# Hemodynamics

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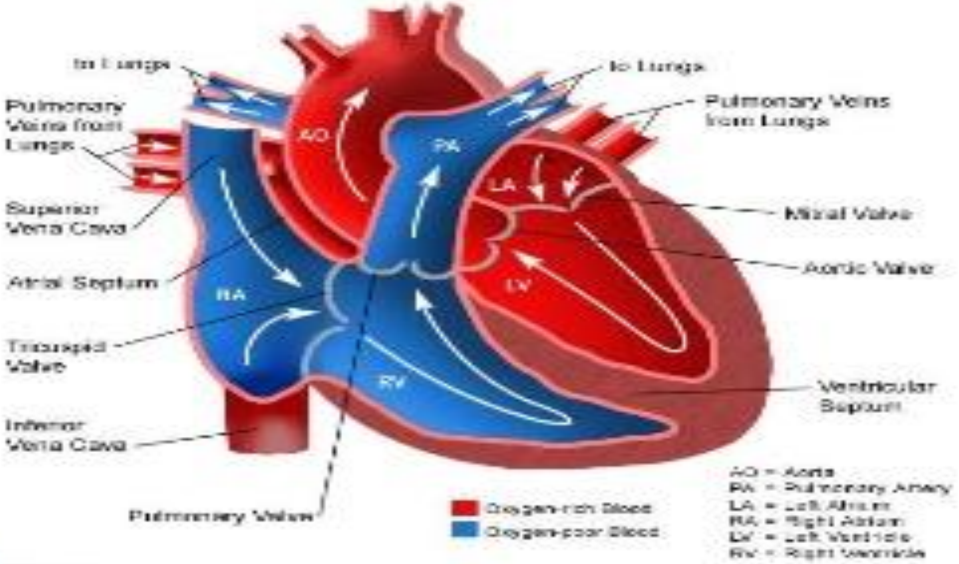
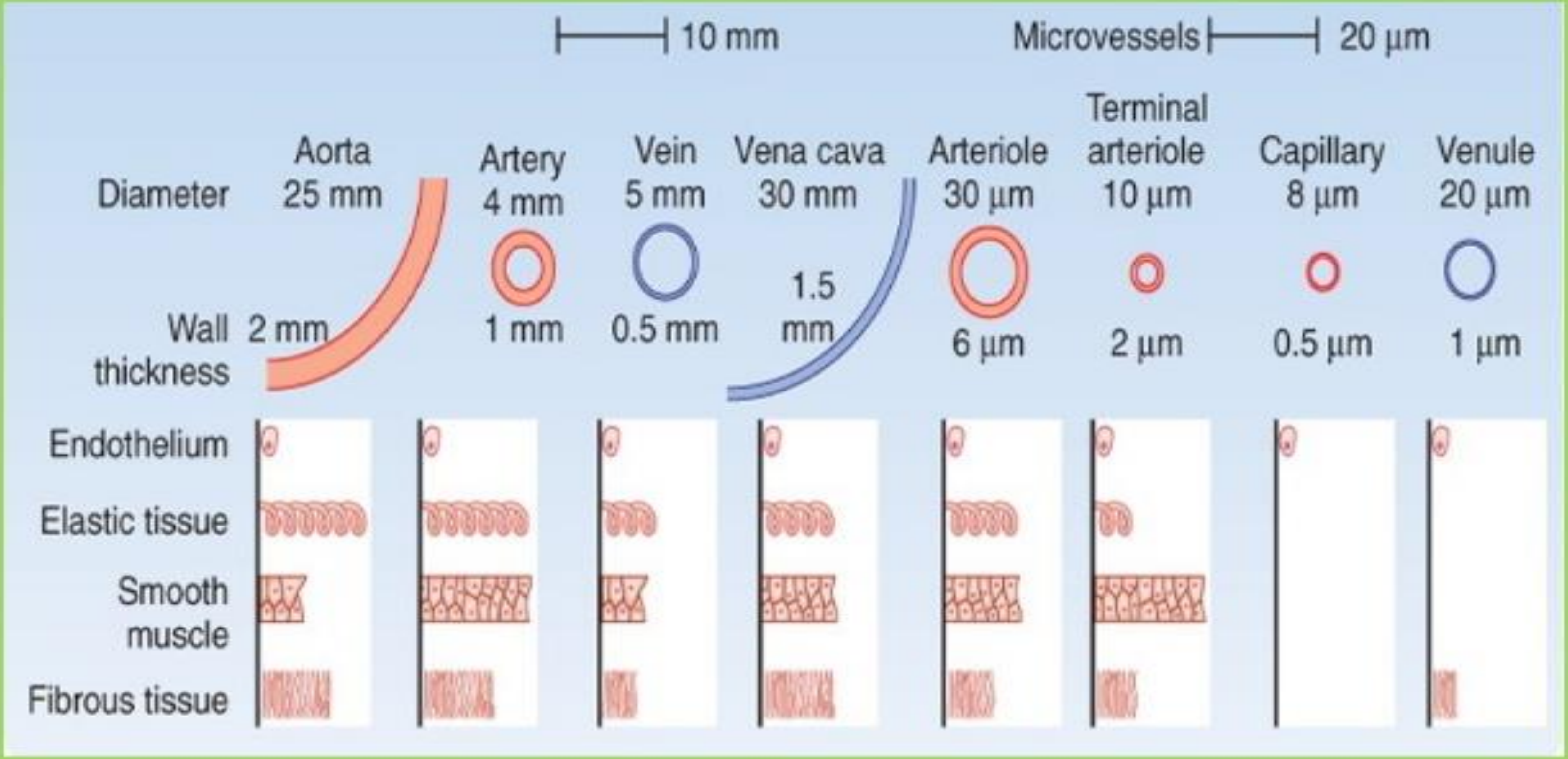
# Hemodynamics

