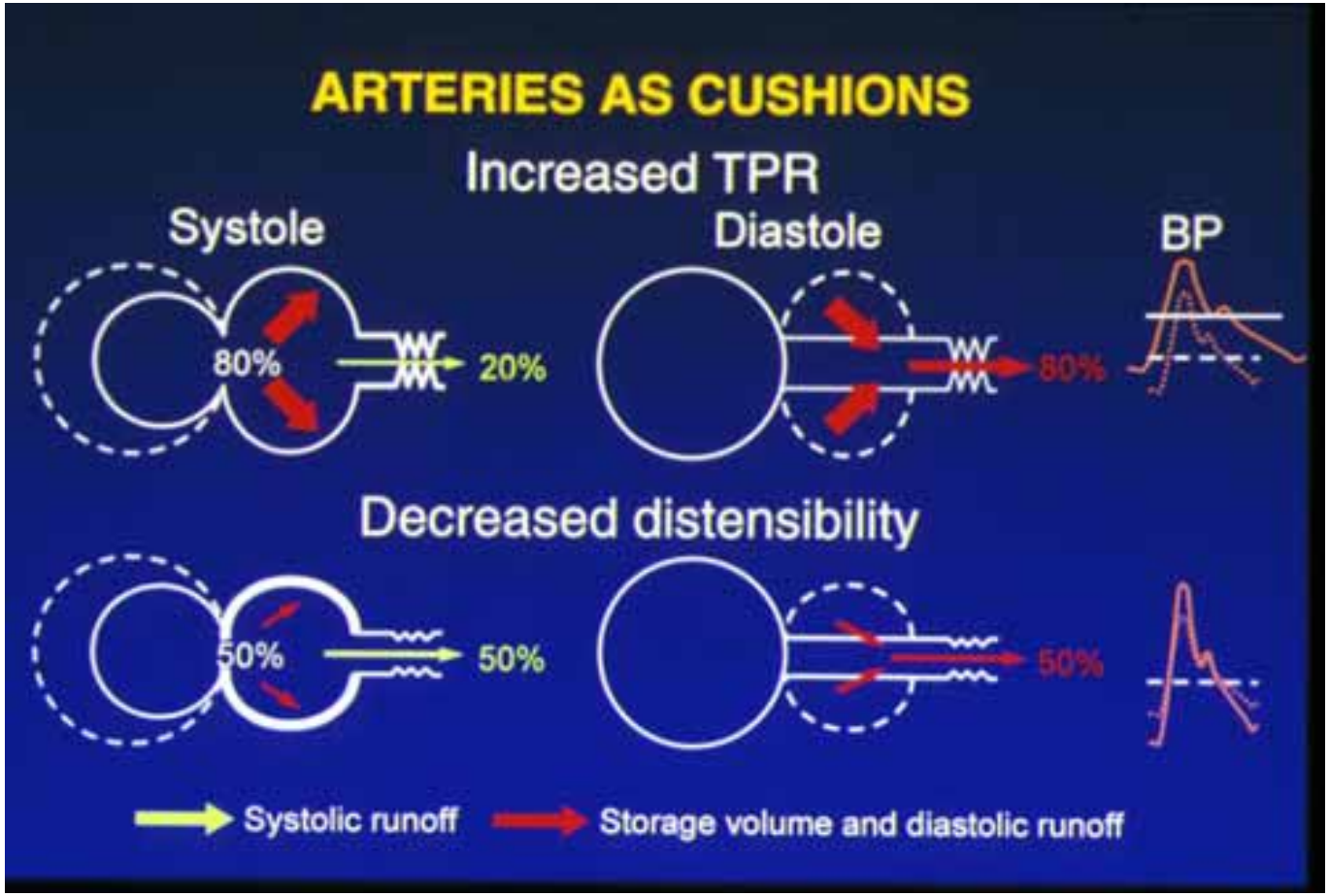

MAP
CO
3
SVR
Vascular Anatomy
1
SV
2
HR
4
Vascular Factors
Preload
Inotropy
Blood Volume
5
Venous Compliance
Tissue Factors
Renal Na+ and H2O handling
Neurohumoral Factors

Figure 12-30

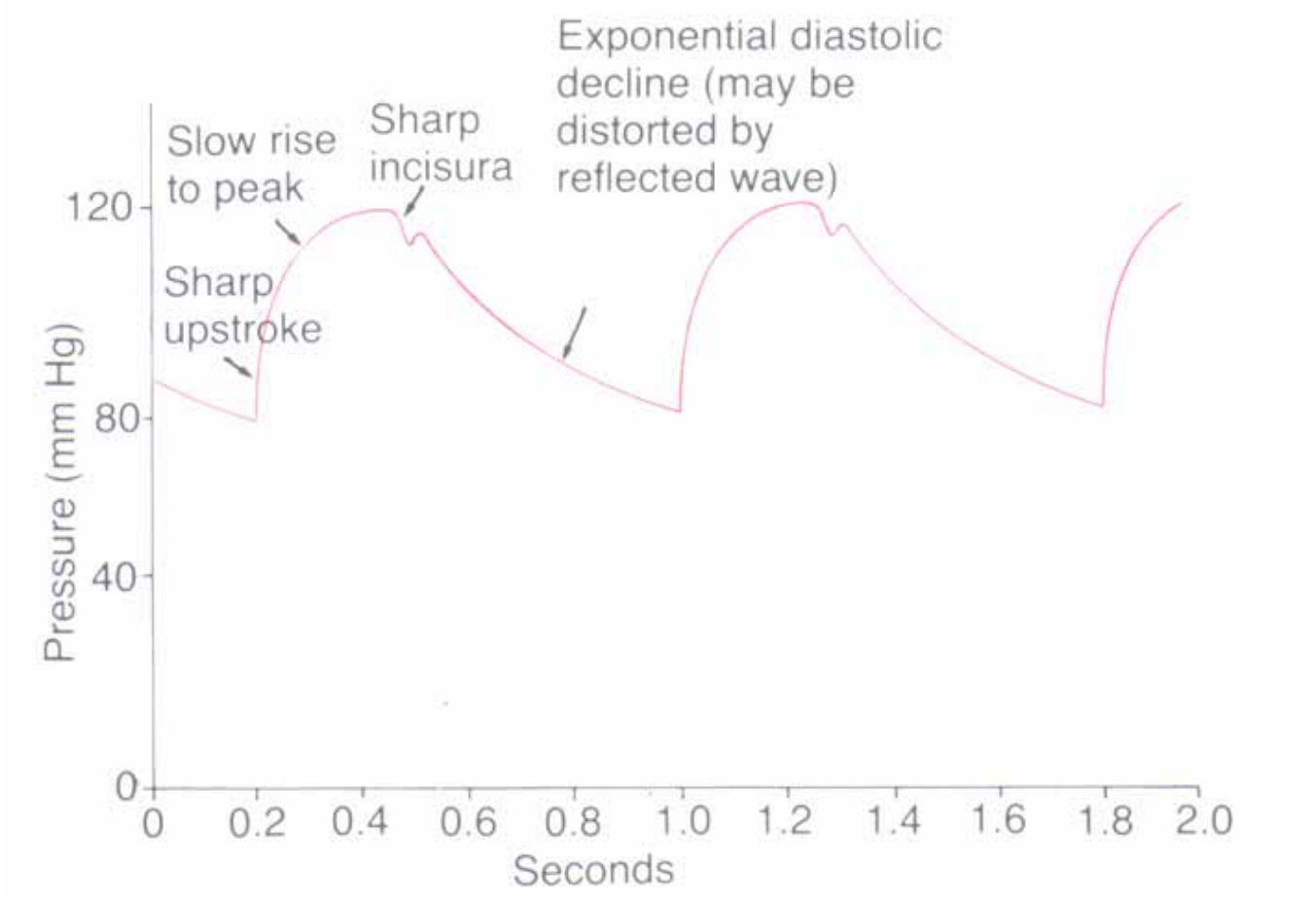
The blood moved in a single heart contraction stretches out the arteries, so that their recoil continues to push on the blood, keeping it moving during diastole.



Movement of blood into and out of the arteries during the cardiac cycle


ARTERIES AS CUSHIONS
Increased TPR
Systole
Diastole
BP
80%
20%
80%
Decreased distensibility
50%
50%
50%
Systolic runoff
Storage volume and diastolic runoff

Arterial pulse



In response to the pulsatile contraction of the heart:

pulses of pressure move throughout the vasculature, decreasing in amplitude with distance

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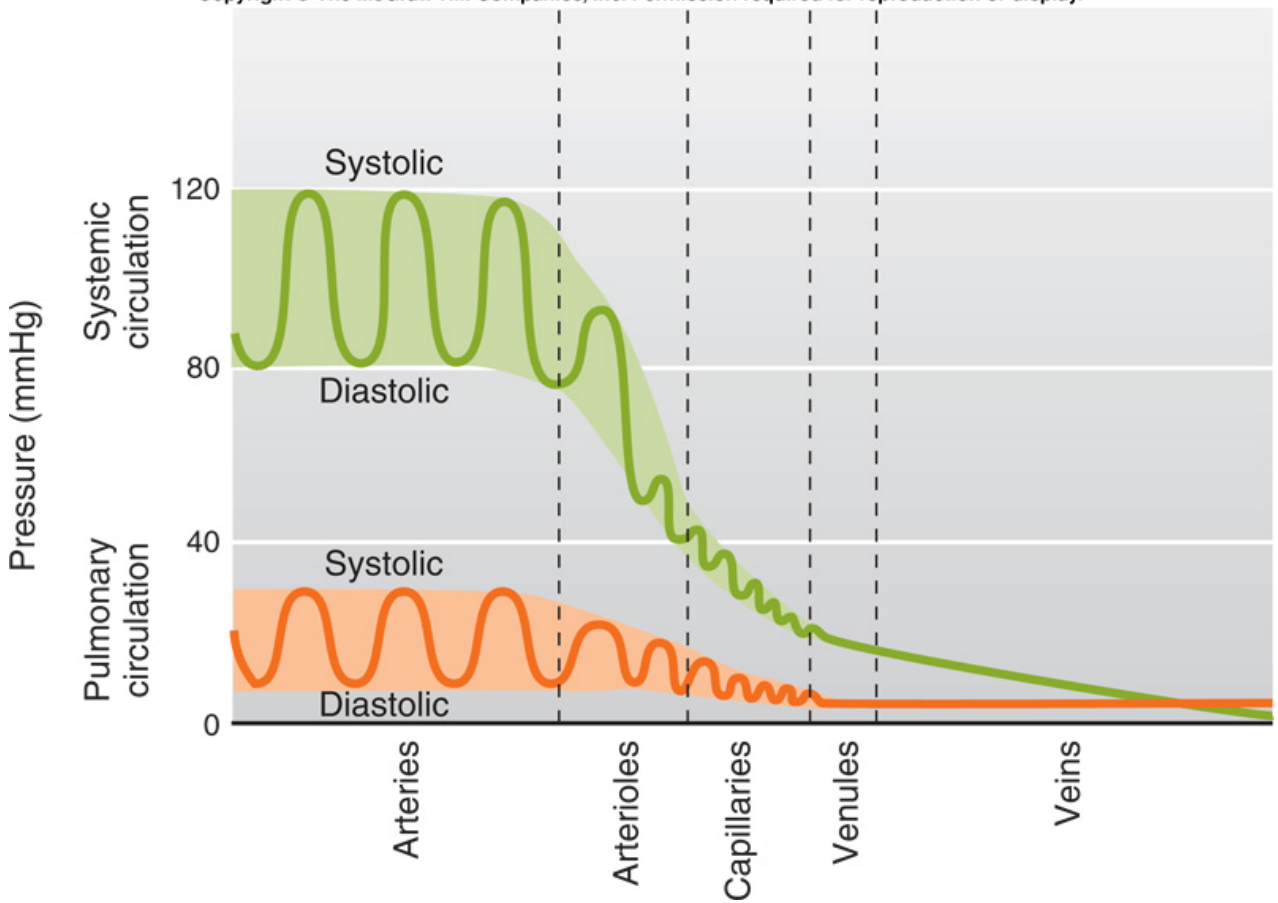
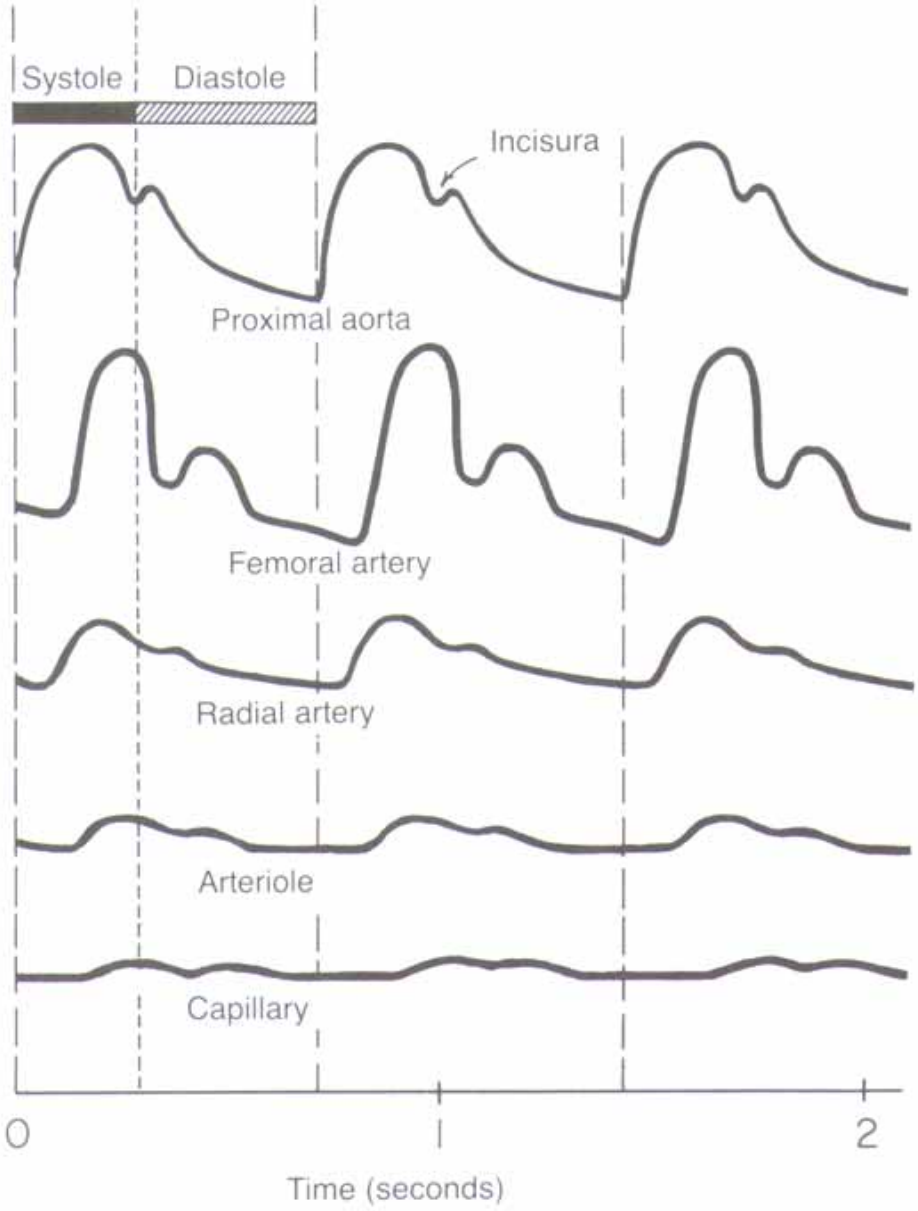
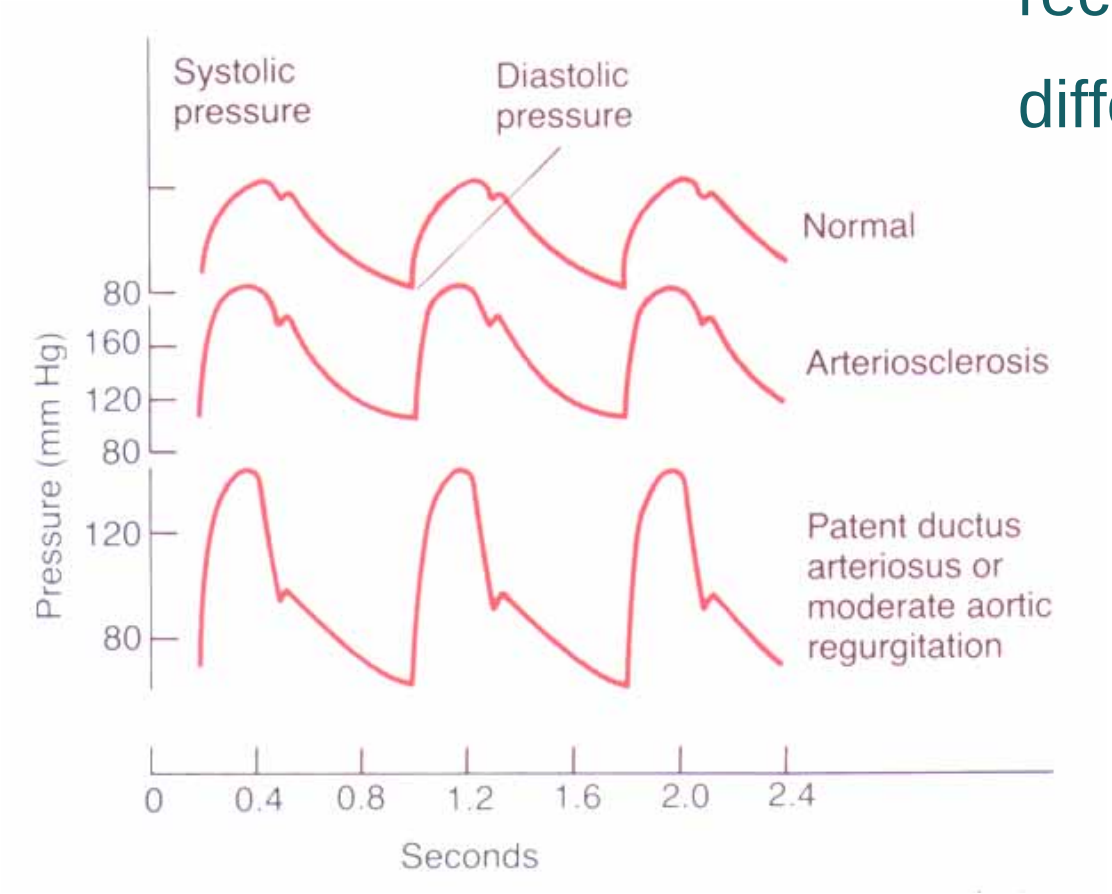


