CVS Hemodynamics

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Objectives

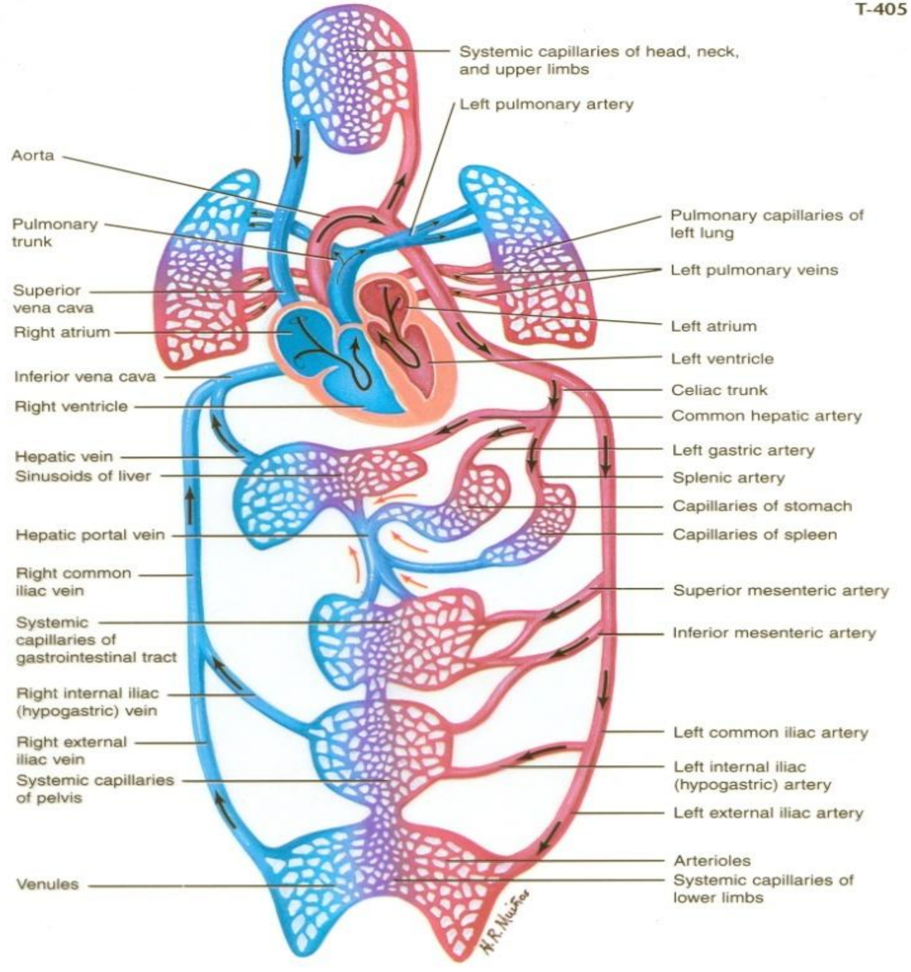
- ✓ point out the physical characteristics of the circulation:
  - distribution of blood volume
  - total cross sectional area
  - velocity
  - blood pressure
- ✓ List the determinants of blood flow
- ✓ Define and calculate blood flow, resistance, and pressure
- ✓ Define and calculate conductance
- ✓ Apply Poiseulle's law

- Resource: Guyton's textbook of medical Physiology

BLOOD FLOW THROUGH BODY TISSUES IS INVOLVED IN:

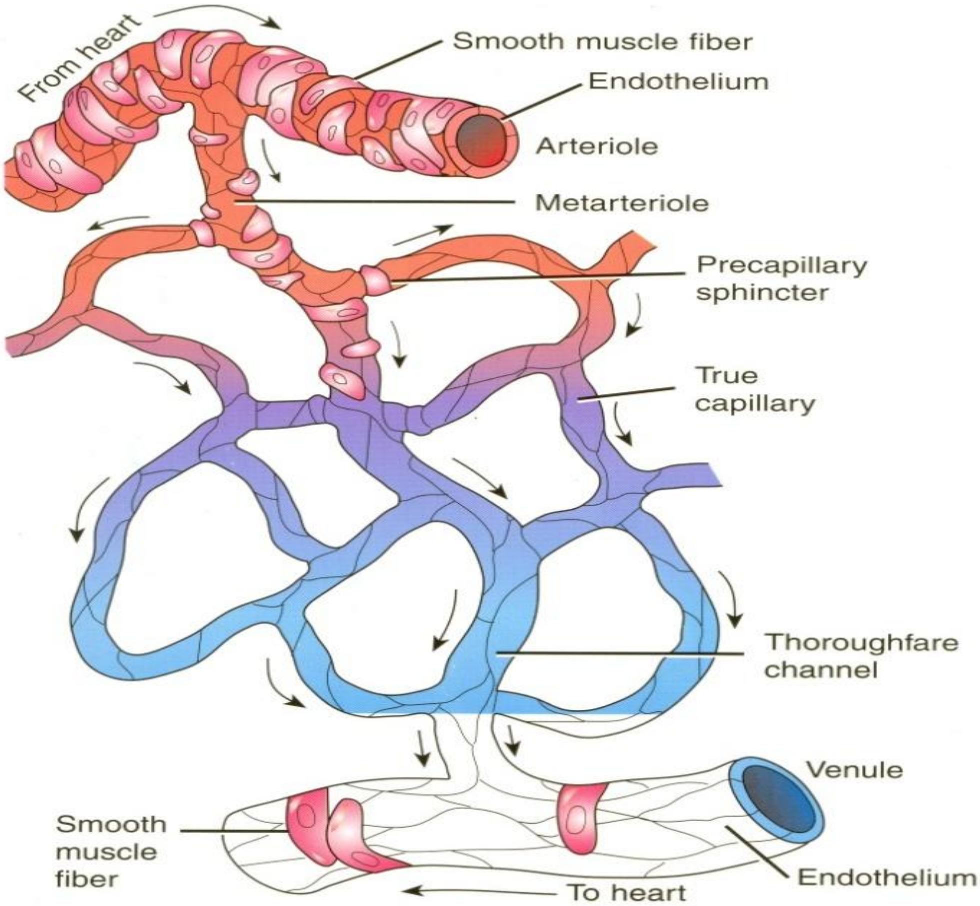
- Delivery of O_2 and removal of CO_2 from tissue cells.
- Gas exchange in lungs.
- Absorption of nutrients from GIT.
- Urine formation in kidneys.

The Circulatory System



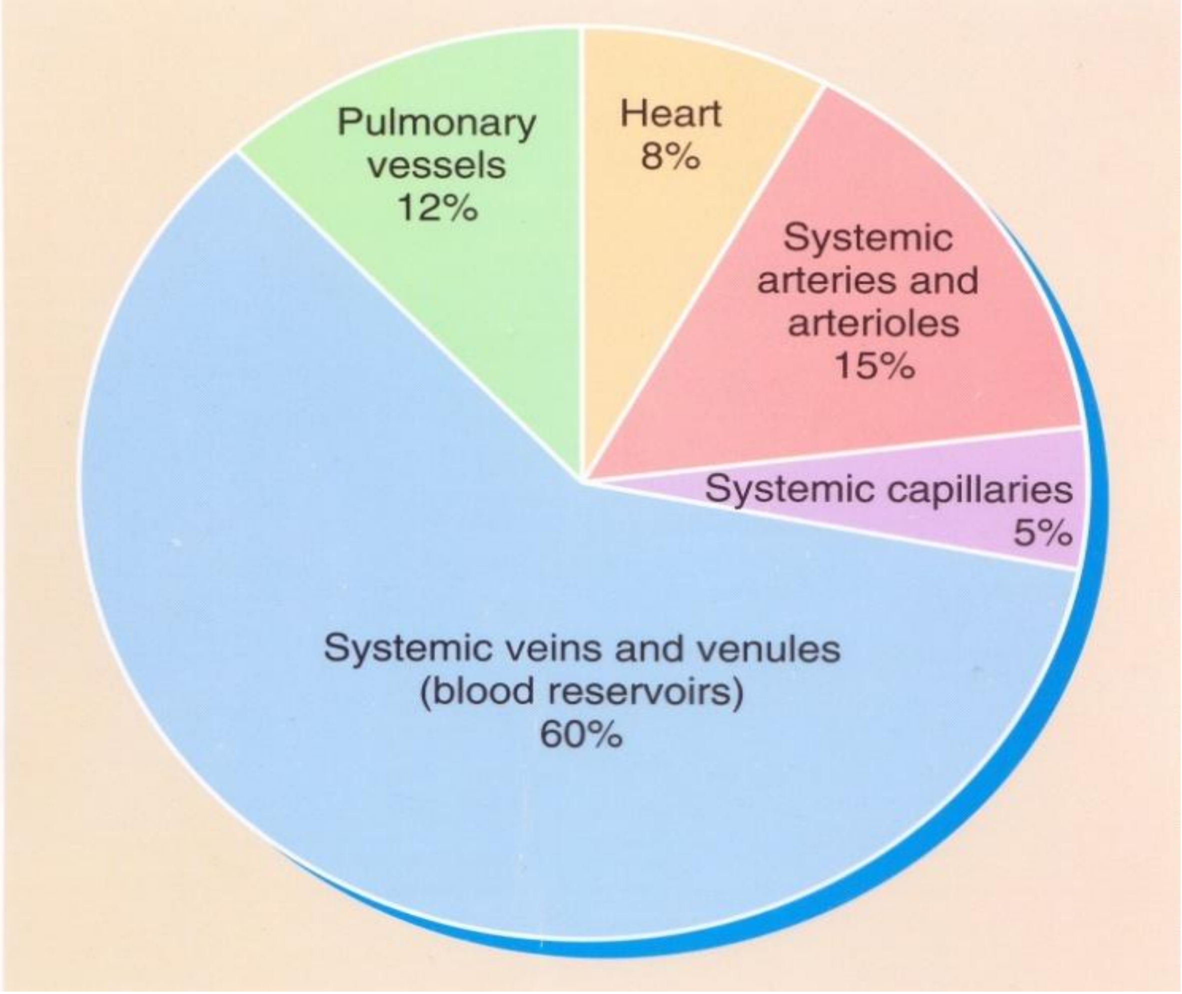
General plan of circulation

The Capillaries



(a) Details of a capillary network

Blood Volume Distribution



The Circulatory System is Composed of the Systemic and Cardiopulmonary Circulation

- Systemic Circulation
  - Serves all tissues except the lungs
  - Contains 84% of blood volume
  - Also called the *peripheral circulation*
- Pulmonary Circulation
  - Serves the lungs
  - Lungs contain 9% of blood volume and heart 7%