## INTRODUCTION

- The word hemo -dynamics – means blood circulation in the human body.
- Cardiovascular hemo -dynamics comprises of blood circulation to the heart and in turn the blood circulation regulated by the heart.



- Hemodynamics is concerned with the mechanical and physiologic properties controlling blood pressure and flow through the body.


10 mm
Microvessels
20 µm
Diameter
Wall thickness
Aorta 25 mm
2 mm
Artery 4 mm
1 mm
Vein 5 mm
0.5 mm
Vena cava 30 mm
1.5 mm
Arteriole 30 µm
6 µm
Terminal arteriole 10 µm
2 µm
Capillary 8 µm
0.5 µm
Venule 20 µm
1 µm
Endothelium
Elastic tissue
Smooth muscle
Fibrous tissue

## Pressure profile in blood vessels

- As blood flows through the systemic circulation, pressure decreases progressively because of the resistance to blood flow.
- Thus, pressure is highest in the aorta and large arteries and lowest in the venae cavae.
- The **largest decrease in pressure occurs across the arterioles** because they are the site of highest resistance.
  - Mean pressures in the systemic circulation are as follows:
    1. Aorta, 100 mm Hg
    2. Arterioles, 50 mm Hg
    3. Capillaries, 20 mm Hg
    4. Vena cava, 4 mm Hg



## rious types of blood sels

| | | FUNCTION |
|---|---|---|
| | | Pulse dampening and distribution |
| | | Distribution |
| | | Distribution and resistance |
| | | Resistance (pressure/flow regulation) |
| | | Exchange |
| Venules | 0.01–0.20 | Exchange, collection, and capacitance |
| Veins | 0.2–5.0 | Capacitance function (blood volume) |
| Vena cava | 35 | Collection |

# SYSTEMIC CIRCULATION

| Structure | Pressure in mmHg |
| --- | --- |
| Left Atrium | 7-8/0 |
| Left Ventricle | 120/0 |
| Aorta & large arteries | 120/80 |
| Arterioles | 60 |
| Capillaries | 25 |
| Venules & large veins | 10 |
| Vena cava (SVC&IVC) | 2 |

# BLOOD DISTRIBUTION

| Vessel | % of blood volume |
|---|---|
| **Systemic** | **84 %** |
| Arteries | 13 % |
| Arteriole | 1-2 % |
| Capillary | 5 % |
| Veins | 64 % |
| **Pulmonary/Heart** | **16 %** |
| Lungs | 9 % |
| Heart | 7 % |