Figure 12-29

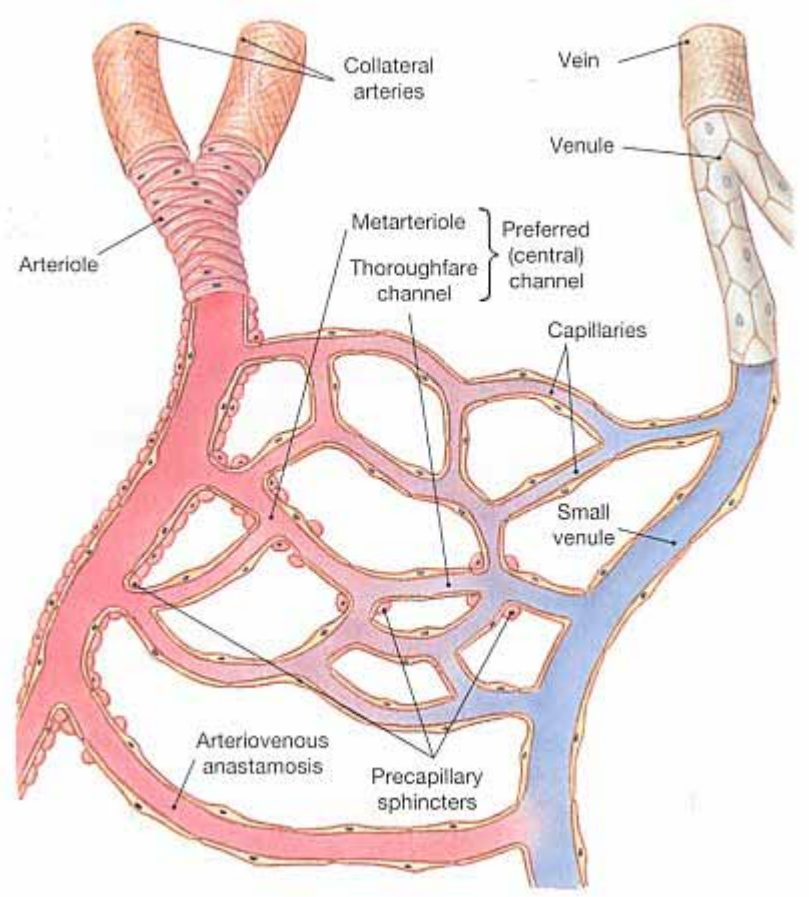


Arterial pulse recorded in different vessels

Arterial pulse recorded under different conditions



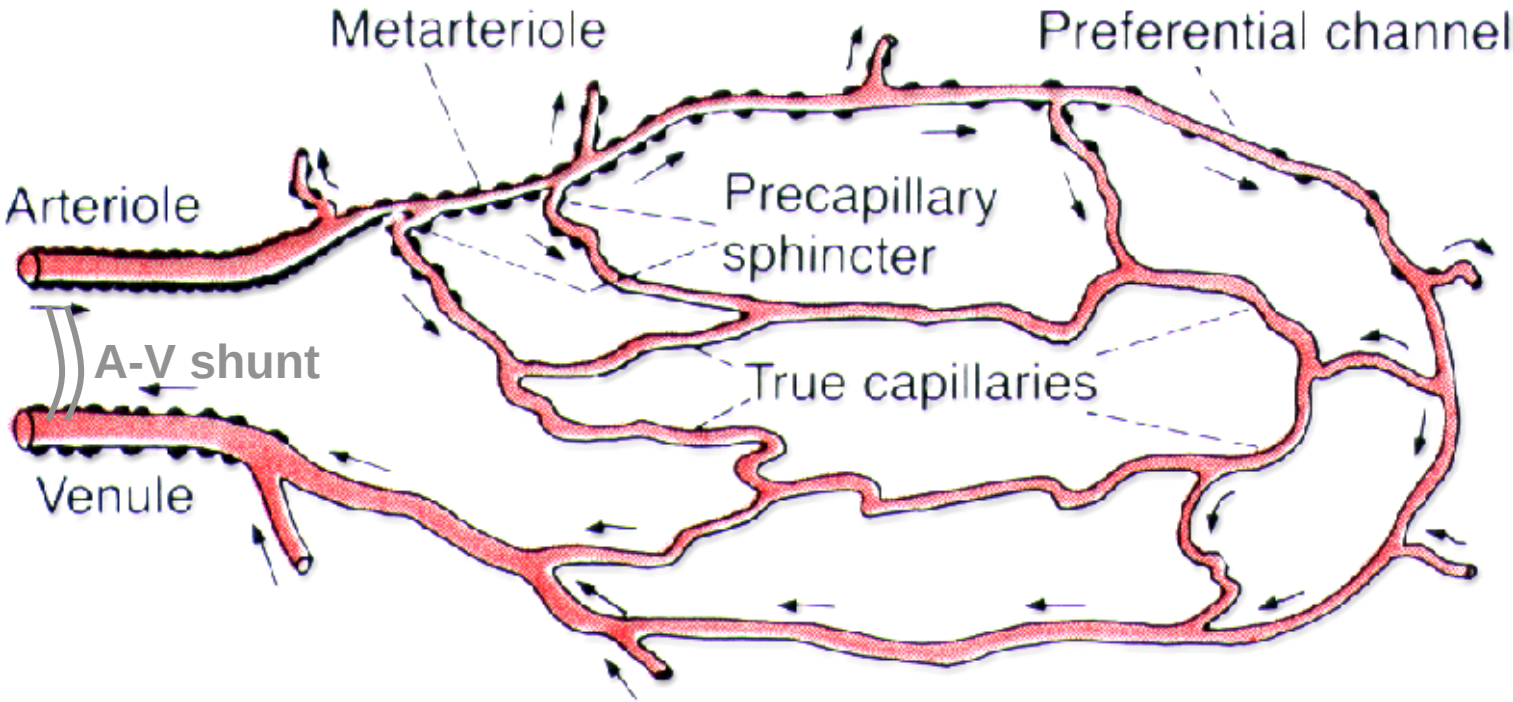
Microcirculation



Function:

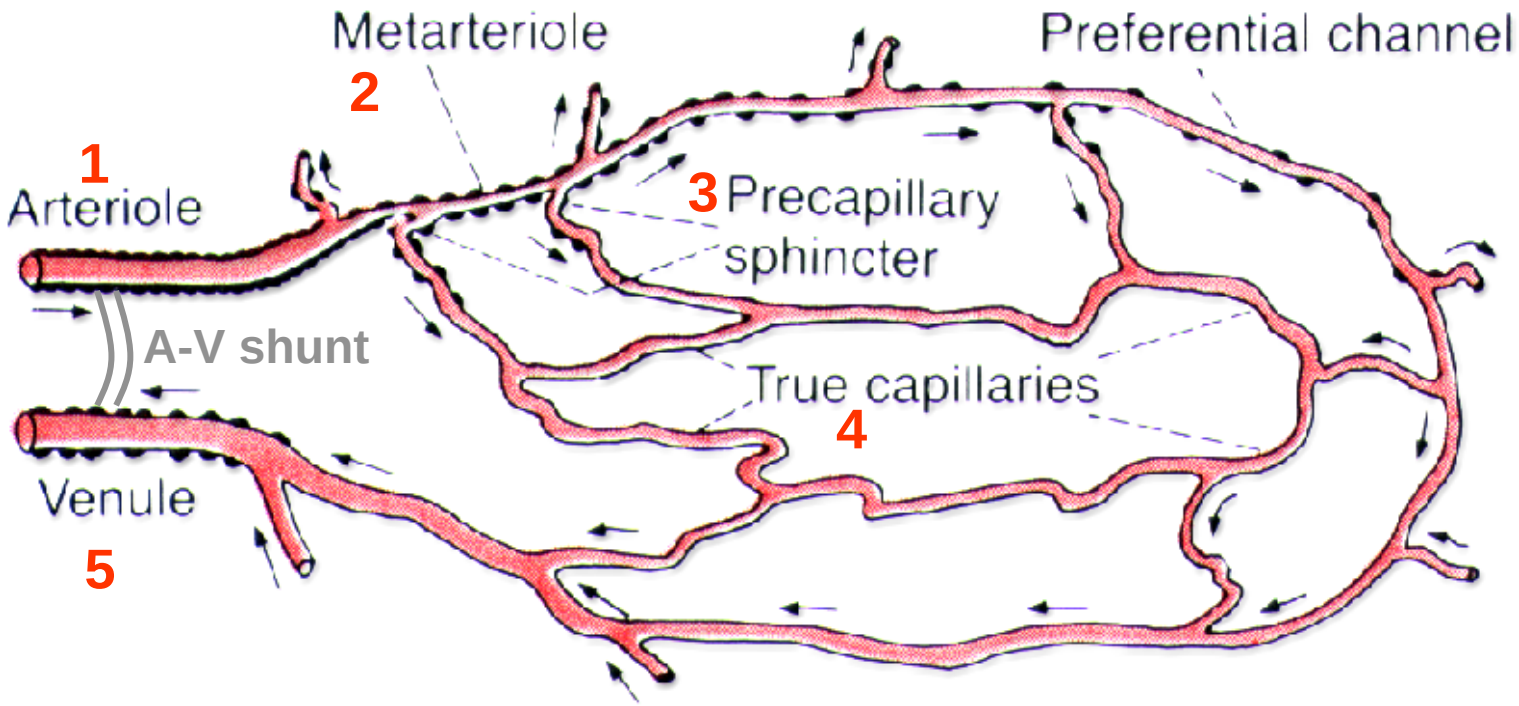
Transfer of substances between blood & the tissues

Structure of microcirculation

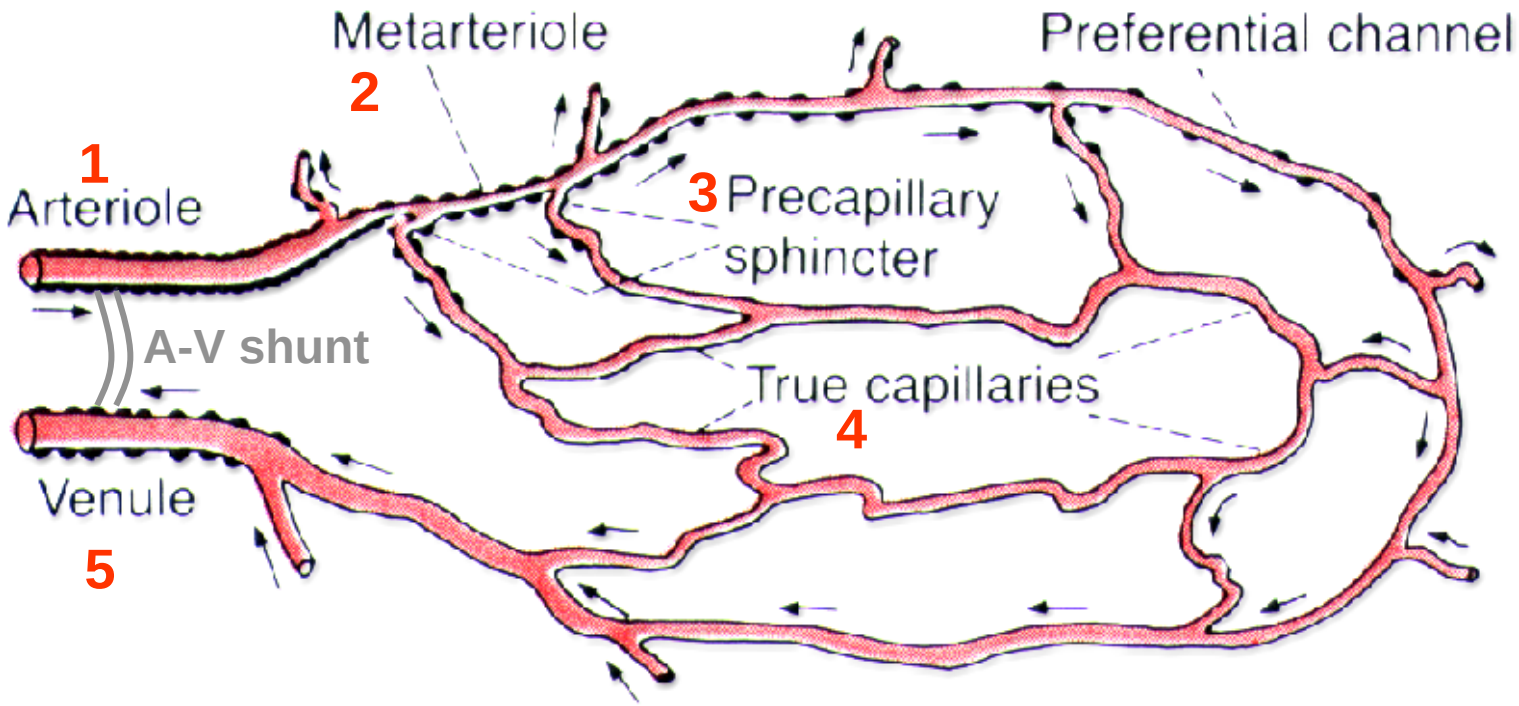


3 pathways

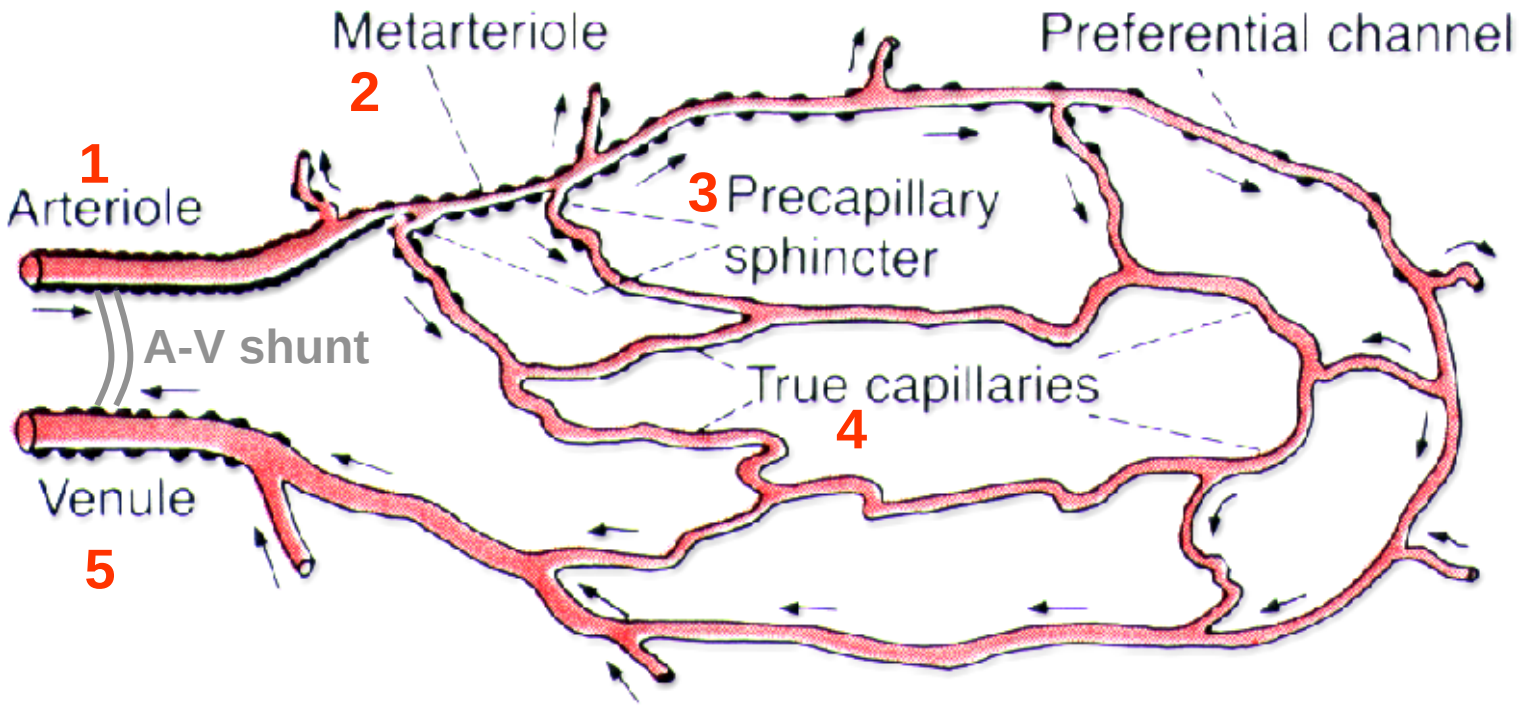
- Circuitous channel (Nutritional channel)



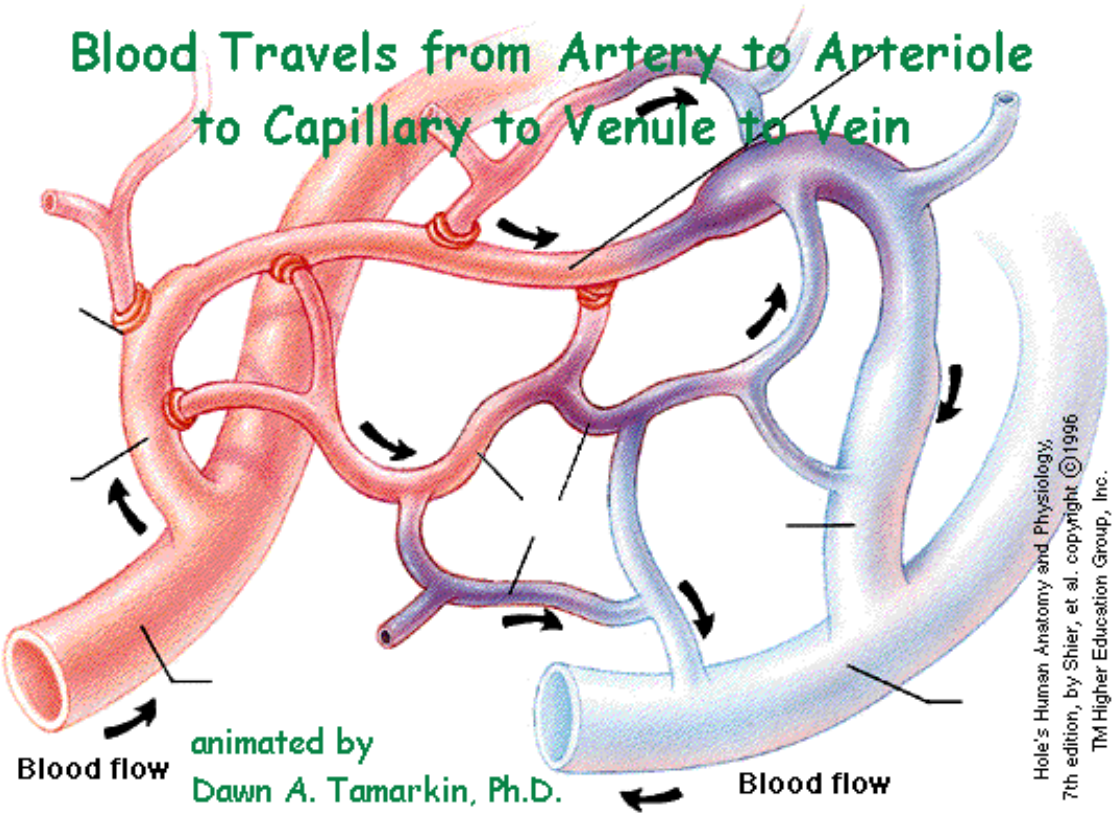
- Thoroughfare channel



- Arteriovenous shunt (A-V shunt)



- Blood travels from artery to arteriole to capillary to venule to vein



Arterioles

Two major roles:

- To be responsible for determining the relative blood flow in individual organs at any given MAP
- To be a major factor in determining MAP

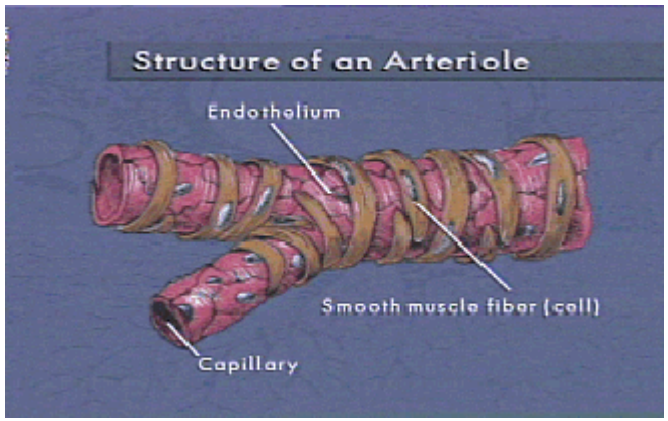


Figure 12-33

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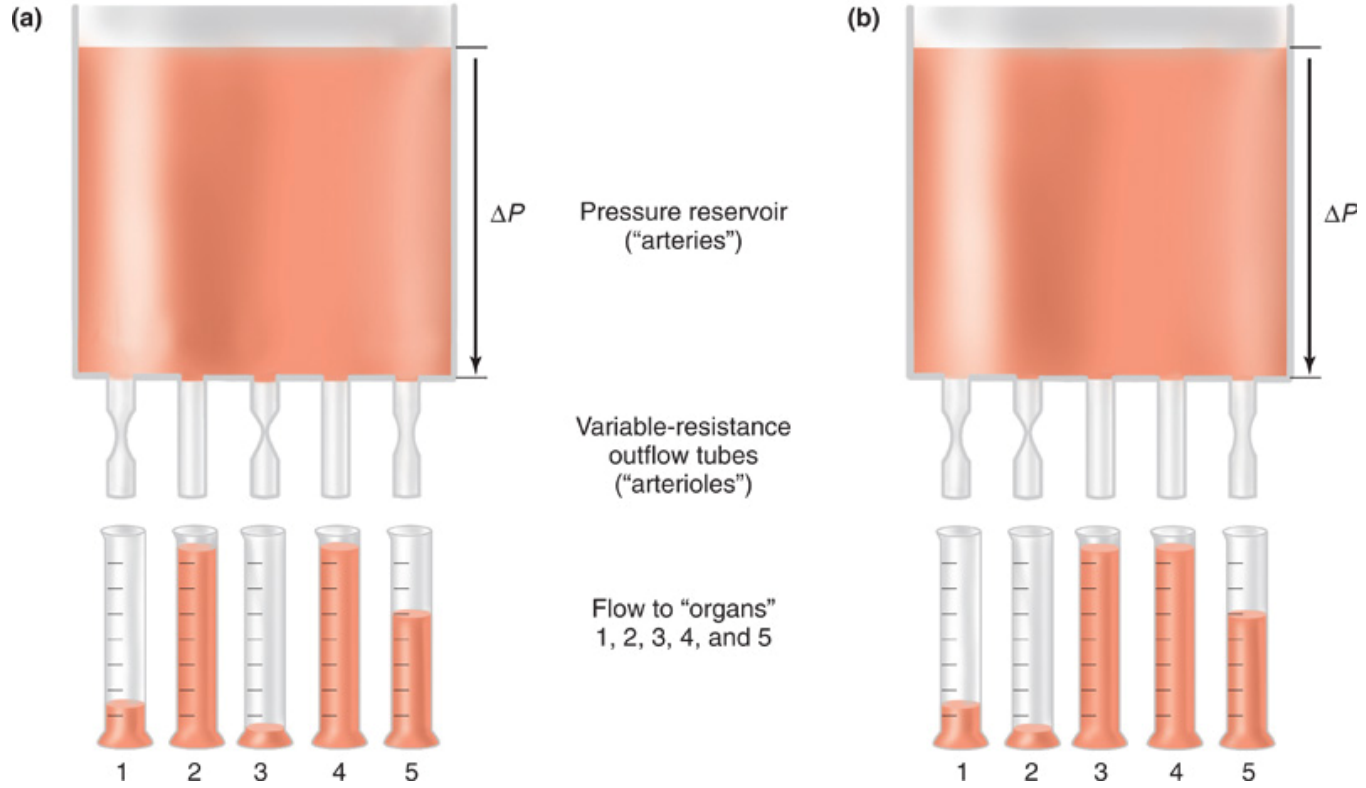

Dynamic adjustments in the blood distribution to the organs is accomplished by relaxation and contraction of circular smooth muscle in the arterioles.