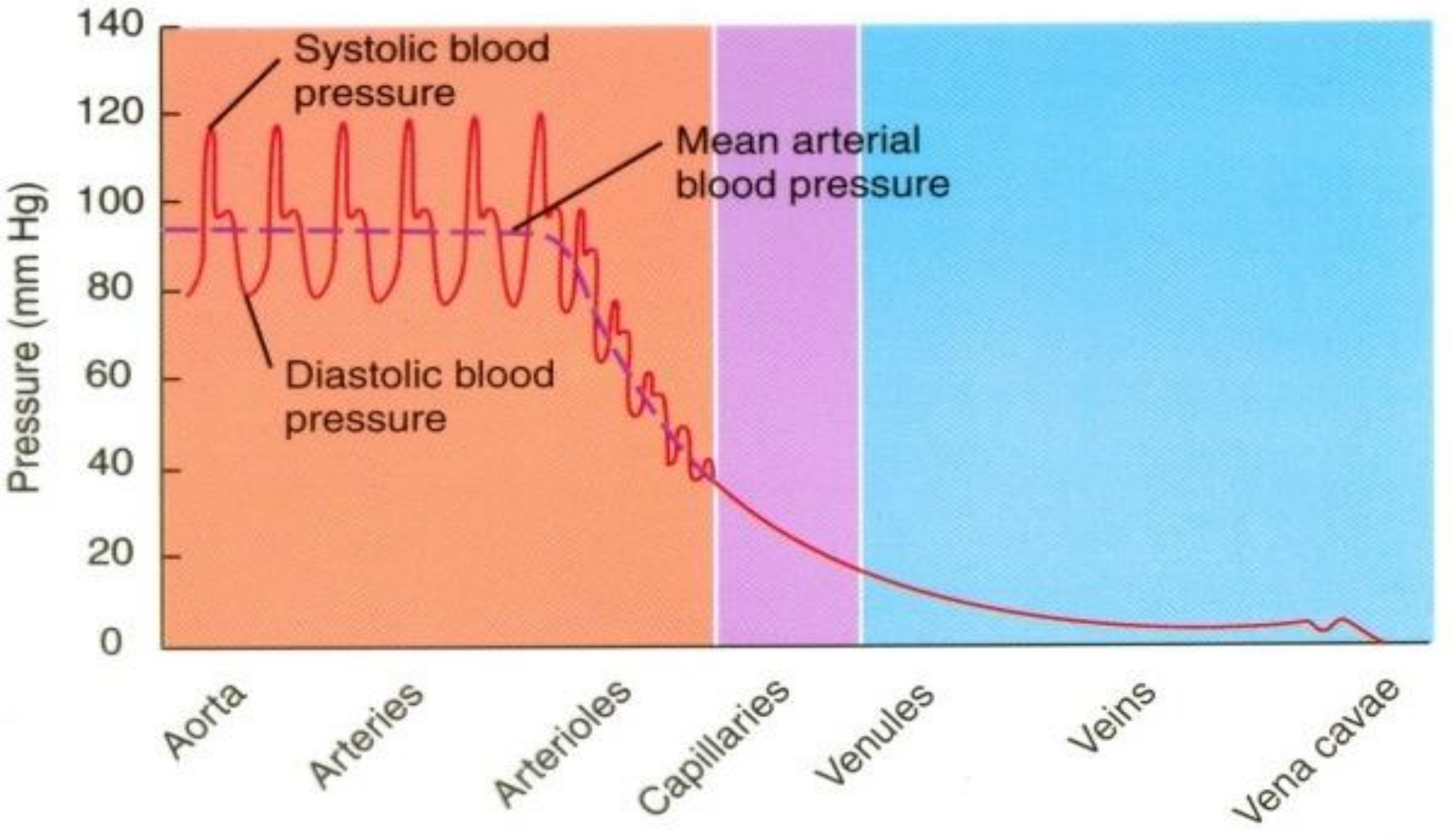
Blood Reservoir Function of Veins

- 60% of blood is in veins
- Under various physiological conditions, blood is transferred into arterial system to maintain arterial pressure.
- The spleen, liver, large abdominal veins, and the venous plexus also serve as reservoirs.
- Spleen also serves as a special reservoir for red blood cells.

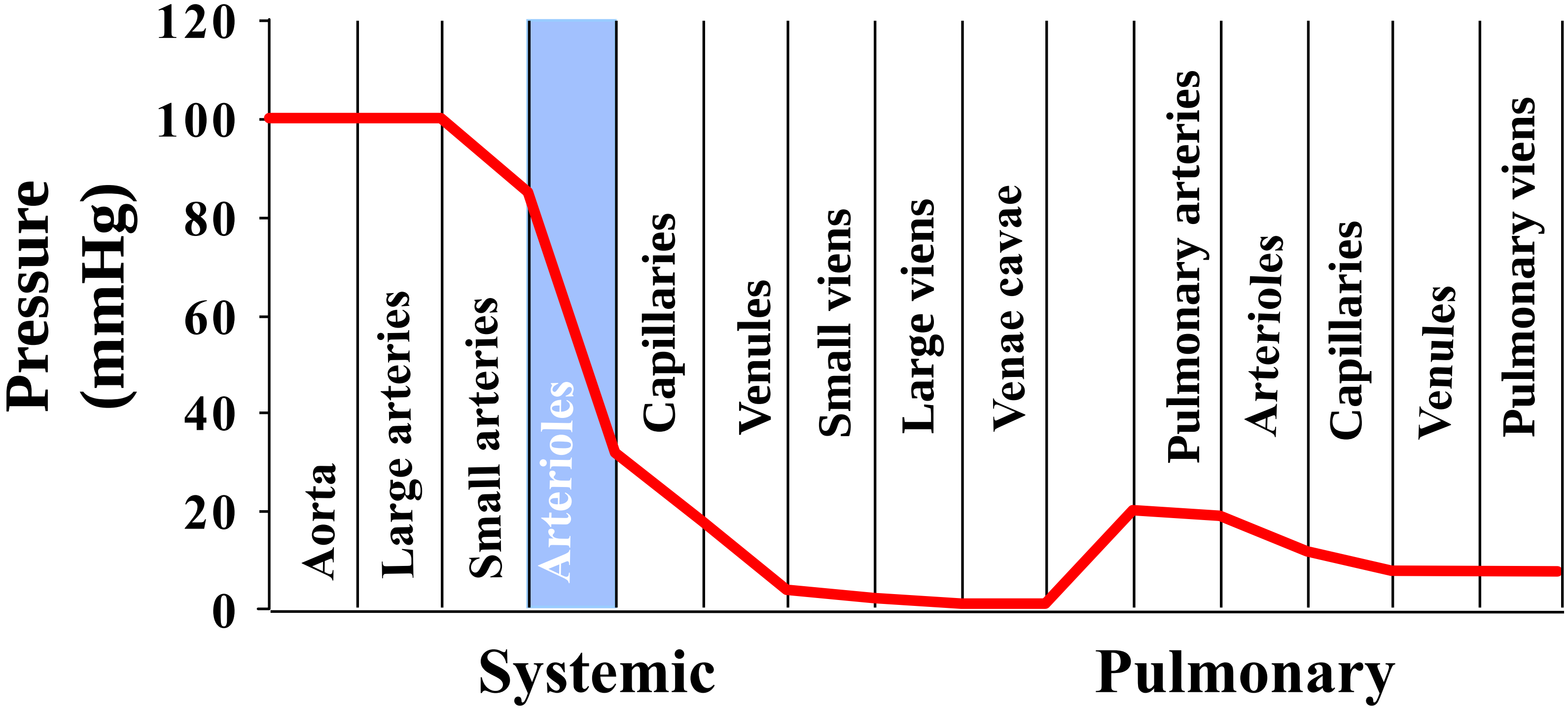
Basic Theory of Circulatory Function

- *Blood flow* to tissues is controlled in relation to tissue needs.
- *Cardiac output* is mainly controlled by local tissue flow.
- *Arterial pressure* is controlled independent of either local blood flow control or cardiac output control.

Pressure Changes through the circulation

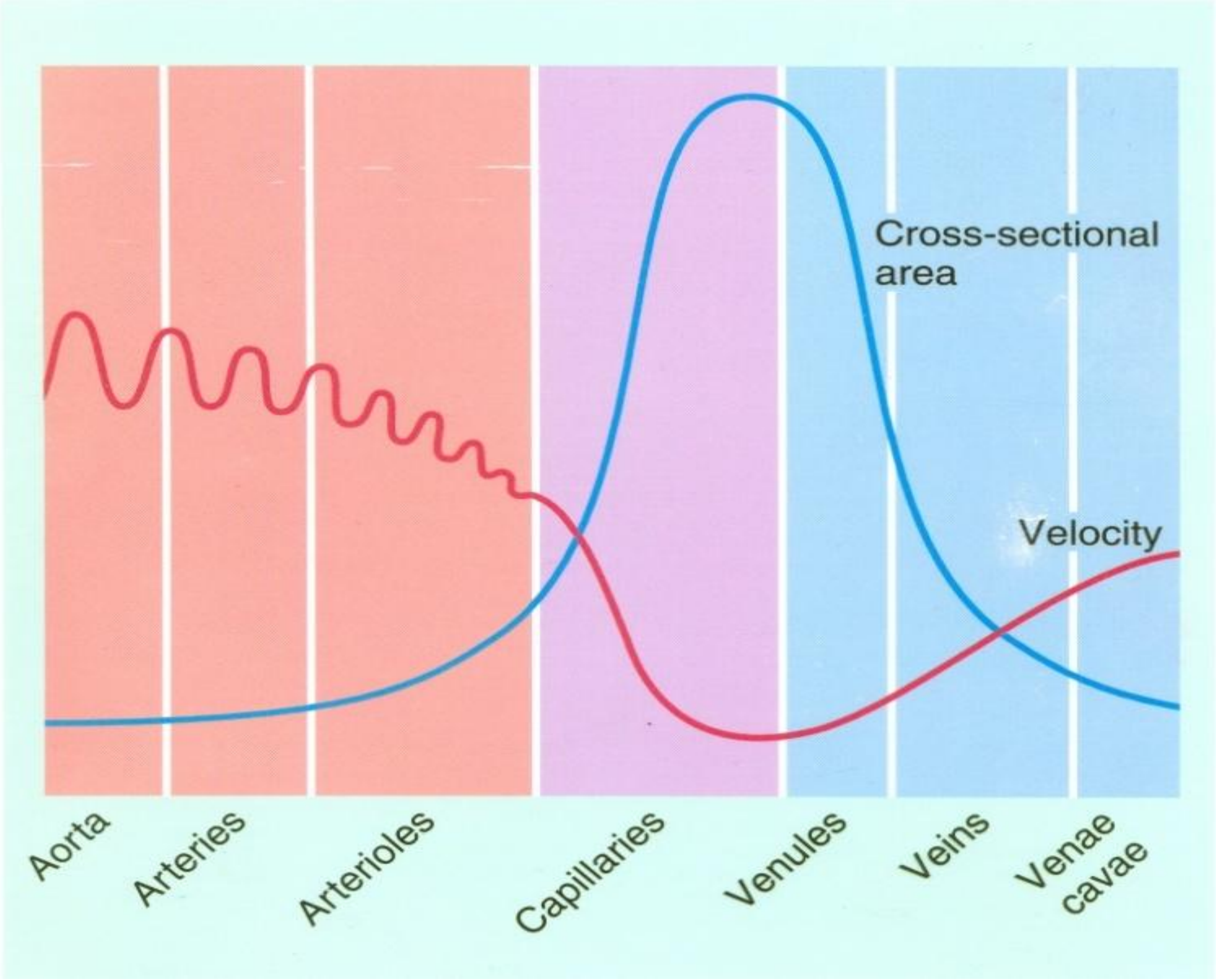


Blood Pressure Profile in the Circulatory System



- **High pressures in the arterial tree**
- **Low pressures in the venous side of the circulation**
- **Large pressure drop across the arteriolar-capillary junction**

