CVS MODULE
PHYSIOLOGY (LECTURE 8)

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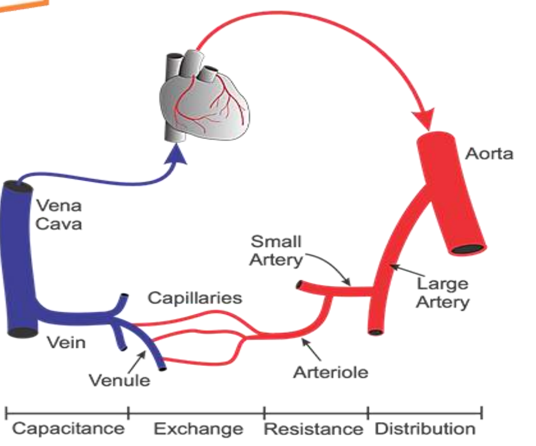
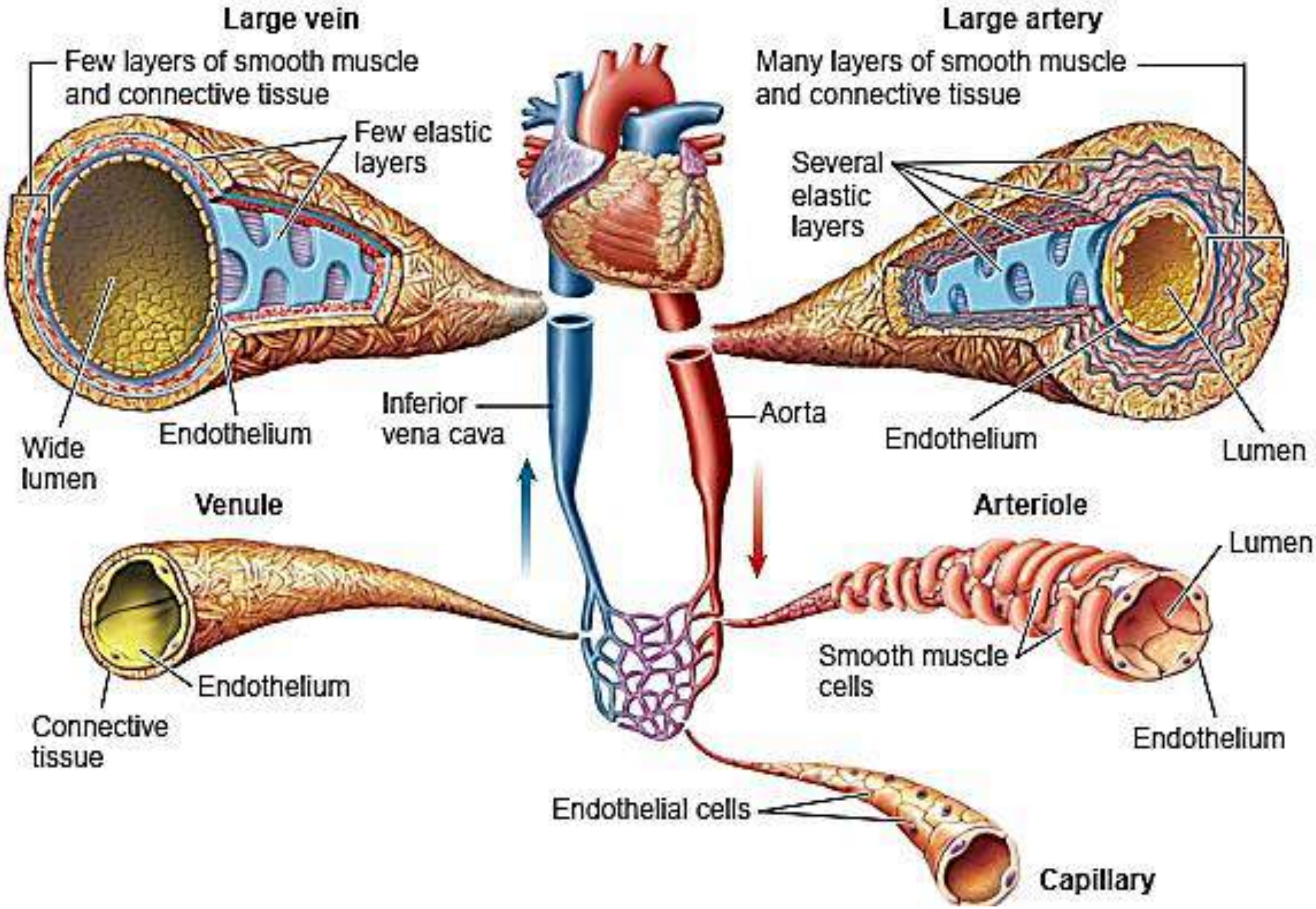
THE VASCULAR SYSTEM