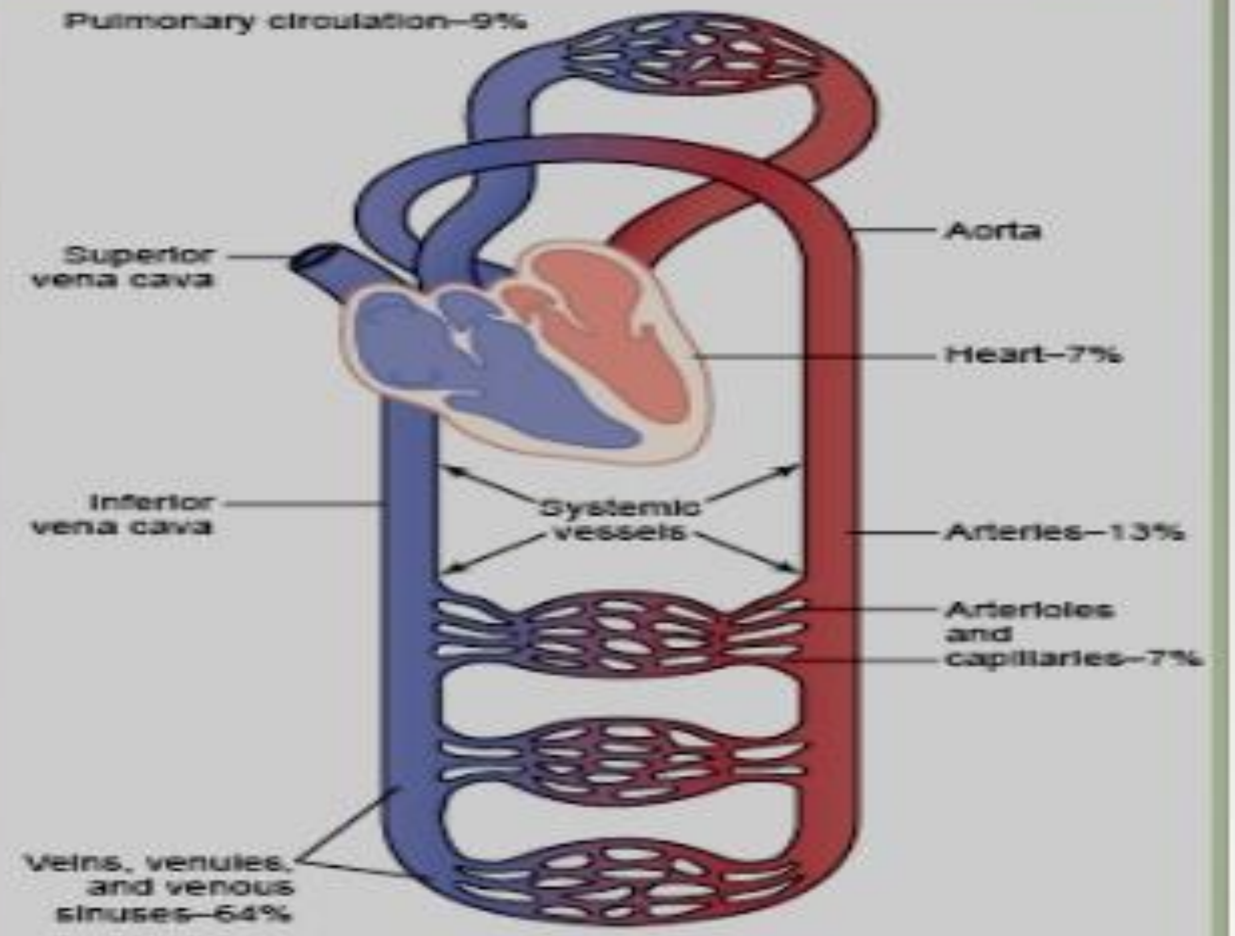



Figure 14–1

Distribution of blood (in percentage of total blood) in the different parts of the circulatory system.

# 3-HEMODYNAMICS

## Physics which deals with blood flow through circulatory system

### Blood flow

- **Amount of blood that flows through any tissue in a given period of time**
- mL/min

- **Over all blood that flows in the circulation at rest in adult is about 5000ml/ min.**

Total blood flow: Volume of blood that circulates through the systemic and pulmonary blood vessels each minute → •**Cardiac Output (CO)**

•**Cardiac output (CO) = heart rate (HR) x stroke volume (SV)**

•Distribution of CO into different body tissues:

1. Pressure difference of different parts of the body

   Pressure ↑ → Blood Flow ↑

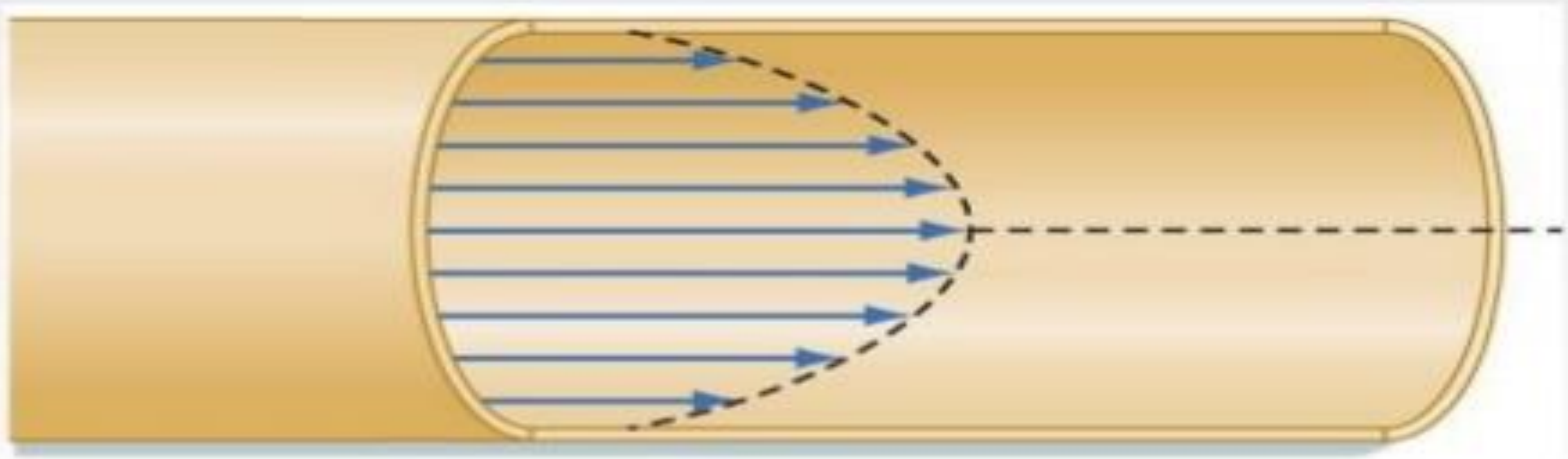
2. Resistance of specific blood vessels to blood flow

   Resistance ↑ → Blood Flow ↓

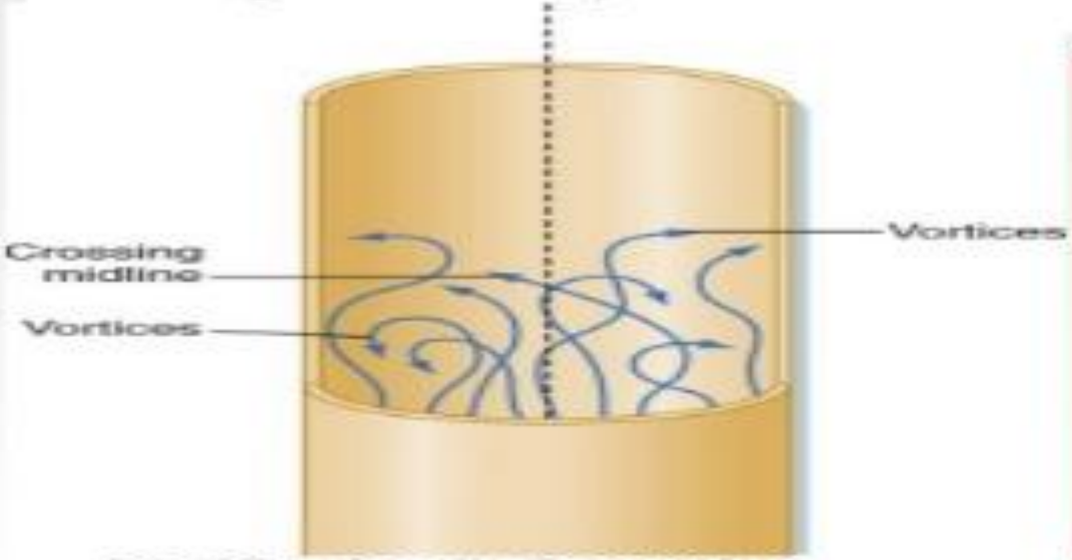
**Blood flow patterns - two types**

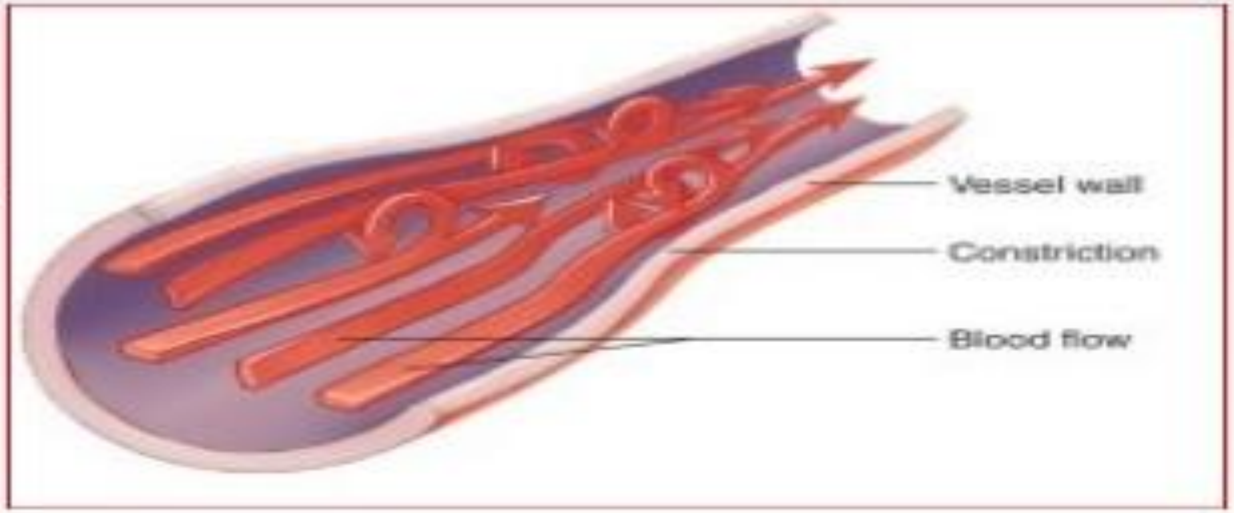
- Laminar blood flow
- Turbulent blood flow