Changes in Cross Sectional Area and Velocity



The Capillaries Have the Largest Total Cross-sectional Area of the Circulation

	cm
Aorta	**2.5**
Small Arterioles	**20**
Arterioles	**40**
Capillaries	**2500**
Venules	**250**
Small Veins	**80**
Venae Cavae	**8**

Velocity of Blood Flow is Greatest in the Aorta

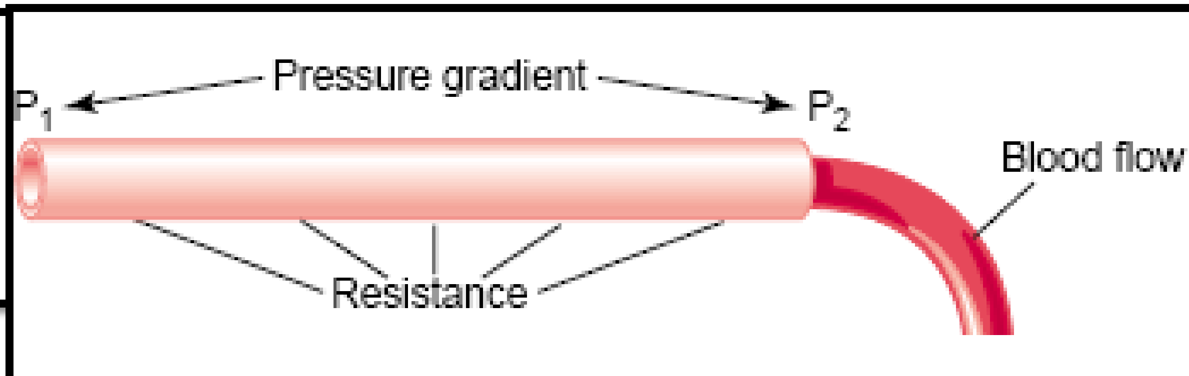
$$\textbf{\textit{Velocity} of Blood Flow} = \frac{\textbf{Blood Flow}}{\textbf{Cross sectional area}}$$

Aorta >Arterioles> Small veins >Capillaries

BLOOD FLOW

- Blood flow or “F“ = Blood flow means simply the quantity of blood that passes a given point in the circulation in a given period of time (mL/Sec).

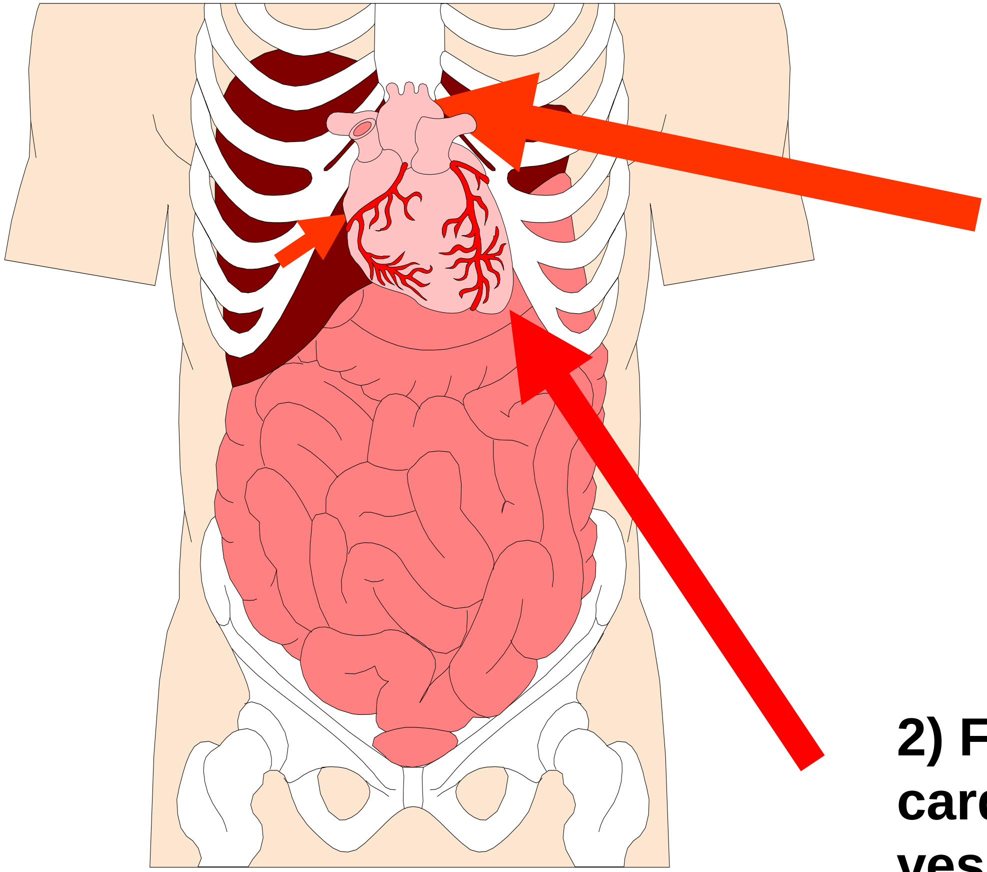
$$F = \frac{\Delta P}{R}$$



In the systemic circulation

***(F) = cardiac output (CO),**

*** the pressure gradient = (difference between mean arterial blood pressure and atrial pressure which is around zero) = mean systemic arterial B.P.**



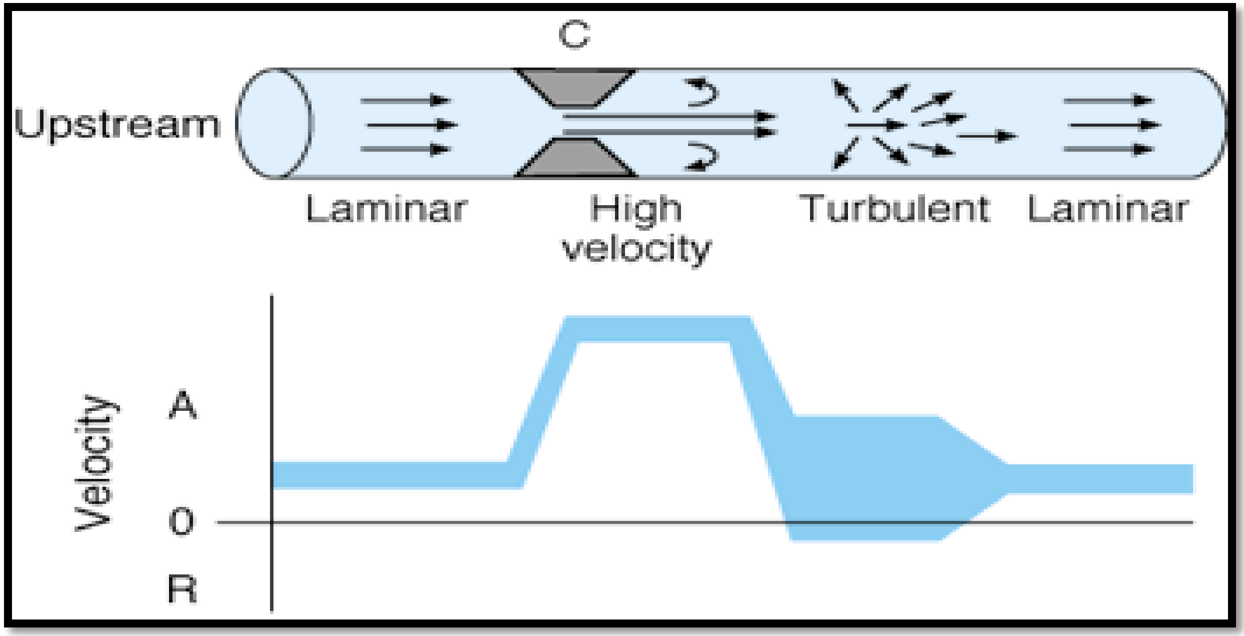
1) Pressure gradient produced by heart pumping moves blood in the system from the arterial to the venous side, 5 l/min

2) Fluid pressure expands cardiac chambers and blood vessels.

$$CO(F) = \frac{\text{mean systemic arterial blood pressure}}{\text{total peripheral resistance}}$$

Average Velocity

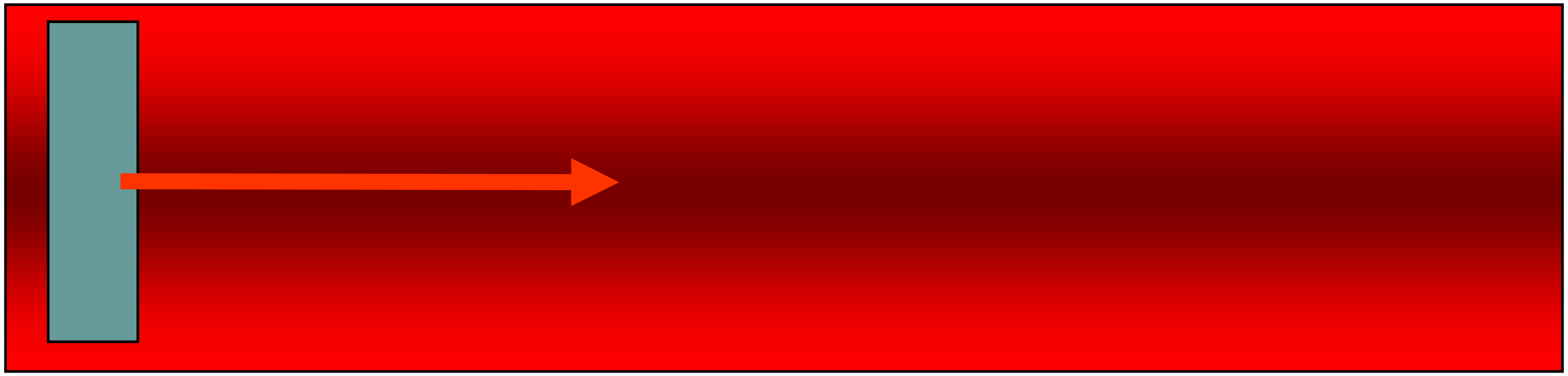
- Velocity (V) is proportionate to flow (F) divided by cross sectional area of the blood vessel (A): F=A*V
- V=F/A



So blood flow is fastest in aorta and slowest in capillaries ?

