HUMAN PHYSIOLOGY (normal)

LECTURE 13. Physiology of the Blood Vessels

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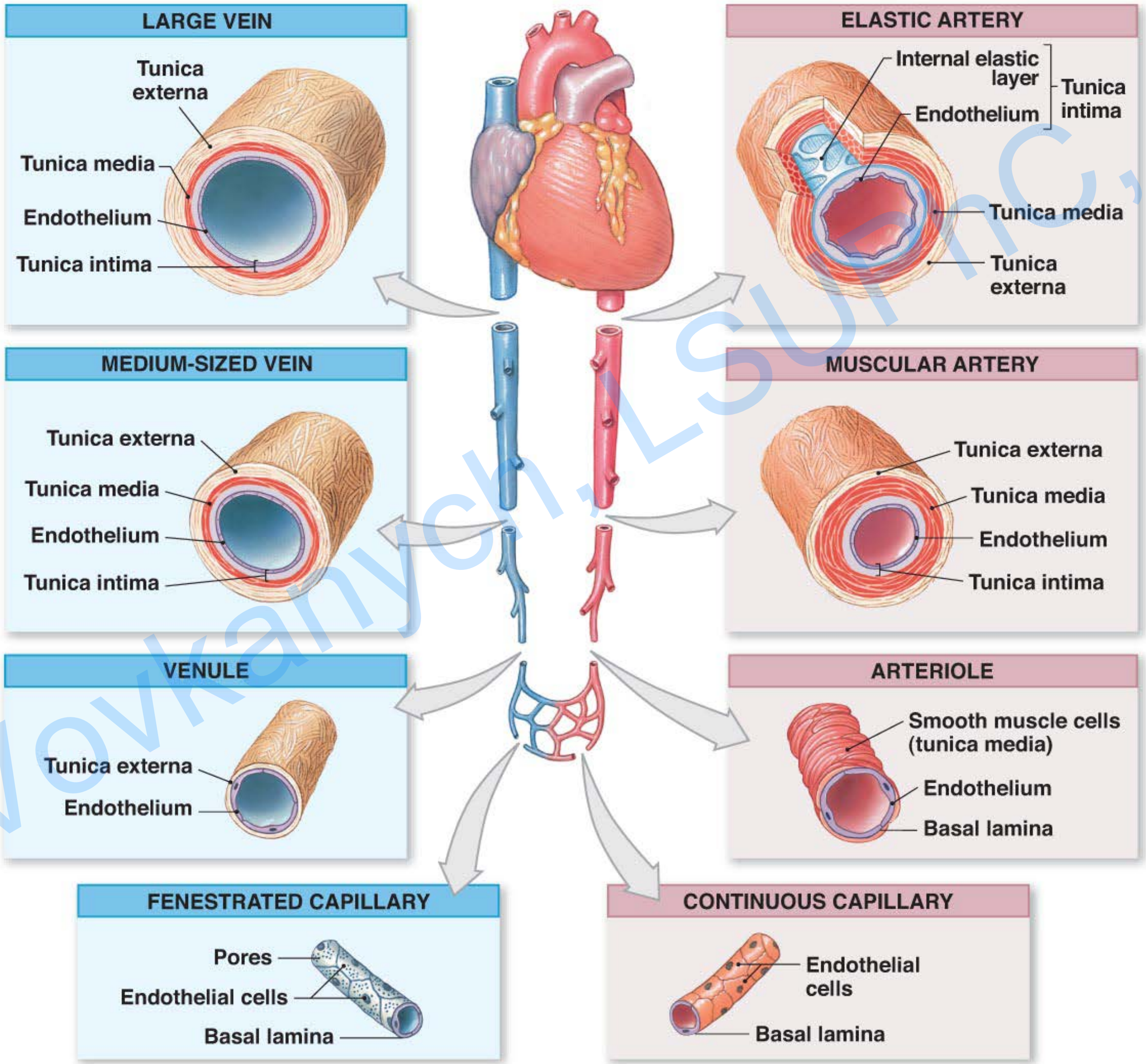
Classes of Blood Vessels

- **Arteries** - carry blood away from heart
- **Arterioles** - are smallest branches of arteries
- **Capillaries** - are smallest blood vessels, exchanger vessels
- **Venules** - collect blood from capillaries
- **Veins** - return blood to heart

The Structure of Vessel Walls

- Walls have **three layers:**
- **Tunica intima**
  - the *endothelial* lining
  - connective tissue layer
  - internal elastic membrane
- **Tunica media**
  - concentric *smooth muscles*
  - elastic and collagen fibers
- **Tunica externa**
  - contains *connective* tissue sheath
  - contains nerve fibers, vasa vasorum (“vessels of vessels”)

Structure and Function of Vessels



The Organization of a Capillary Bed

Collaterals

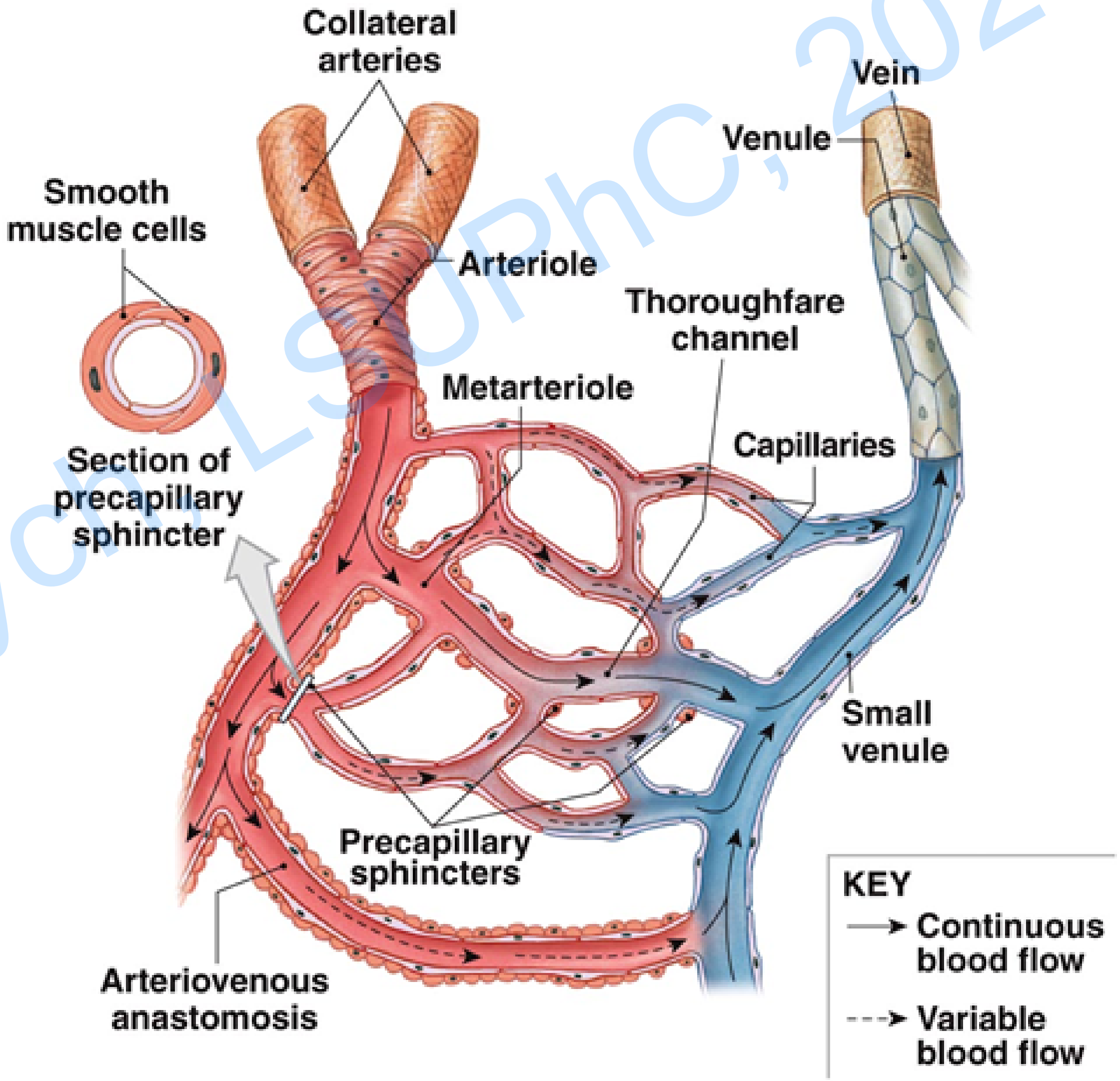
- Multiple arteries that contribute to one capillary bed

Arteriovenous anastomoses

- Direct connections between arterioles and venules

Capillary Sphincter

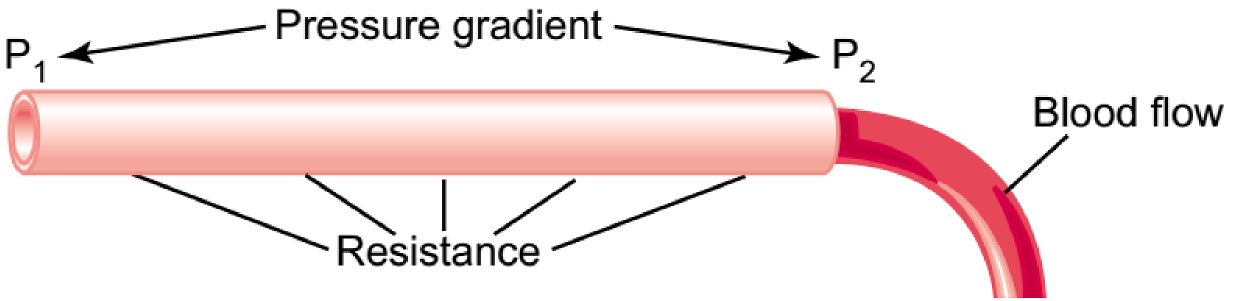
- Opens and closes, causing capillary blood to flow in pulses



Hemodynamics

- **Hemodynamics** refers to the study of movement of blood (blood flow) through circulatory system.
- **Blood flow** (BF) means the quantity (volume) of blood that passes a given point in the circulation in a given period
- According to **Hagen-Poiseuille** equation, volume (Q) of any fluid flowing through a tube (vessel) is:
  - *Directly* proportional to **pressure gradient** ($P_1 - P_2$)
  - *Inversely* proportional to the **resistance** of blood vessels (R)

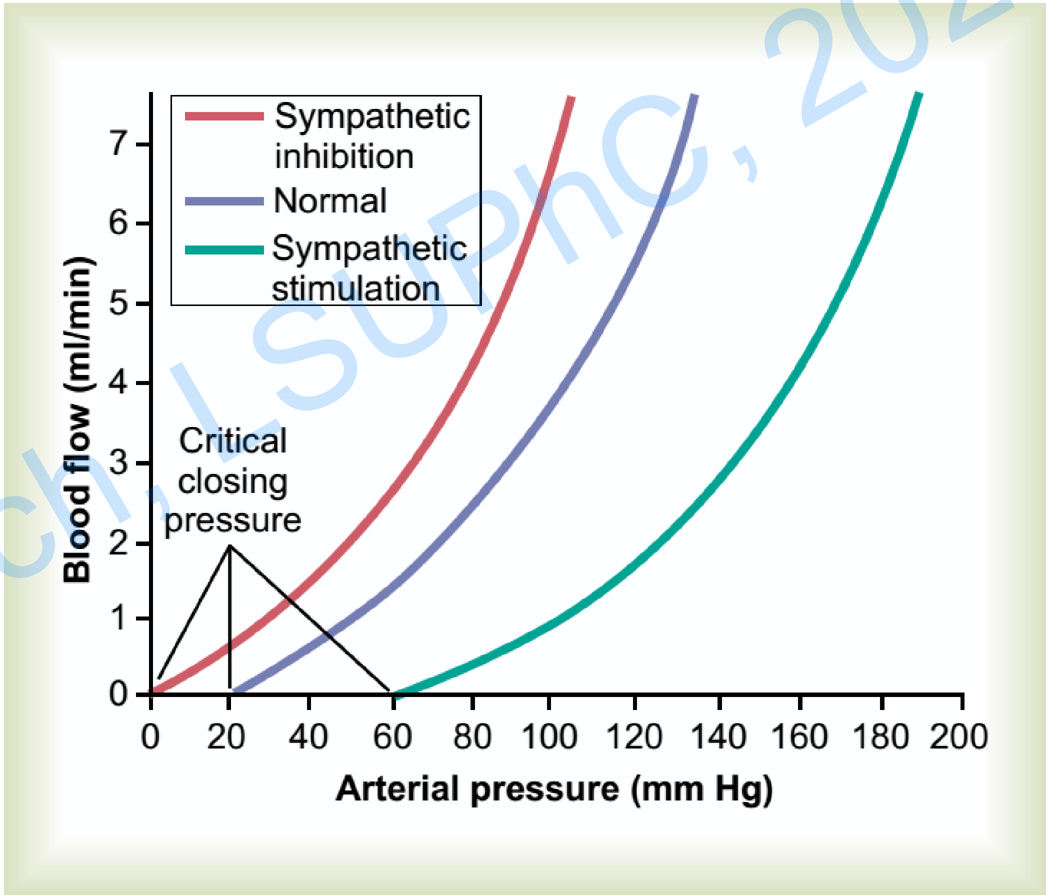
$$Q = \frac{P_1 - P_2}{R}$$



Hemodynamics. Role of Blood Pressure

Increase in arterial pressure:

- increases the **force** that pushes blood through the vessels
- Increase the **diameter** of the vessels and decreases vascular resistance
- greater pressure increases the blood flow in both of these ways