- **Laminar flow**
  - Streamlined; interior of blood vessel is smooth and of equal diameter along its length
  - Outermost layer moving slowest and center moving fastest



- **Turbulent flow**
  - Interrupted
  - Rate of flow exceeds critical velocity
  - Fluid passes a constriction, sharp turn, rough surface
  - Partially responsible for heart sounds
  - Sounds due to turbulence not normal in arteries and is probably due to some constriction; increases the probability of thrombosis



**Probability Of Turbulence** Chance of turbulent are determine by the probability of turbulence which is denoted as

*Re (Reynolds number)* = **vρD/η**

The tendency for turbulent flow are

*Directly proportion to*

- Velocity of blood flow (**v in cm/sec.**)
- Density of the blood (**ρ in kg/m3**)
- Diameter of the blood vessel (**D**)

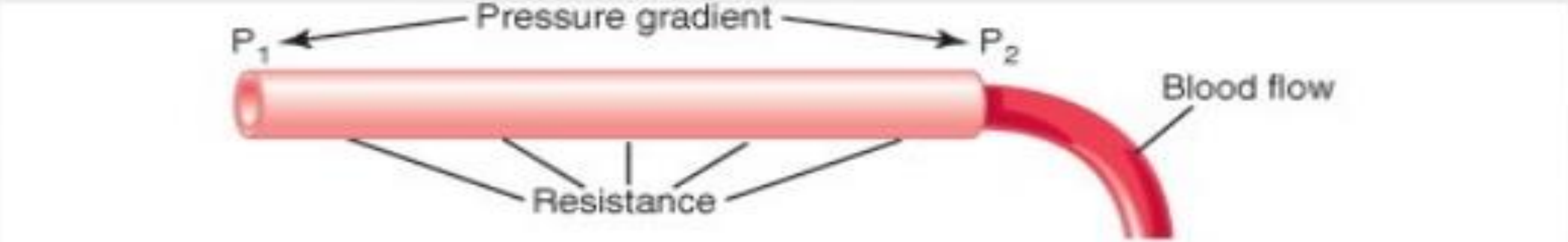
*Inversely proportion to*

- Viscosity of blood (**η in poise**)

Blood flow is determined by following factors

- Pressure difference b/w two ends of vessels
- Vascular resistance

$F = \Delta P/R$



## Blood flow

- can be expressed by the following equation:

$$Q = \Delta P/R$$

or

$$\text{Cardiac output} = \frac{\text{Mean arterial pressure} - \text{Right atrial pressure}}{\text{Total peripheral resistance (TPR)}}$$

*where:*

Q = flow or cardiac output (mL/min)

ΔP = pressure gradient (mm Hg)

R = resistance or total peripheral resistance (mm Hg/mL/min)

**INTERRELATIONSHIP B/W FLOW, PRESSURE AND RESISTANCE**
**Studied by French Physiologist Poiseuille's in 1842 in rigid tube in Newtonian fluid**
**Known as Poiseuille's - Hagen law or Poiseuille-Hagen equation**