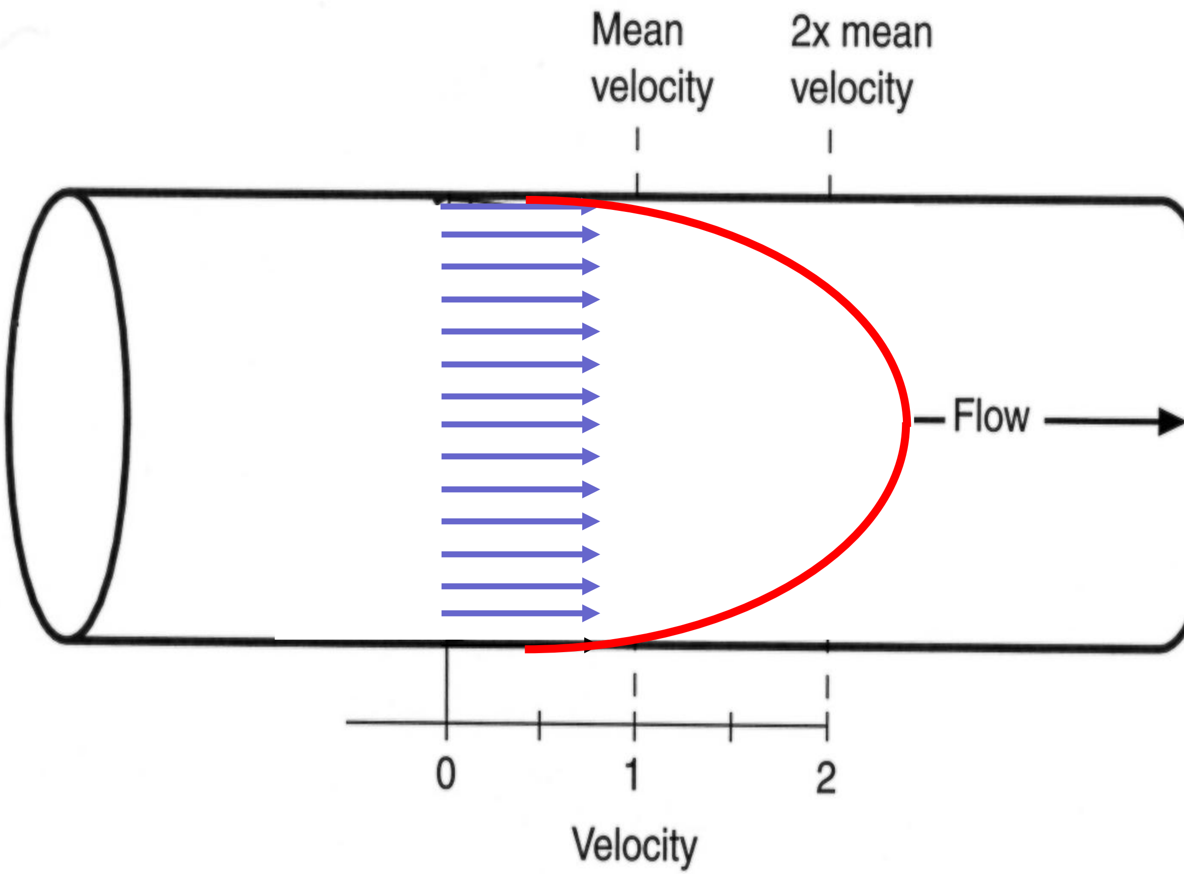
Laminar vs. Turbulent Flow

Blood does not flow as a plug in *large* vessels.



How does it flow ?

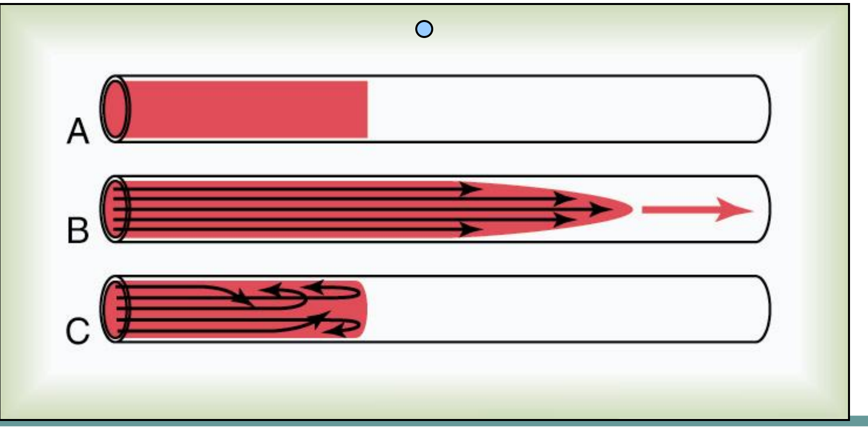
Laminar flow: Definition:



- **The fluid nearest the vessel wall flows the slowest, and fluid in the center of the tube moves the most rapidly.**
- **This produces layers (‘*laminae*’) with uniform speeds at certain distances from the wall.**
- **If the flow rate is increased then the trend for turbulence will increase .**

Blood Flow

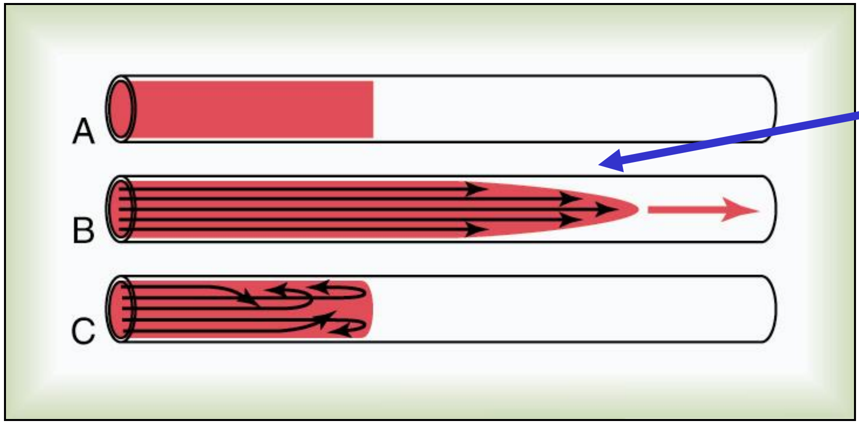
- *Blood flow* is the quantity of blood that passes a given point in the circulation in a given period of time.
- *Unit of blood* flow is usually expressed as milliliters (ml) or Liters (L) per minute.
- Overall flow in the circulation of an adult is 5 liters/min which is the *cardiac output.*



Blood Vessel

Characteristics of Blood Flow

- Blood usually flows in streamlines with each layer of blood remaining the same distance from the wall, this type of flow is called *laminar flow*.
  - When laminar flow occurs, the velocity of blood in the center of the vessel is greater than that toward the outer edge creating a parabolic profile.