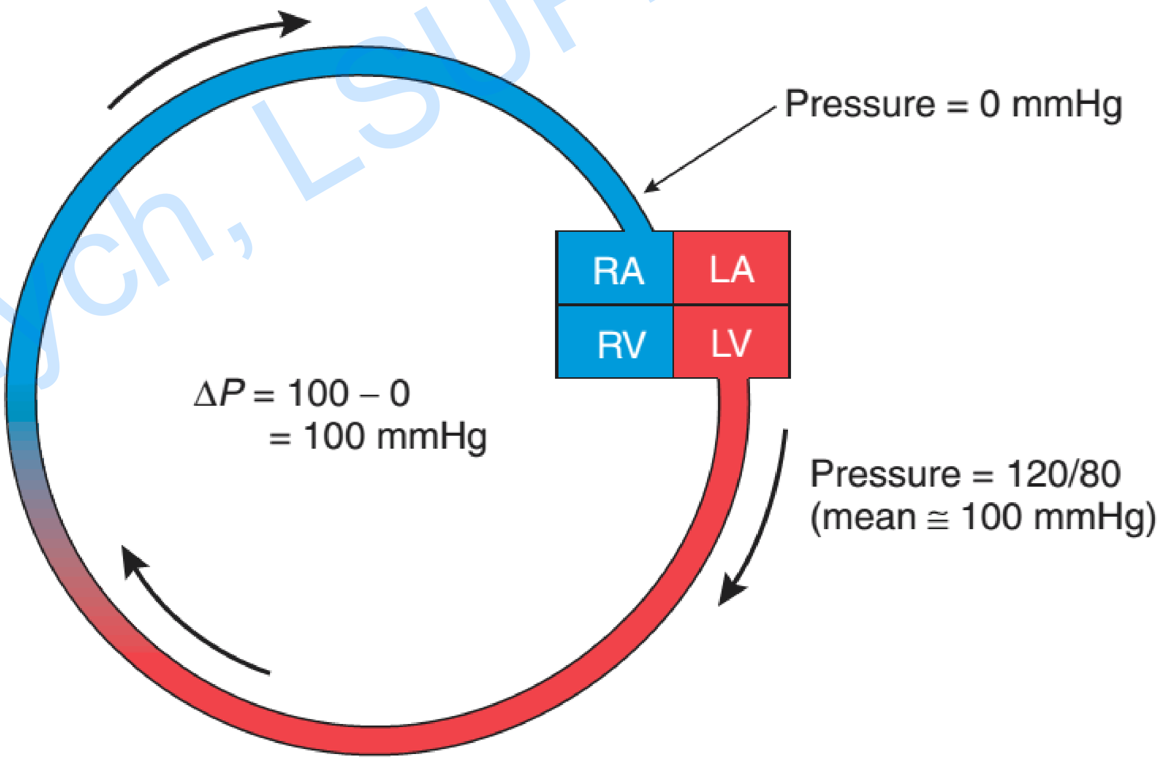


Large changes in **blood flow** that can be caused by either increased or decreased **sympathetic nerve stimulation** of the peripheral blood vessels

Hemodynamics. Pressure gradients

Pressure gradient in different areas of vascular bed

Blood vessels	Pressure gradient (mm Hg)
Between **aorta** and **vena cava**	100 (93)
Between beginning of **arteries** and end of **arterioles**	70
Between arterial and venous ends of **capillaries**	15

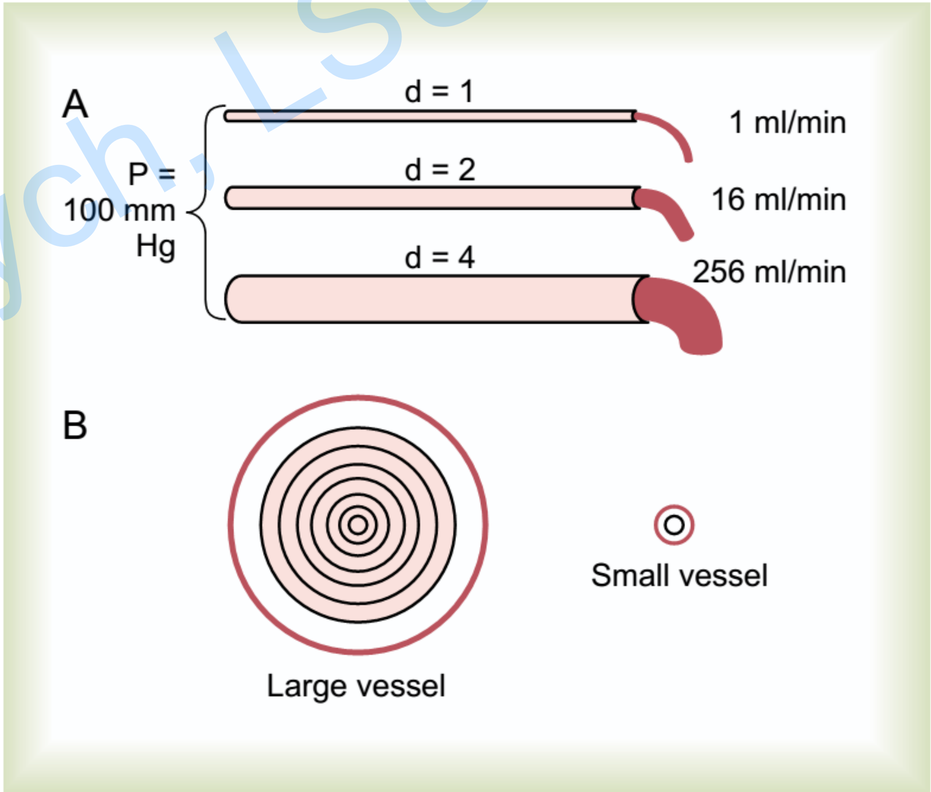


Hemodynamics. Role of Vascular Resistance

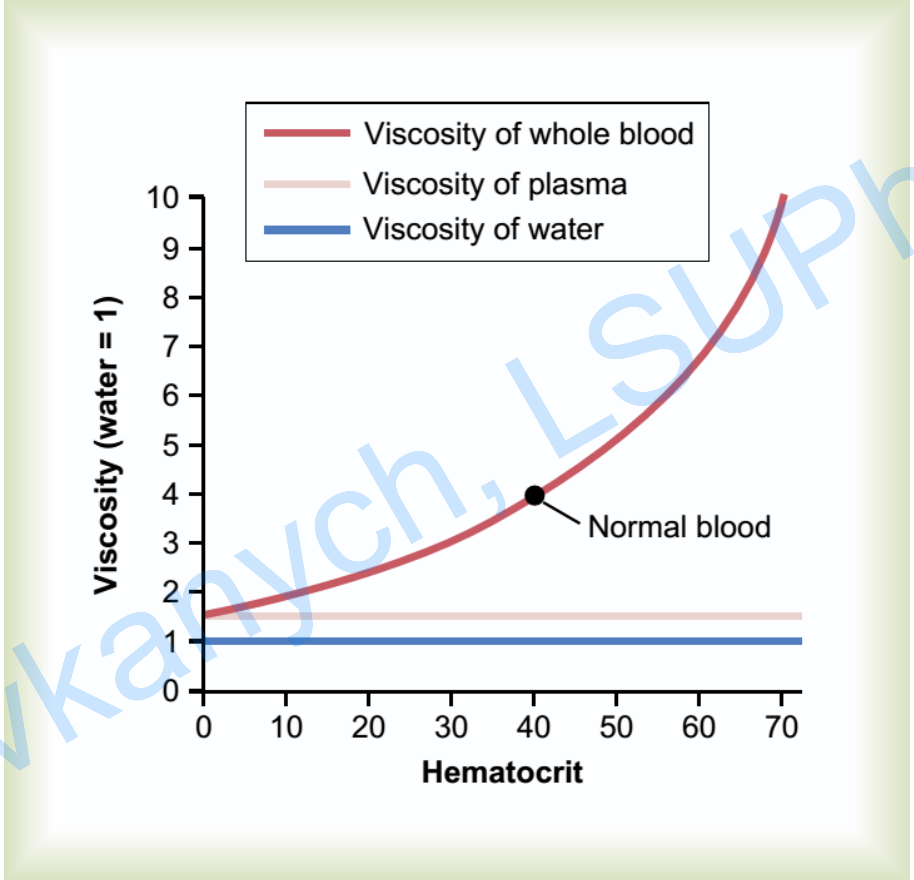
The **resistance** (peripheral resistance) of blood vessels (R) is:

- *Directly* proportional to **length** of the tube (l)
- *Directly* proportional to **viscosity** (η) of the blood
- *Inversely* proportional to the **fourth power of radius** (r^4) of the vessel

$$\mathbf{R = \frac{8\,l\,\eta}{\pi\, r^4}}$$



Hemodynamics. Role of Blood Viscosity

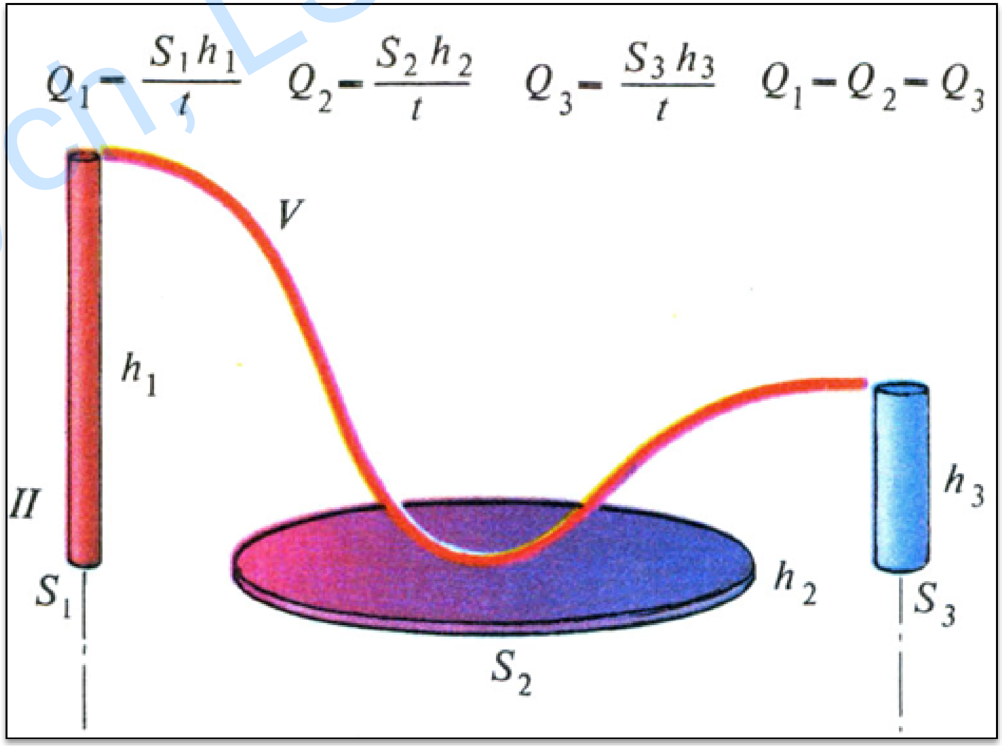


The viscosity of blood increases drastically as the hematocrit increases

Hemodynamics. Velocity of Blood Flow

- **Velocity** (V) of blood flow is the rate at which blood flows through a particular region of the body
- Velocity (V) of blood flow is:
  - *Directly* proportional to **blood flow** (Q)
  - *Inversely* proportional to **total cross-sectional area** of the vessels (S)

$$\mathbf{V = \frac{Q}{S}}$$



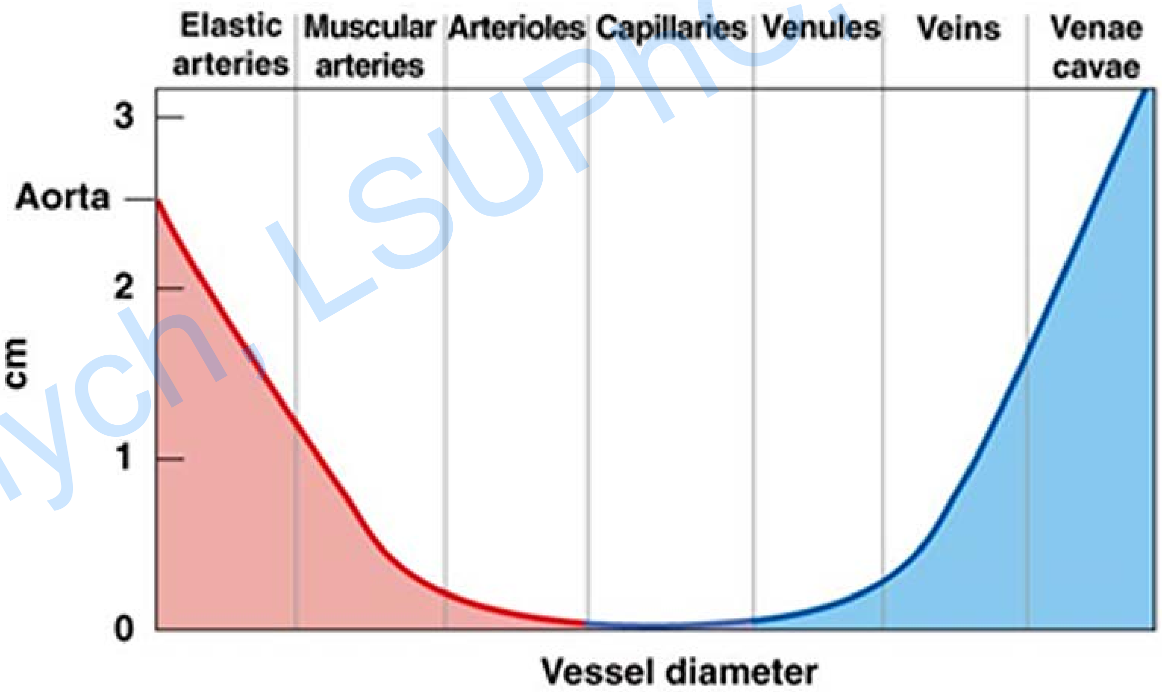
Hemodynamics. Circulation Time

- **Circulation time** is the time taken by blood to travel the whole of the circulatory system (**total circulation time**) or its part (**circulation time**)
- Circulation time is decreased when the **velocity of blood flow** is increased
- **Total circulation time** is about the time of 30 heartbeat