Click here to play the
Arteriolar Radius & Blood Flow
Flash Animation

Click here to play the Arteriolar Resistance & BP Flash Animation

Local Control of Blood Flow

- The mechanism independent of nerves or hormones by which organs and tissues alter their own arteriolar resistances, thereby self-regulating their blood flows
  - Active hyperemia
  - Flow autoregulation
  - Reactive hyperemia
  - Local response to injury

Figure 12-34

Local control of organ blood flow

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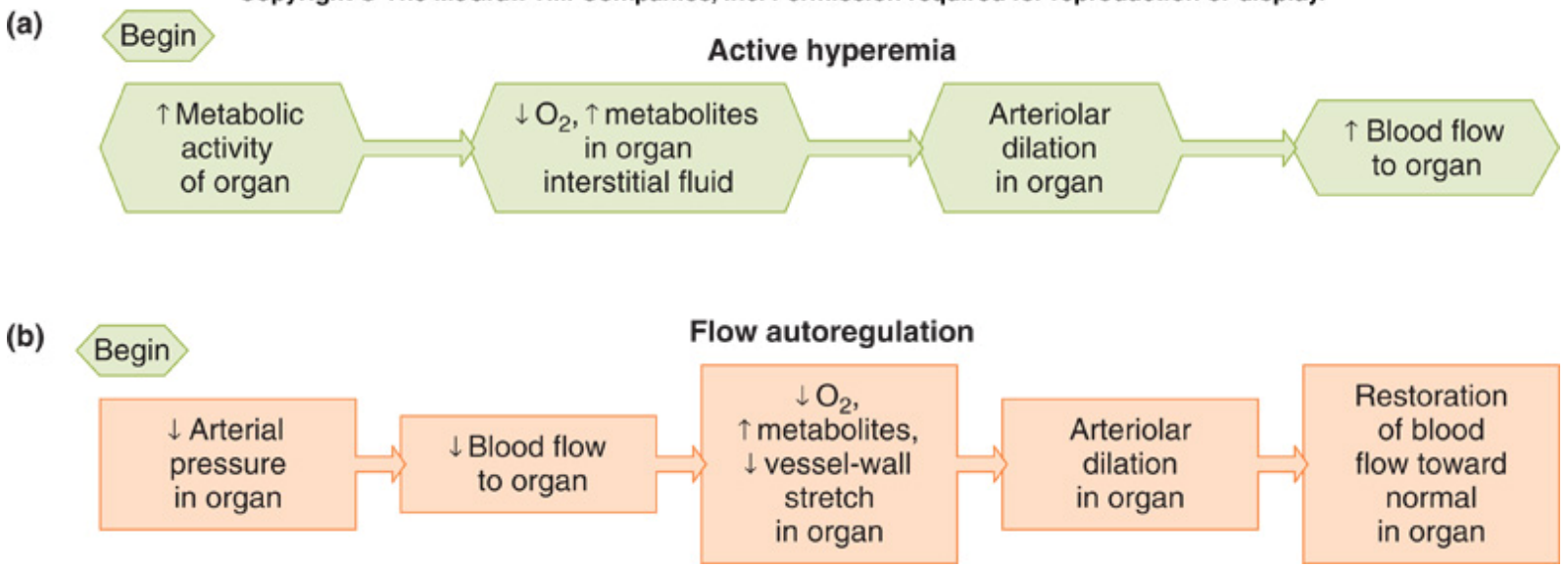
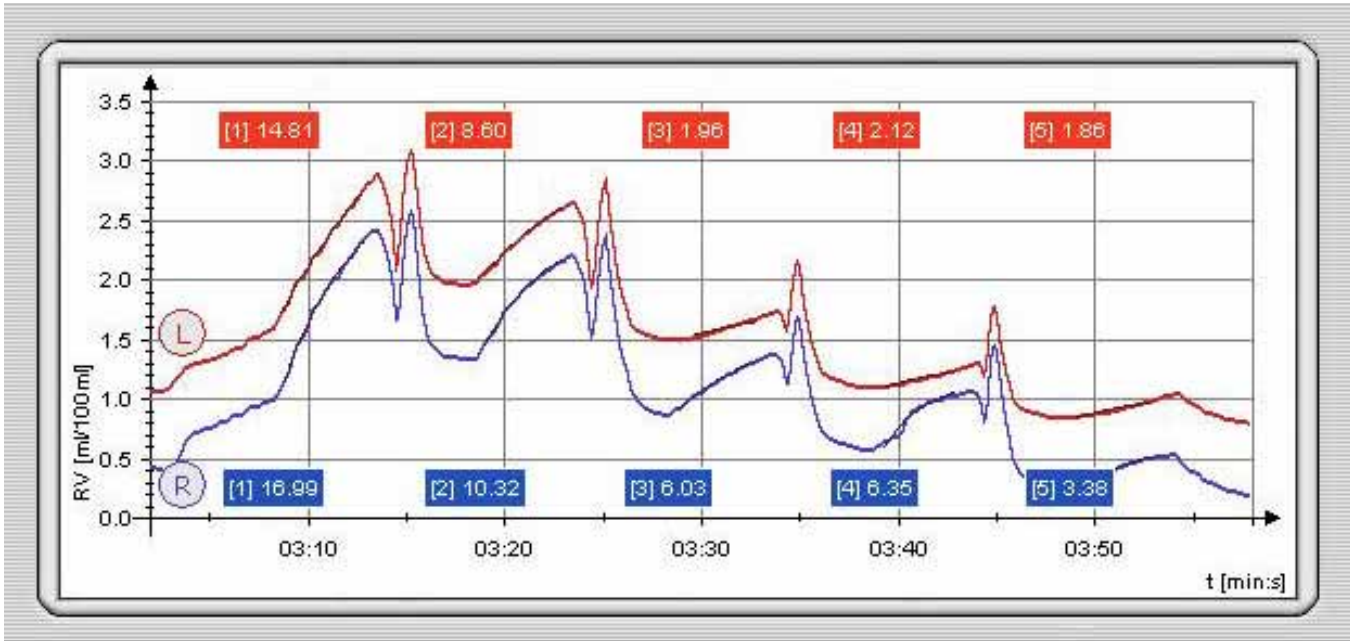
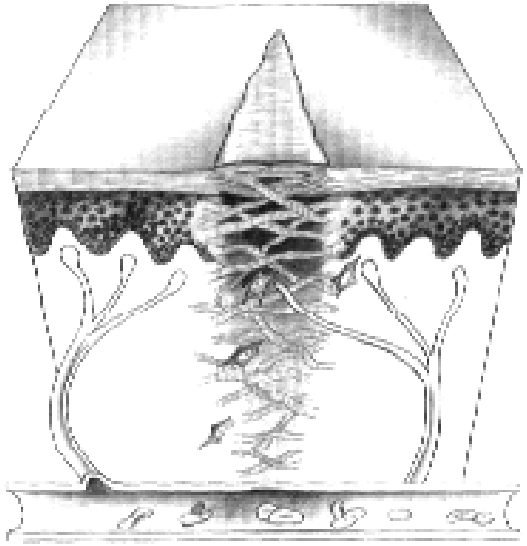


Active hyperemia and flow autoregulation differ in their cause but both result in the production of the same local signals that provoke vasodilation.

- Reactive hyperemia – When an organ or tissue has had its blood supply completely occluded, a profound transient increase in its blood flow occurs as soon as the occlusion is released



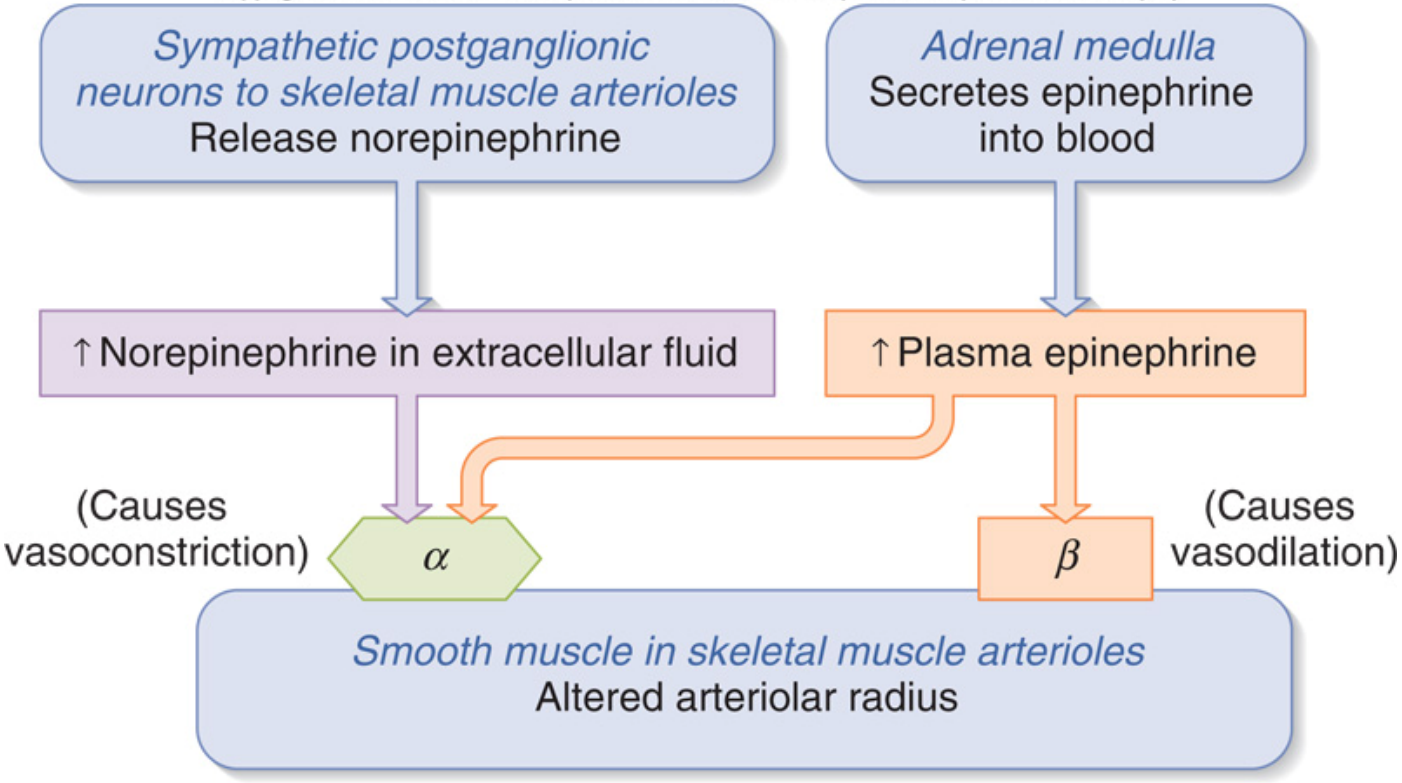
- Response to injury – Tissue injury causes a variety of substances to be released locally from cells or generated from plasma precursors. These substances make arteriolar smooth muscle relax and cause vasodilation in an injured area



Extrinsic Control

- Sympathetic nerves
- Parasympathetic nerves
- Noncholinergic, nonradrenergic autonomic neurons (NO or other noncholinergic vasodilator substances)
- Hormones (epinephrine, angiotensin II, vasopressin, atrial natriuretic peptide)

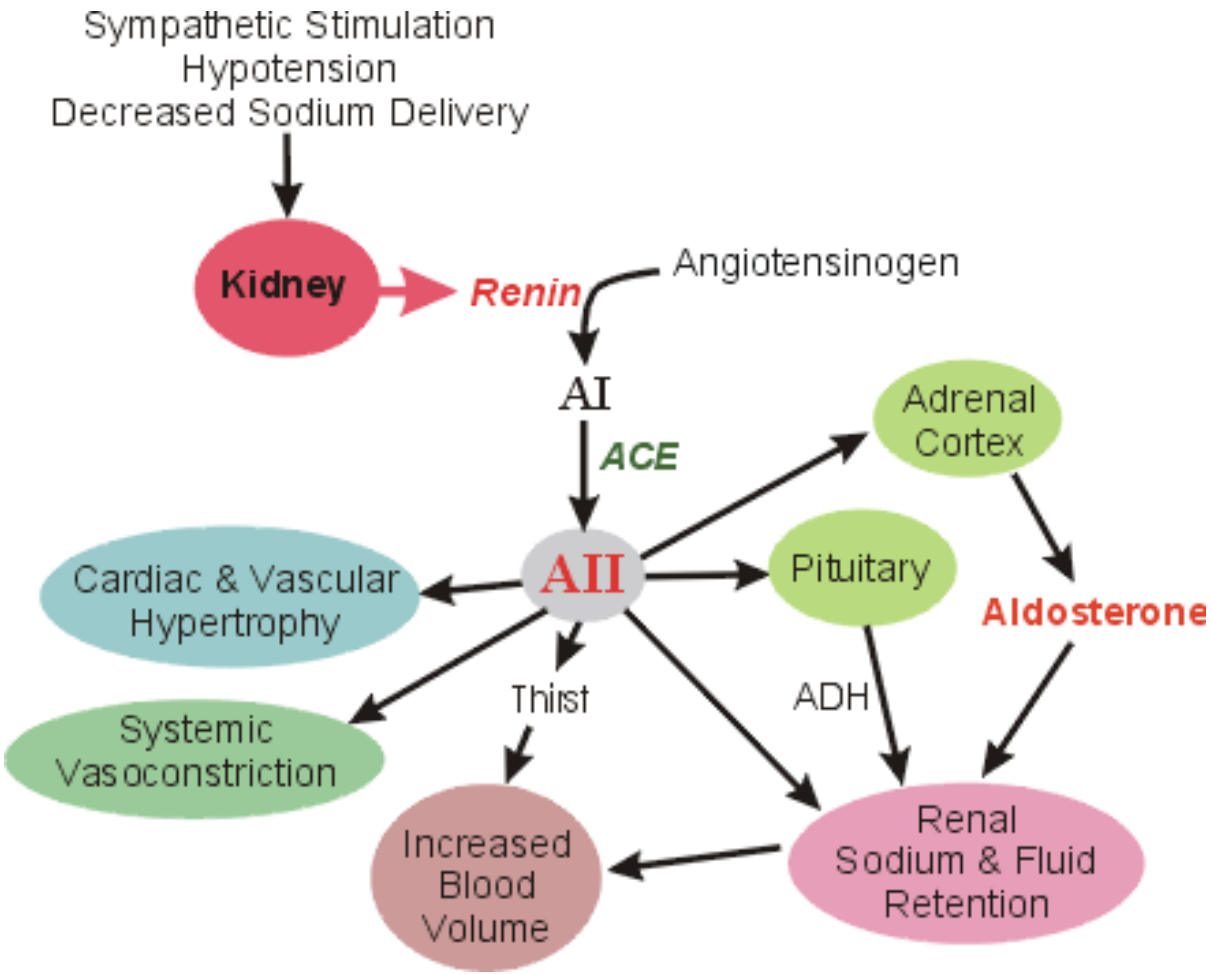
Figure 12-35



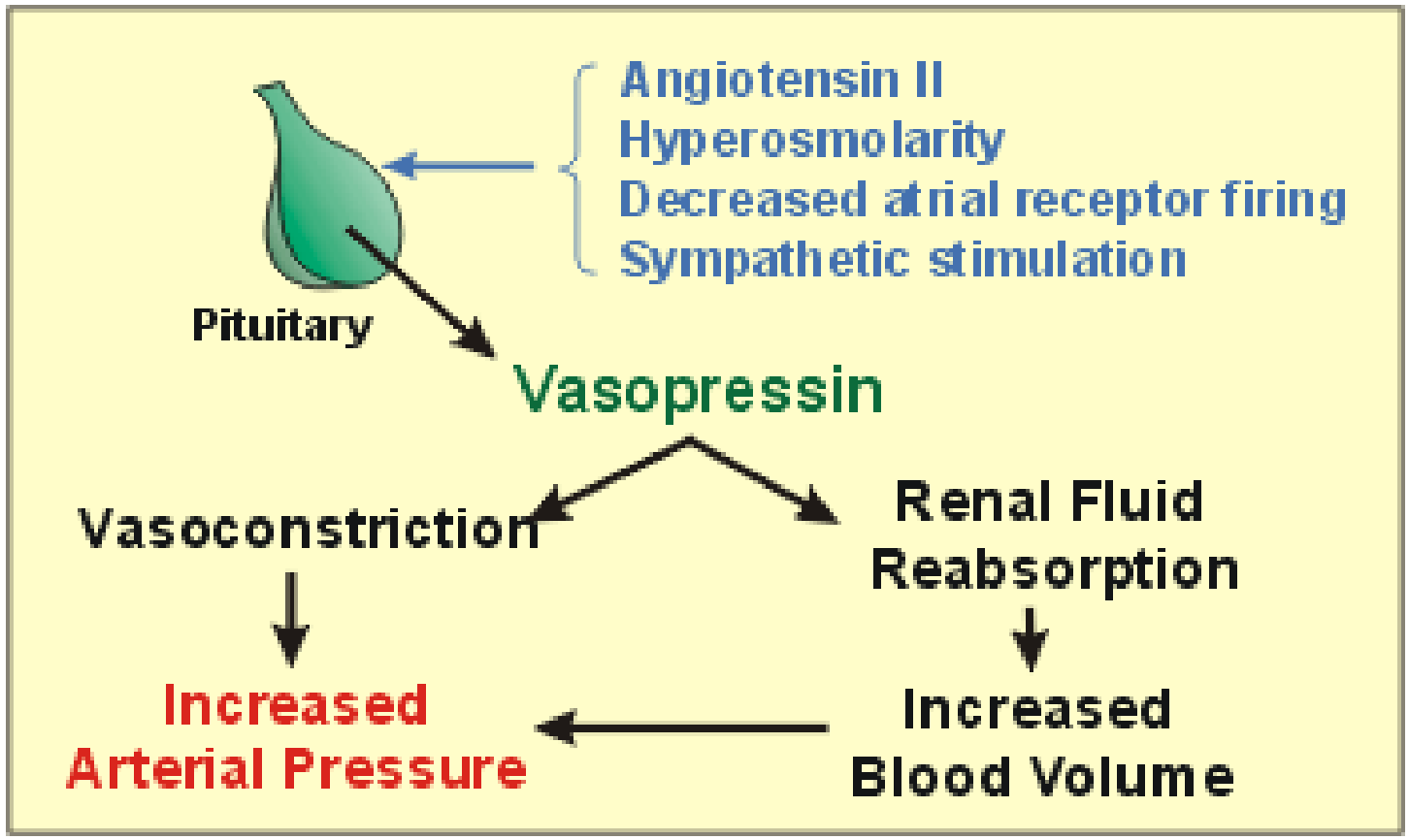
Sympathetic stimulation of *alpha*-adrenergic receptors cause vasoconstriction to decrease blood flow to that location.