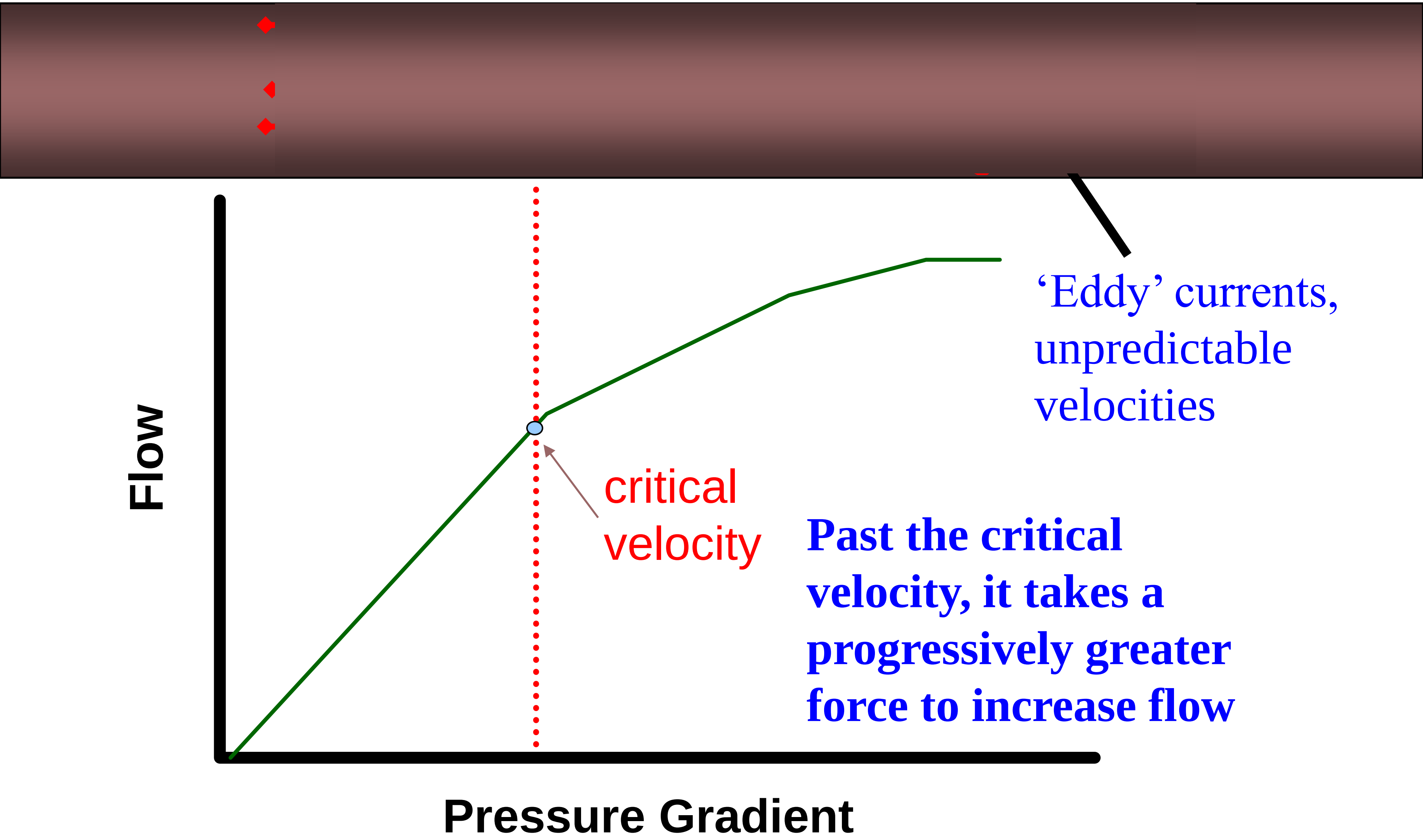


Blood Vessel

Turbulent flow: Definition

$$\text{Reynold's No (Re)} = \frac{v.d.\rho}{\eta}$$

If Re is > 400 then Turbulent flow



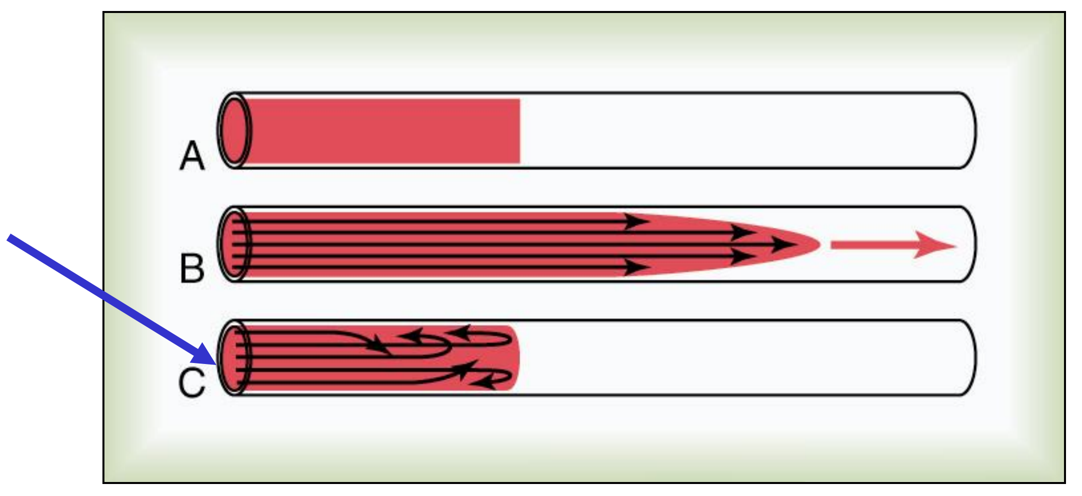
Past the critical velocity, it takes a progressively greater force to increase flow

Laminar Vs. Turbulent Blood Flow

Causes of turbulent blood flow:

- high velocities
- sharp turns in the circulation
- rough surfaces in the circulation
- rapid narrowing of blood vessels

Turbulent flow



- Laminar flow is silent, whereas turbulent flow tend to cause *murmurs*.
- Murmurs or *bruits* are important in diagnosing vessels stenosis, vessel shunts, and cardiac valvular lesions.

Clinical significance of turbulence?

- **Normally** : at the branching of vessels and at roots of aorta and pulmonary arteries .

- **Pathologically:**

1. Constriction of arteries by atherosclerotic plaque.
2. In severe anemia.
3. Stenotic and incompetent cardiac valves.

The peripheral resistance:

- It is the resistance to blood flow through a vessel caused by friction between the moving fluid and the vascular wall.

- Most of the resistance to blood flow occurs in arterioles (50%) and capillaries (25%) so it is called peripheral.

Hemodynamic laws

- Ohm’s law: F =ΔP/R
  - F = Flow, ΔP = Change in Pressure,
    R = Resistance

$$CO = \frac{MAP - Rt.AtrialP}{TPR}$$

CO = cardiac output, MAP = mean arterial pressure, TPR = total peripheral resistance. Since Rt. Atrial pressure = 0 then

$$CO = \frac{MAP}{TPR}$$

Hemodynamic laws… cont

- Poiseuille's law

  $F = \pi \Delta P r^4 / 8\eta L$

  F = flow,

  ΔP = change in pressure

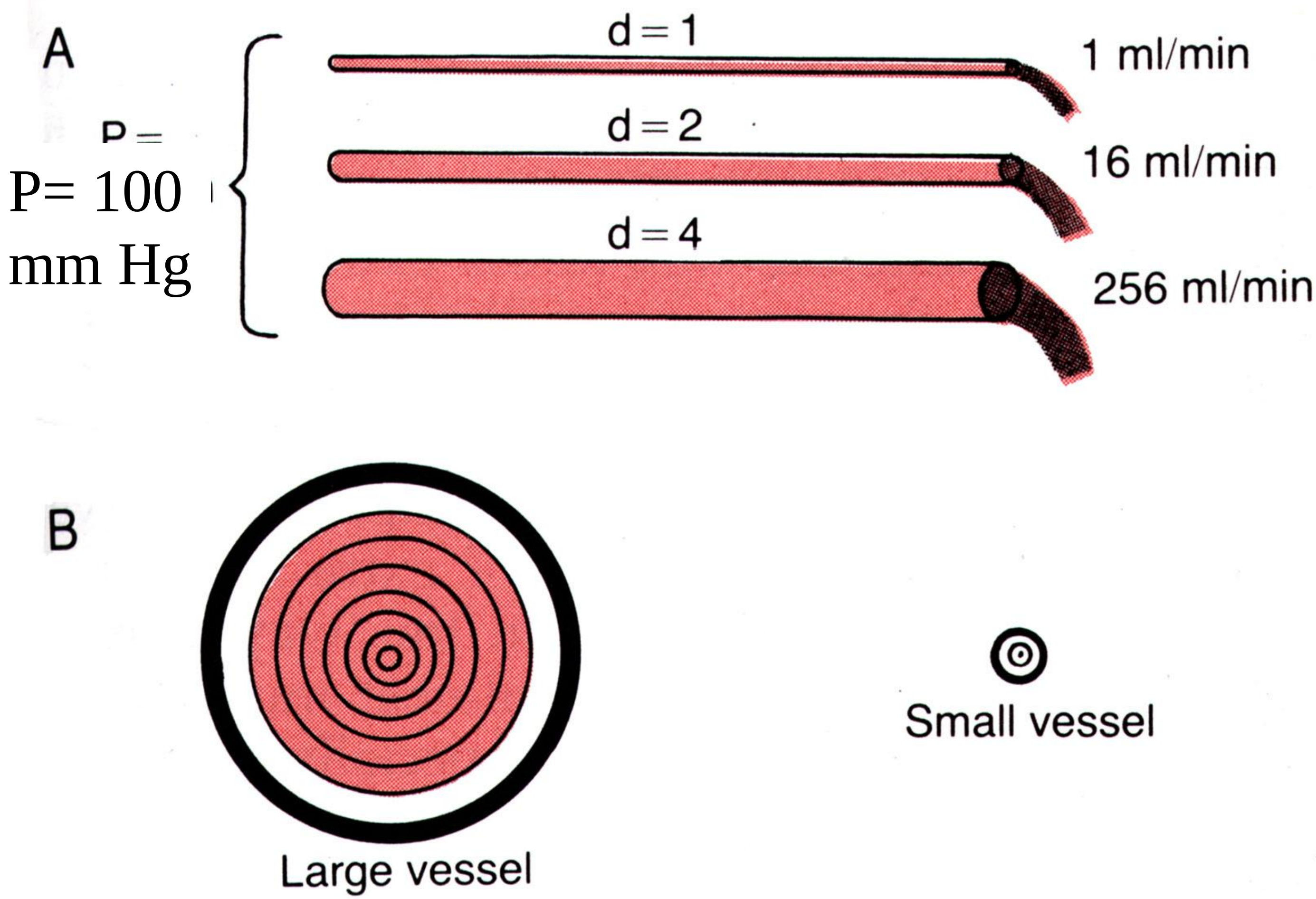
  r = radius of the vessel

  η (eta) = viscosity

  L = length of the vessel

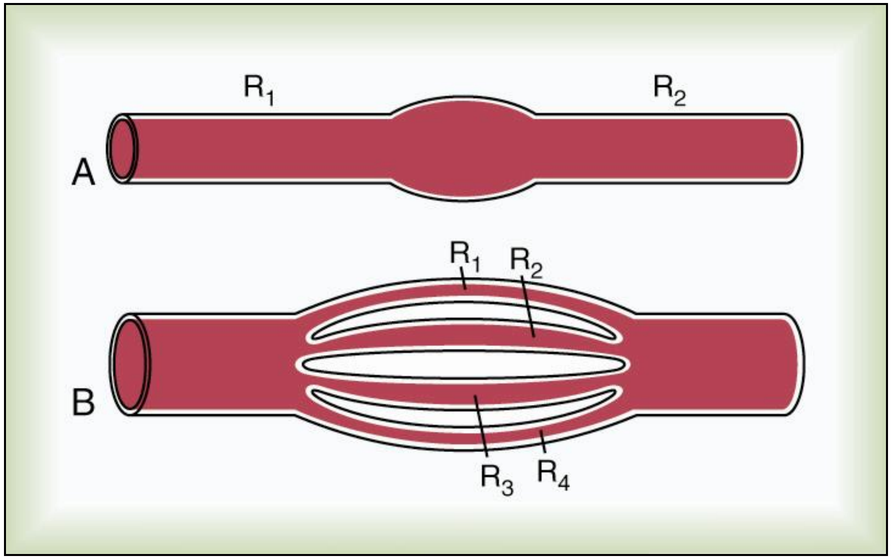
  Then Resistance, $R = 8\eta L / \pi r^4$

Effect of Vessel Diameter on Blood Flow



Parallel and Serial Resistance Sites in the Circulation

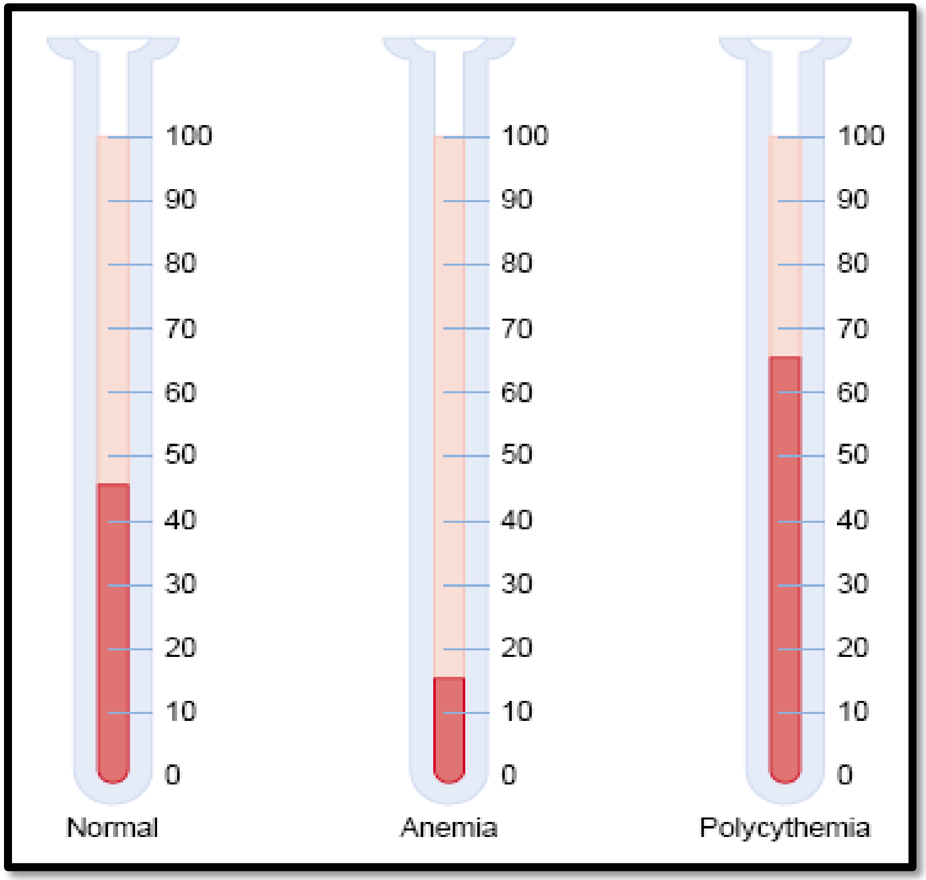
$$R_{total} = R_1 + R_2 + R_3 + R_4 \ldots$$