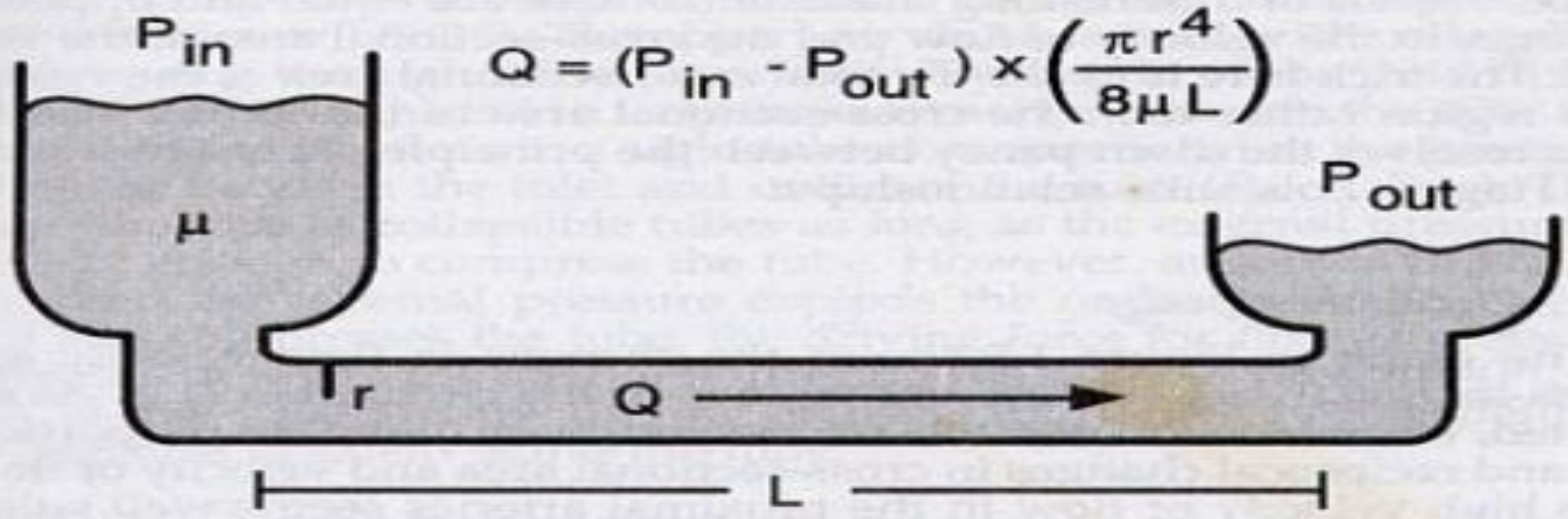



**Figure 1.4.** The forces that govern steady flow in rigid tubes. $P_{in}$ = inlet pressure, $P_{out}$ = outlet pressure, $Q$ = flow, $\mu$ = viscosity, $r$ = radius, $L$ = length.

$$Q = \frac{\pi (P_i - P_o) r^4}{8 \eta l}$$

$$Q = \frac{\Delta P \Pi r^4}{8 \eta l}$$

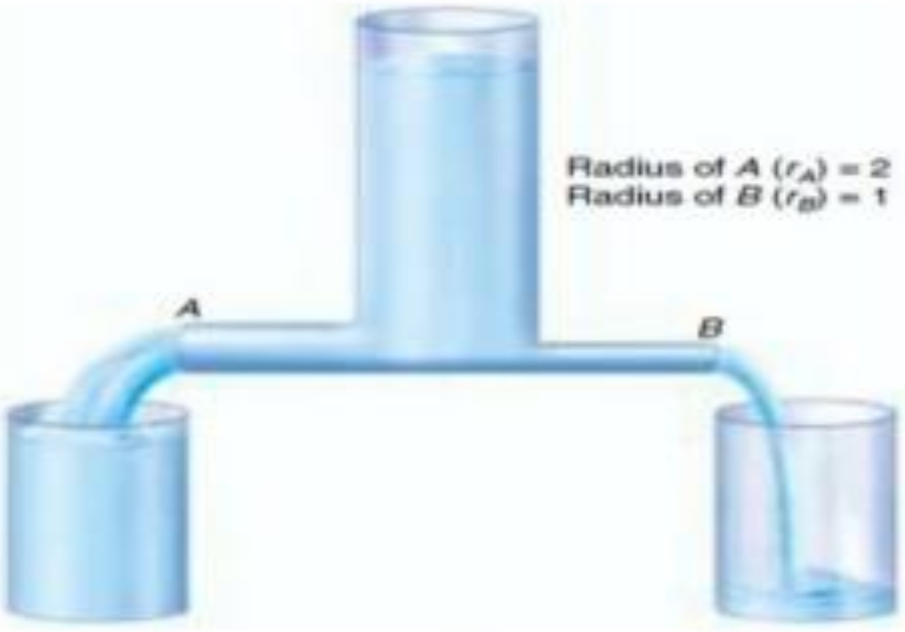
According mathematical calculation in Principles of physics, Resistance is represented as -