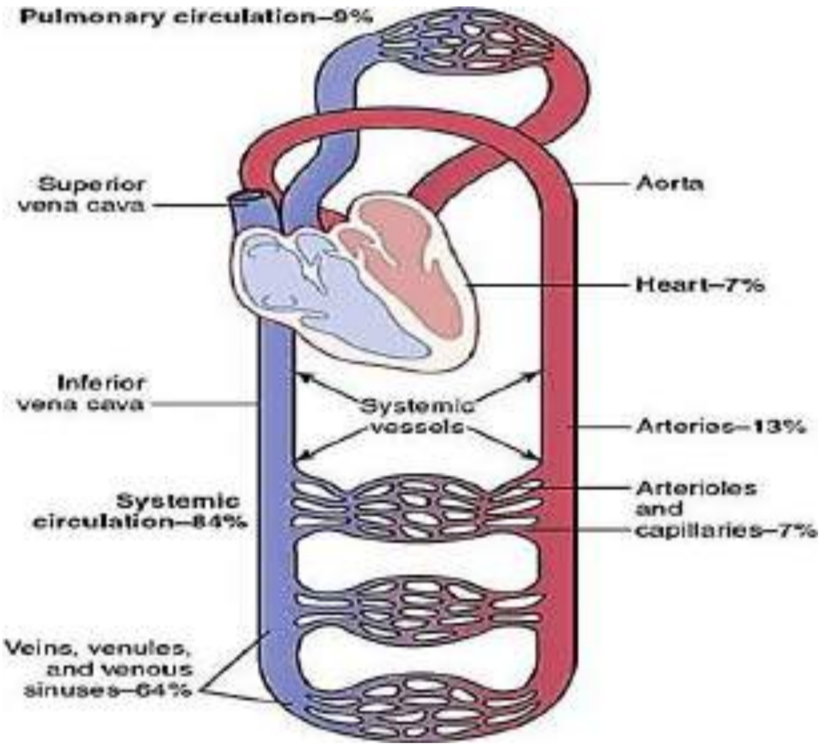
The blood vessels include:

- Elastic vessels: aorta and large arteries.
- Resistance vessels: small arteries and arterioles **(mainly arterioles)**.
- Exchange vessels: capillaries.
- Capacitance vessels (volume reservoir): veins.