Sympathetic stimulation of *beta*-adrenergic receptors lead to vasodilation to cause an increase in blood flow to that location.

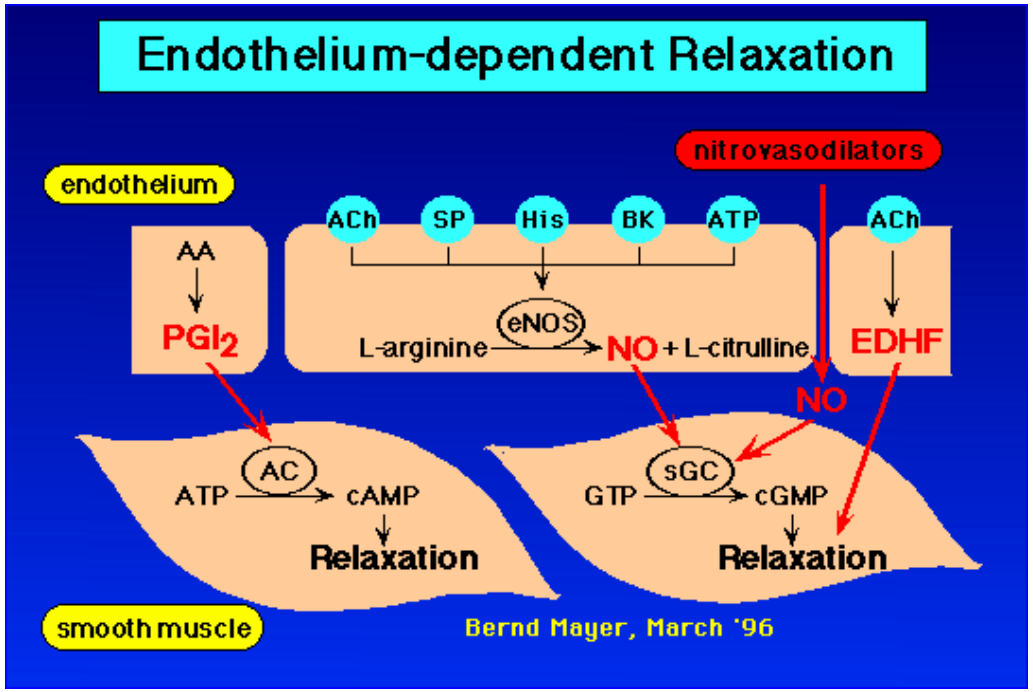
Renin-angiotensin system



Vasopressin



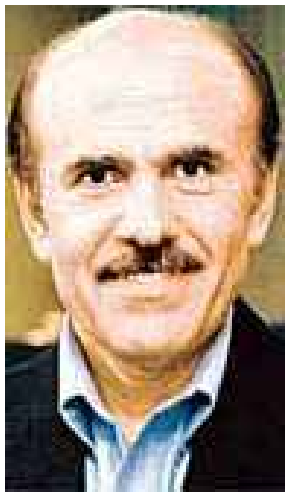
Endothelium-derived vasoactive substances



- Vasodilator factors
  - PGI_2 – prostacyclin
  - EDRF (endothelium-derived relaxing factor, nitric oxide)
  - EDHF (endothelium-dependent hyperpolarizing factor)

The 1998 Nobel Prize in Physiology or Medicine

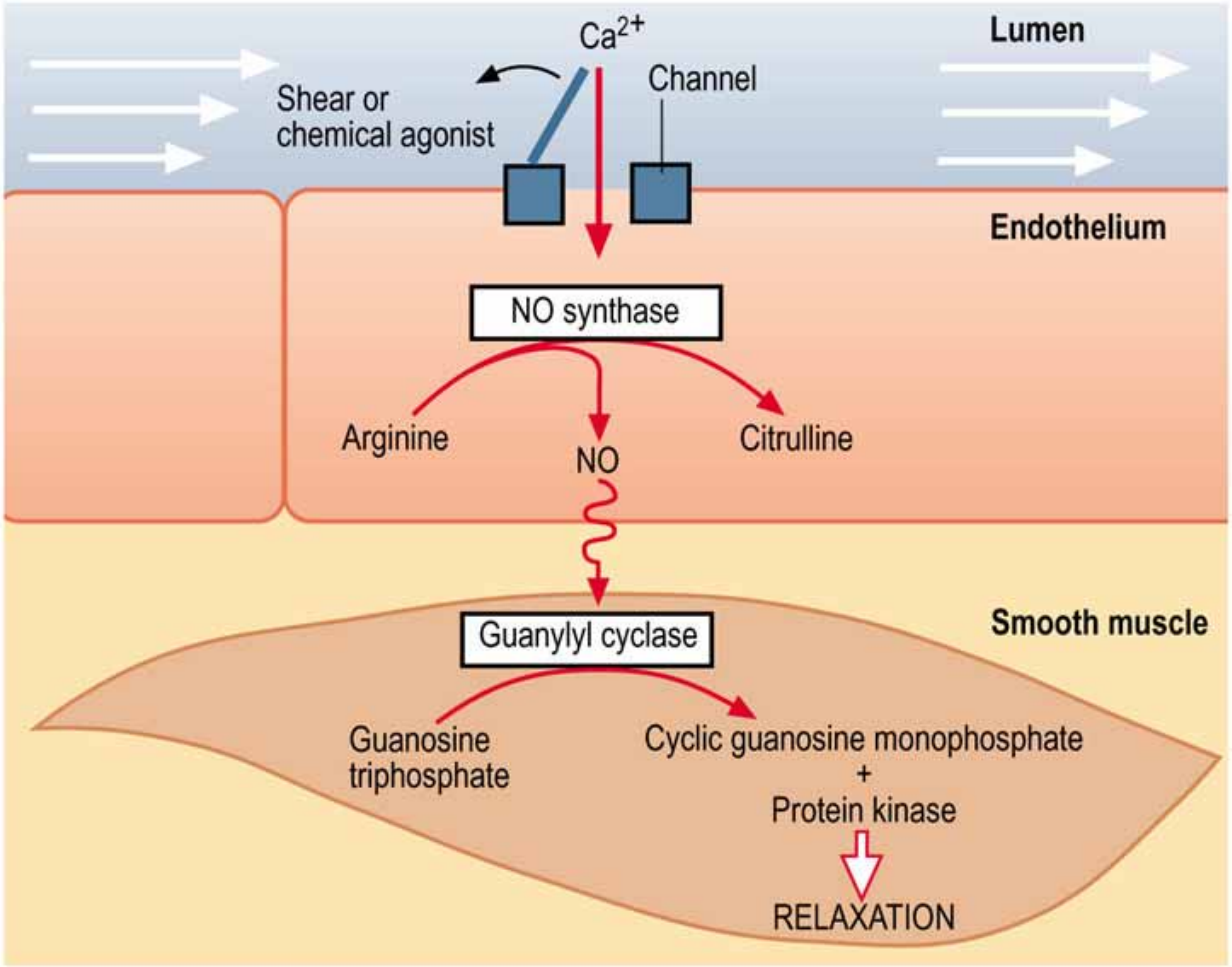
Nitric oxide as a signaling molecule in the cardiovascular system



Louis J Ignarro

Ferid Murad

Robert F Furchgott



- **Vasoconstrictor factors – Endothelin-1**

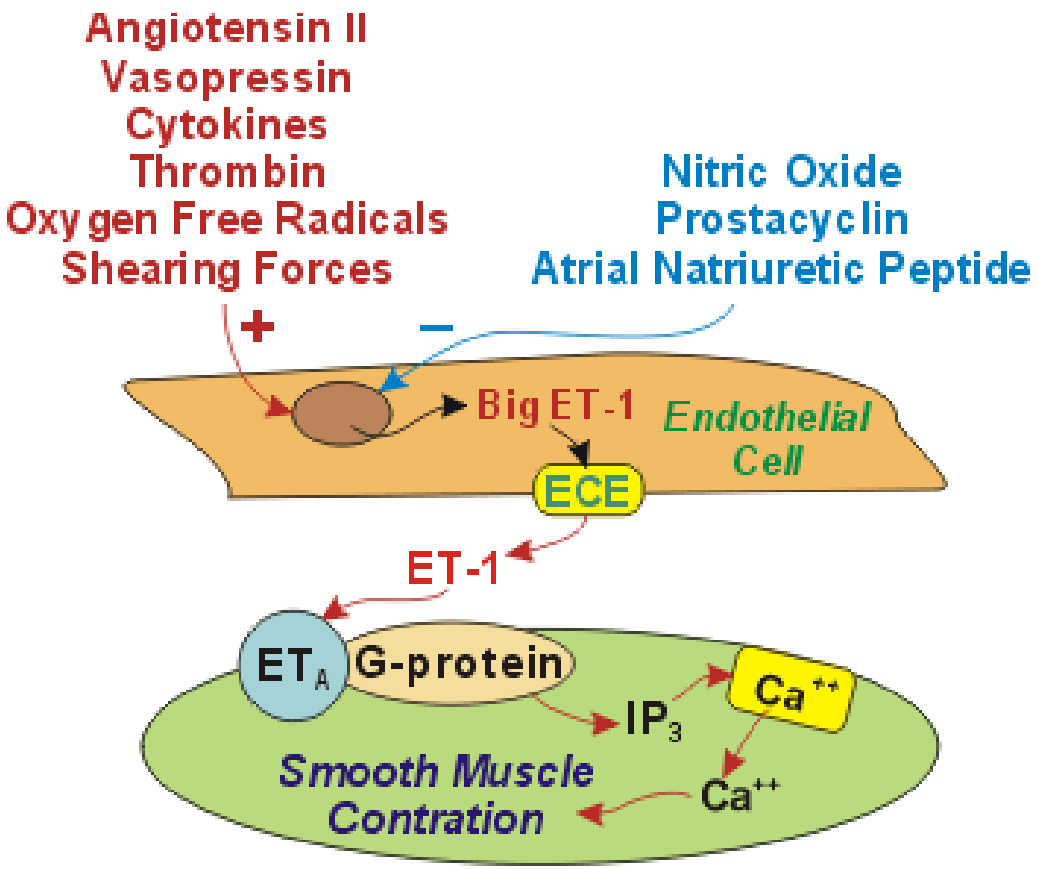


Figure 12-36

Major factors affecting arteriolar radius

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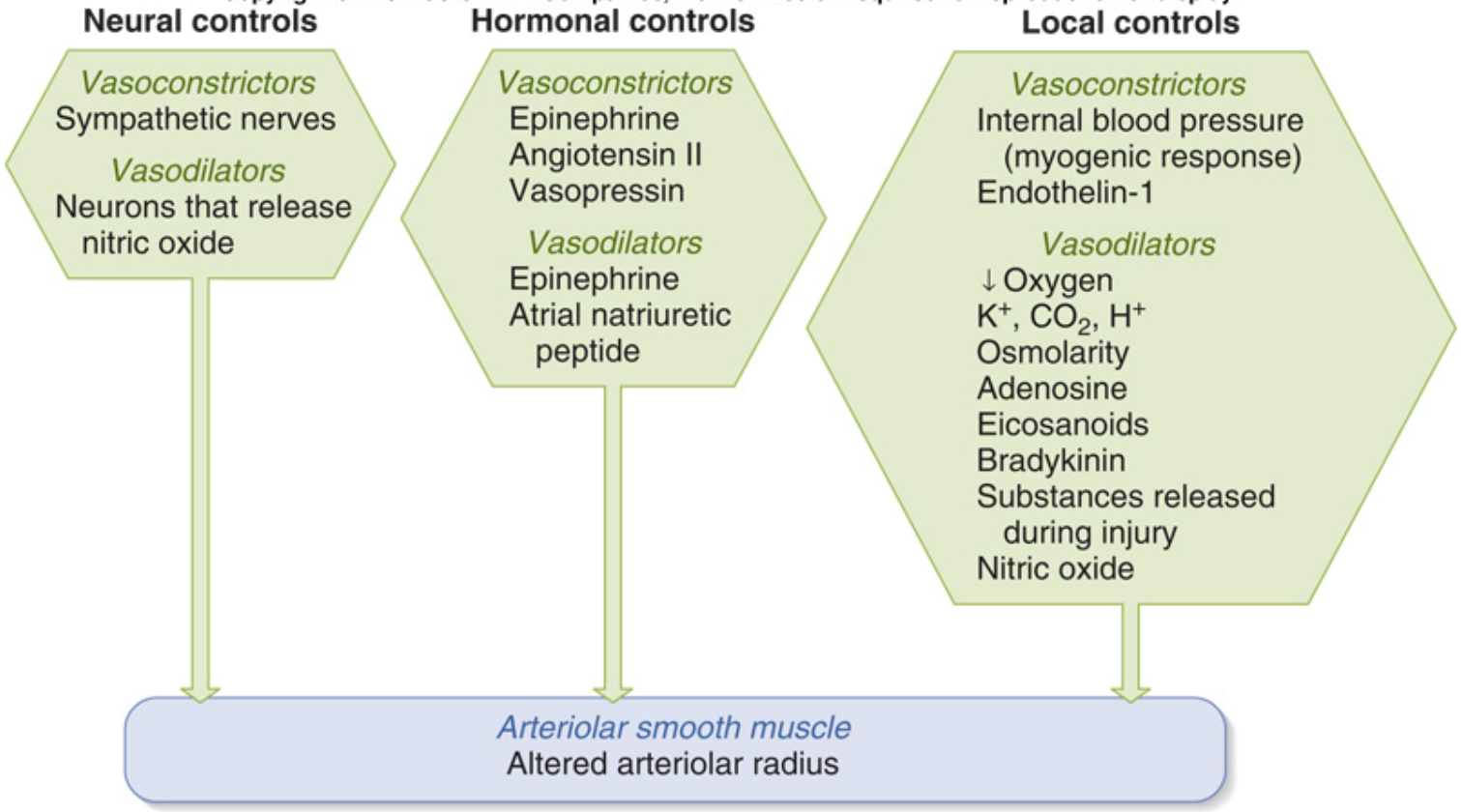

Diversity among signals that influence contraction/relaxation in vascular circular smooth muscle implies a diversity of receptors and transduction mechanisms.

TABLE 12–5 Reference Summary of Arteriolar Control in Specific Organs

Heart

High intrinsic tone; oxygen extraction is very high at rest, and so flow must increase when oxygen consumption increases if adequate oxygen supply is to be maintained.

Controlled mainly by local metabolic factors, particularly adenosine, and flow autoregulation; direct sympathetic influences are minor and normally overridden by local factors.

During systole, aortic semilunar cusps block the entrances to the coronary arteries, and vessels within the muscle wall are compressed; thus coronary flow occurs mainly during diastole.

Skeletal Muscle

Controlled by local metabolic factors during exercise.

Sympathetic nerves cause vasoconstriction (mediated by alpha-adrenergic receptors) in reflex response to decreased arterial pressure.

Epinephrine causes vasodilation via beta-2 adrenergic receptors when present in low concentration, and vasoconstriction, via alpha-adrenergic receptors, when present in high concentration.

GI Tract, Spleen, Pancreas, and Liver ("Splanchnic Organs")

Actually two capillary beds partially in series with each other; blood from the capillaries of the GI tract, spleen, and pancreas flows via the portal vein to the liver. In addition, the liver also receives a separate arterial blood supply.

Sympathetic nerves cause vasoconstriction, mediated by alpha-adrenergic receptors, in reflex response to decreased arterial pressure and during stress. In addition, venous constriction causes displacement of a large volume of blood from the liver to the veins of the thorax.

Increased blood flow occurs following ingestion of a meal and is mediated by local metabolic factors, neurons, and hormones secreted by the GI tract.

Kidneys

Flow autoregulation is a major factor.

Sympathetic nerves cause vasoconstriction, mediated by alpha-adrenergic receptors, in reflex response to decreased arterial pressure and during stress. Angiotensin II is also a major vasoconstrictor. These reflexes help conserve sodium and water.

Brain

Excellent flow autoregulation.

Distribution of blood within the brain is controlled by local metabolic factors.

Vasodilation occurs in response to increased concentration of carbon dioxide in arterial blood.

Influenced relatively little by the autonomic nervous system.

Skin

Controlled mainly by sympathetic nerves, mediated by alpha-adrenergic receptors; reflex vasoconstriction occurs in response to decreased arterial pressure and cold, whereas vasodilation occurs in response to heat.

Substances released from sweat glands and noncholinergic, nonadrenergic neurons also cause vasodilation.

Venous plexus contains large volumes of blood, which contributes to skin color.

Lungs

Very low resistance compared to systemic circulation.

Controlled mainly by gravitational forces and passive physical forces within the lung.

Constriction, mediated by local factors, occurs in response to low oxygen concentration—just opposite that which occurs in the systemic circulation.

Capillaries

- Main function:
  - Exchange of nutrients and metabolic end products

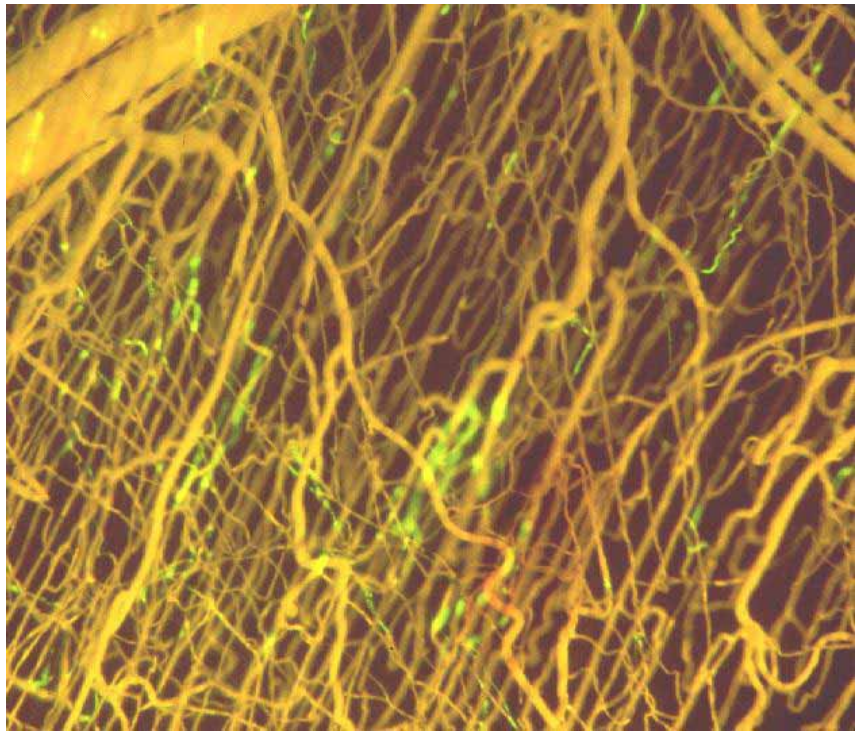

Figure 12-38

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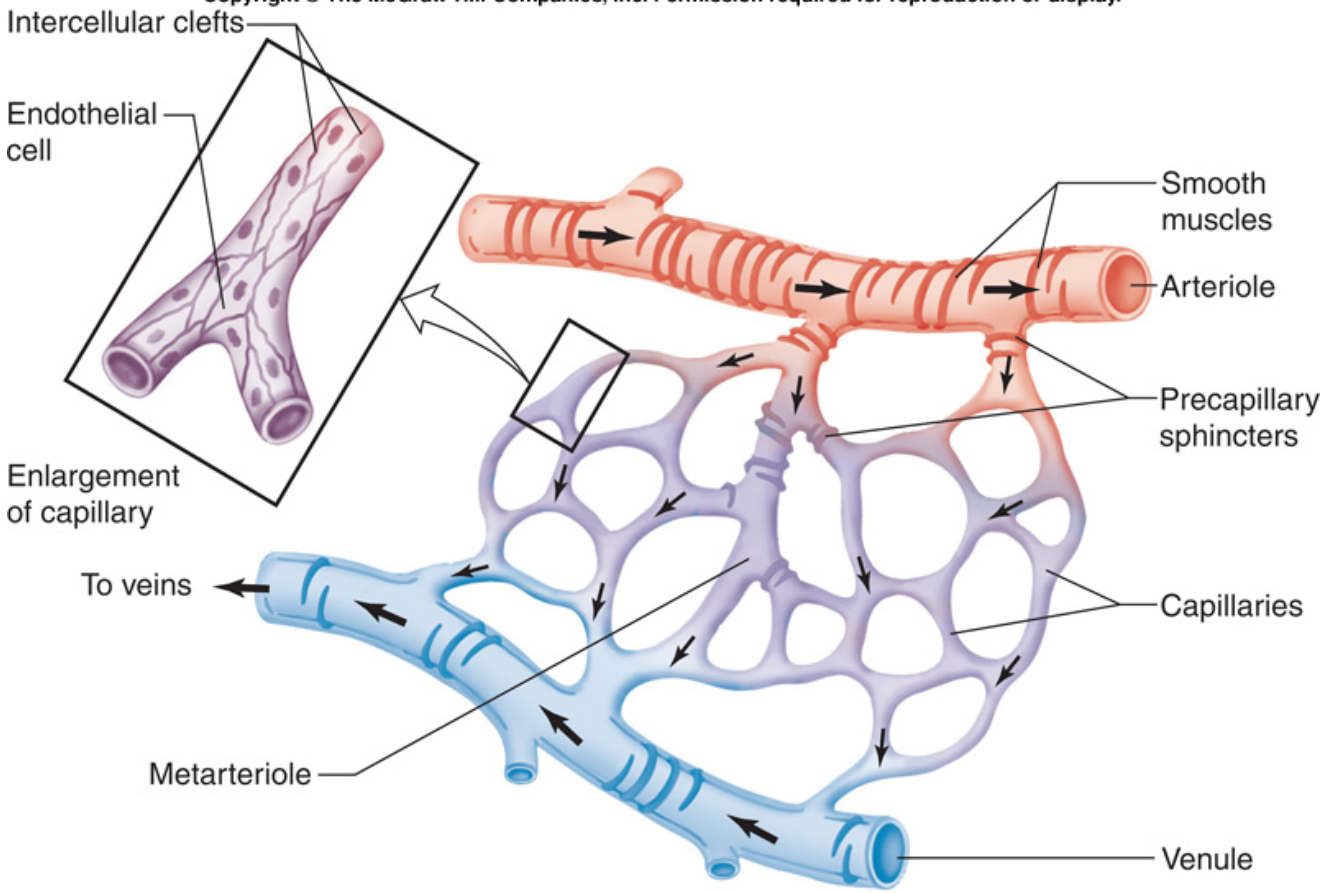

Capillaries lack smooth muscle, but contraction/relaxation of circular smooth muscle in upstream metarterioles and precapillary sphincters determine the volume of blood each capillary receives.