- The **total circulation time** (from arm vein to arm vein) at rest - **25 seconds** (22 to 28 seconds)
- **Shortest** circulation time (arm vein to heart): 4 seconds
- **Pulmonary** circulatory time (arm vein to lung): 6 seconds (4 to 6 seconds)
- Arm vein to carotid artery: 14 seconds (12 to 15 seconds)

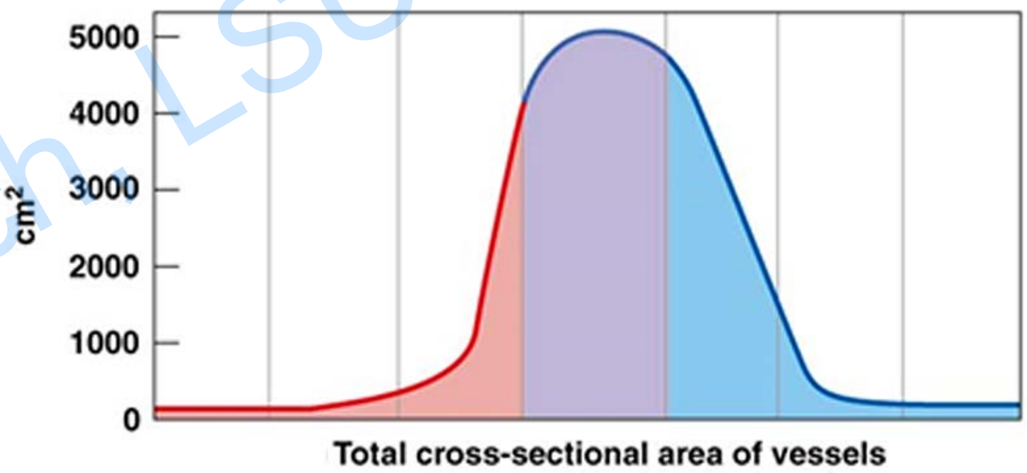
Hemodynamics and Vessels Diameter

Kind of Vessels	Diameter (mm)
Aorta	10
Arteries	1
Arterioles	0.02
Capillaries	0.008
Venules	0.03
Veins	6.0
Vena cava	12.5



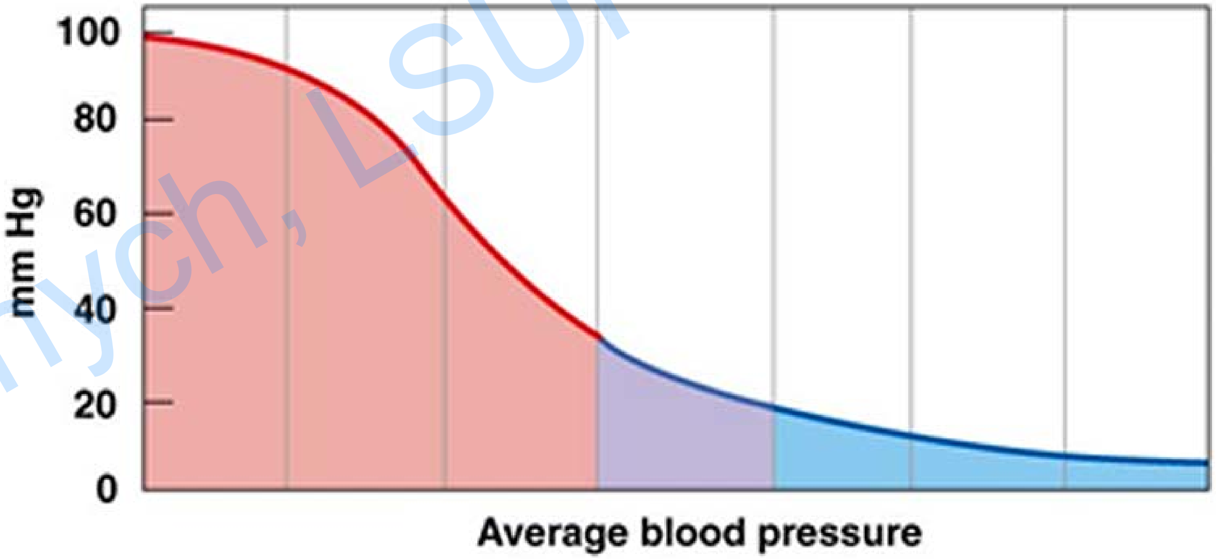
Hemodynamics and Cross-sectional area

Kind of Vessels	Number	Total Cross-Sectional Area (cm^2)
Aorta	1	2
Arteries	600	5.0
Arterioles	$40 * 10^6$	125
Capillaries	$1.2 * 10^9$	3500
Venules	$80 * 10^6$	570
Veins	40	11
Vena cava	2	4



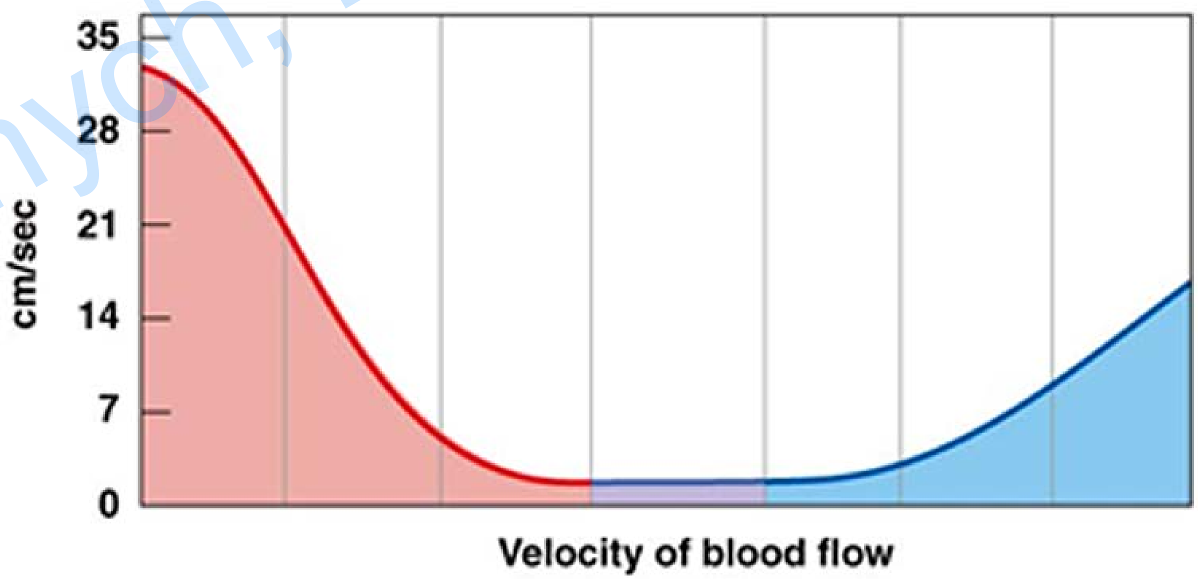
Hemodynamics. Average Blood Pressure

Kind of Vessels	Average blood pressure (mm Hg)
Aorta	100
Arteries	70
Arterioles	40
Capillaries	15-20
Venules	10-15
Veins	5
Vena cava	-2 - 2



Hemodynamics. Blood Flow Velocity

Kind of Vessels	Average blood flow velocity (cm/sec)
Aorta	70-40
Arteries	20
Arterioles	1.5
Capillaries	0.05
Venules	1.0
Veins	5
Vena cava	20



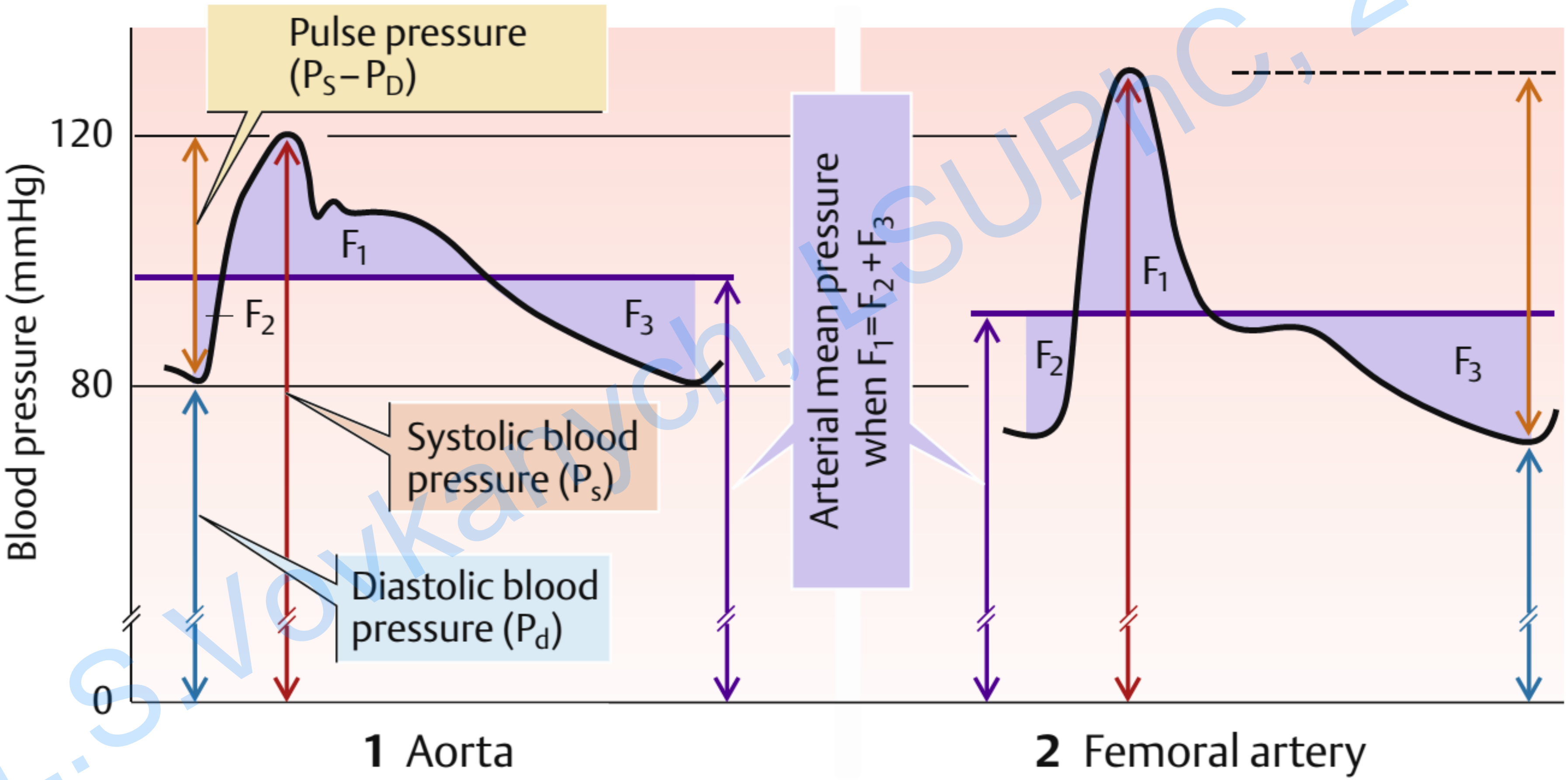
Arterial Blood Pressure

- The **hydrostatic pressure** in the arterial system, that pushes the blood through vessels
- Arterial blood pressure is expressed in four different terms:
  - **Systolic** blood pressure
  - **Diastolic** blood pressure
  - **Pulse** pressure
  - **Mean** arterial blood pressure (MAP)

Arterial Blood Pressure

- **Systolic** blood pressure (systolic pressure) - the maximum pressure exerted in the arteries during systole of heart
  - Normal value: 120 mm Hg (110 – 130 mm Hg)
- **Diastolic** blood pressure (diastolic pressure) - minimum pressure exerted in the arteries during diastole of heart
  - Normal value: 80 mm Hg (70 – 90 mm Hg)
- **Pulse** pressure is the difference between the systolic pressure and diastolic pressure
  - Normal value: 40 mm Hg (120 – 80 = 40)
- **Mean** arterial blood pressure is the average pressure existing in the arteries. It is the diastolic pressure plus one third of pulse pressure
  - Normal value: 93 mm Hg (80 + 1/3 * 40 = 93)