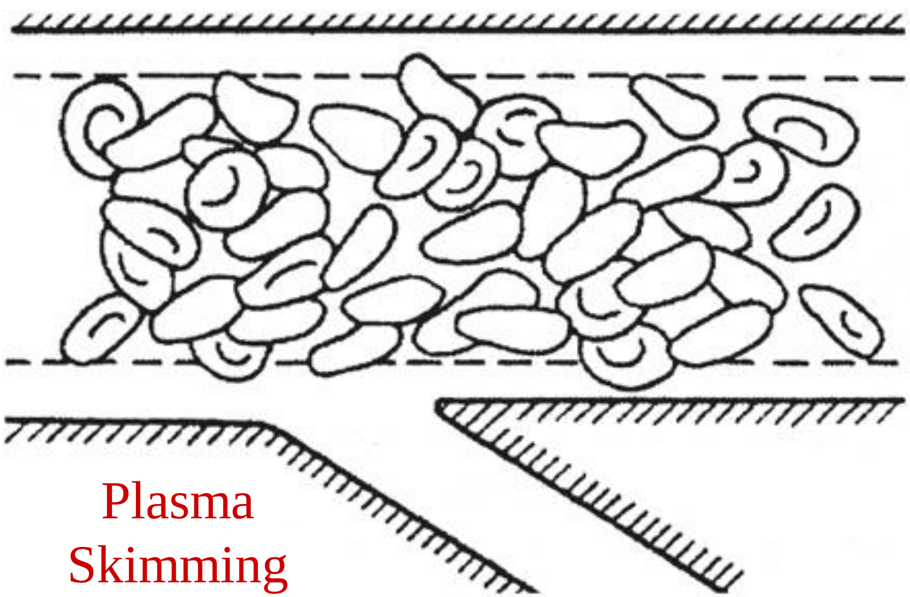
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \ldots$$

Factors influencing Blood Viscosity

1) Hematocrit.
2) Plasma proteins.
3) Diameter of the blood vessel.
4) Temperature.

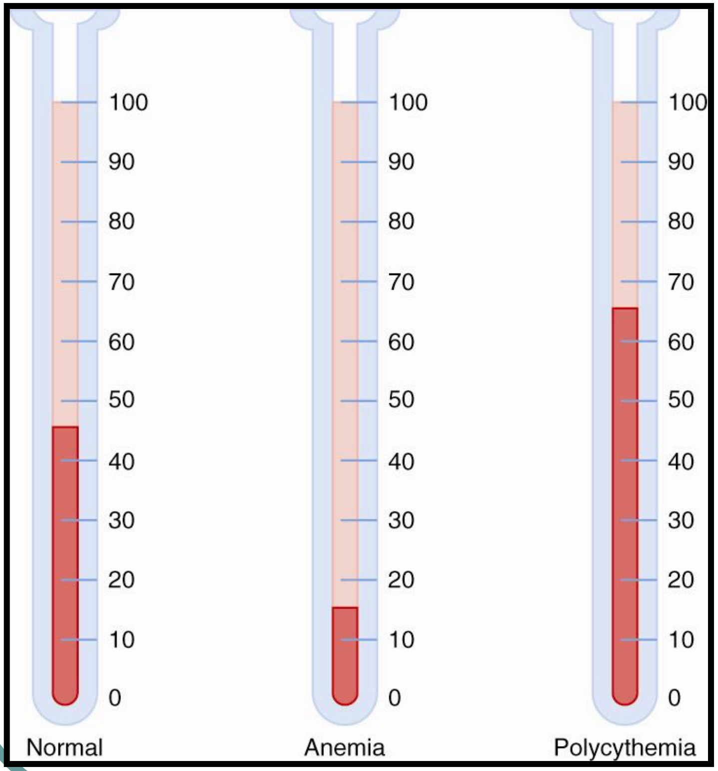


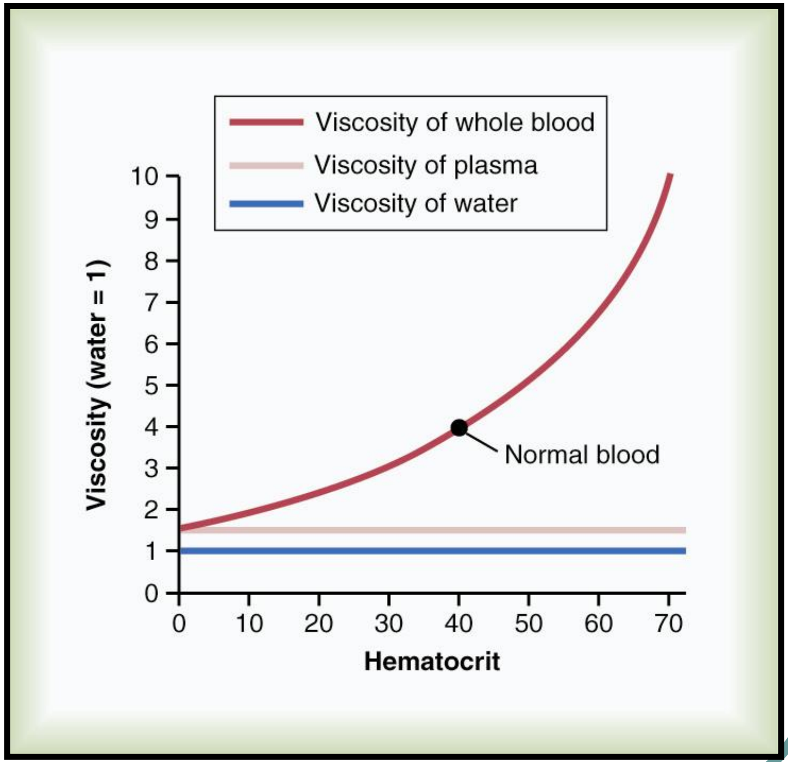
Hematocrits in a healthy (normal) person and in patients with anemia and polycythemia.



Plasma Skimming

Hematocrit and Viscosity Effects on Blood Flow





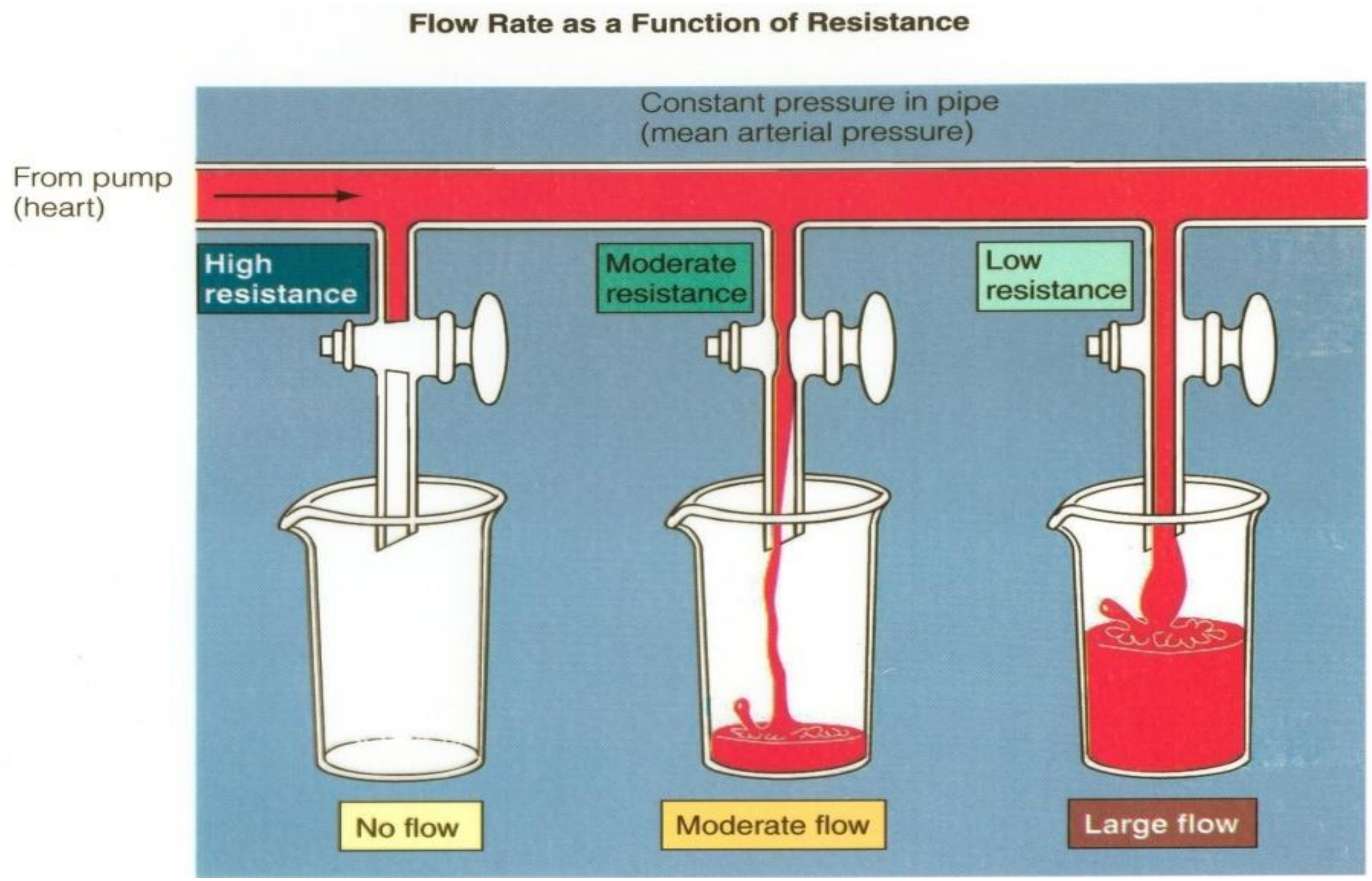
How Would a Decrease in Vascular Resistance Affect Blood Flow?