Figure 12-37

Capillary walls are a single endothelial cell in thickness.

The capillary is the primary point exchange between the blood and the interstitial fluid (ISF).

Intercellular clefts assist the exchange.

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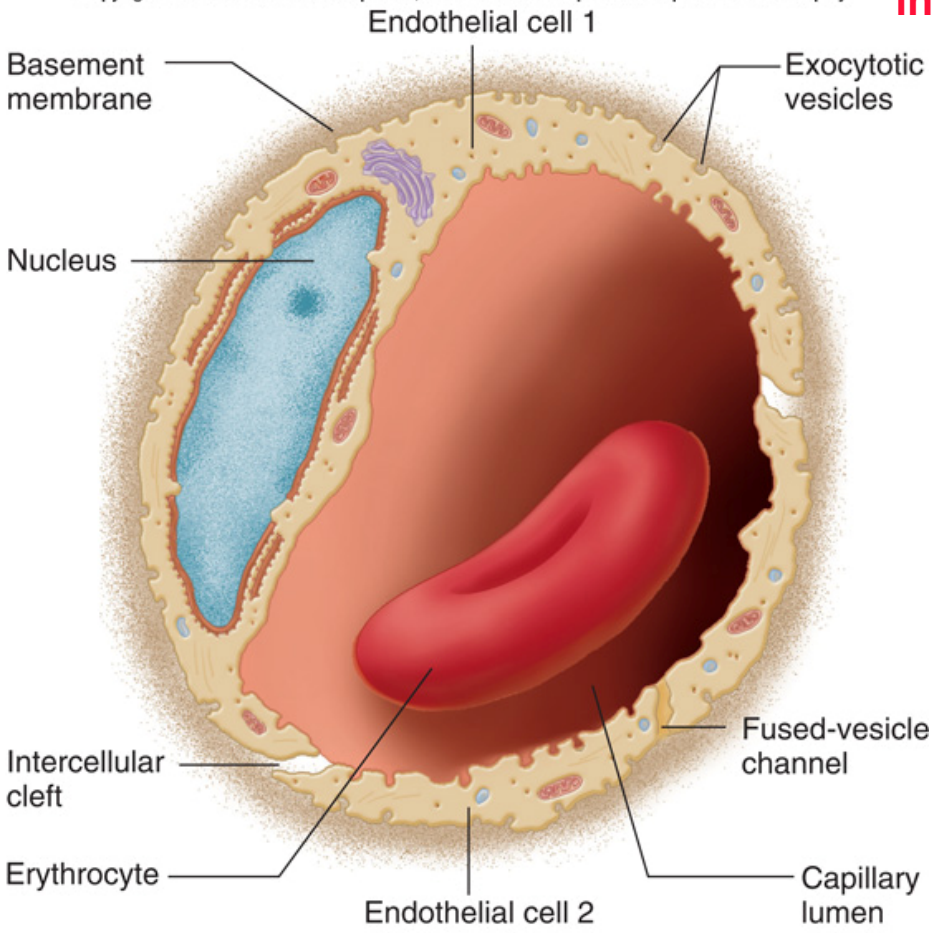
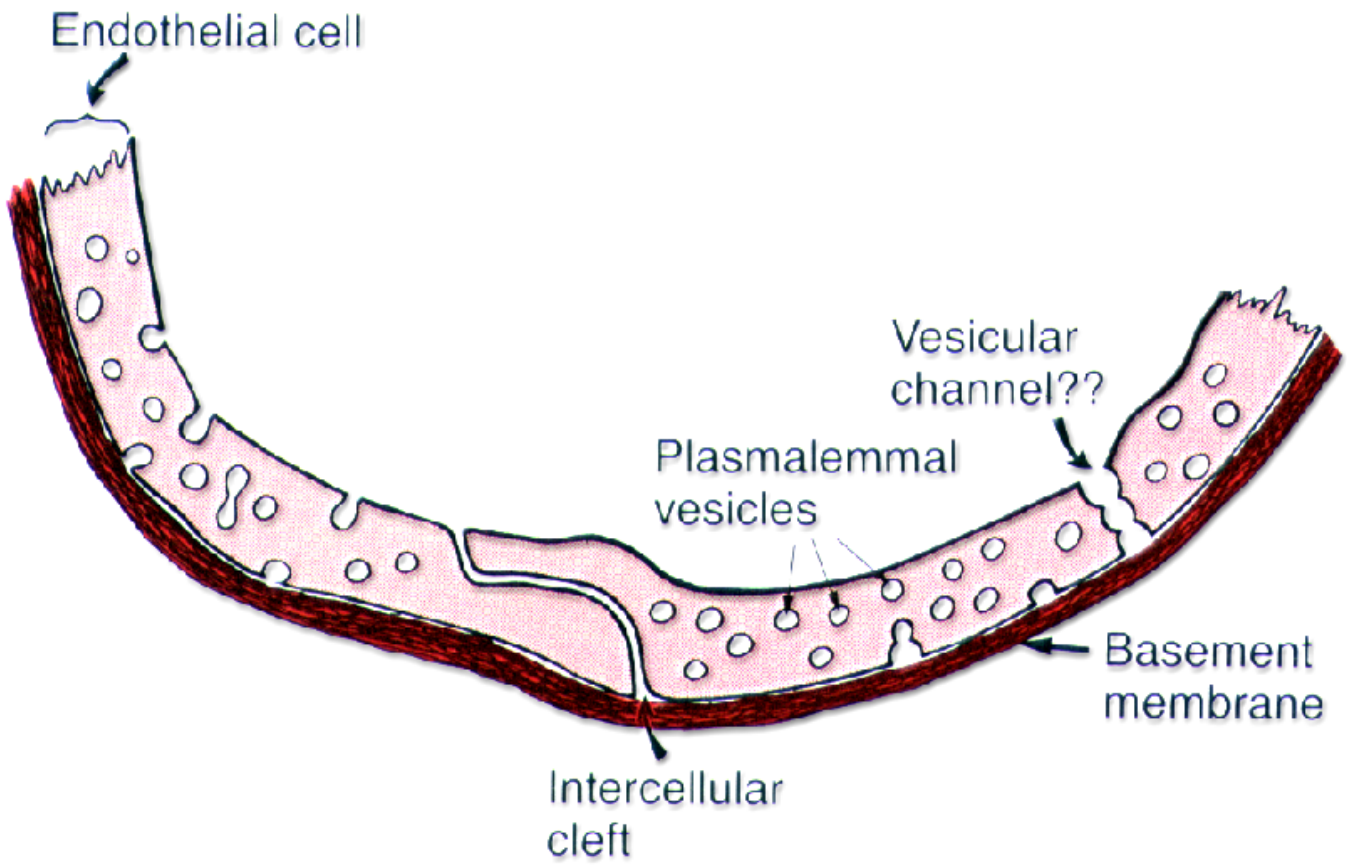


(a)

Structure of capillary wall



Structure of the capillary wall

- Continuous: found in muscle, skin, lung, central nervous system
- Fenestrated: found in exocrine glands, renal glomeruli, intestinal mucosa
- Discontinuous: found in liver, spleen, bone marrow

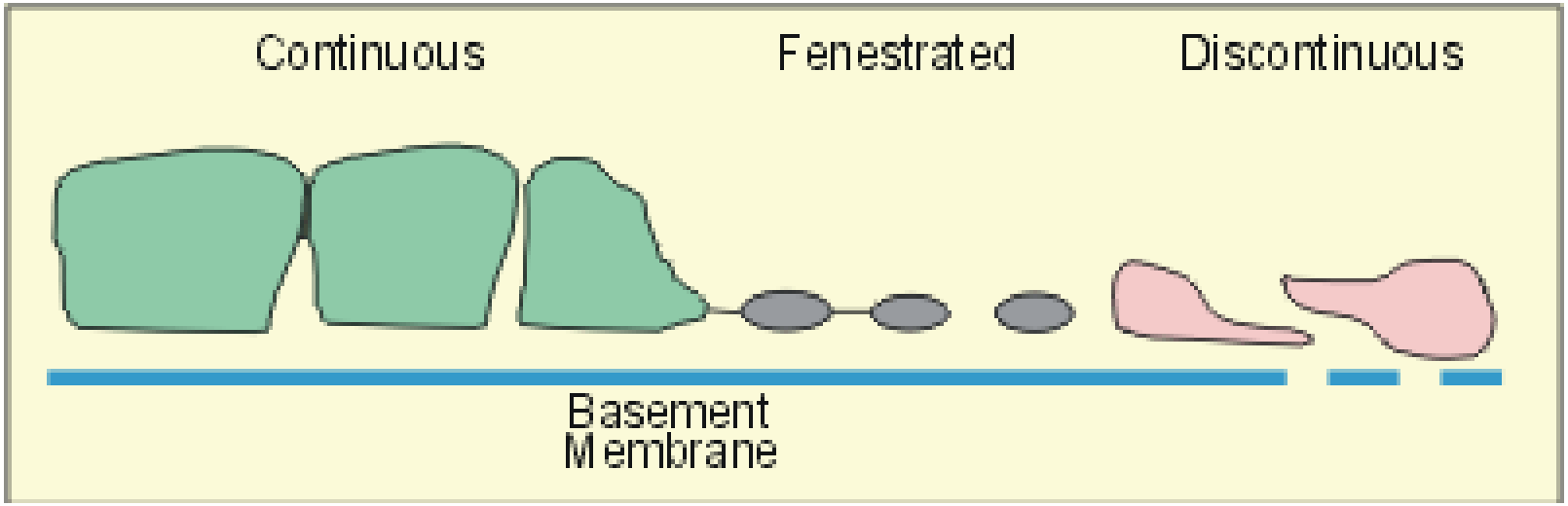
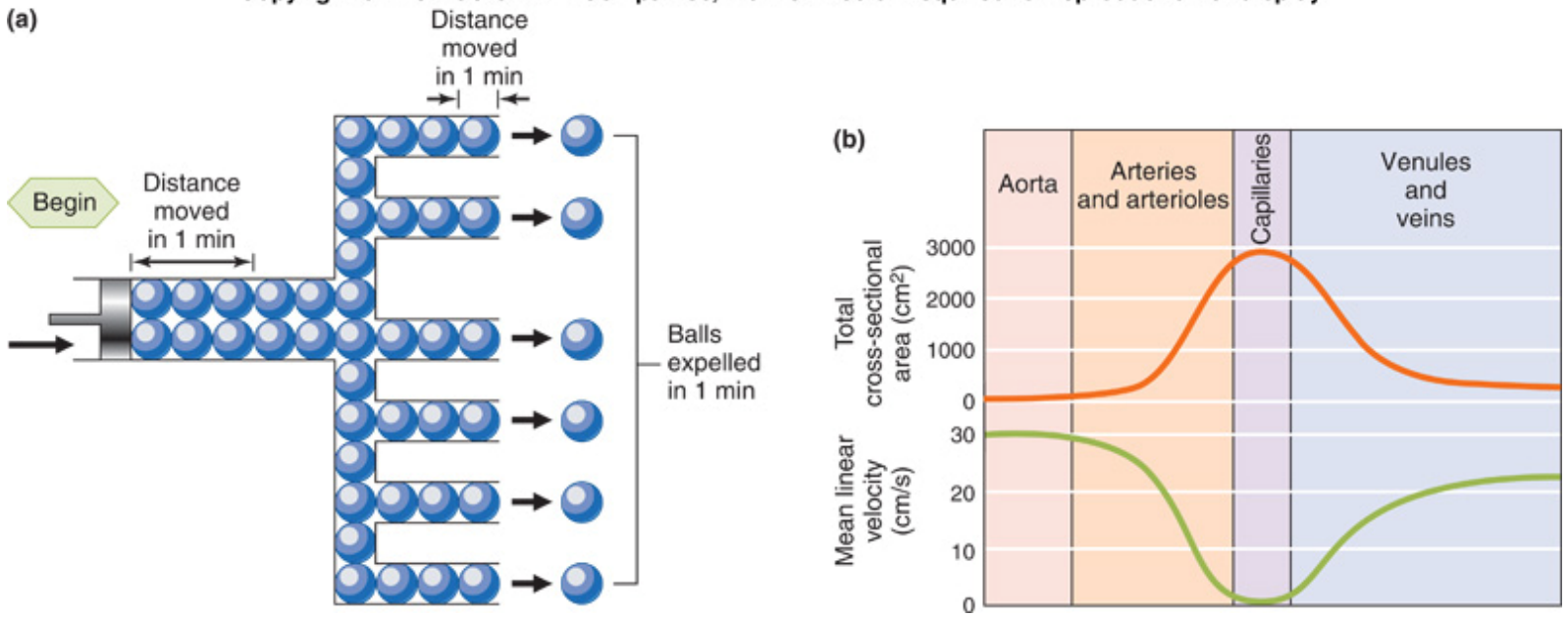


Figure 12-39

Relationship between total cross-sectional area and flow velocity



Six balls *in* per minute

mandates six balls *out* per minute.

Therefore, the velocity of the balls in the smaller tubes is slower.

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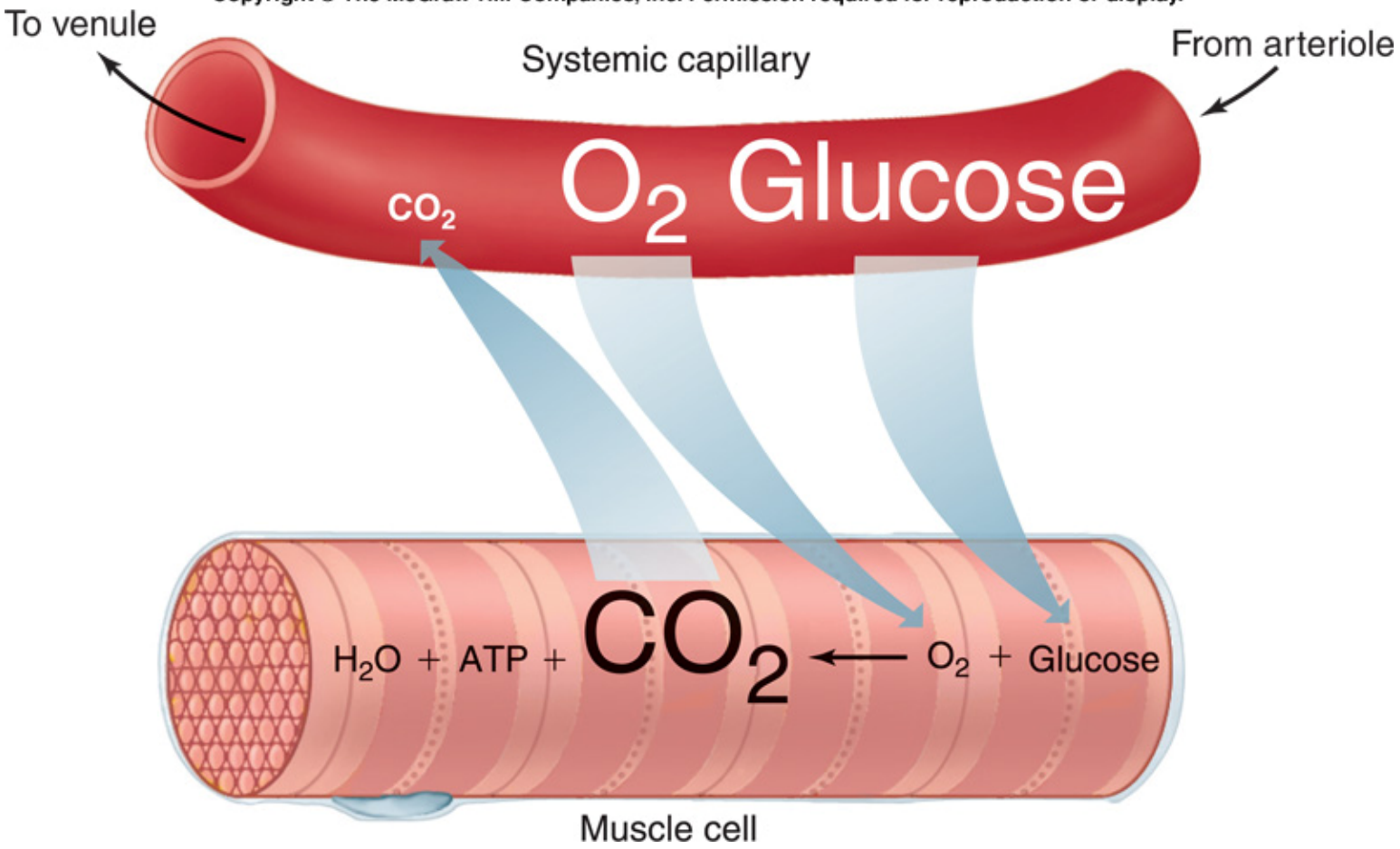


There are many, many capillaries, each with slow-moving blood in it, resulting in adequate time and surface area for exchange between the capillary blood and the ISF.