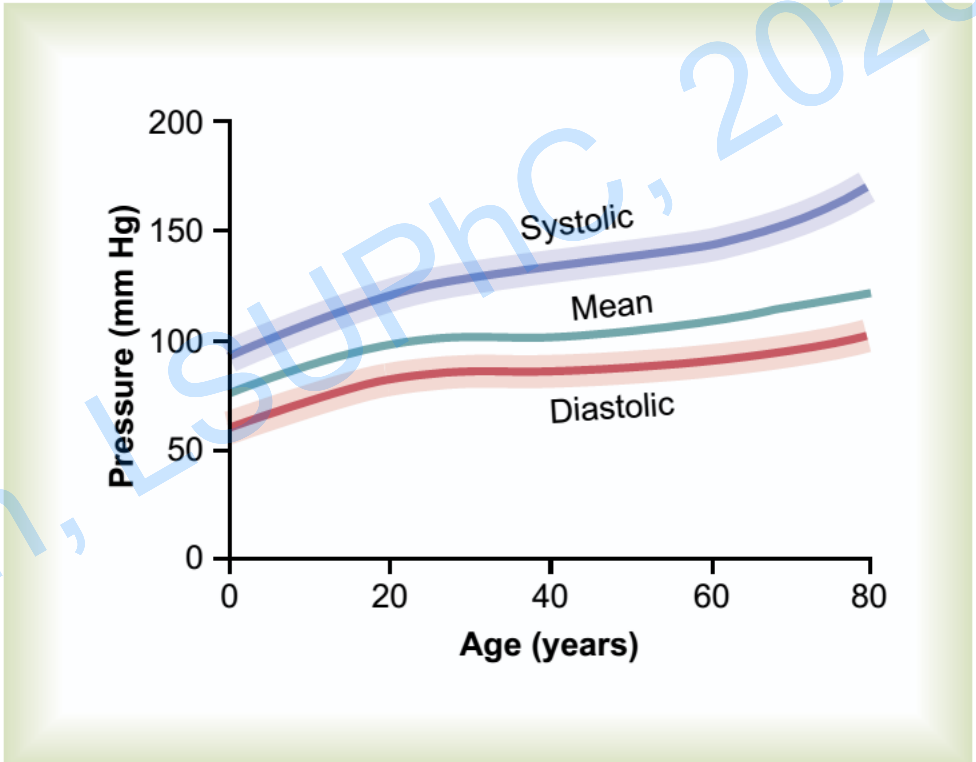
Arterial Blood Pressure



Physiological Variations in Arterial Blood Pressure

Influence of **Age**

- Newborn : 40/70 mm Hg
- After 6 month : 50/90 mm Hg
- After 1 year : 55/95 mm Hg
- At puberty : 80/120 mm Hg
- At 50 years : 85/140 mm Hg
- At 70 years : 90/160 mm Hg
- At 80 years : 95/180 mm Hg

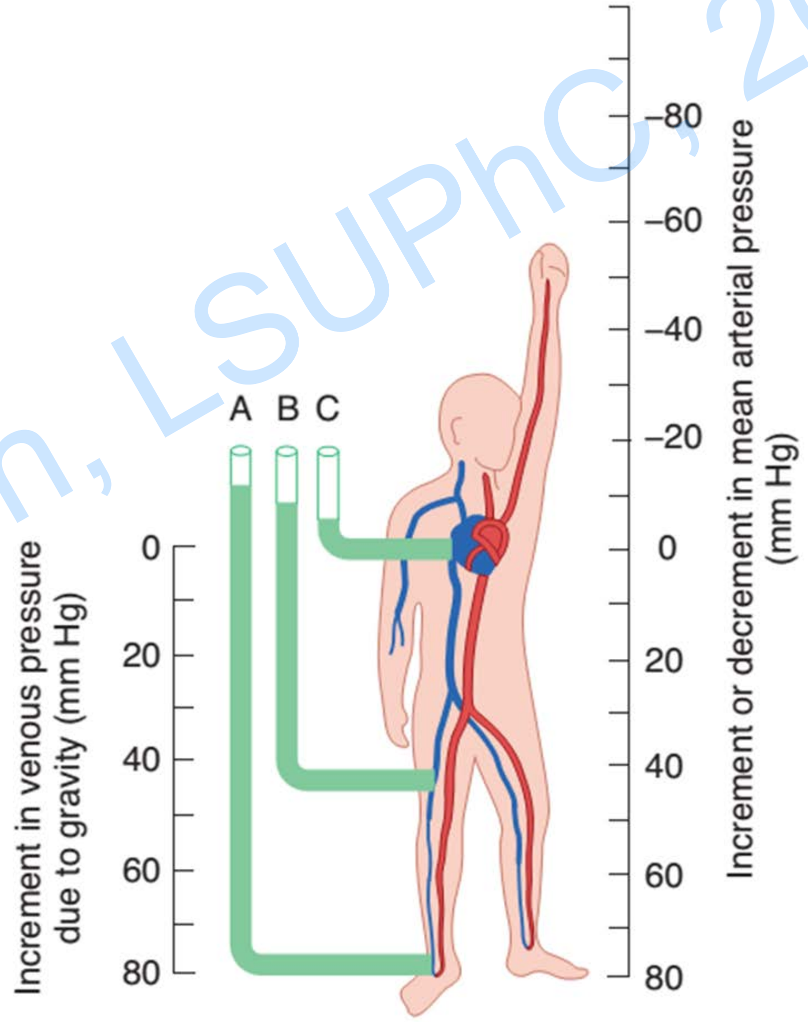


Influence of **other factors**:

- Pressure in **obese** persons is higher
- Pressure decreases at **rest** (sleep, absence of activity) and increases during **activity** (emotion, exercises etc.). During the physical exercises diastolic pressure may decrease

Physiological variations in Arterial Blood Pressure

Effects of gravity on the arterial and venous blood pressure



Factors Determining Arterial Blood Pressure

Arterial blood pressure	Factors
Directly proportional to	• Cardiac output • Heart rate • Peripheral resistance • Blood volume • Venous return • Velocity of blood flow • Viscosity of blood
Inversely proportional to	• Elasticity of blood vessel • Diameter of blood vessel

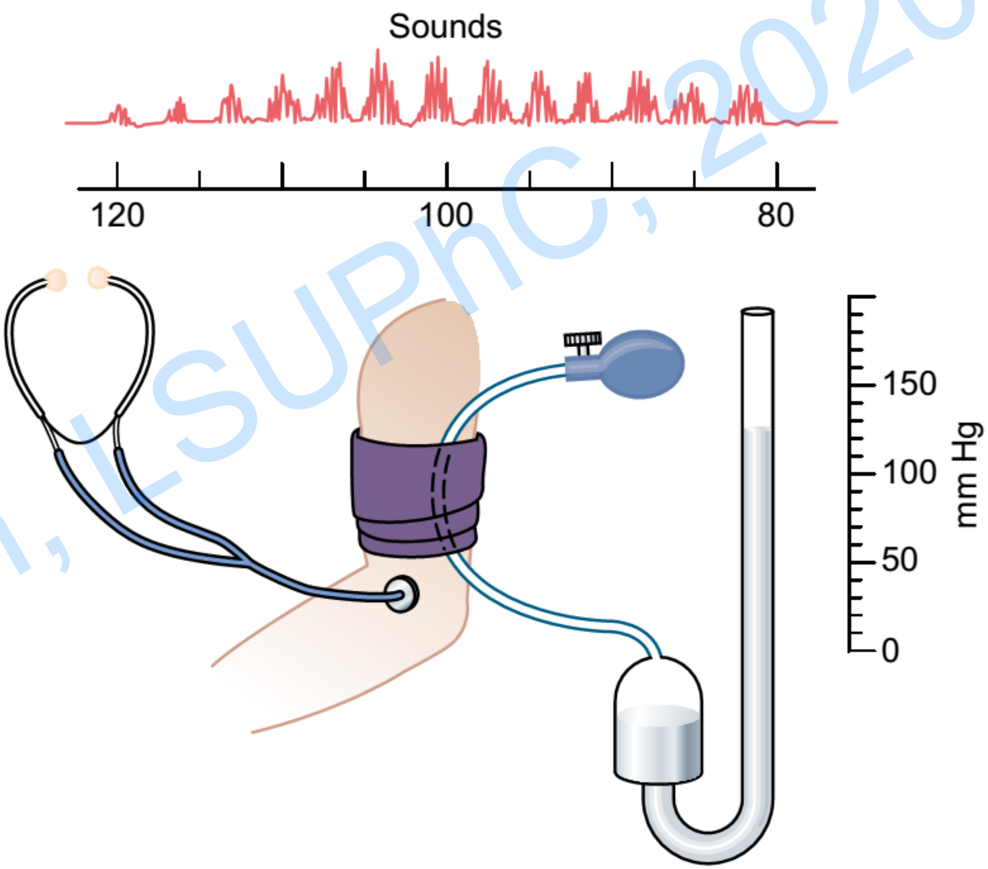
Measurement of arterial blood pressure

Blood pressure is measured by **two methods**:

- **Direct method** - employed only in animals
  The artery (usually carotid) is cannulated and connected to a manometer, the blood pressure can be recorded continuously in the form of graph
- **Indirect method** - apparatus that are used to measure blood pressure in human is called sphygmomanometer
- There are three indirect methods:
  - **Palpatory** method
  - **Auscultatory** method
  - **Oscillatory** method

Auscultatory Method

- The arm **cuff** of sphygmomanometer is **tied around upper arm**
- **Pressure is increased** in the cuff
- Brachial artery is compressed and blood flow is obstructed
- Chest piece of the **stethoscope is placed** over the antecubital fossa
- The **pressure** in the cuff is **slowly reduced**



- Series of sounds (**Korotkoff sounds**) are heard through the stethoscope
- **Appearance** of sounds indicates **systolic** pressure
- **Disappearance** of sounds indicates **diastolic** pressure

Pathological variations of arterial blood pressure

- **Hypertension** is defined as the persistent high blood pressure
  - systolic pressure > 150 mm Hg
  - diastolic pressure > 90 mm Hg

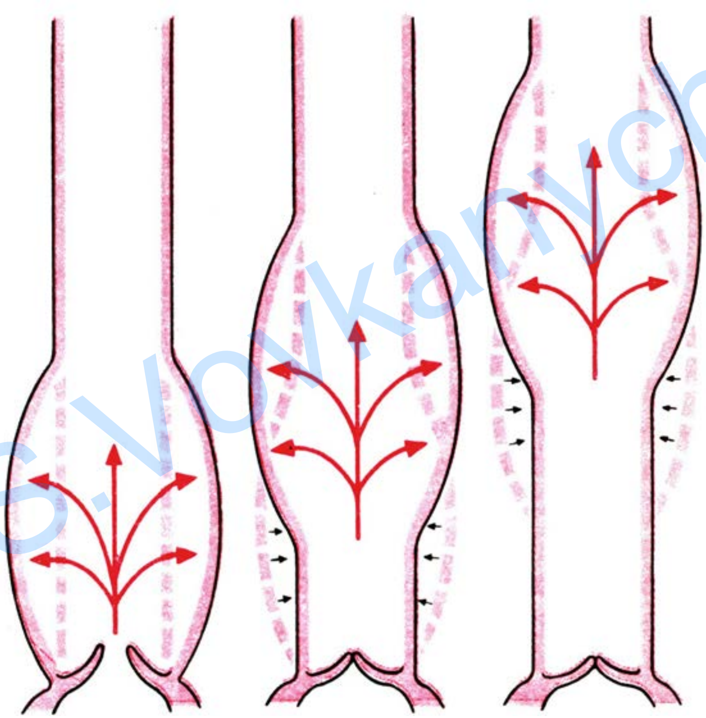
- **Hypotension** is the low blood pressure.
  - systolic pressure < 100 mm Hg
  - diastolic pressure < 70 mm Hg

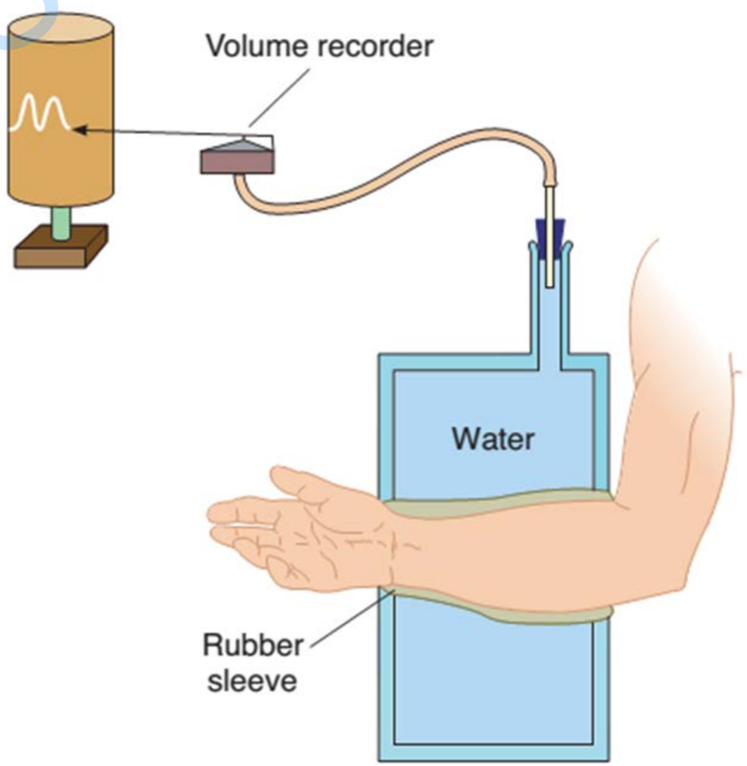
Arterial Pulse

Pressure changes transmitted in the **form of waves** through arterial wall and blood column from heart to periphery

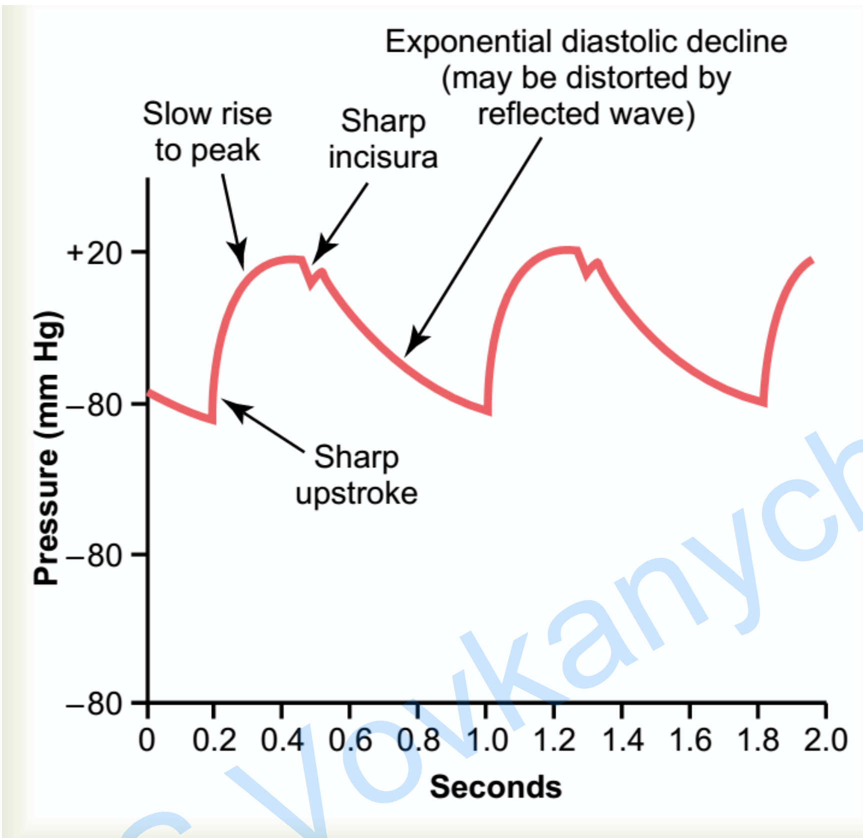
Is **caused** by the ejection of blood into aorta.