$$\uparrow \text{FLOW} = \frac{\Delta P}{\downarrow \text{RESISTANCE}}$$

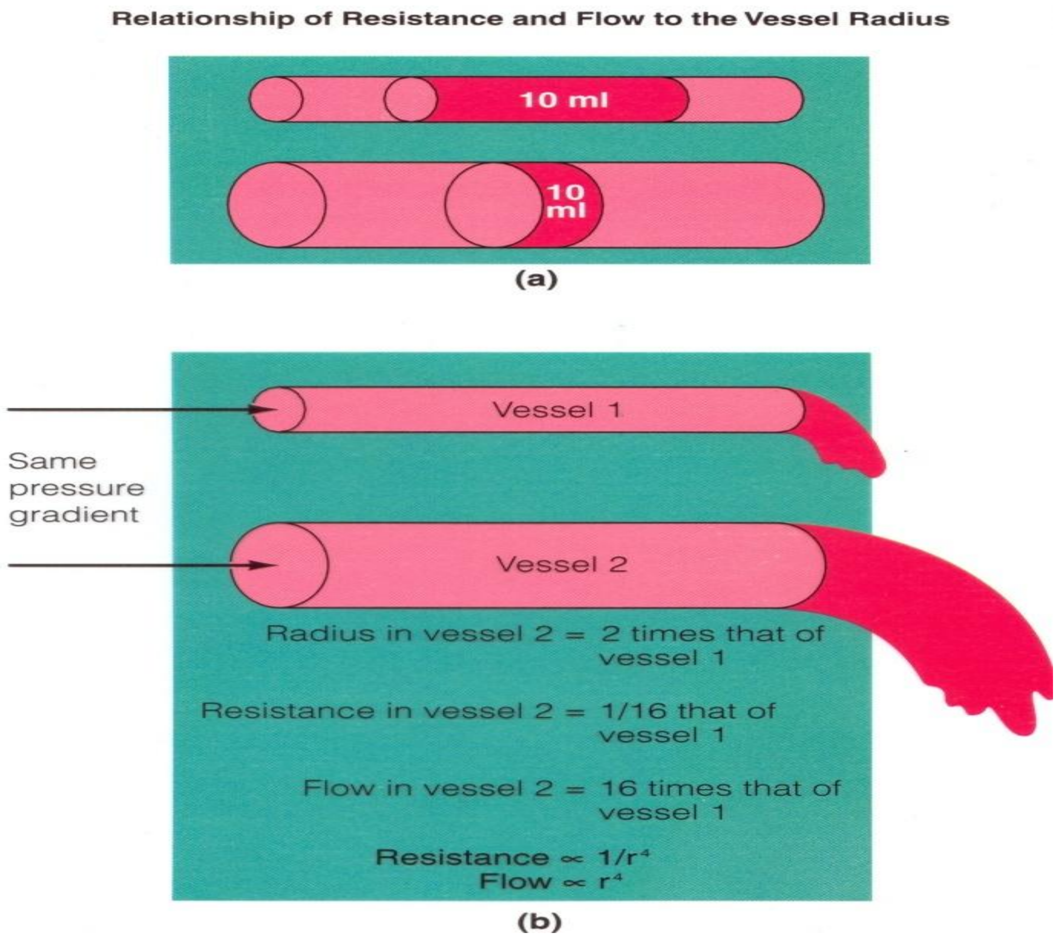
Conversely,

$$\downarrow \text{FLOW} = \frac{\Delta P}{\uparrow \text{RESISTANCE}}$$

Poiseuille's law …cont

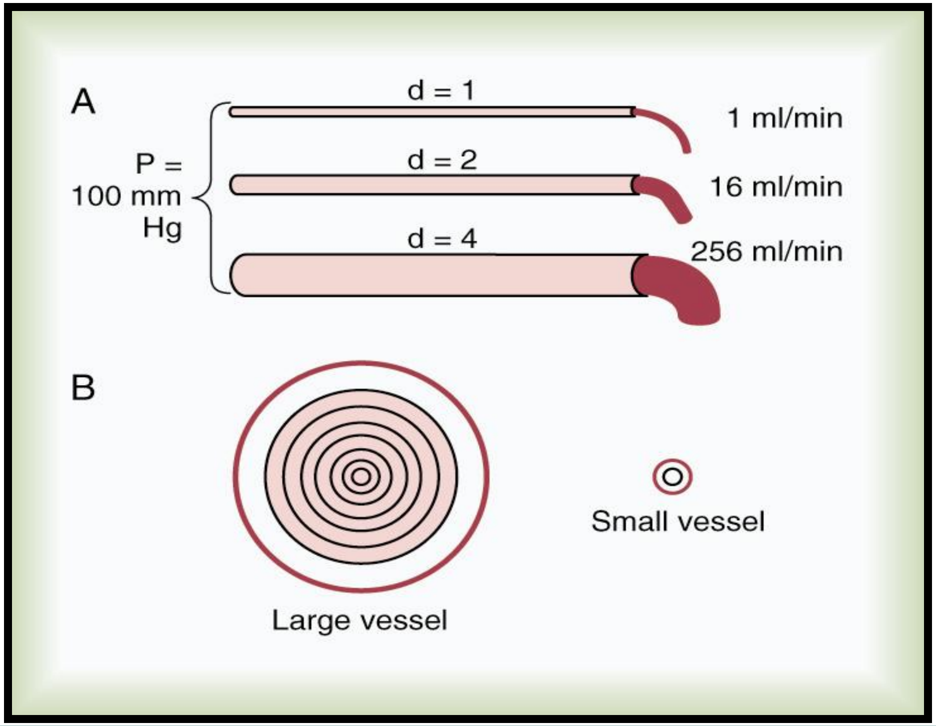


Poiseuille's law …cont

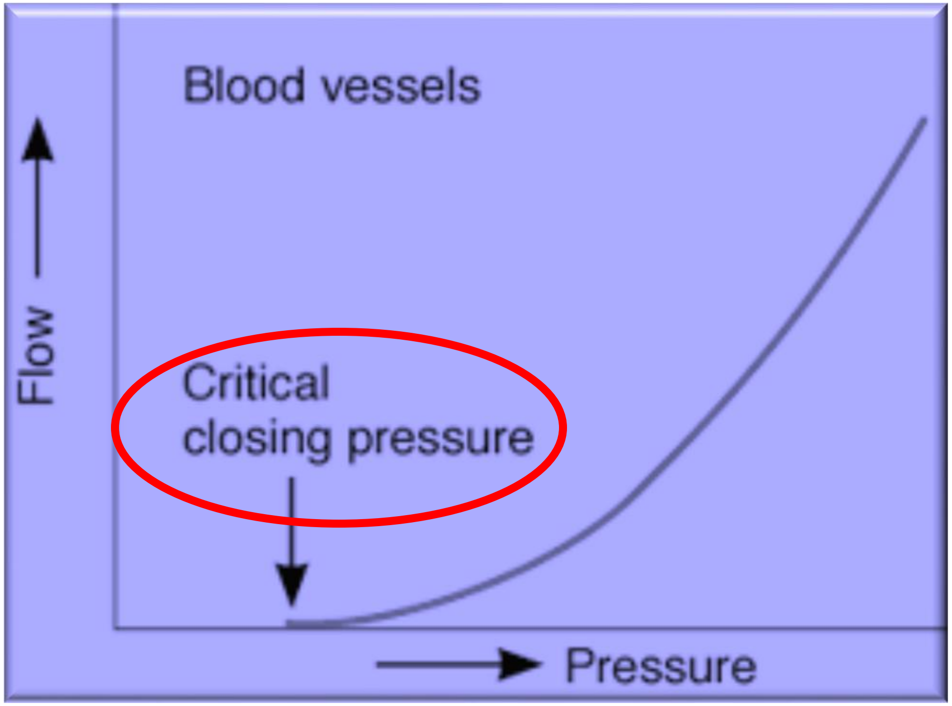


Effect of Vessel Diameter on Blood Flow

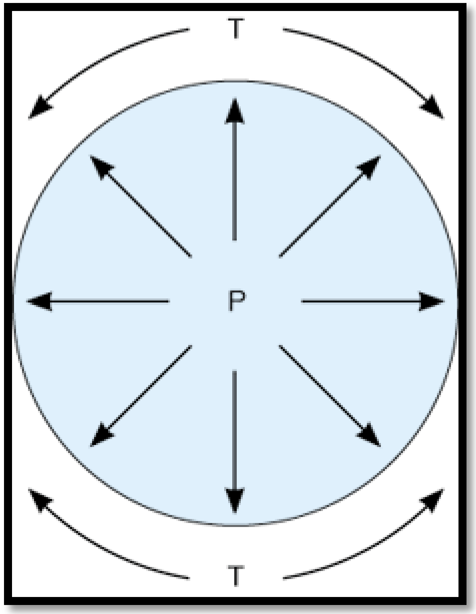
- Conductance is very sensitive to change in *diameter* of vessel.
- The conductance of a vessel increases in proportion to the *fourth power of the radius.*



Relation of pressure to flow in thin-walled blood vessel.



Law of Laplace:
i.e. T = P x r and P = T/r



Relation between distending pressure (P) and wall tension (T) in a hollow viscus

Hemodynamic laws… cont

- Dispensability = proportional change in volume per unit change in pressure

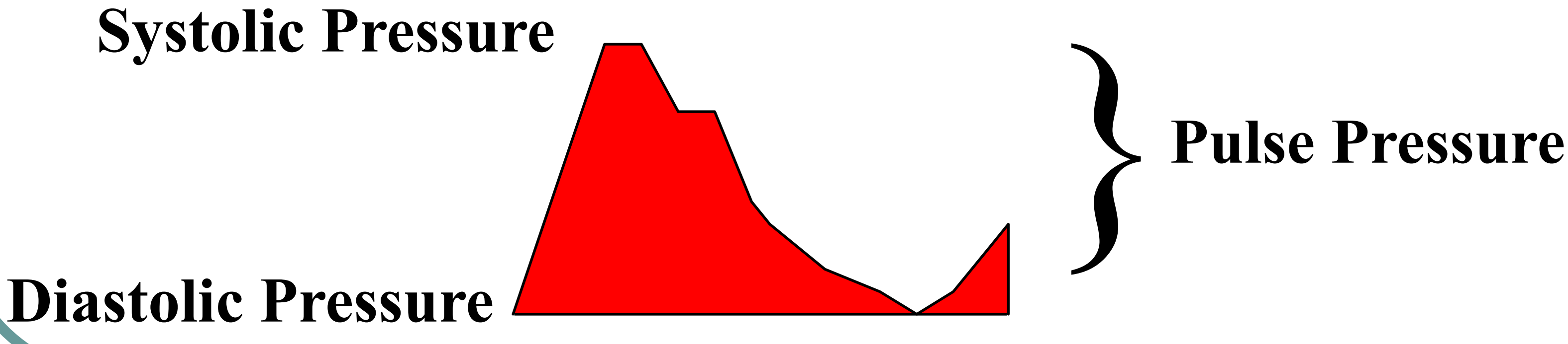
  $D = \Delta V/\Delta P*V$

- Compliance total change in volume per unit change in pressure

  $C = (\Delta V/\Delta P) = D*V$

Arterial Pulsations

- The height of the pressure pulse is the *systolic pressure* (120mmHg), while the lowest point is the *diastolic pressure* (80mmHg).
- The difference between *systolic* and *diastolic pressure* is called the *pulse pressure* (40mmHg).