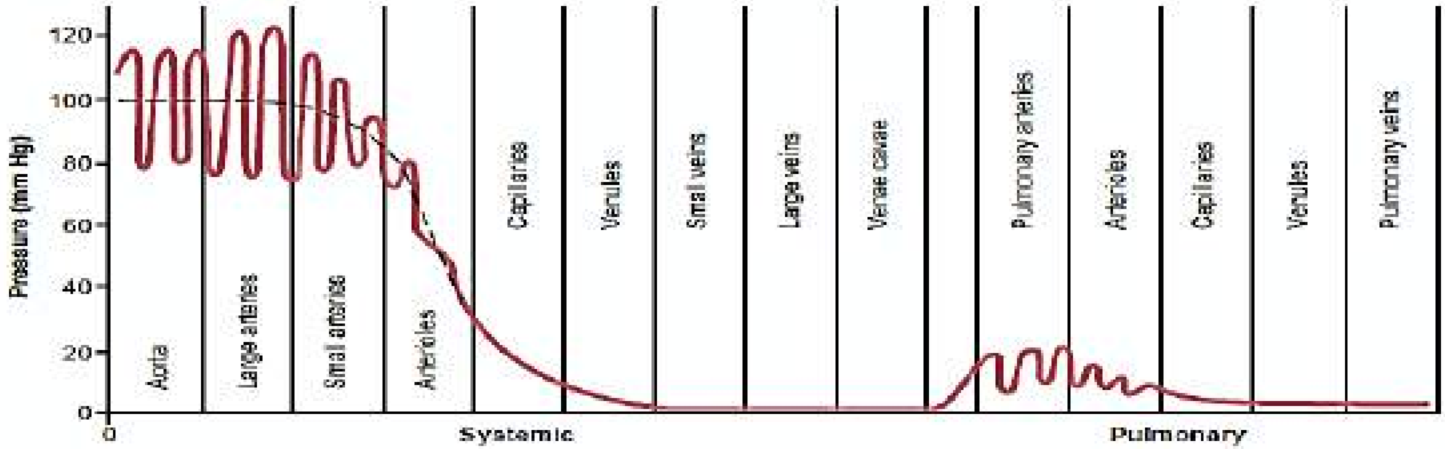

Large vein
Few layers of smooth muscle and connective tissue
Few elastic layers
Wide lumen
Endothelium
Inferior vena cava
Aorta
Large artery
Many layers of smooth muscle and connective tissue
Several elastic layers
Endothelium
Lumen
Venule
Endothelium
Connective tissue
Arteriole
Lumen
Smooth muscle cells
Endothelium
Endothelial cells
Capillary

Volumes of blood in different parts of circulation

- Pulmonary circulation: 9%
- Heart: 7%
- Systemic circulation = 84% :
- ✓ Arteries: 13%
- ✓ Arterioles and capillaries: 7%
- ✓ Veins: 64%



Pressures in various portions of circulation



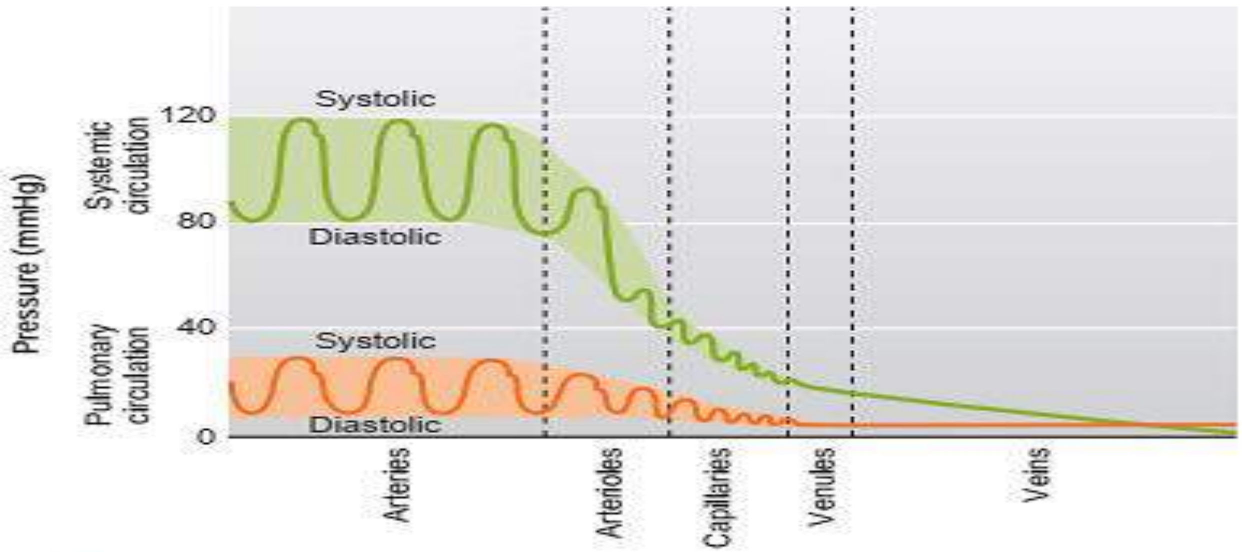


Figure 12.29 Pressures in the systemic and pulmonary vessels.