Average velocity of pulse wave transmitting varies between 7 and 9 meter/second

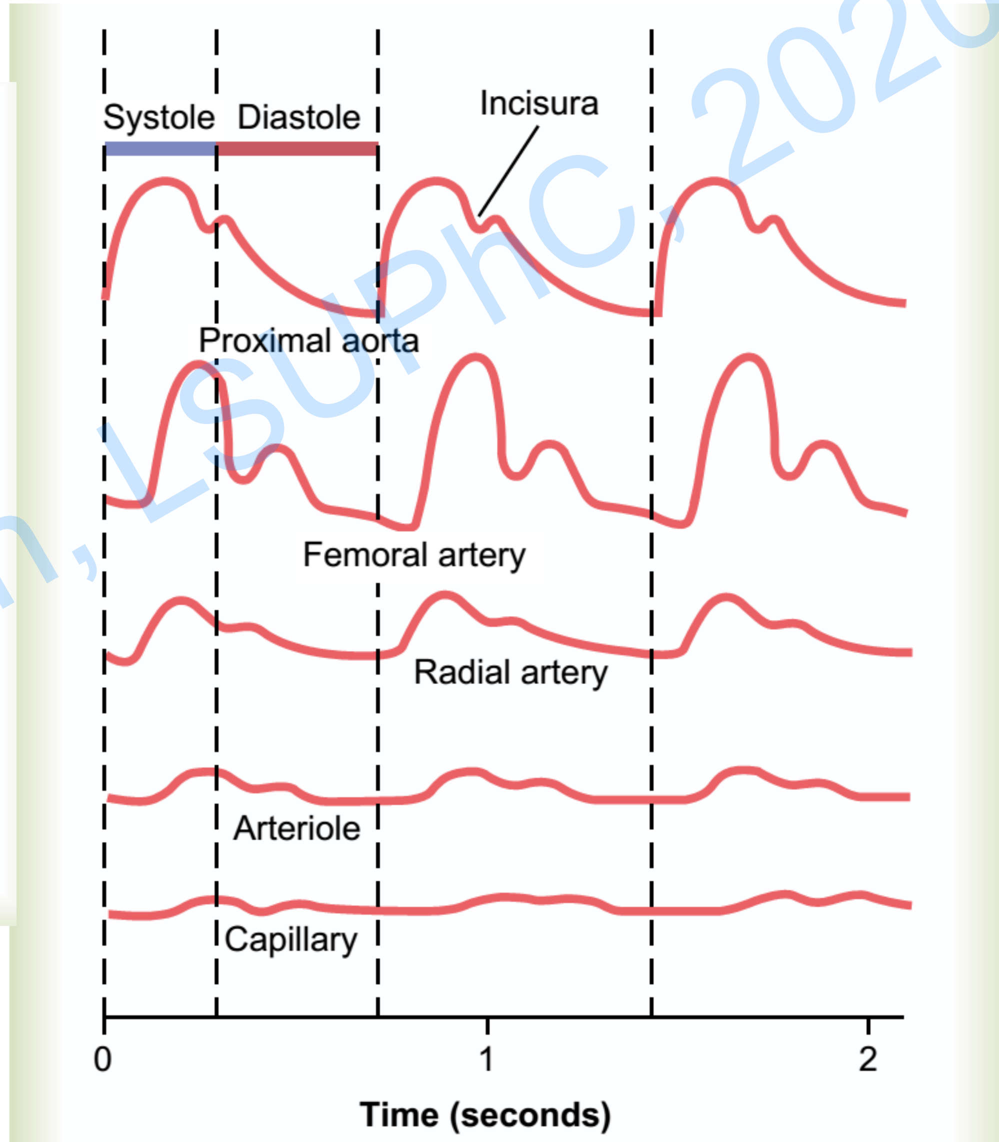




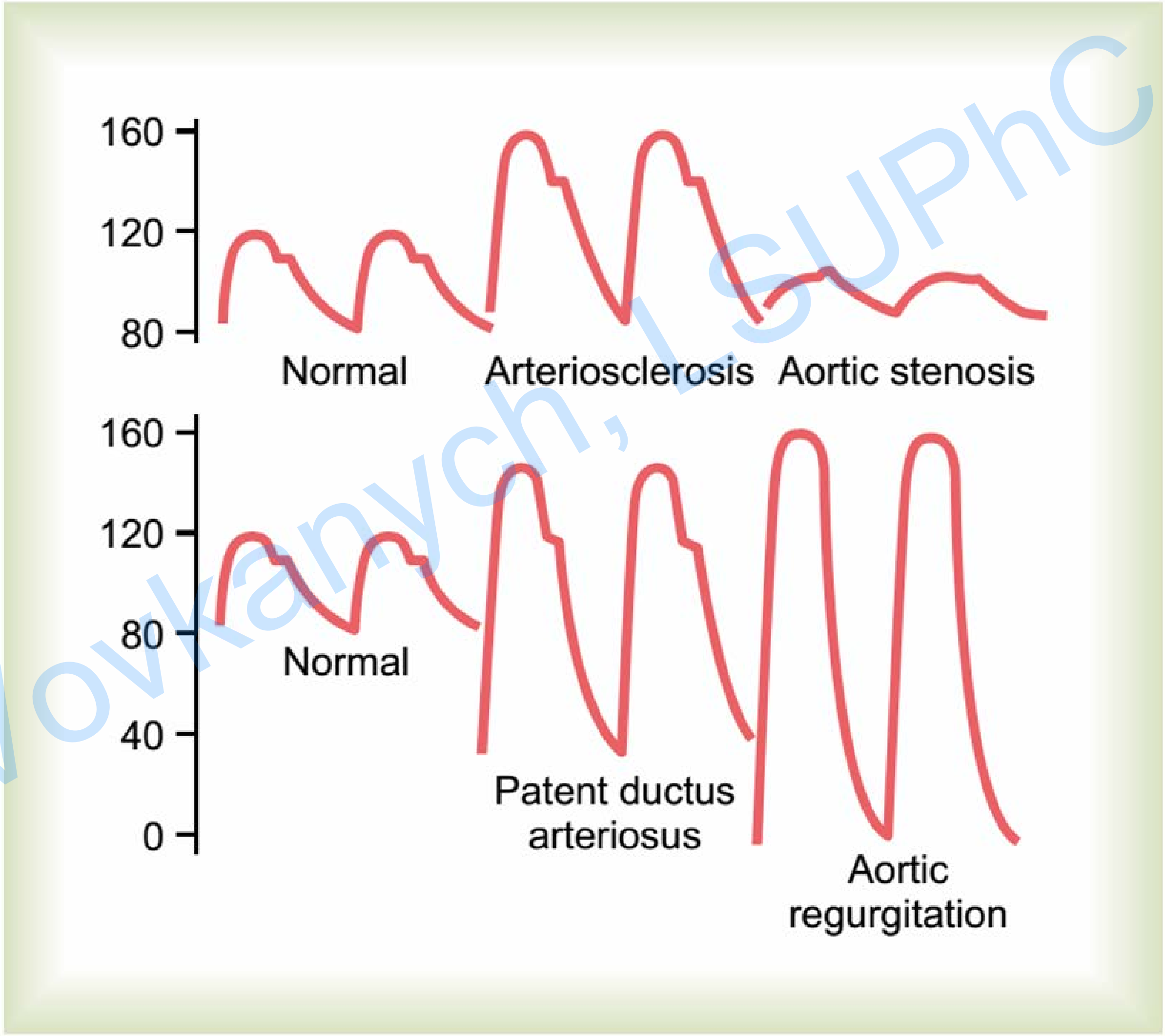
The Pulse Wave in Different Arteries



Aorta and other arteries



The Pathological Changes in Pulse Wave



Features of Capillaries

- **Total number** of capillaries - 10 billion
- Average **length** - 0.5 to 1 mm
- Average **diameter** - 8 μm
- **Surface area** of all capillaries - 500 to 700 sq m
- **Velocity of blood flow** - 0.05 cm/second
- It facilitates exchange of substances between capillaries and tissues
- **Function** of capillaries – **exchange** of substances between blood and tissues by the following processes:
  - **Diffusion**
  - **Filtration**
  - **Reabsorption**

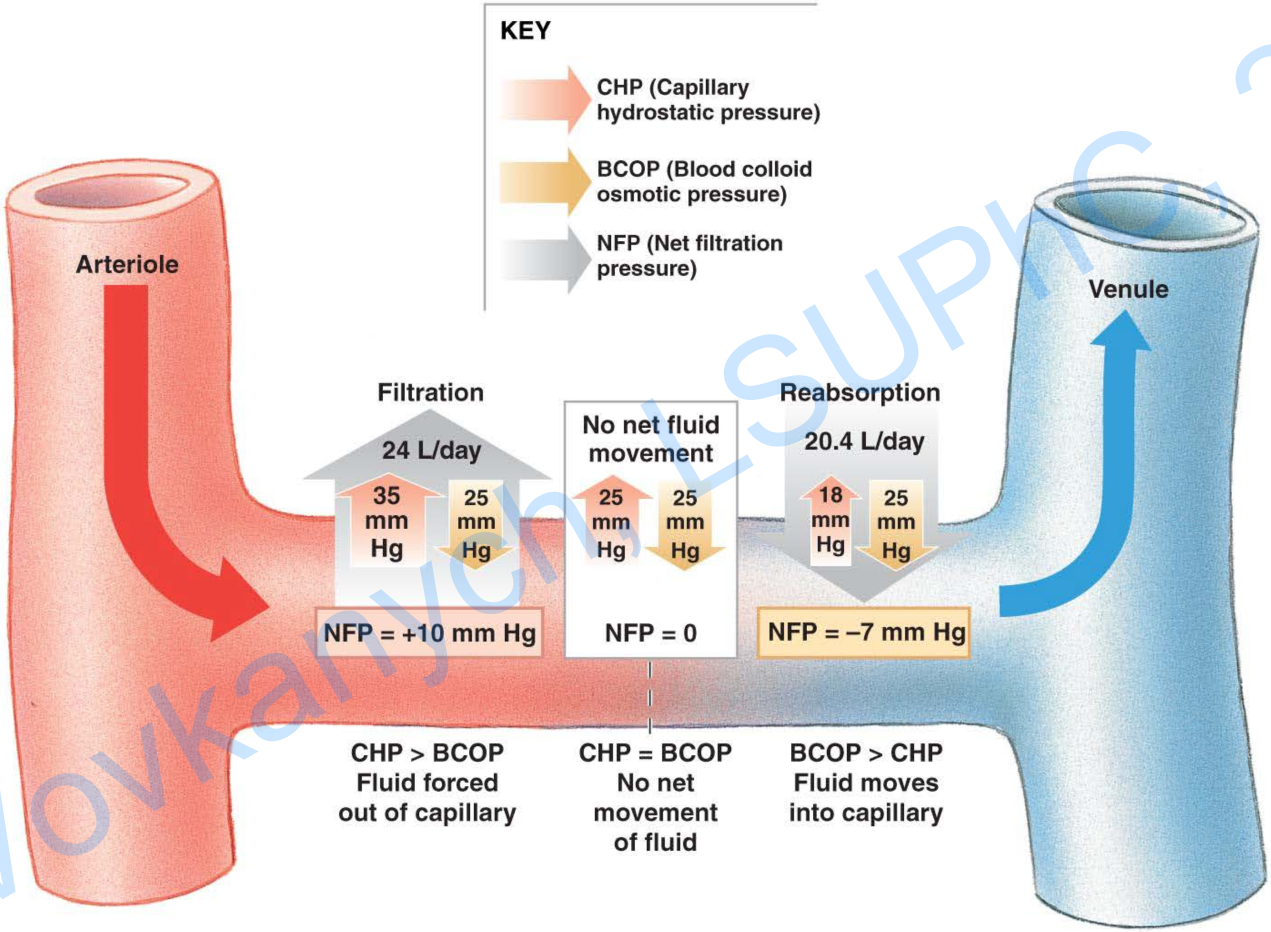
Exchange Processes in Capillaries

- **Diffusion** – movement of ions or molecules along the concentration gradient. Diffusion routes:
  - **Water, ions, and small molecules** such as glucose - diffuse between adjacent endothelial cells
  - **Some ions** (Na^+, K^+, Ca^{2+}, Cl^-) - diffuse through channels in plasma membranes
  - **Large, water-soluble compounds** - pass through fenestrated capillaries
  - **Lipids and lipid-soluble materials** (such as O_2 and CO_2) - diffuse through endothelial plasma membranes
- **Filtration** – movement of water and small solutes by the hydrostatic pressure gradient (**net filtration pressure**)
- **Reabsorption** - movement of water and small solutes by **colloid osmotic pressure** (oncotic pressure of plasma proteins)