- Diffusion
- Pinocytosis
- Filtration and Reabsorption

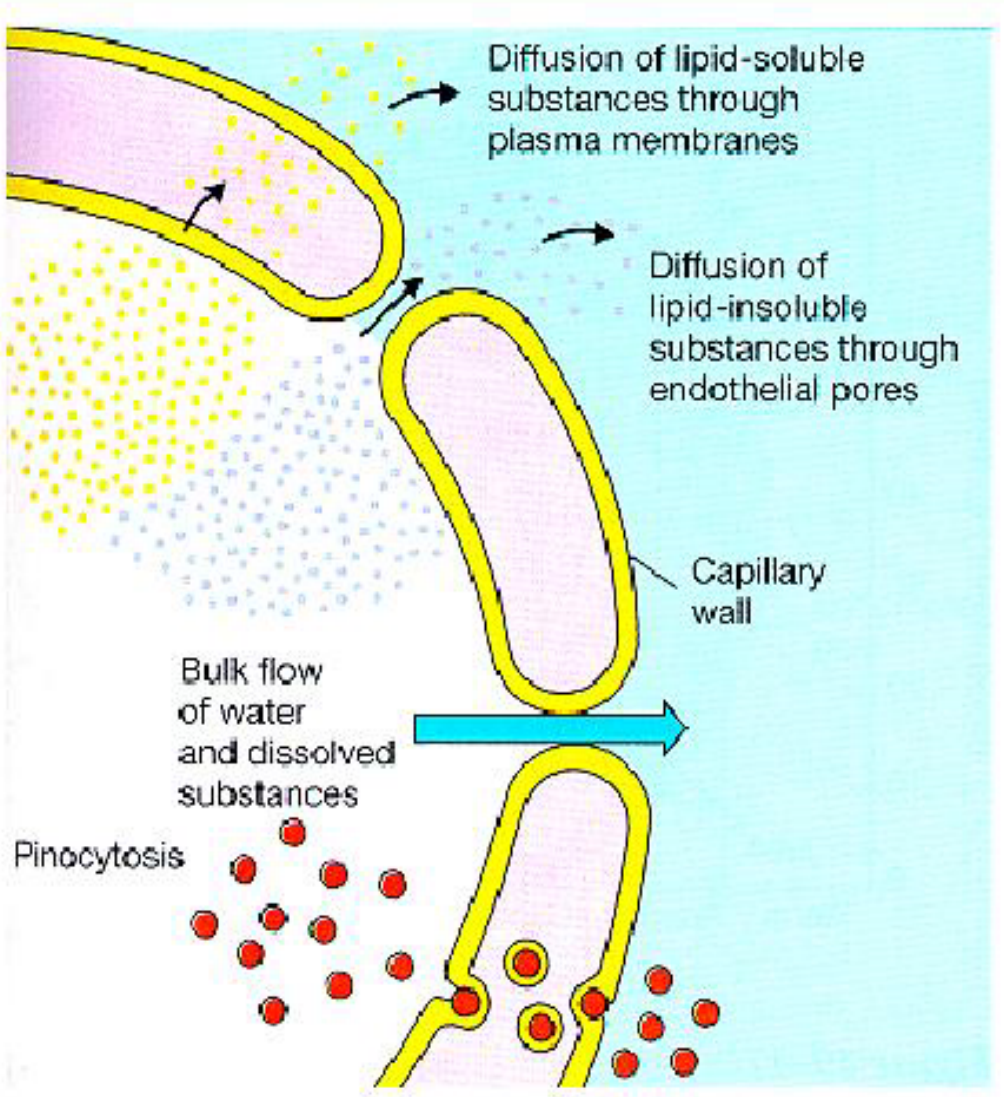
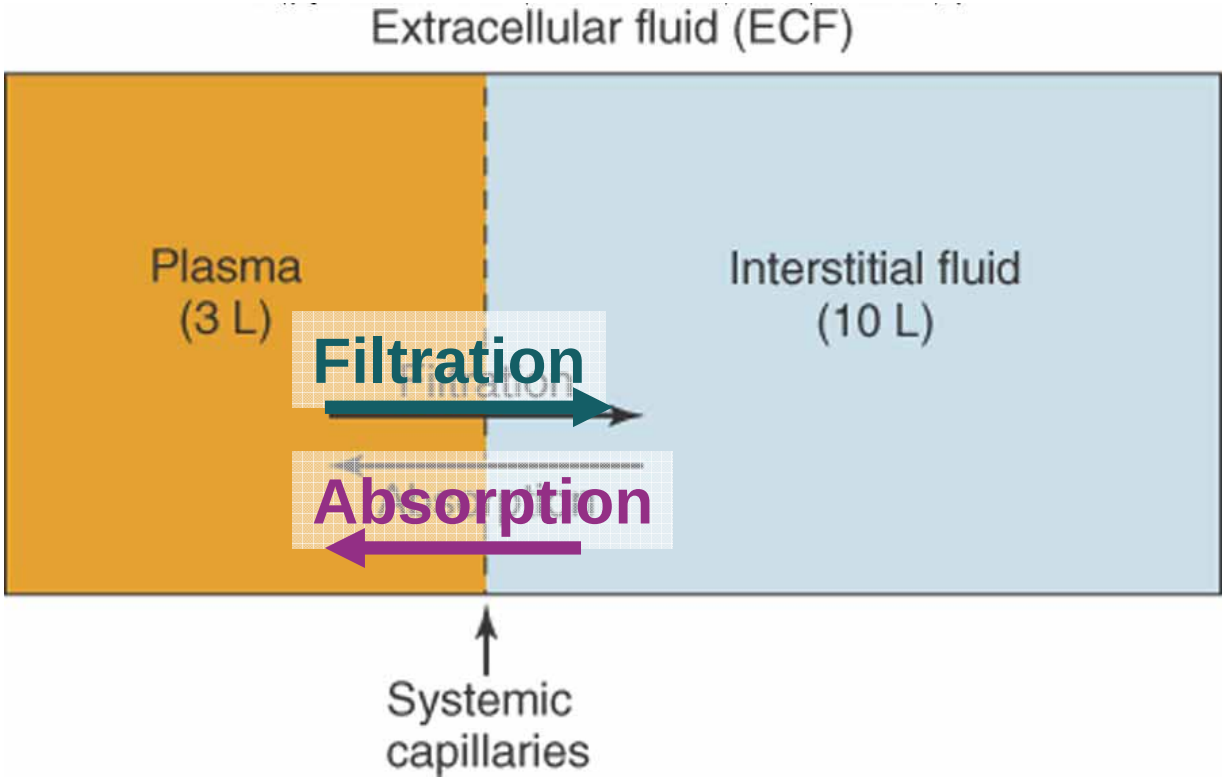


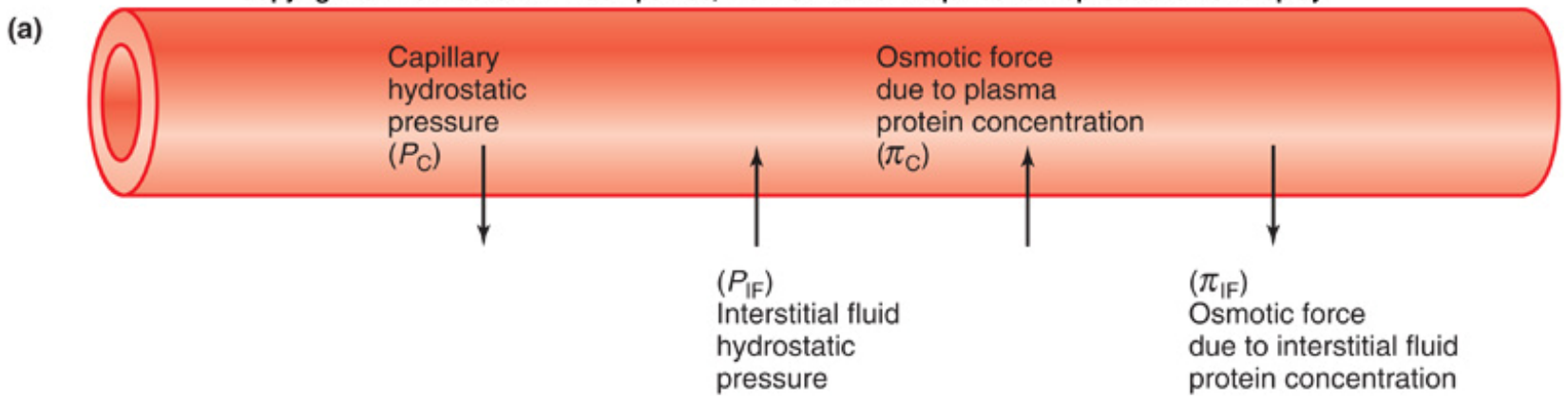
Figure 12-41

Movement of fluid and solutes out of the blood is called filtration.

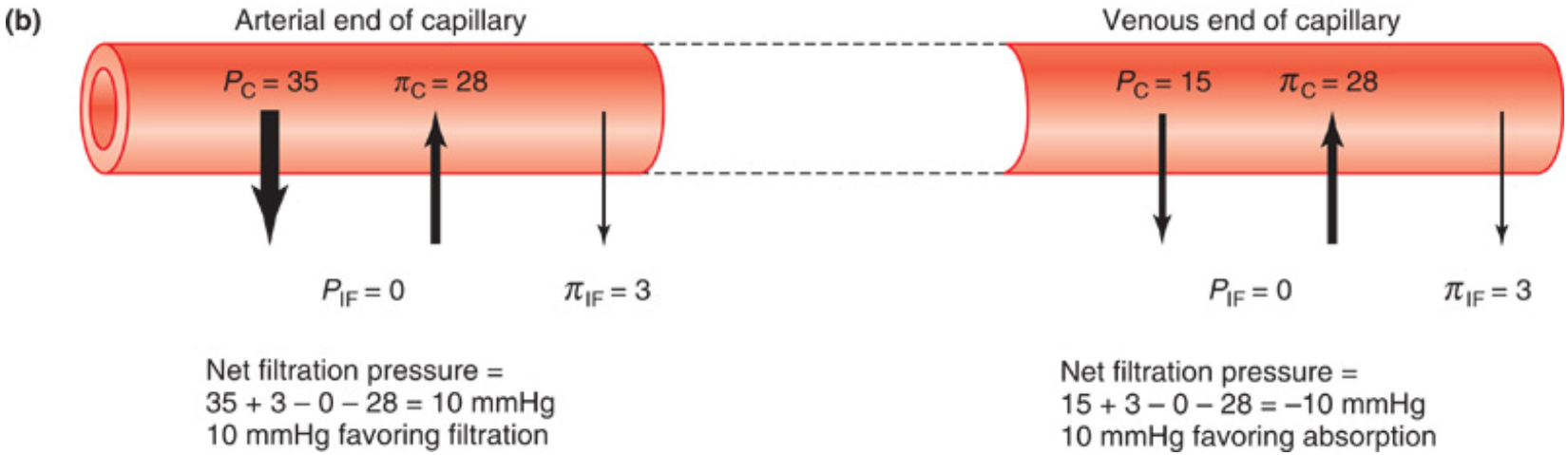


Movement of fluid and solutes into the blood is called absorption.

Net filtration pressure (or Effective filtration pressure)

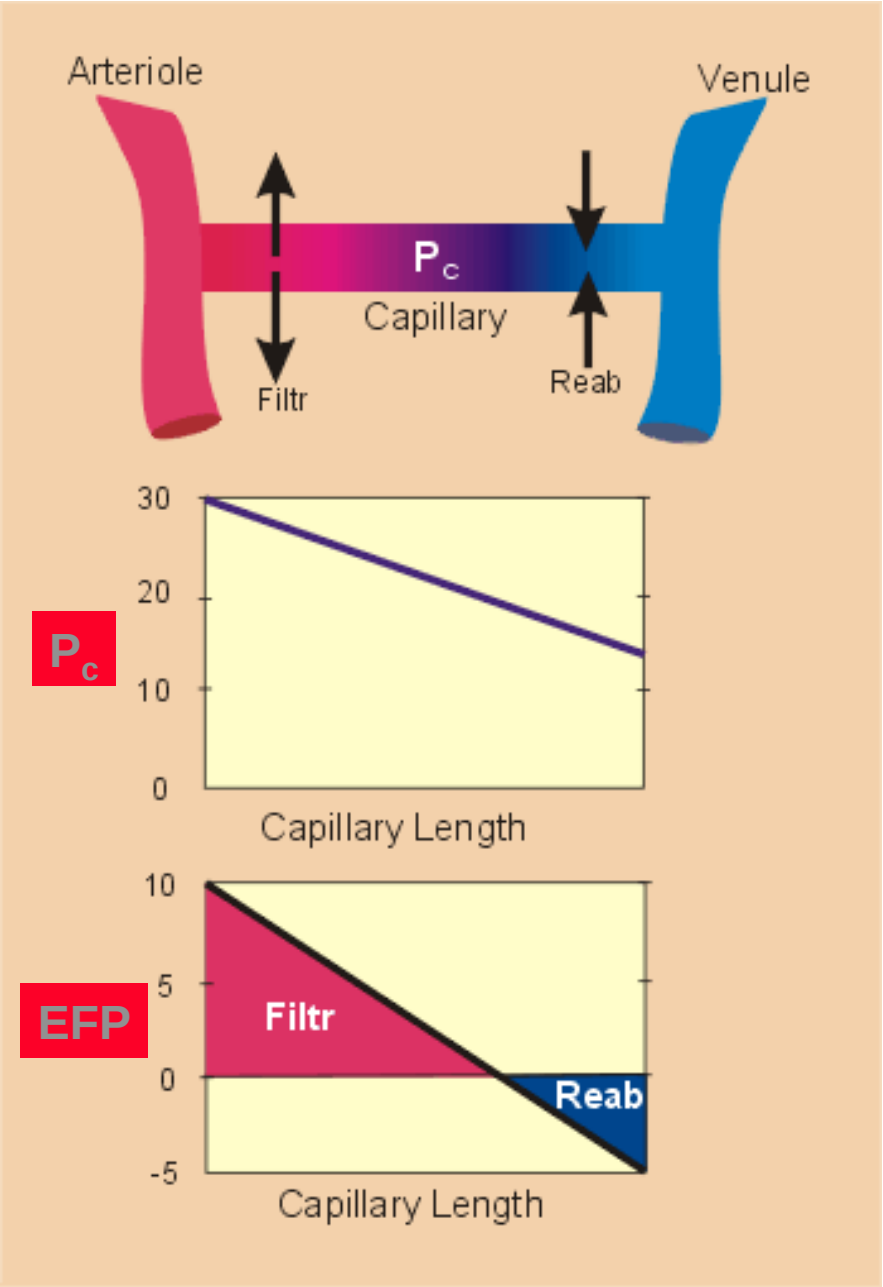


Net filtration pressure = $P_C + \pi_{IF} - P_{IF} - \pi_C$



EFP + →Filtration

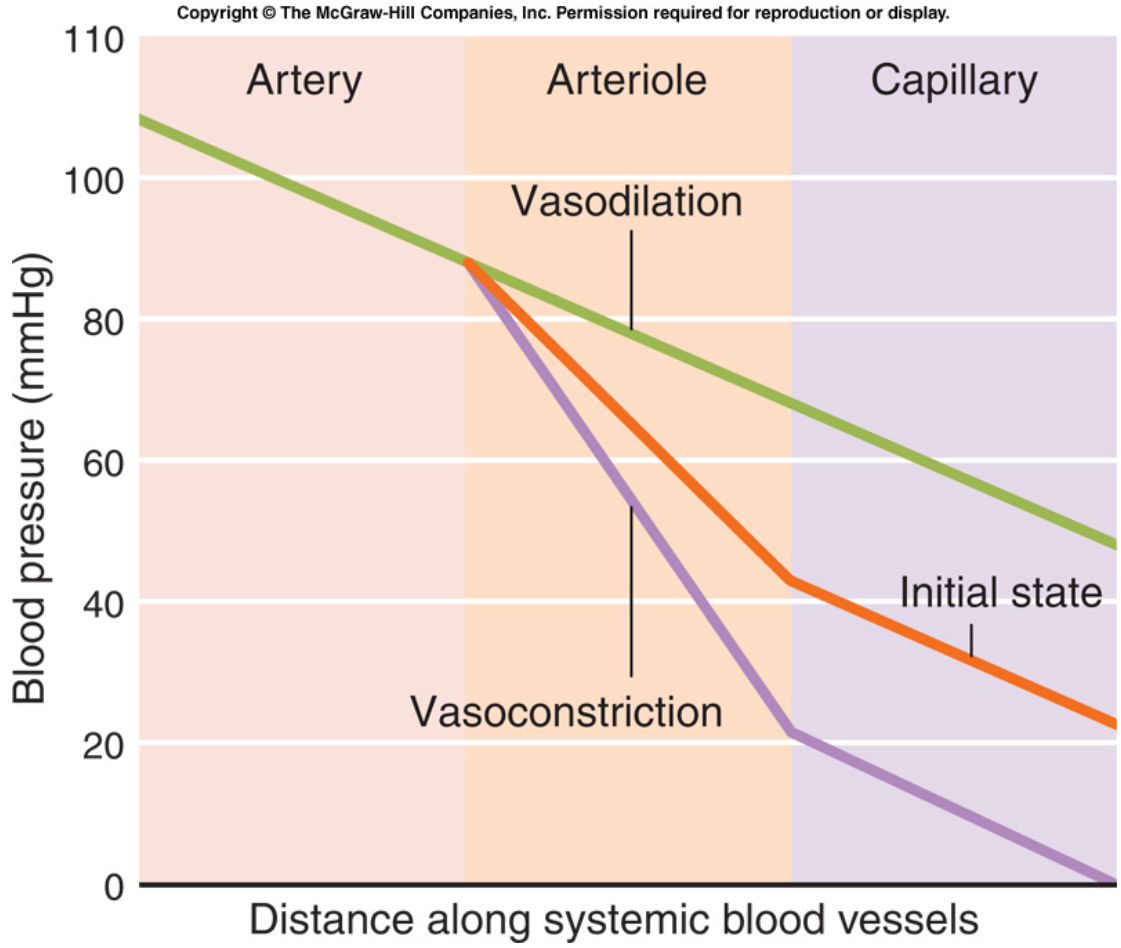
EFP - → Reabsorption



Click here to play the
Fluid Change Across Capillary Wall
Flash Animation

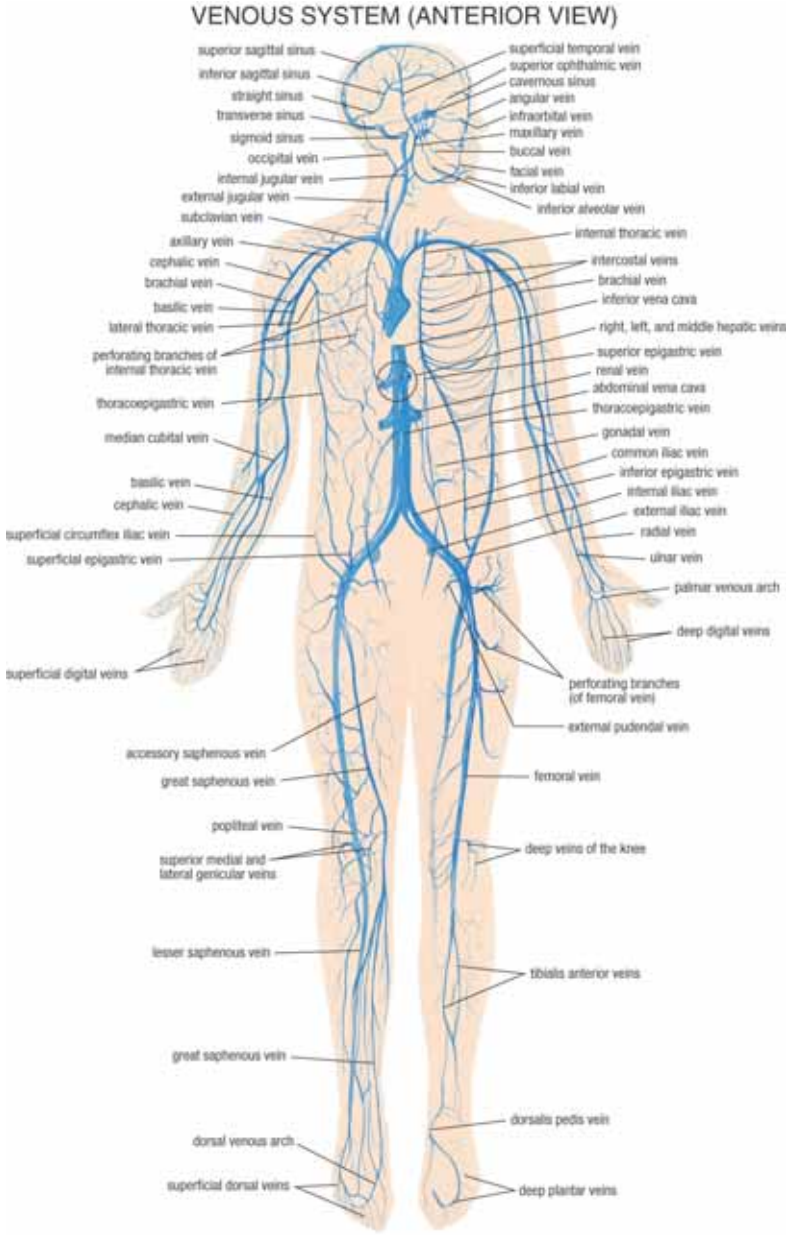
Figure 12-43

Effects of arteriolar vasodilation or vasoconstriction on capillary blood pressure



Dynamic changes in vasodilation/vasoconstriction in the arterioles regulate downstream pressures and flow rates.