Hemodynamics

Hemodynamics :

It is the study of the forces involved in circulation of blood. Understanding the hemodynamic state of an individual is essential when assessing cardiovascular disease.

Biophysics of blood flow

The blood flow (F) through any organ:

- **F is directly proportionate to the pressure gradient (Δ P).**
- **F is inversely proportionate to resistance (R).**

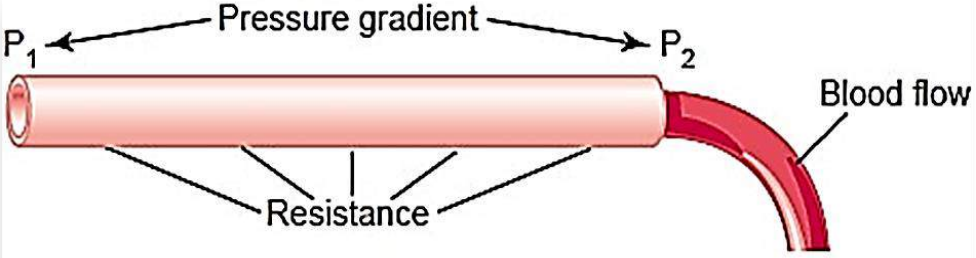


Figure 14–3

Interrelationships among pressure, resistance, and blood flow.

The blood flow (F) is represented by the following equation:

$$F = \frac{\text{Pressure gradient}}{\text{Resistance}} = \frac{\Delta P}{R}$$

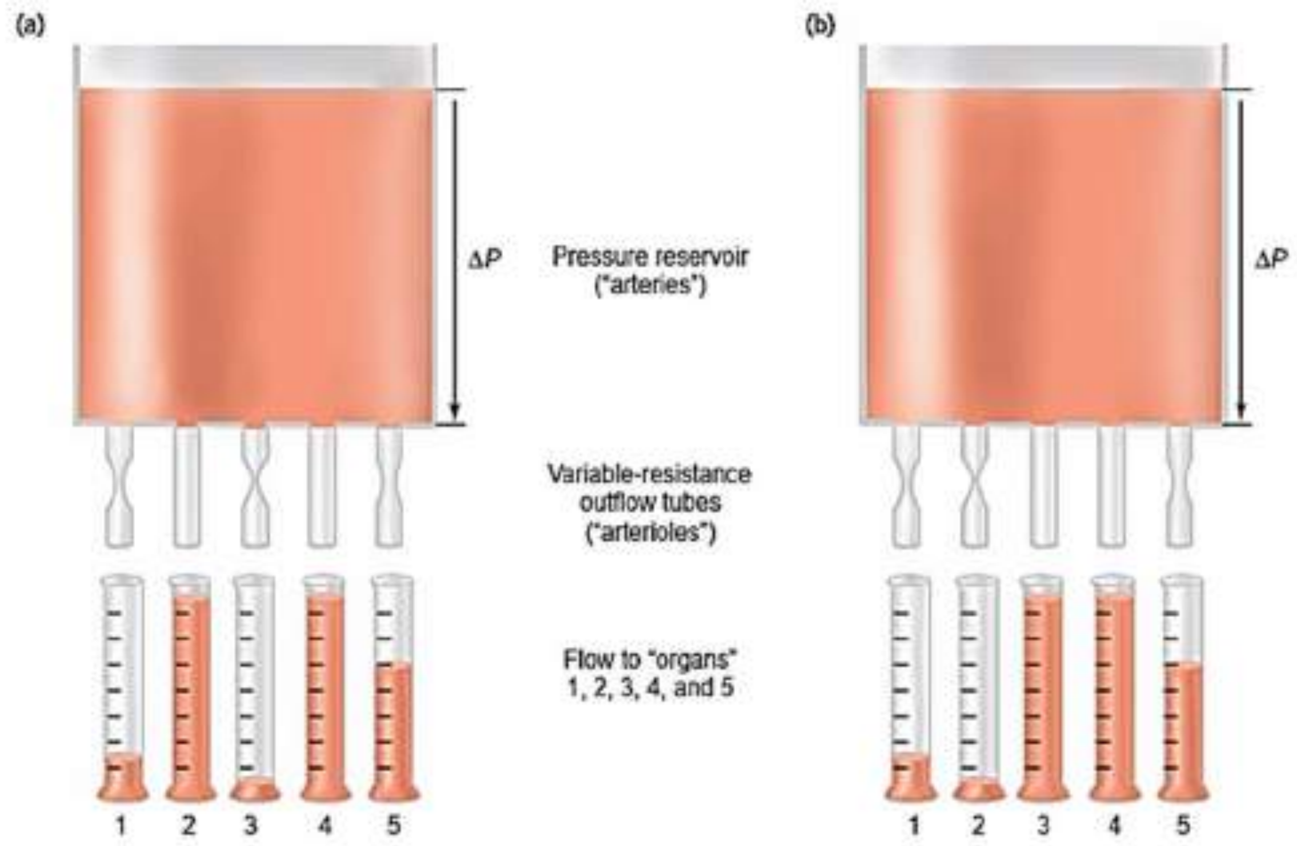
F_{organ} = (MAP – Venous pressure)/Resistance $_{organ}$