Capillary Pressures and Capillary Exchange

- **Capillary pressure** is the pressure exerted by the blood contained in capillary
- It is responsible for the **exchange** of various substances between blood and interstitial fluid through capillary wall
- Generally, the pressure in the **arterial end** of the capillary is about 30 to 32 mm Hg and in **venous end** it is 15 mm Hg.
- In **kidneys**, the glomerular capillary pressure is high
- In **lungs**, the pulmonary capillary pressure is low
- Capillary **oncotic pressure** – the osmotic pressure, exerted by the plasma proteins, staying within the capillaries
- **Normal** oncotic pressure is about 25 mm Hg
- It plays an important role in **reabsorption** across capillary membrane

Capillary Exchange



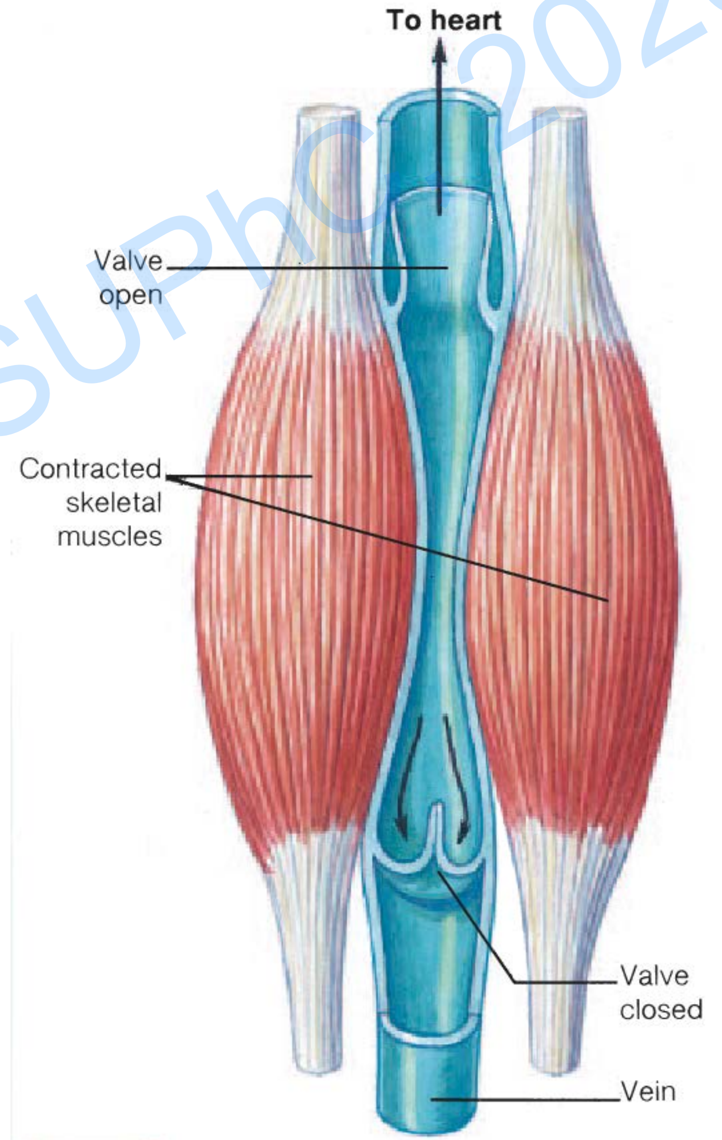
- At **arterial end** of capillary fluid moves **out** of capillary
- At **venous end** of capillary fluid moves **into** capillary
- Capillaries **filter more than they reabsorb**, excess – to lymphatic vessels

Venous Pressure and Venous Return

Venous pressure determines the amount of blood returned to atrium
Central venous pressure - pressure in vena cava (4.6 mm Hg) and right atrium (0 mm Hg)

Additional mechanisms of increase of the venous blood return

- The **muscular pump**: compression of peripheral veins by the skeletal muscles pushes blood toward heart (one-way valves)
- The **respiratory pump**: inhaling decreases thoracic pressure, exhaling raises thoracic pressure



Venous Pressure and Venous Return

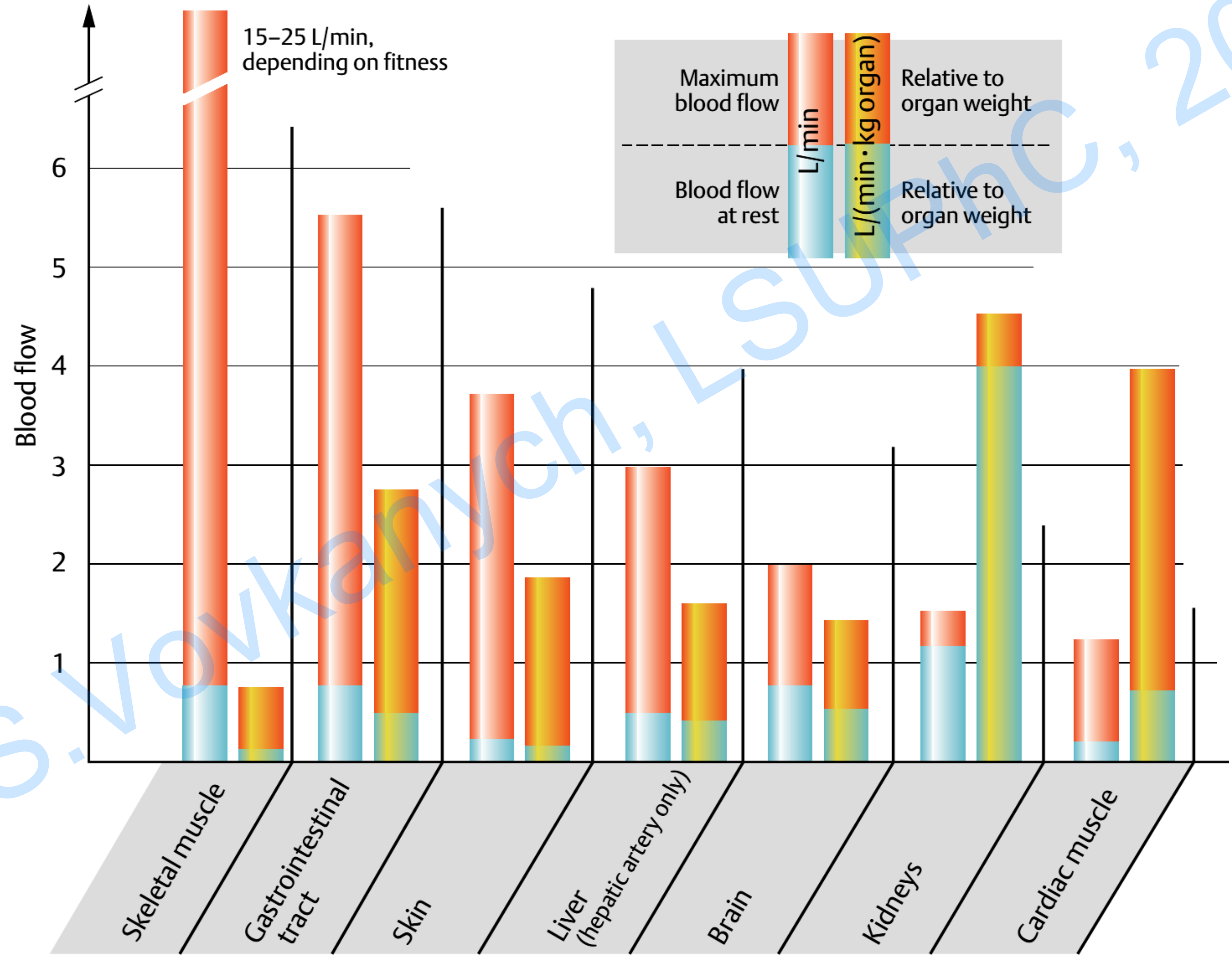
Venous pressure

- *directly* proportional to the **volume of blood** in the venous system
- *inversely* proportional to **peripheral resistance**

Venous pressure increases in:

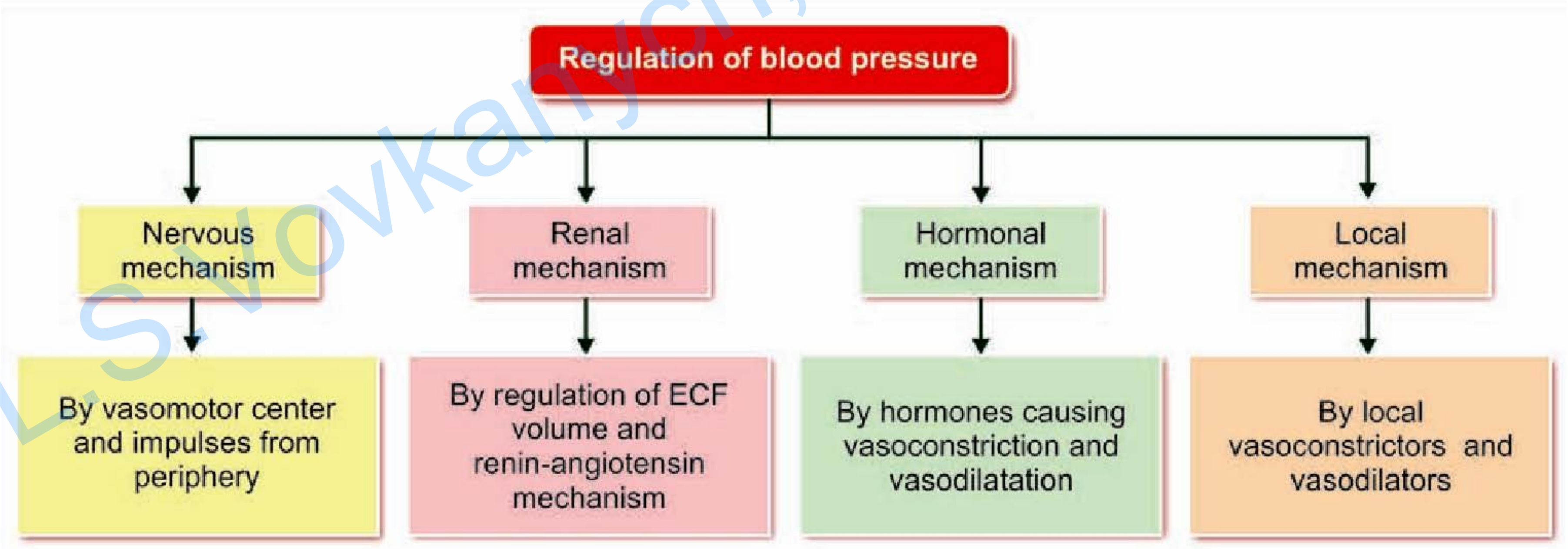
- **Changing** from standing to supine position
- **Forced expiration** (Valsalva maneuver). During inspiration, the central venous pressure decreases because of decreased intrathoracic pressure. During expiration, it increases because of increased intrathoracic pressure.
- Contraction of **abdominal** and limb muscles
- Effect of **gravity** during prolonged travelling or standing. Weight of the column of blood in veins influences the venous pressure. During prolonged standing, the pressure in lower extremities is more (90 cm H_2O)

Changes in Blood Flow to Organs



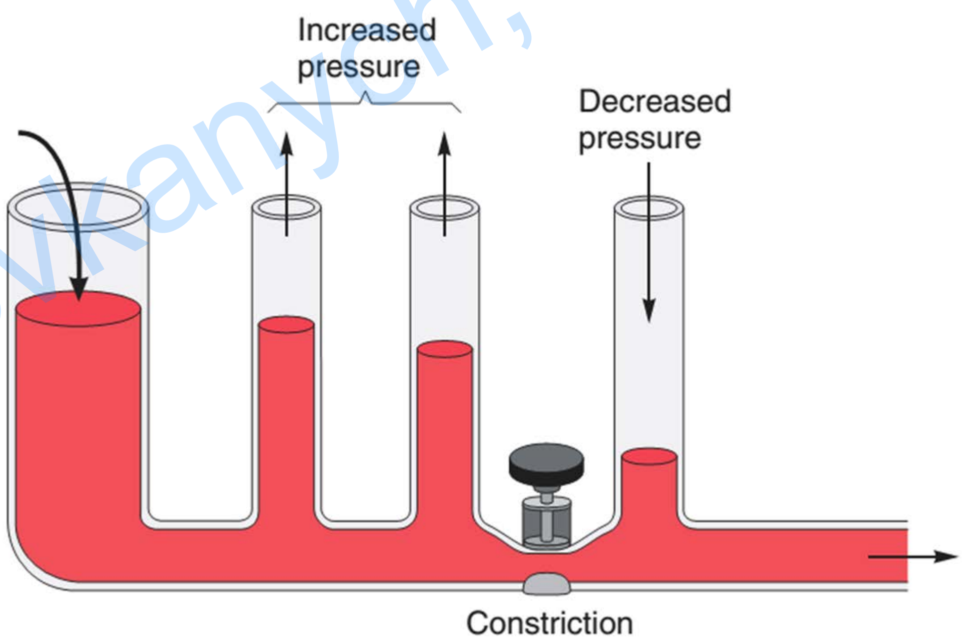
Regulation of Arterial Blood Pressure

- There are **four main regulatory mechanisms** to maintain the blood pressure within normal limits:
  - **Nervous** mechanism (short-term)
  - **Renal** mechanism (long-term)
  - **Hormonal** mechanism
  - **Local** mechanisms