Venous pressure and venous return



- Venous pressure
  - Peripheral venous pressure——

    the pressure in the peripheral veins
  - Central venous pressure (CVP)——

    the pressure in the thoracic vena cava & the right atrium 4~12cmH_2O

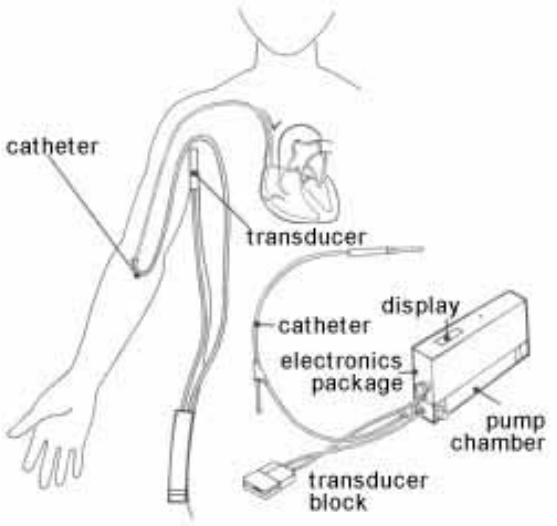
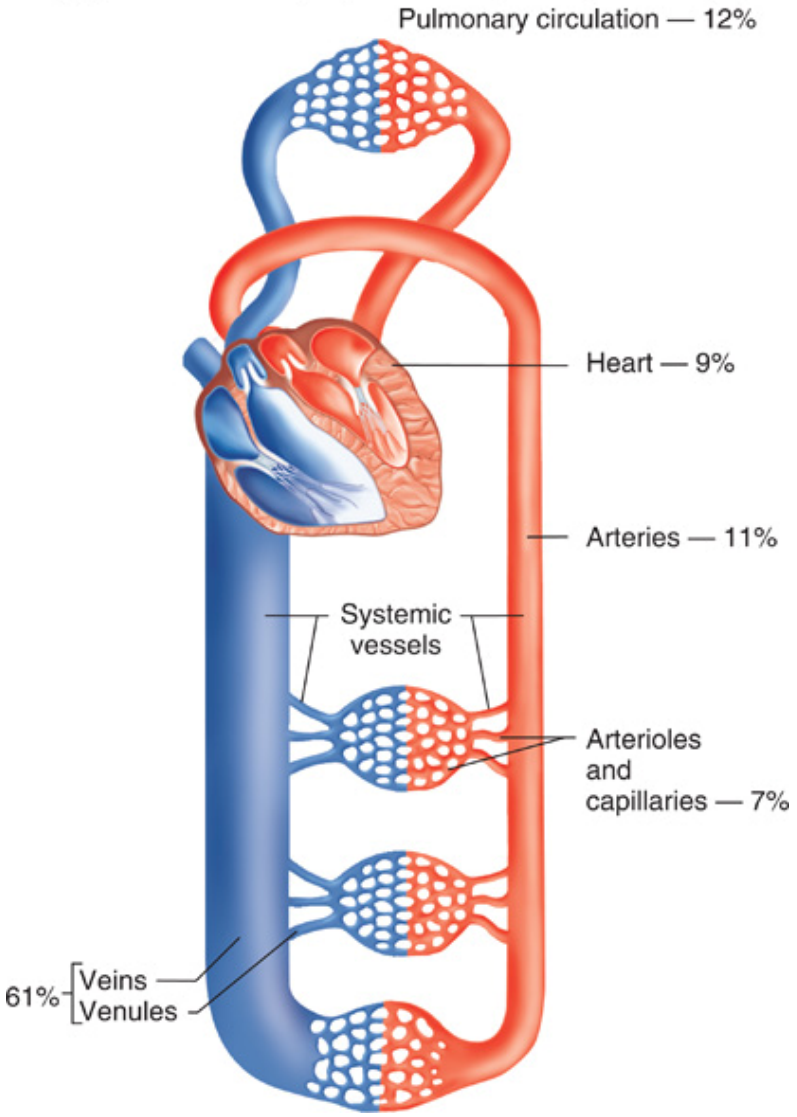


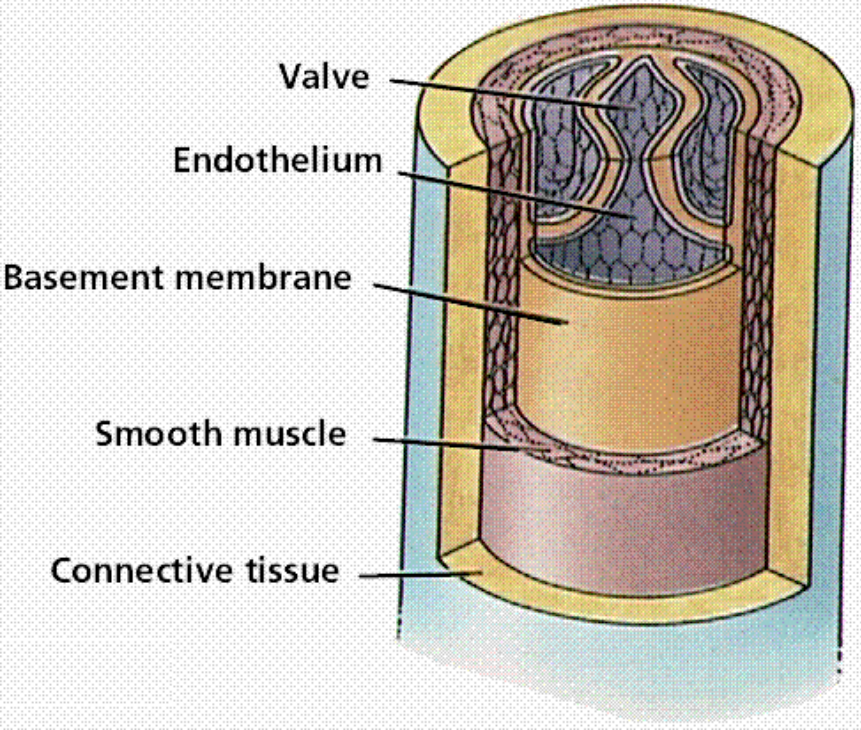
Figure 12-44

At rest, approx. 60% of the total blood volume is in the veins. Sympathetically mediated venoconstriction can substantially increase venous return to the heart.

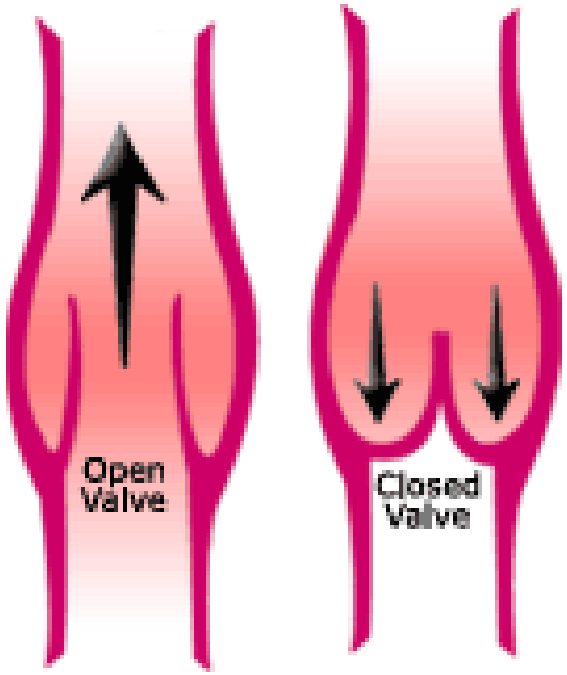


Determinants of venous pressure

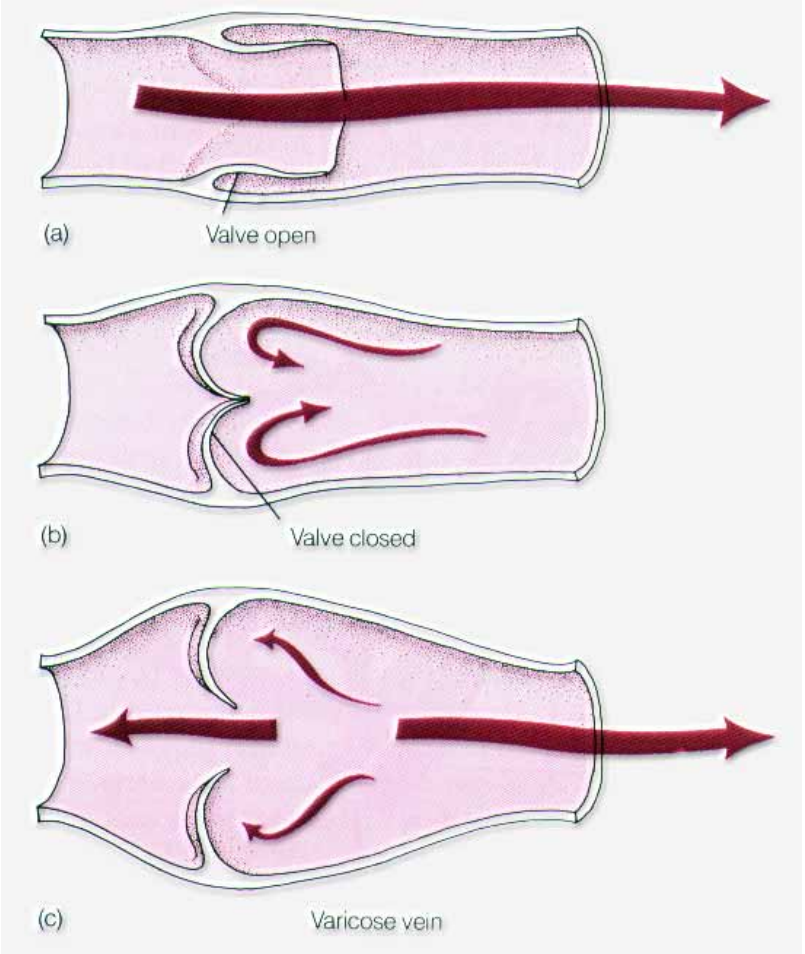
- Contraction of venous smooth muscle
  - Sympathetic neurons
  - Hormonal and paracrine vasodilators and vasoconstrictors
- Skeletal muscle pump
- Respiratory pump



Venous valve



Varicose vein



Varicose vein

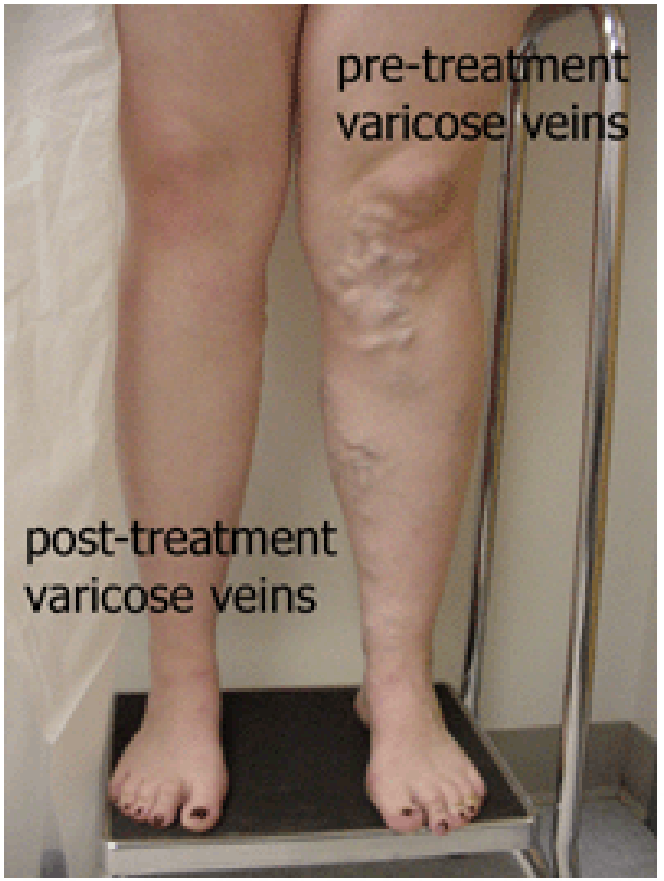
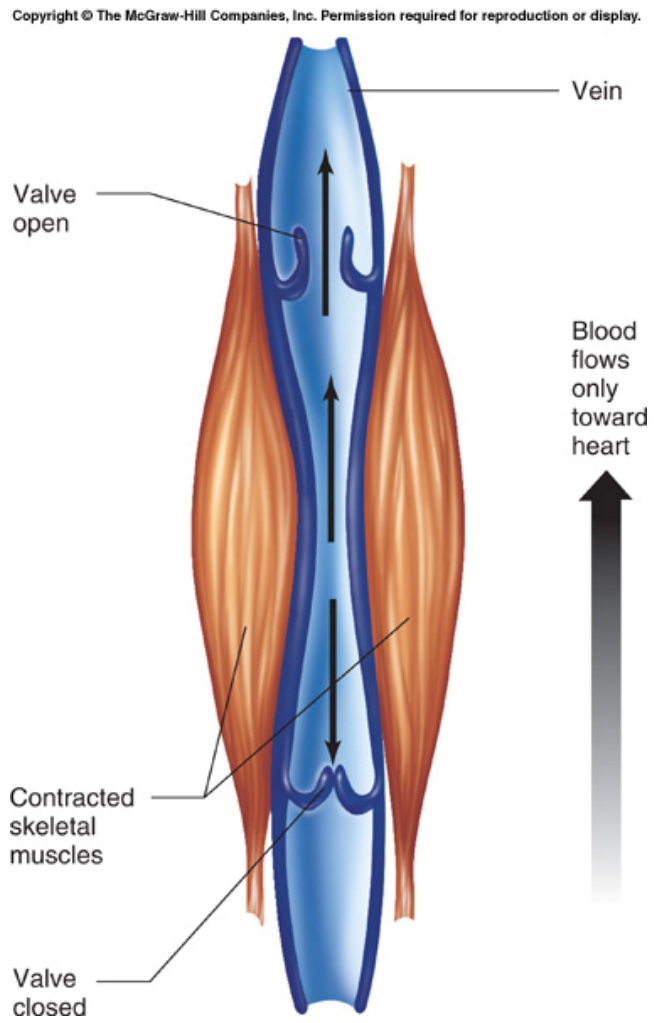


Figure 12-45



Venous flow is assisted by the skeletal muscle pump mechanism working in combination with one-way valves.

Respiratory activity (Respiratory pump)

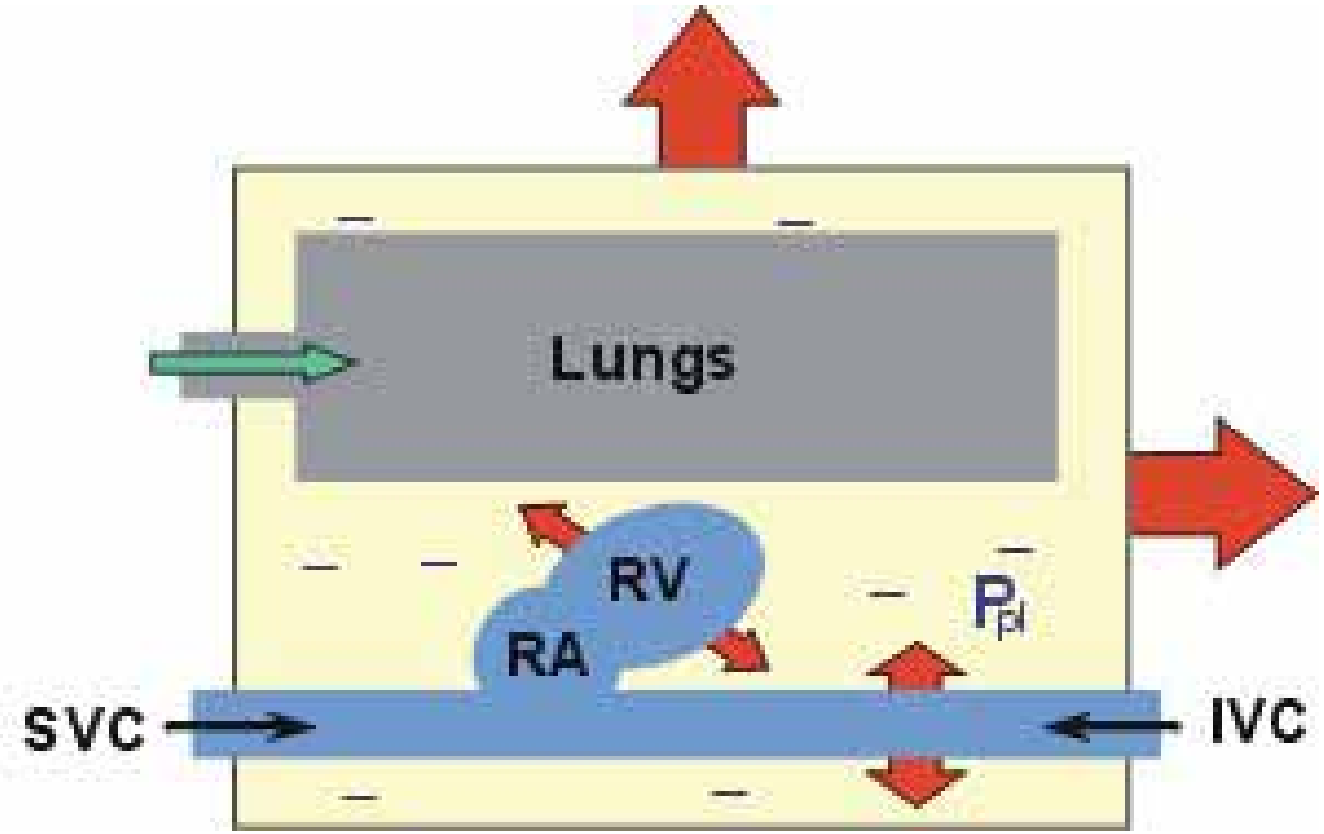
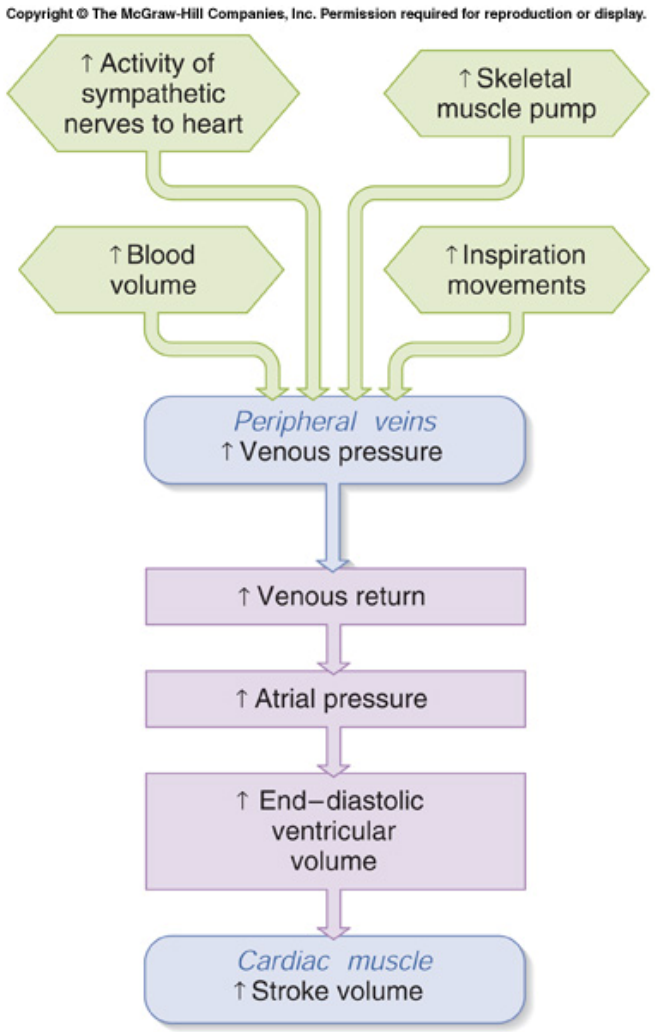


Figure 12-46



Alterations in "venous return" alter end-diastolic volume (EDV); increased EDV directly increases stroke volume and cardiac output.