**$R = 8\eta l / \Pi r^4$**

After replacing these values in Poiseuille's law by R
Blood flow Q will be

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

- The equation for blood flow (or cardiac output) is analogous to **Ohm's law** for electrical circuits ($I = V/R$), where flow is analogous to current, and pressure is analogous to voltage.
- The pressure gradient ($\Delta P$) drives blood flow.
- Thus, blood flows from high pressure to low pressure.
- Blood flow is inversely proportional to the resistance of the blood vessels.




$$R = \frac{1}{r^4}$$

$$R_A = \frac{1}{(r_A)^4} = \frac{1}{2^4} = \frac{1}{16} = 0.0625$$

$$R_B = \frac{1}{(r_B)^4} = \frac{1}{1^4} = \frac{1}{1} = 1.0$$

Therefore $R_B = 16\ R_A$

$$\text{Flow} = \frac{\Delta P}{R}$$

Therefore flow in $B = \frac{1}{16}$ th of flow in $A$

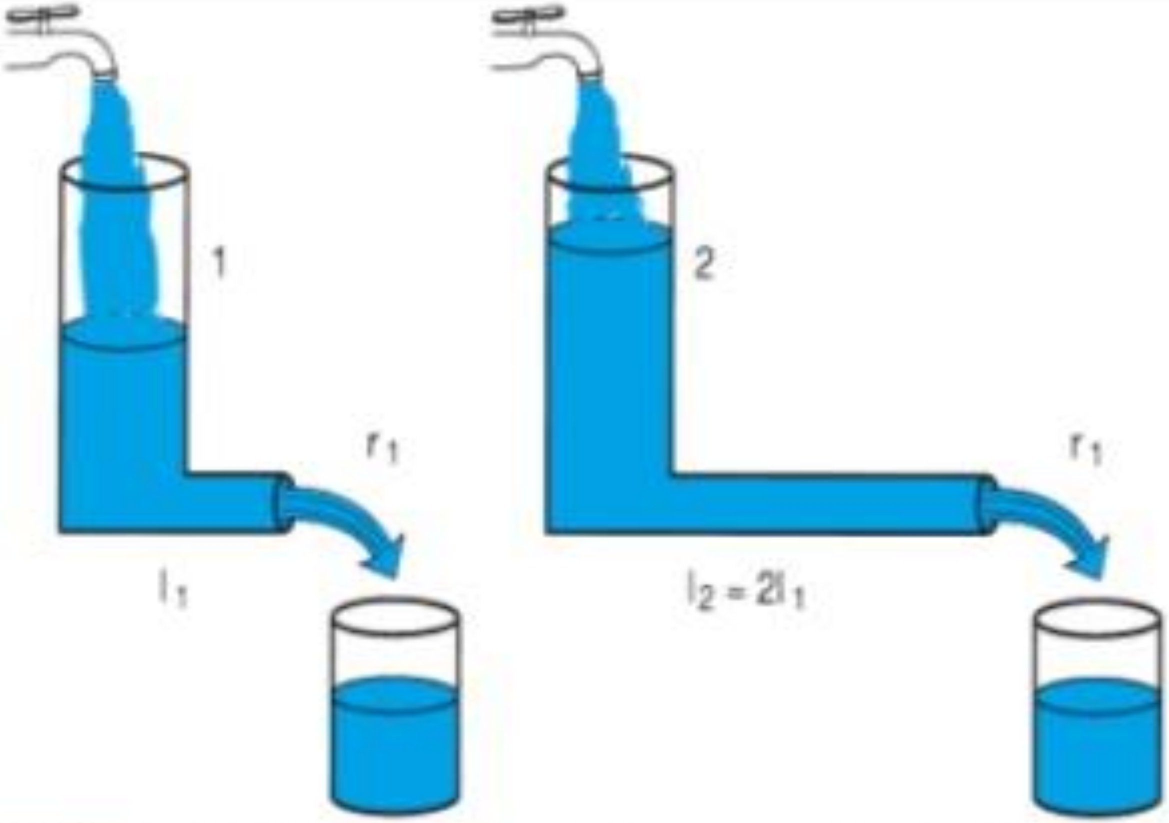
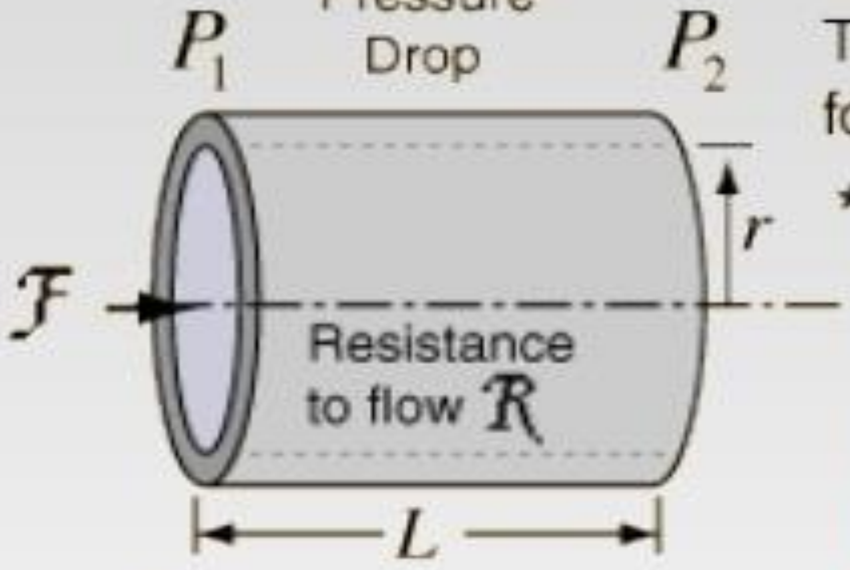