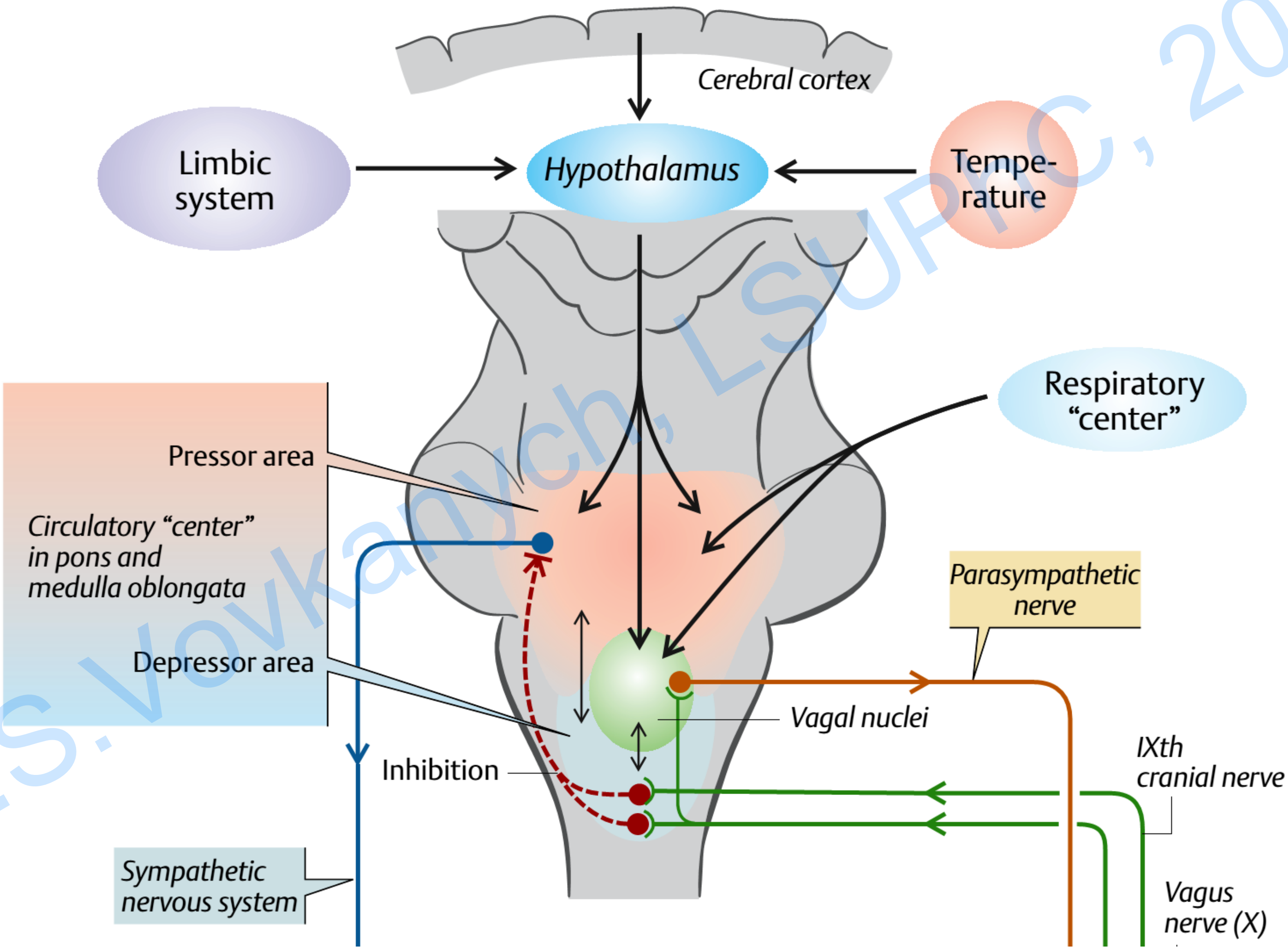


Nervous Mechanism

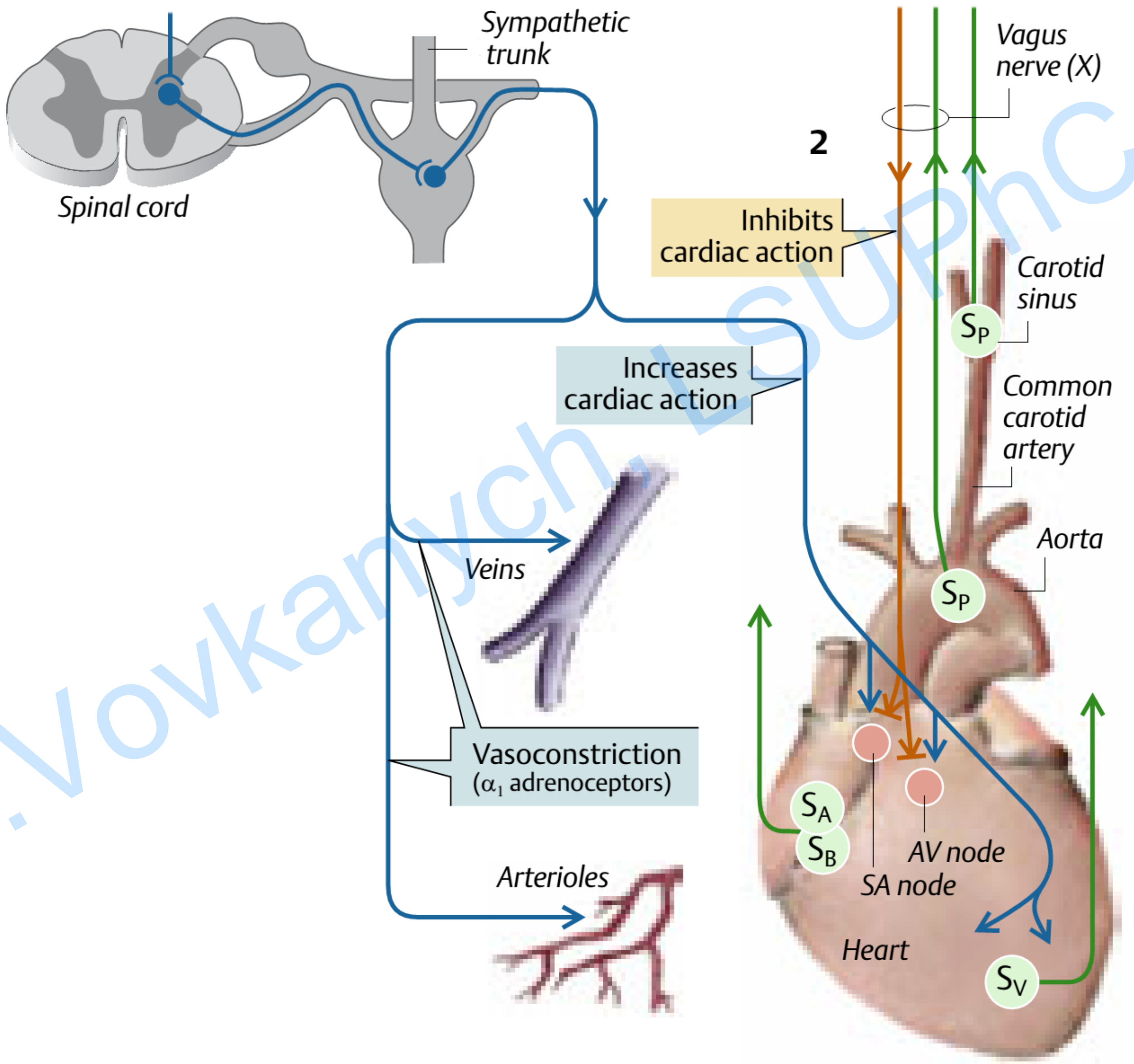
- Operates through the **vasomotor center**, bilaterally situated in medulla oblongata and the lower part of the pons
- **Vasoconstrictor** (pressor) area - causes vasoconstriction (decrease of vessels diameter) and rise in arterial blood pressure
- **Vasodilator** (depressor) area – causes vasodilatation (increase of vessels diameter) and is also concerned with cardioinhibition