Venous pressure is normally close to zero, so
F_{organ} = MAP/Resistance $_{organ}$

Mean arterial pressure (MAP):

- **Definition: It is the average pressure over a complete cardiac cycle of systole and diastole.**
- **MAP is not the simple arithmetic mean of systolic and diastolic pressures.**
- **MAP can be approximated by adding one third of the pulse pressure to the diastolic pressure.**
- **Pulse pressure = systolic pressure (SP)-diastolic pressure (DP)**
- **MAP = DP + 1/3 pulse pressure**
- **Thus,**
- **MAP = 80 + 1/3 (40) = 93 mmHg.**

- Because the **MAP is the same throughout the body, differences in flows between organs** depend entirely on the relative **resistances of their respective arterioles**.
- Arterioles contain smooth muscle, which can either relax and cause the vessel radius to increase (vasodilation), or contract and decrease the vessel radius (vasoconstriction).



In the systemic circulation,

Since (F) = cardiac output (CO)

$$\text{So, CO} = \frac{\text{MAP}}{\text{R}}$$

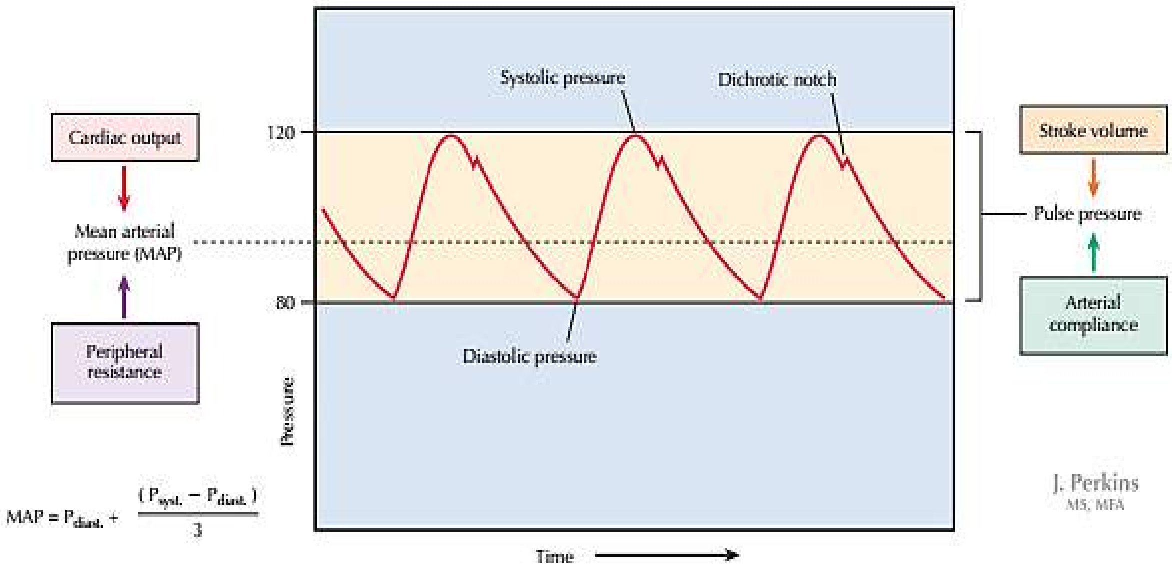