The Lymphatic System

- The lymphatic system is a network of small organs (lymph nodes) and tubes (lymphatic vessels) through which lymph flows

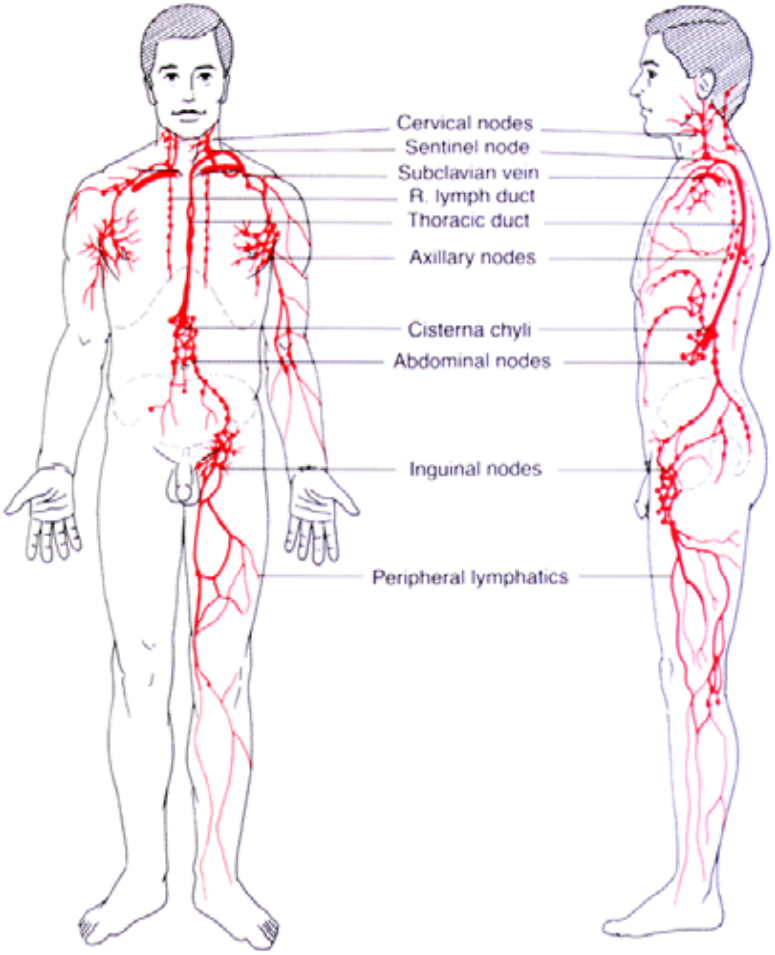
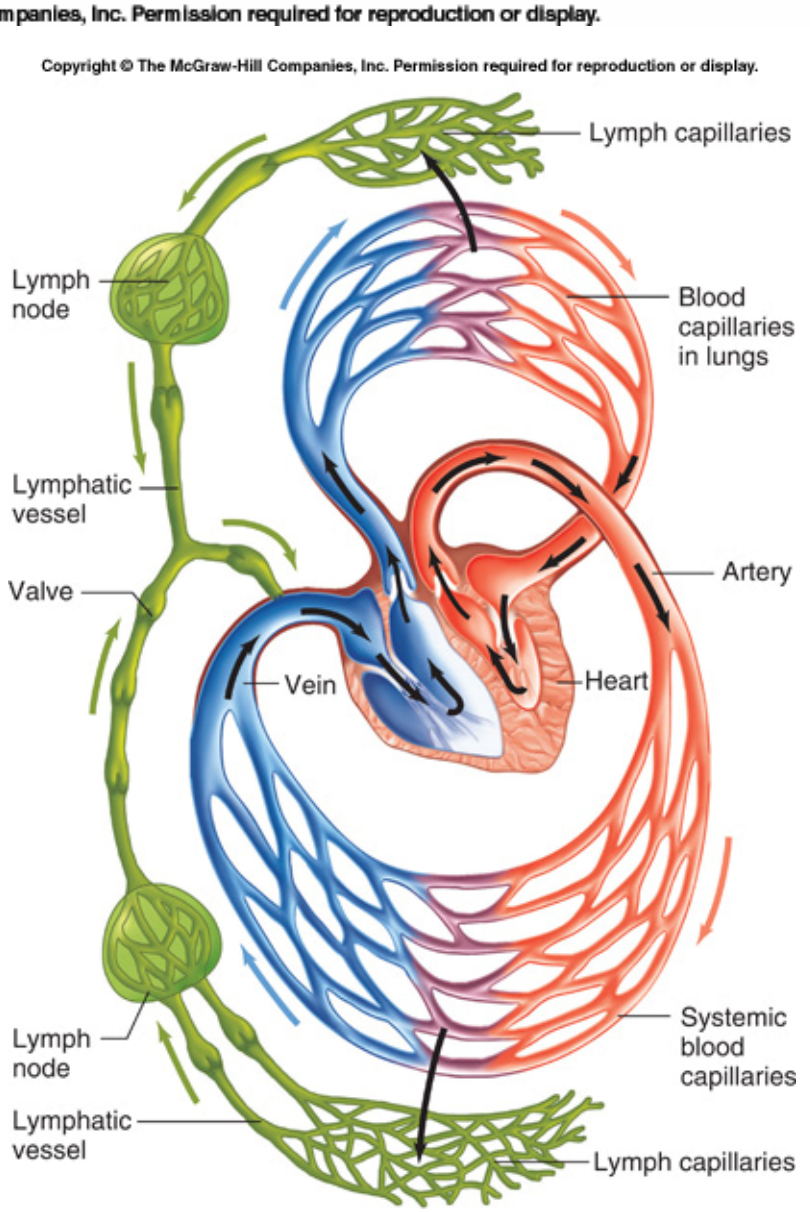
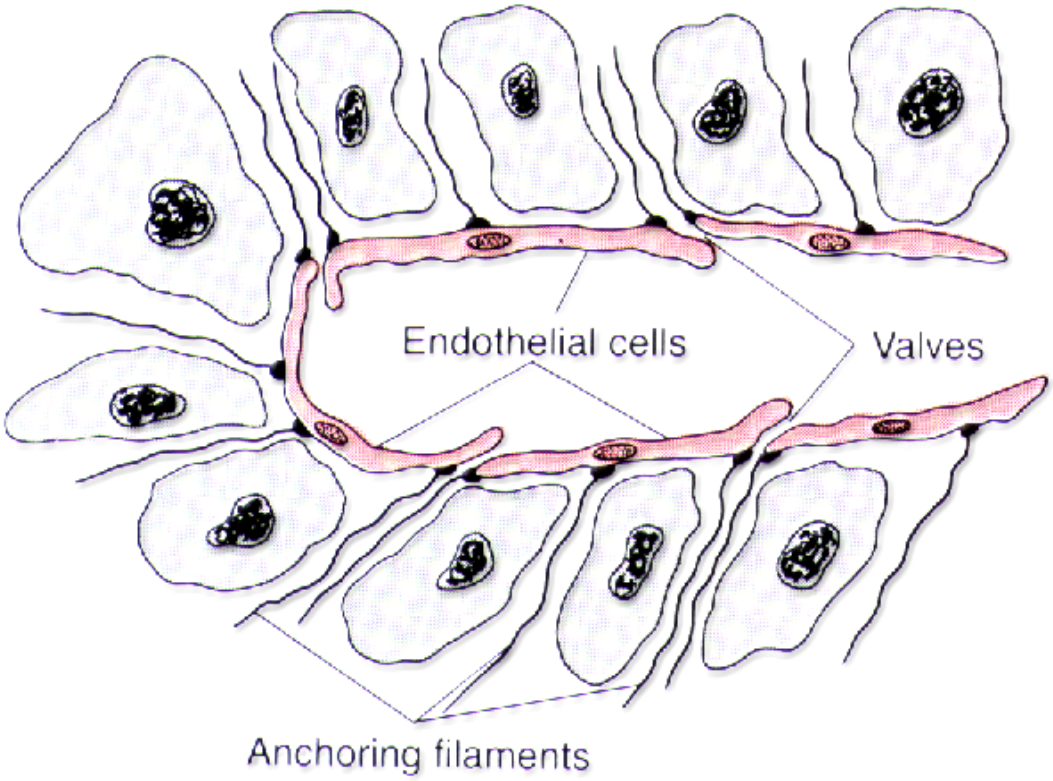


Figure 12-47

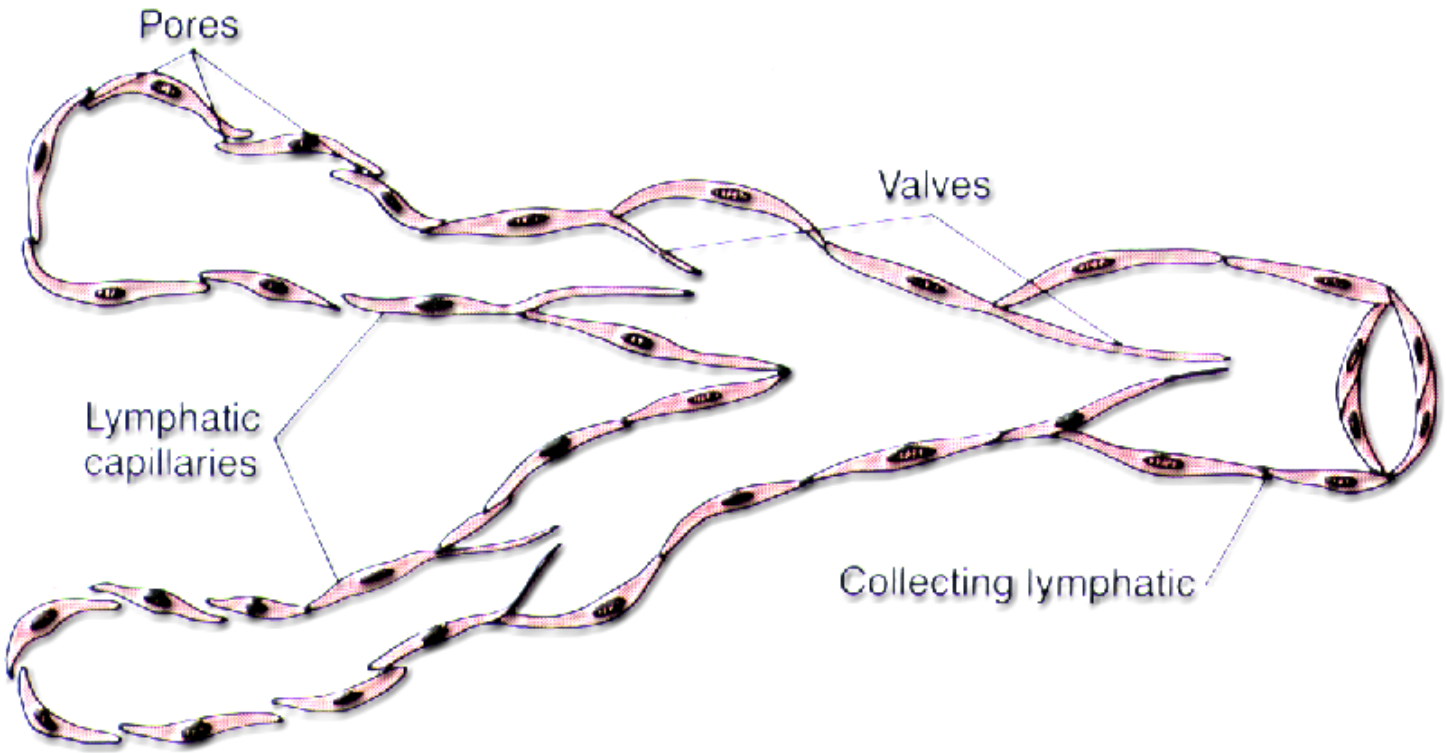
Lymphatic fluid, formed by the slight mismatch between filtration and absorption in the capillaries, returns to the blood in the veins.

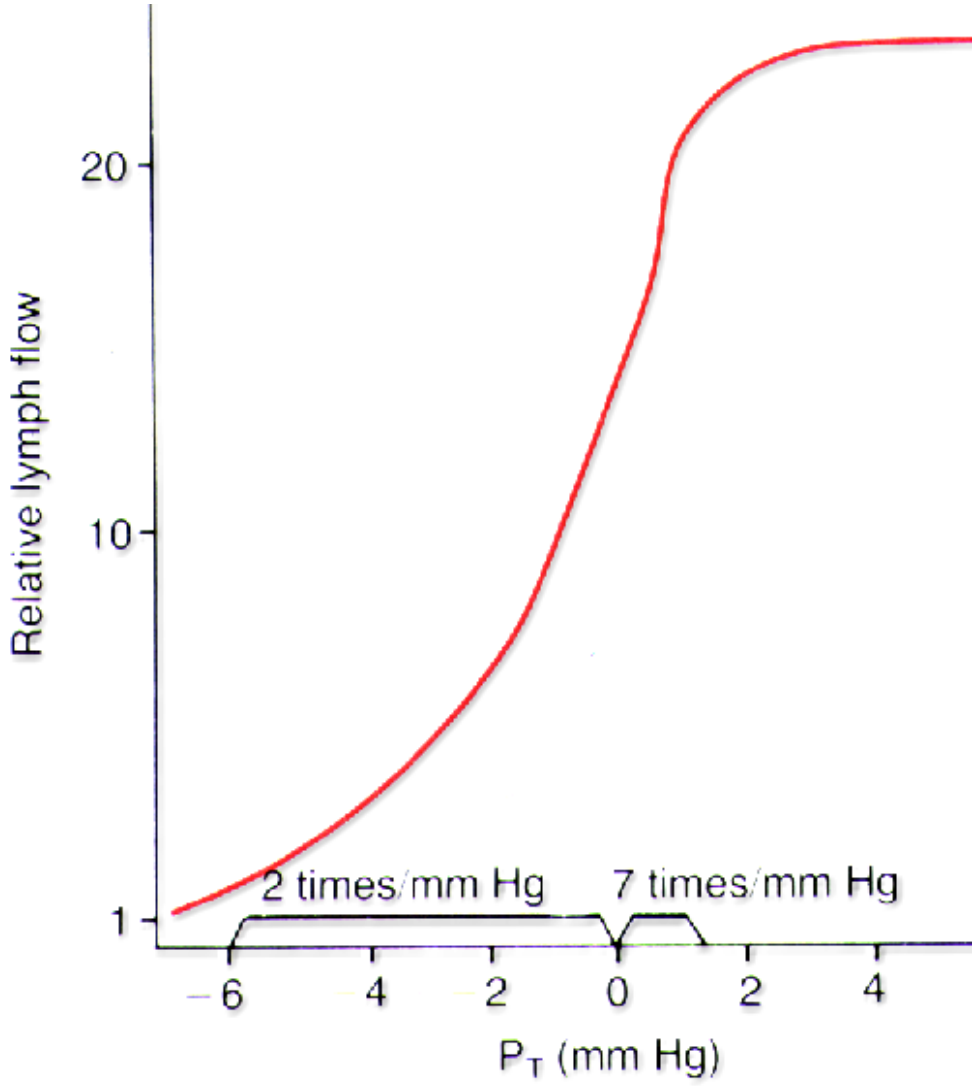


Terminal lymphatics



Lymphatic pump





Relation between interstitial fluid pressure and lymph flow

Significance of lymphatic return

- Absorption of protein
- Transportation of fat and other nutrients
- Balance between plasma and interstitial fluid
- Protection

Elephantiasis:

Chronic, often extreme enlargement and hardening of cutaneous and subcutaneous tissue, especially of the legs and external genitals, resulting from lymphatic obstruction and usually caused by infestation of the lymph glands and vessels with a filarial worm.

Figure 12-51

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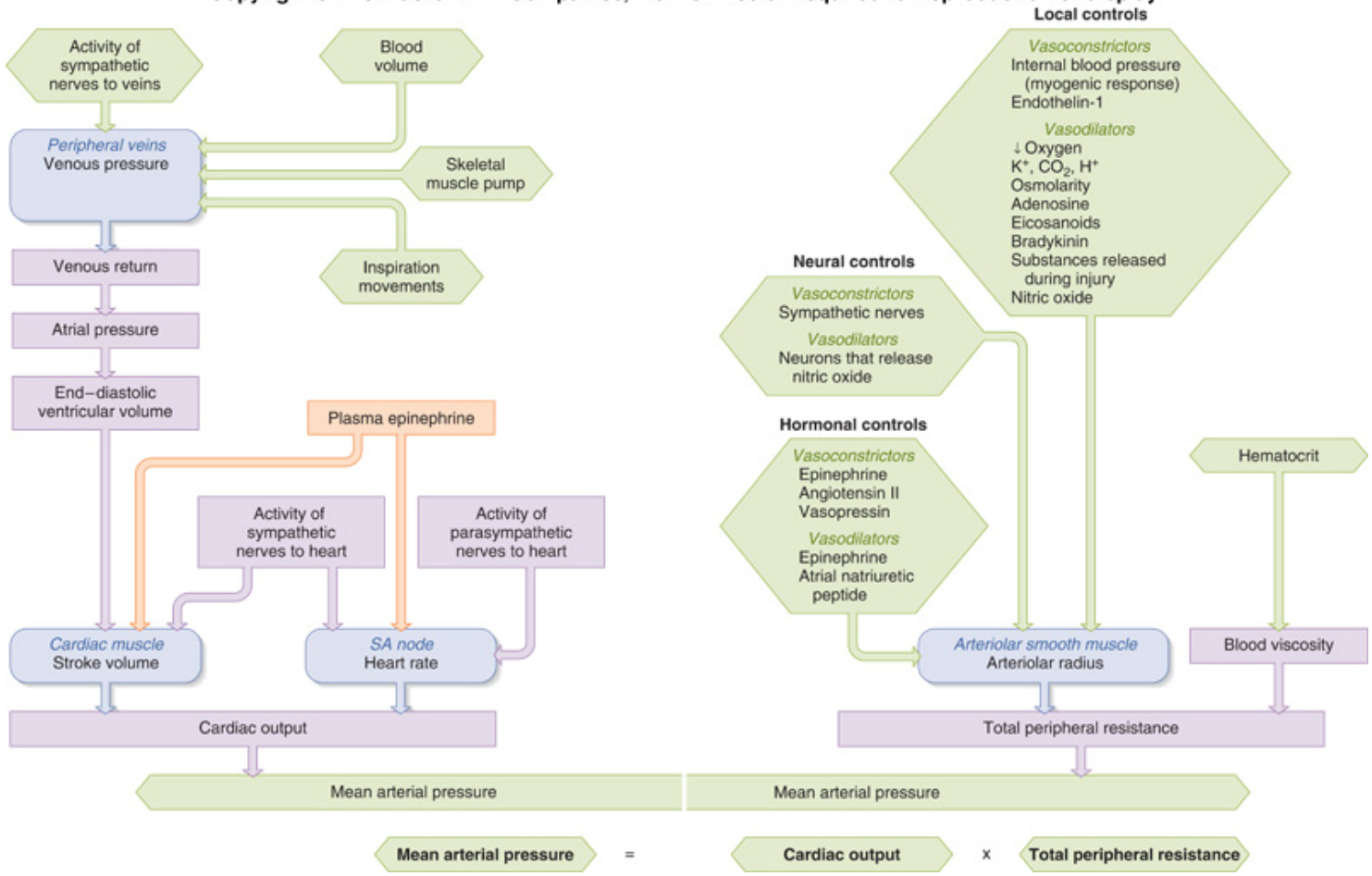

A summary of dynamic changes in MAP and TPR.

Figure 12-52

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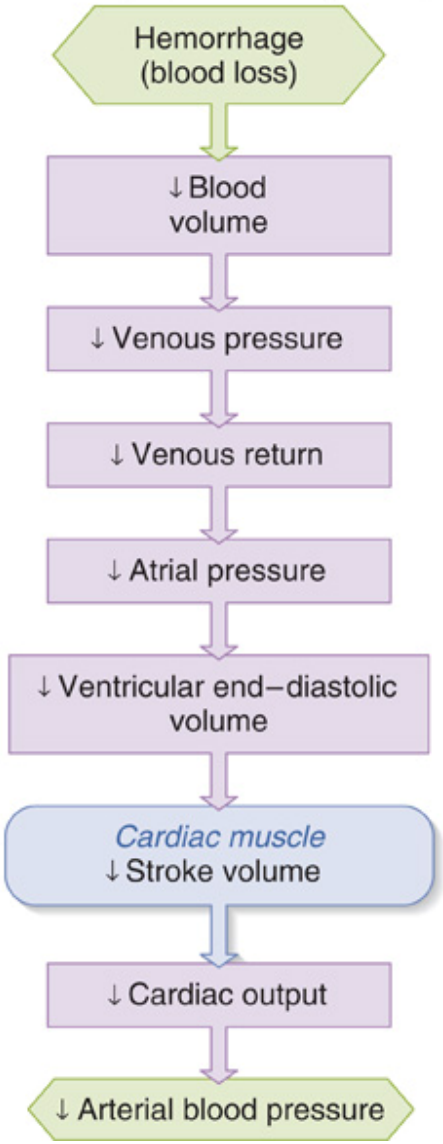

Blood loss causes a reduction in MAP, which, if left unchecked, would result in rapid and irreversible damage to the brain and the heart.

The End.