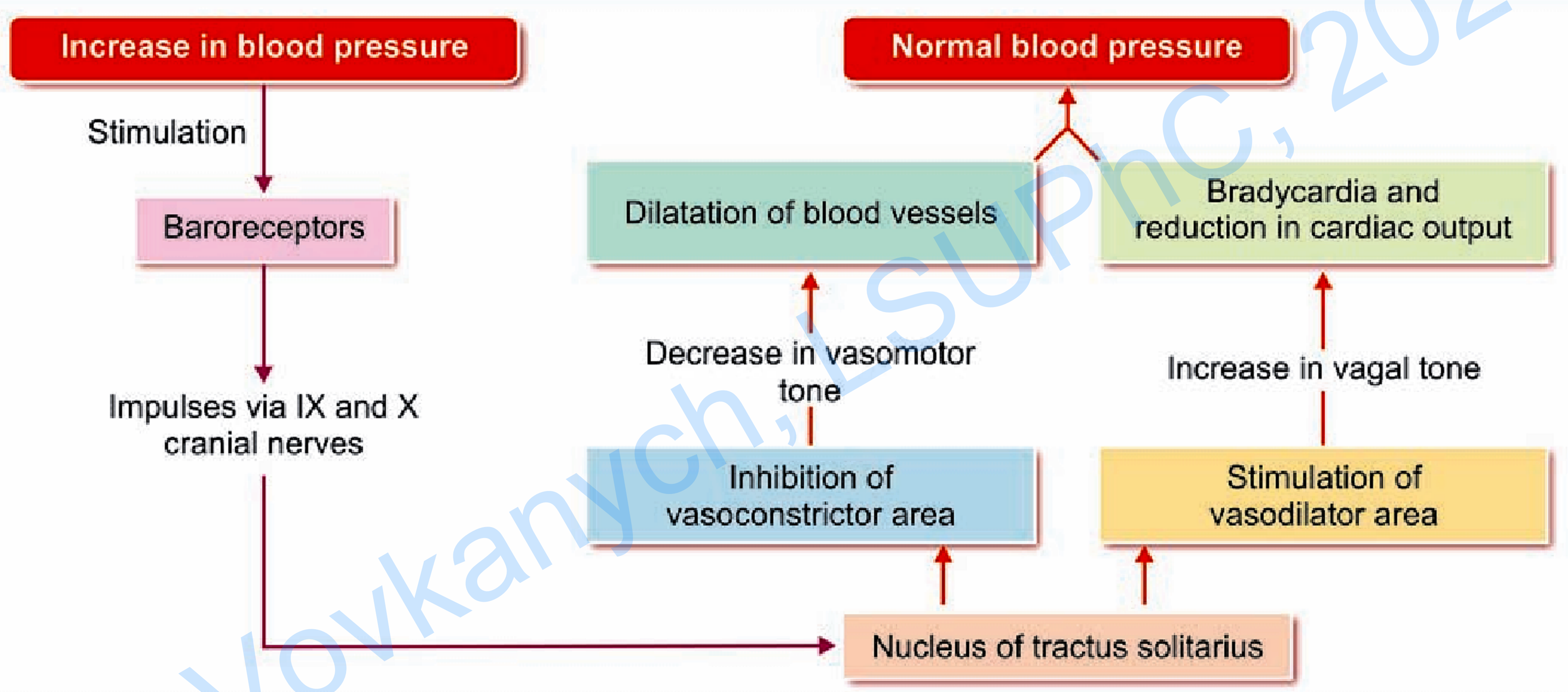
Structure of Vasomotor Center



Efferent Influence of Vasomotor Center



Nervous Mechanism



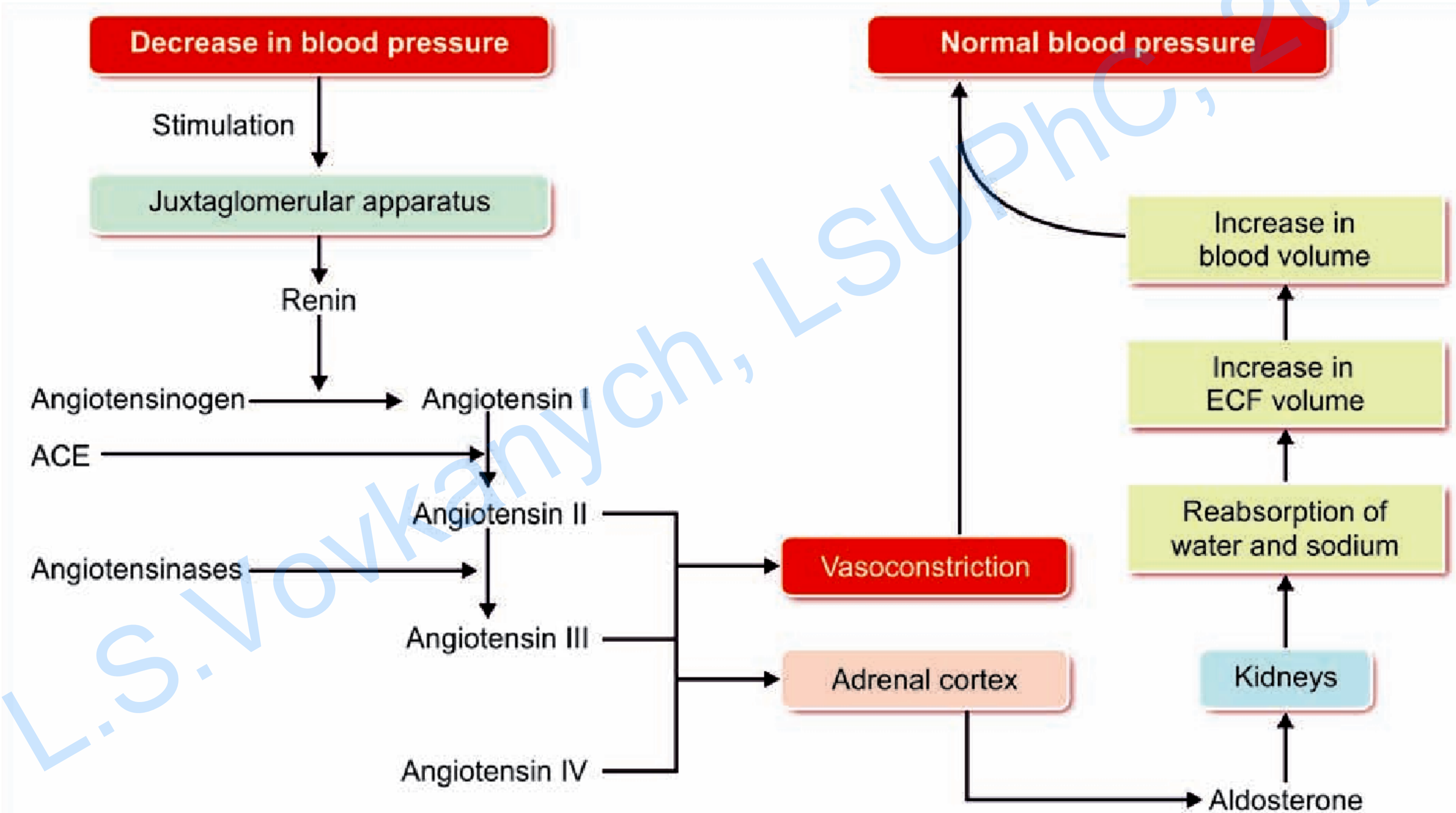
Baroreceptors are situated in the carotid sinus and wall of the aorta
Vasomotor center is also sensitive to the **chemoreceptor** impulses
Vasomotor center is controlled by the impulses from **the higher centers** in the brain and influenced by activity of respiratory center

Renal Mechanism

Kidneys regulate arterial blood pressure by two ways:

- By regulation of **extracellular fluid** (ECF) volume
  - even a slight increase in blood pressure **increases** the water excretion
  - it causes the **decrease** in ECF volume and blood volume
  - that brings the arterial blood pressure **back to normal** level
- Through **renin-angiotensin mechanism**

Renin-angiotensin Mechanism



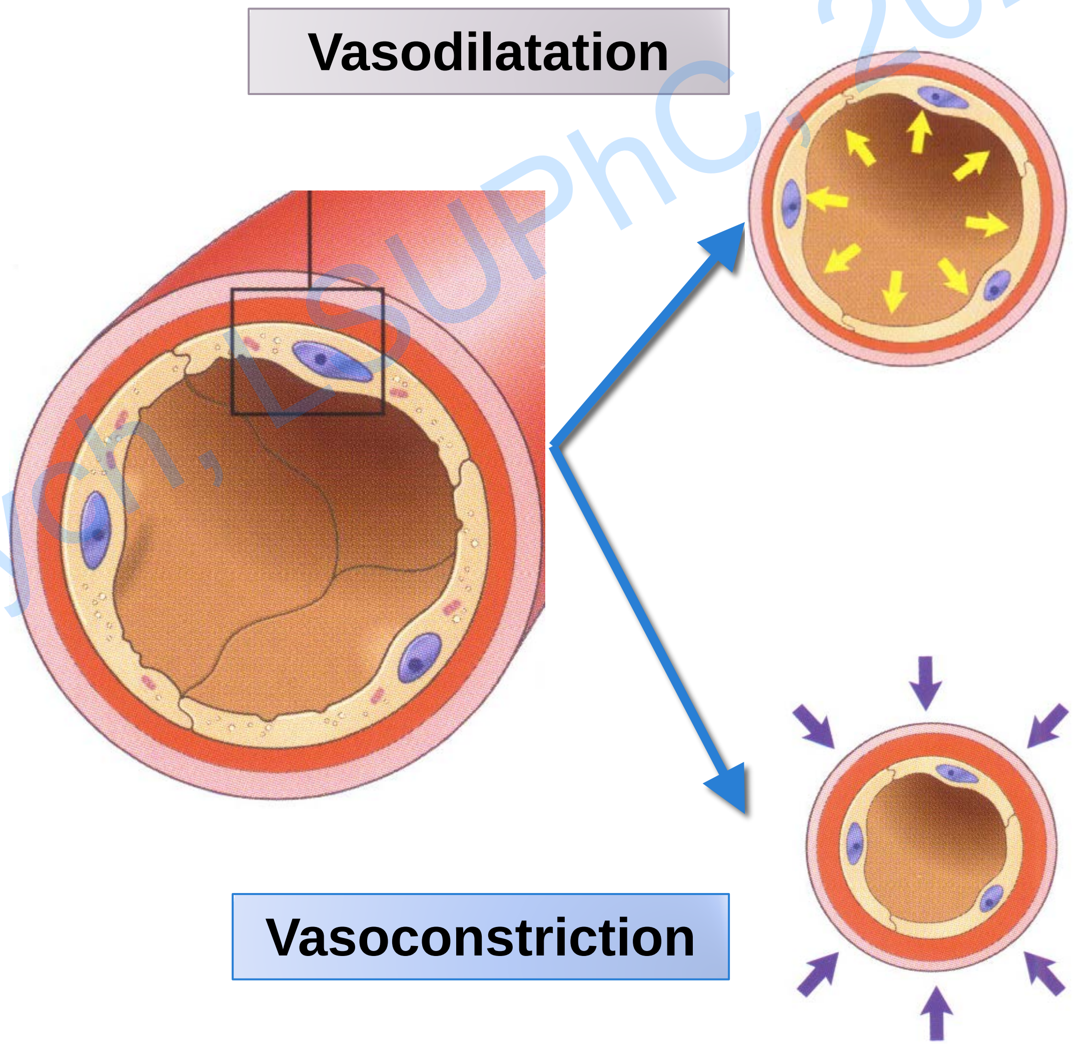
Hormonal Mechanism

Increase arterial blood pressure	**Decrease arterial blood pressure**
Hormones	
Adrenaline Thyroxine Aldosterone Vasopressin Angiotensin *Serotonin*	Vasoactive intestinal polypeptide (VIP) Atrial natriuretic peptide Brain natriuretic peptide C-type natriuretic peptide *Bradykinin* *Prostaglandin* *Histamine*

Local Regulation of Blood Flow (Autoregulation)

Autoregulation has two functions:

- help to **maintain** a constant blood flow to certain organs when the blood pressure changes
- **adjust** the blood flow according to changes in **metabolic activity** of an organ (metabolic autoregulation)



Theories of Autoregulation

Myogenic theory

- The **intrinsic contractile property** of the smooth muscle fibers present in the blood vessels is responsible for autoregulation
- Sudden **stretching of blood vessels** causes **contraction** of smooth muscle fibers present in the wall of the vessels
- **Increase** of arterial blood pressure causes **vasoconstriction** and **decrease** – causes **vasodilatation**

Metabolic theory

- Normal blood flow is maintained by the **metabolic end products**

Autoregulation mechanisms are **well developed** in the kidneys, but it has also been observed in the mesentery, skeletal muscle, brain, liver, and myocardium

Local Mechanism. Metabolic theory

Local **vasoconstrictor** substances are derived from vascular endothelium, are called **endothelium-derived constricting factors** (EDCF)

Local **vasodilators** are of two types:

1. Vasodilators of **metabolic origin**, accumulation of which (due to the reduced blood flow) dilate the blood vessels
2. Vasodilators of **endothelial origin** - Nitric oxide (NO)

Vasoconstrictors	Vasodilators
Endothelium-derived constricting factors	Carbon dioxide Lactate Hydrogen Adenosine Nitric oxide
Local temperature decrease	local temperature increase

Cardiovascular Changes during Exercise

Exercise is generally **classified** into two types depending upon the type of muscular contraction:

Dynamic exercise

- In this type of exercise, the heart rate, force of heart contraction, cardiac output and systolic blood pressure increase
- The diastolic blood pressure is unaltered or decreased (no changes or decrease in peripheral resistance)

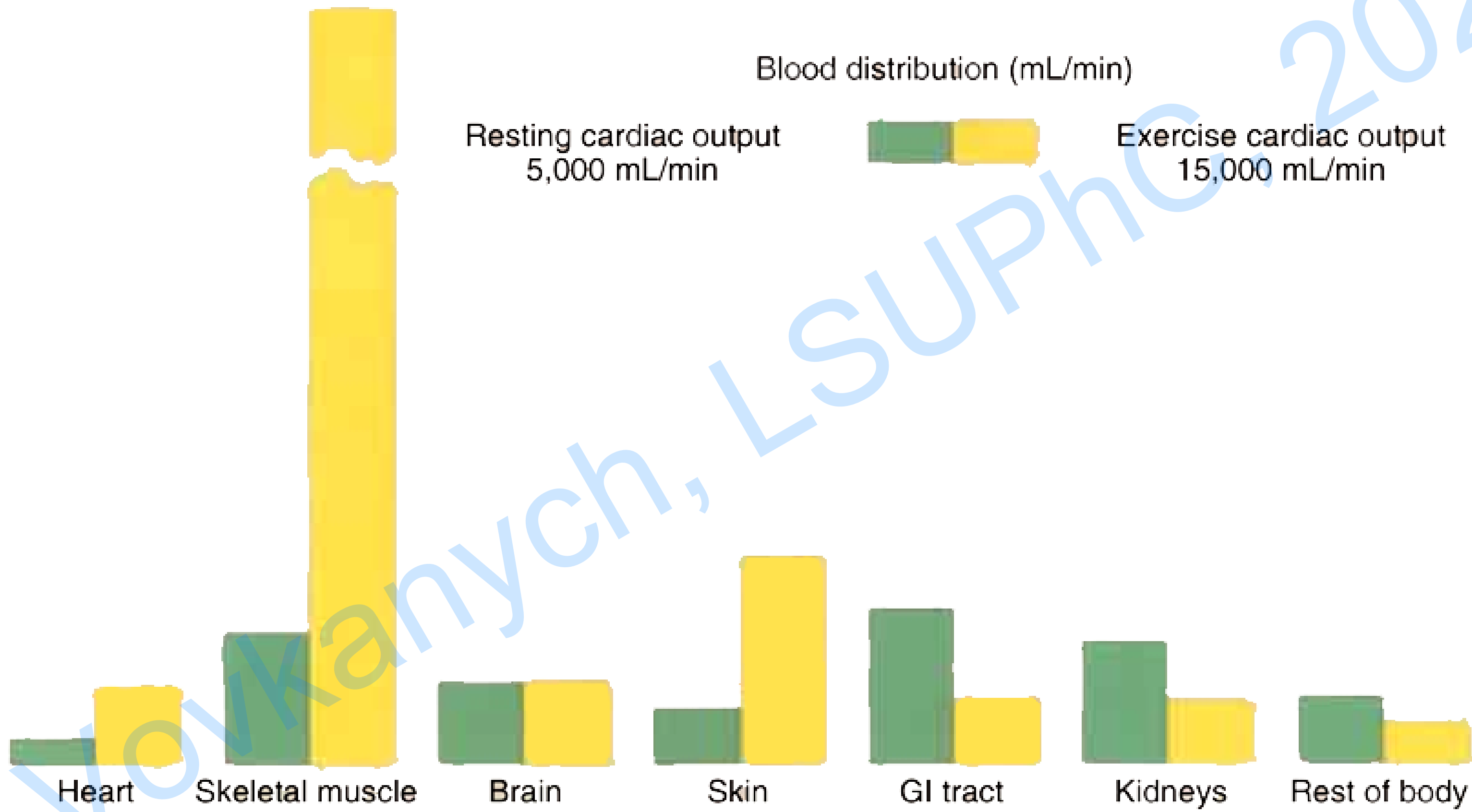
Static exercise (isometric muscular contraction)

- Smaller increase in heart rate, force of contraction, much smaller increase in cardiac output
- Large increase in systolic blood pressure, the diastolic blood pressure also increases
- Large increase in peripheral resistance, decrease (even stoppage) in blood flow through active muscles

Cardiovascular Changes during Exercise

- **Heart rate** - increases up to 180 beats/minute
- **Cardiac output** - increases up to 20-35 L/minute (because of increase in heart rate and stroke volume)
- **Venous return** - increases remarkably (because of muscle pump, respiratory pump and splanchnic vasoconstriction)
- Amount of **blood flowing to skeletal muscles** - great increase (in rest - 3 to 4 mL/100 g of the muscle/minute; moderate exercise - 60 to 80 mL; severe exercise - up to 90 to 120 mL)
- The factors, that are **responsible for the increase** - vasodilatation in muscles, induced by sympathetic cholinergic fibers, and local mechanisms (hypercapnia, hypoxia, accumulation of lactic acid, rise in temperature etc.)

Cardiovascular Changes during Exercise



	Heart	Skeletal muscle	Brain	Skin	GI tract	Kidneys	Rest of body
Resting	215 mL	1,035 mL	645 mL	430 mL	1,205 mL	950 mL	515 mL
% of total	4%	21%	13%	9%	24%	19%	10%
Exercise	645 mL	10,710 mL	645 mL	1,635 mL	510 mL	510 mL	330 mL
% of total	4.5%	71%	4.5%	11%	3.5%	3.5%	2%

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