And

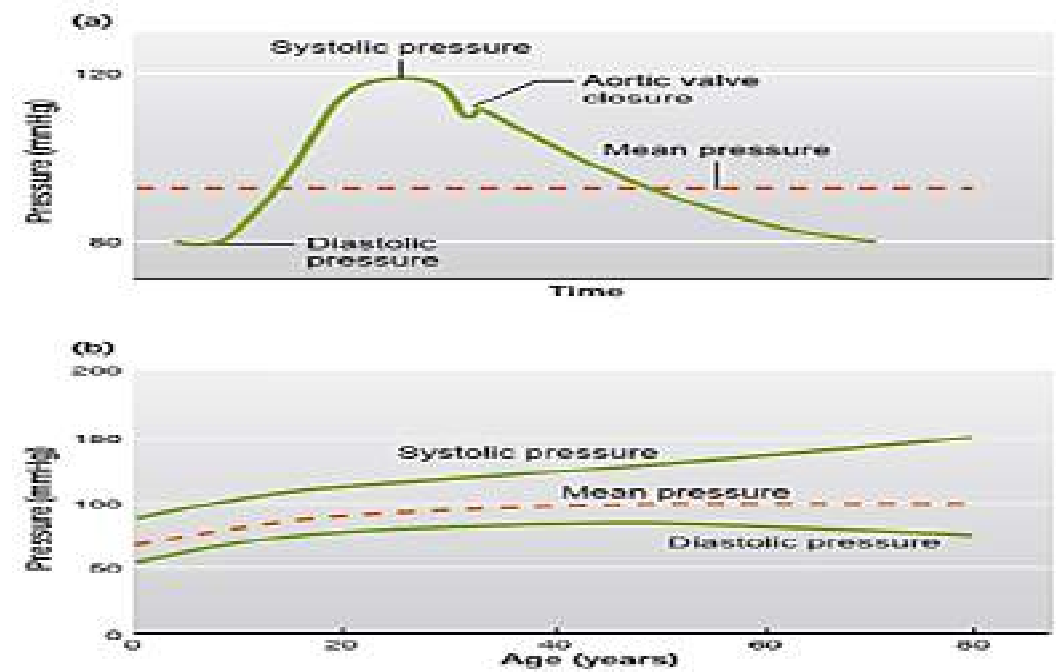
The MAP = CO X Peripheral resistance.

Mean arterial pressure (MAP):

It is dependent on CO and peripheral resistance (PR).

Most of the resistance to blood flow occurs in the arterioles, so it is called peripheral.


Systolic pressure
Dichrotic notch
Cardiac output
120
Mean arterial pressure (MAP)
80
Peripheral resistance
Diastolic pressure
Pressure
Stroke volume
Pulse pressure
Arterial compliance
J. Perkins
MS, MFA
MAP = P diast. + (P syst. − P diast.) / 3
Time


(a)
Systolic pressure
120
Aortic valve closure
Mean pressure
Pressure (mmHg)
80
Diastolic pressure
Time
(b)
200
150
Systolic pressure
100
Mean pressure
Diastolic pressure
50
Pressure (mmHg)
0
0
20
40
60
80
Age (years)

The factors that affect (R) :

Poiseuille-Hagen formula

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

R = resistance of the vessel to the flow

L = length of the vessel

η = viscosity of the fluid

r = radius of the vessel

The resistance (R) to the flow of a fluid through a vessel is:

- **Directly proportionate to the length of the vessel.**
- **Directly proportionate to the viscosity of the fluid.**
- **Inversely proportionate to the fourth power of the radius of the vessel.**

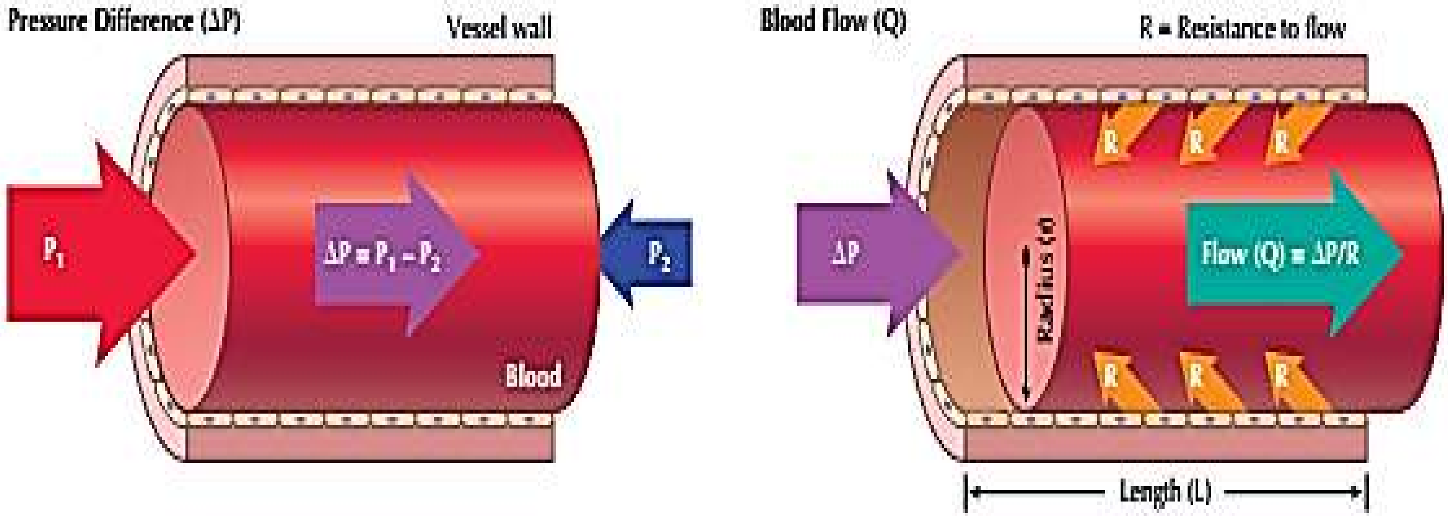
The blood flow (F) through a vessel can be described by Poiseuille's law:

$$F = \frac{\Delta P \pi r^4}{\eta 8 L}$$

Where F is flow, ΔP is the pressure gradient from one end of a tube to the other, r^4 is the fourth power of radius of the tube, η is the viscosity of the fluid, and L is the length of the tube.

Based on Poiseuille's law, flow (F) through a tube will be:

- **Directly proportional to the longitudinal pressure gradient (inflow pressure minus outflow pressure).**
- **Directly proportional to the fourth power of the radius of the tube.**
- **Inversely proportional to the length of the tube.**
- **Inversely proportional to the viscosity of the fluid.**



Resistance to Flow (R)

- ✓ **Of the factors affecting flow through a tube, the most important is the radius** of the tube.
- ✓ Physiological regulation of regional blood flow mainly involves changes in **radius** (vasodilation and vasoconstriction) of the small arteries and **arterioles**.
- ✓ **Viscosity of blood: It is about 3-4 times more than the viscosity of water**. It is due to plasma proteins, and the blood cells (RBCs). Under normal circumstances, viscosity of blood is not an issue; however, changes in **hematocrit** are associated with large changes in blood viscosity, as occur in **anemia (decreased viscosity) and polycythemia (increased viscosity)**.
- ✓ **Length of blood vessels:** It is constant in the human organism.