FIGURE 8 Fluid is added at the same rate of flow to two containers that differ only in the lengths ($l$) of their outflow tubes such that the length in example 2 is twice that in example 1. The radii ($r$) of tubes 1 and 2 are equal. The column of water in each container will rise until the pressure exerted by that column is large enough to cause outflow to equal inflow. Because the resistance to flow in example 2 is twice that in example 1, column height will be twice as great in example 2 at steady state.




Suppose the original flowrate is 100 $cm^3$/sec. The effect of changes in the parameters is as follows:

| | | |
|---|---|---|
| *Double length | ⟹ 50 | $cm^3$/sec |
| Double viscosity | ⟹ 50 | $cm^3$/sec |
| Double pressure | ⟹ 200 | $cm^3$/sec |
| Double radius | ➡ 1600 | $cm^3$/sec |

$$\mathcal{R} = \frac{8\eta L}{\pi r^4}$$ where $\eta$ = viscosity

* With other parameters held at original values

$$\text{Volume Flowrate} = \mathcal{F} = \frac{P_1 - P_2}{\mathcal{R}} = \frac{\pi(\text{Pressure difference})(\text{radius})^4}{8(\text{viscosity})(\text{length})}$$

A 19% increase in radius will double the volume flowrate!

## A small amount of arterial occlusion can have a surprisingly large effect!


| Occlusion* | If pressure is 120 mmHg, Flowrate = | Pressure to restore normal Flowrate: |
|---|---|---|
| 0% | 100 $cm^3$/min | 120 mmHg |
| 20% | 41 $cm^3$/min | 293 mmHg |
| 50% | 6.3 $cm^3$/min | 1920 mmHg |
| 80% | 0.16 $cm^3$/min | 75,000 mmHg |

*20% occlusion here is taken to mean a reduction of the inside radius by 20%, to 80% of its original radius.

**A 19% decrease in radius will halve the volume flowrate!**

**Blood Flow Examples**
**Suppose you have an emergency requirement for a five-fold increase in blood volume flow rate (like being chased by a big dog)? How does your body supply it?**

According to Poiseuille's law, a five-fold increase in blood pressure would be required if the increase were supplied by blood pressure alone!
*But the body has a much more potent method for increasing volume flow rate in the vasodilatation of the small vessels called arterioles*

Since the smaller vessels provide most of the resistance to flow, the arterioles in their position just prior to the capillaries can provide a major controlling influence on the volume flow rate. This system of small vessels can constrict flow to one part of the body while enhancing the flow to another to meet changing demands for oxygen and nutrient.

# Poiseuille's law

- The Poiseuille's formula express the discharged streamlined volume flow through a smooth-walled circular pipe:
  - $V = \pi\, p\, r^4 / 8\, \eta\, l$
- *where*

  *V = discharge volume flow ($m^3/s$)*

  *p = pressure difference between the ends of the pipe ($N/m^2$, Pa)*

  *r = internal radius of pipe (m)*

  *l = length of pipe (m)*

  *η = viscosity of fluid*
- **Resistance (R)**
  - **Opposes Flow**
- **Tube length (L)**
  - ***1.Constant in body***
- **Tube radius (r)**
  - **1.Can radius change?**
- **Fluid viscosity (*η*) (eta)**
  - **Can blood viscosity change??**

# Further readings

- https://cdn.intechopen.com/pdfs/35915/InTech-Hemodynamics.pdf
- https://courses.lumenlearning.com/suny-ap2/chapter/blood-flow-blood-pressure-and-resistance-no-content/
- https://www.youtube.com/watch?v=5EchkYvRkxs
- https://www.youtube.com/watch?v=ytCuHh5PwwY

- Books
  - Physiology By Guyton and Hall
  - Physiology By Any Author available to you

THANK YOU