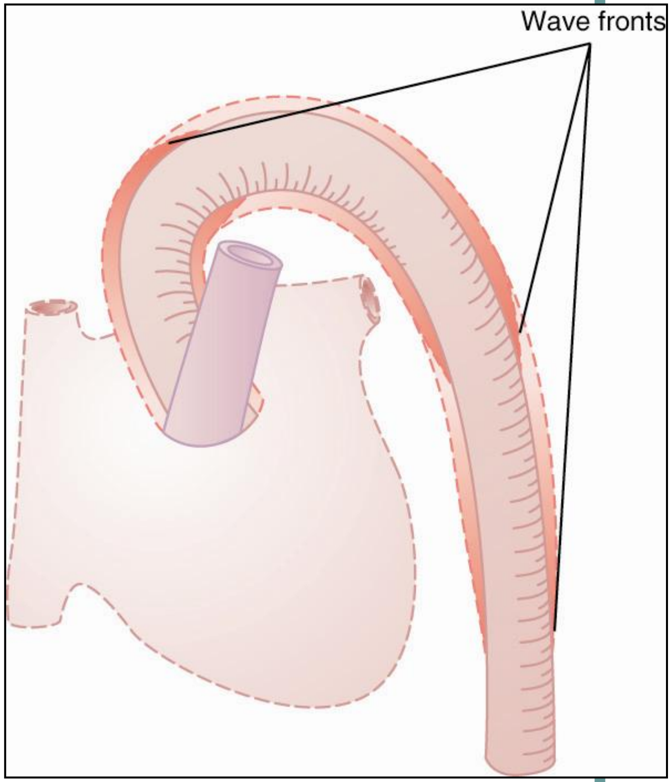
Pulse Pressure

- Definition: Systolic pressure – Diastolic pressure
- Factors affect pulse pressure (PP)
  - Stroke volume (SV)- ↑ SV ↑ PP
  - Compliance (C) - ↑ C↓ PP
  - PP ≈ $\frac{SV}{C}$
  - Pulse wave travels through the arterial wall
  - Velocity of travel of wave is inversely proportional to compliance
  - Velocity in aorta around 5 meters/sec., 10 meters/sec in medium sized and up to 40 meters in arterioles

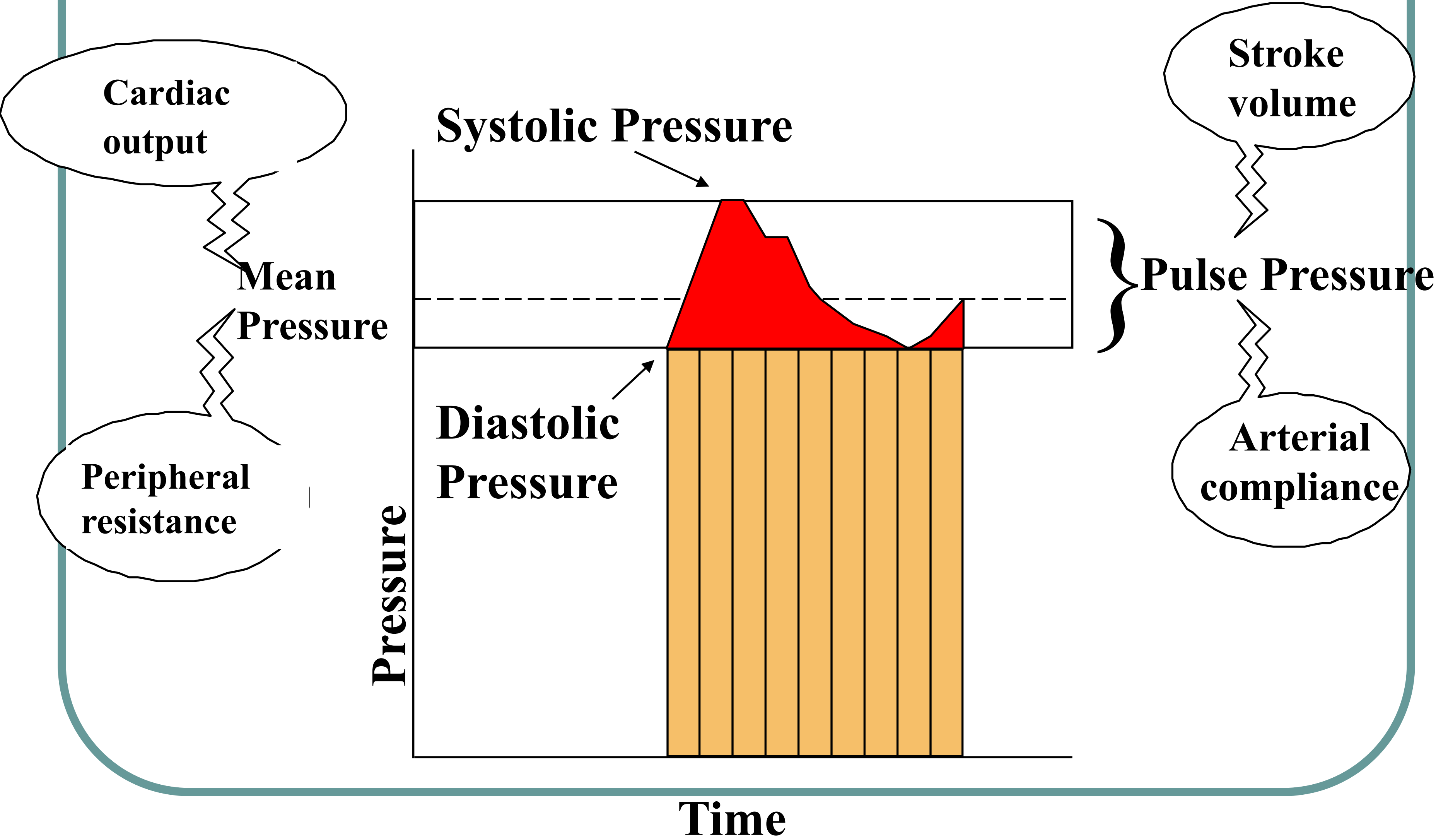
Factors Affecting Pulse Pressure

- *Stroke volume*—increases in stroke volume increase pulse pressure, conversely decreases in stroke volume decrease pulse pressure.

- *Arterial compliance*—decreases in compliance increases pulse pressure; increases in compliance decrease pulse pressure.

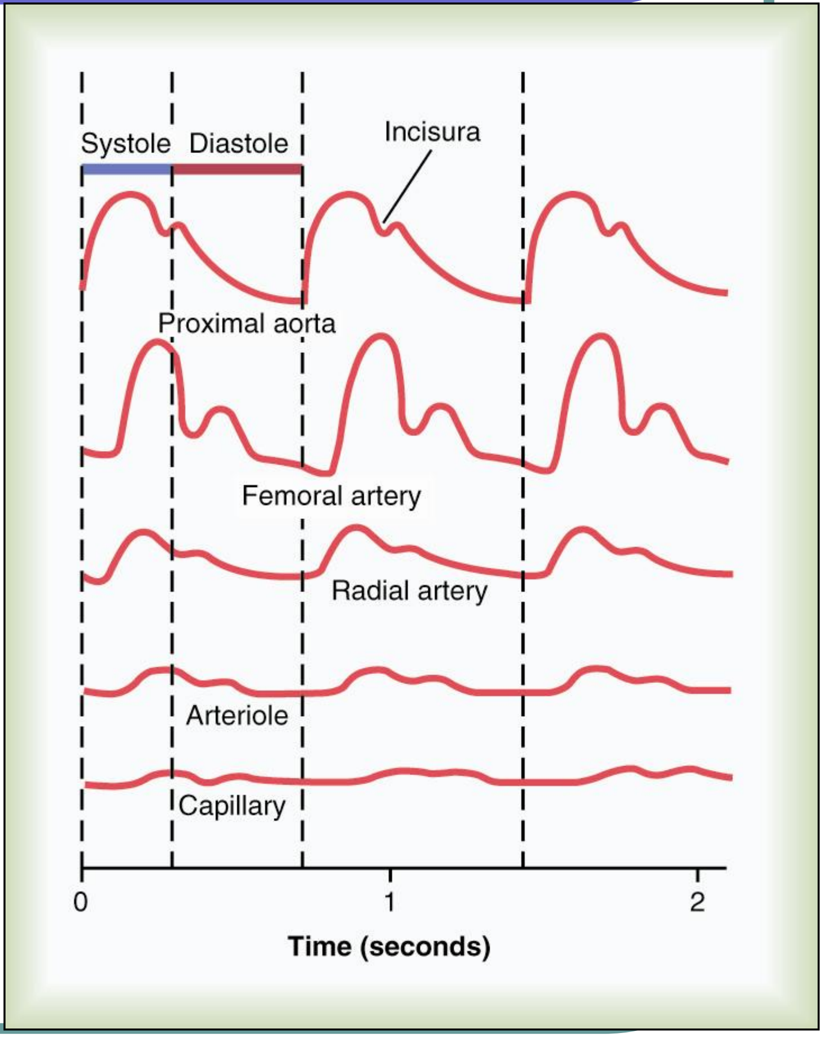


Arterial Pulse



Damping of Pulse Pressures in the Peripheral Arteries

- ❖ The intensity of pulsations becomes progressively less in the smaller arteries. Pulsations travel along the wall of the arteries
- ❖ The degree of damping is proportional to the resistance of small vessels and arterioles and the compliance of the larger vessels.



Abnormal Pressure Pulse Contours

- *Arteriosclerosis*–decreases compliance of arterial tree, thus leading to increase in pulse.
- *Patent ductus arteriosus*–associated with low diastolic pressure and high systolic pressure, net result is very high pulse pressure.
- *Aortic regurgitation*–condition associated with backward flow of blood through the aortic valve. Low diastolic and high systolic pressure leads to high pulse pressure.

Vascular Distensibility

- *Vascular Distensibility* is the fractional increase in volume for each mmHg rise in pressure
- Veins are 8 times more distensible than arteries
- Pulmonary arteries are relatively distensible
- Vascular Distensibility = $\frac{\text{Increase in volume}}{\text{Increase in pressure} \times \text{Original volume}}$

Vascular Capacitance

- *Vascular capacitance* is the total quantity of blood that can be stored in a given portion of the circulation for each mmHg.
- *Capacitance* = Distensibility x volume
- The capacitance of veins is 24 times that of arteries.

$$\text{Vascular compliance} = \frac{\text{Increase in volume}}{\text{Increase in pressure}}$$

Volume-pressure Relationships in Circulation

- ⌘Any given change in volume within the arterial tree results in larger increases in pressure than in veins.
- ⌘When veins are constricted, large quantities of blood are transferred to the heart, thereby increasing cardiac output.

Thank You