Units of resistance (R)

R can be measured in units of mm Hg/ml/second or R units.

R can be calculated from **F** and the **pressure gradient** as follows:

Since $F = \frac{\text{Pressure gradient}}{R}$,

Then, Pressure gradient= (F) X (R)

And

$$\mathbf{R} = \frac{\textbf{Pressure gradient}}{\textbf{(F)}}$$

- ✓ Accordingly, R can be obtained by dividing the pressure gradient (in mmHg) by the flow (in ml/second) and the result is expressed in R units.
- ✓ One R unit refers to the resistance that allows the flow of 1 ml blood/second at a pressure gradient of 1 mmHg.
- ✓ In the systemic circulation, if F (the left ventricular CO) is 90 ml/second and the pressure gradient is 90 mmHg, then R= 90/90 = 1 R unit.
- ✓ In the pulmonary circulation, if the pressure gradient is 13 mmHg, then R= 13/90 = about 0.14 R unit.

METHODS FOR MEASURING BLOOD FLOW

Blood flow (F) can be measured by:

1. Using the Doppler flow meter.
2. Applying the Fick's principle.
3. Plethysmography.
4. Special method:

Renal blood flow (RBF) can be determined using the clearance of PAH.

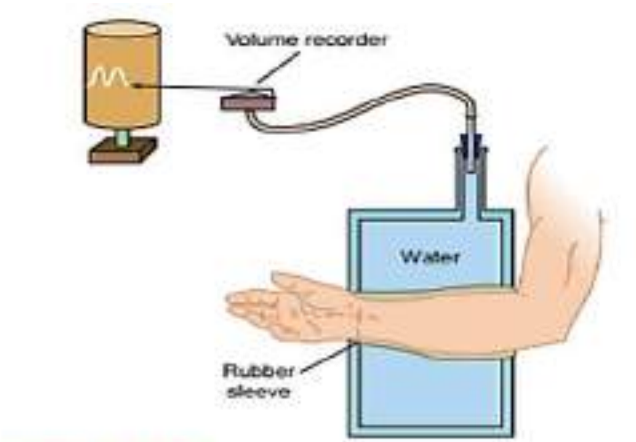
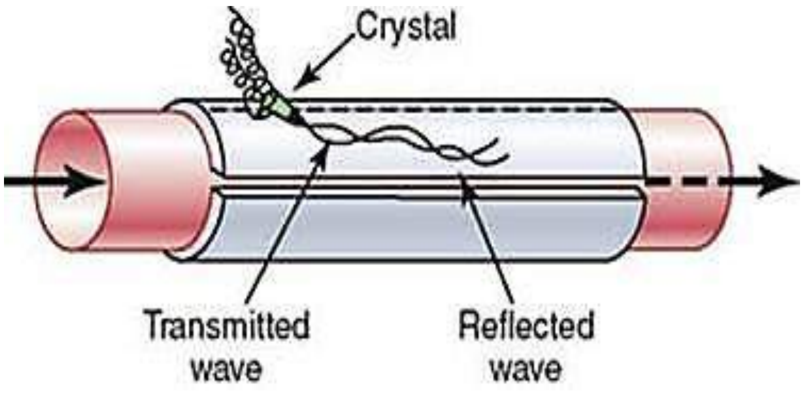


FIGURE 32–20 Plethysmography.



VELOCITY OF BLOOD FLOW

Blood velocity (V) is calculated by dividing the blood flow (ml/second) / cross sectional area; A (cm^2). $V = F / A$

Blood velocity at any point in circulatory system is inversely proportional to the total cross sectional area (A) at that point.

In the aorta (fastest velocity): The blood flow (= CO) is about 90 ml/second and its cross sectional area is about 2.5 cm^2. So, velocity of blood flow = 90/2.5 = 36 cm/second.

In capillaries:

- Velocity of blood flow is slow (0.2-0.3 mm/second) as the cross sectional area of capillaries is wide (3000 - 4500 cm^2).
- The lowest velocity in capillaries is beneficial in terms of exchange of dissolved substances between blood and tissues.

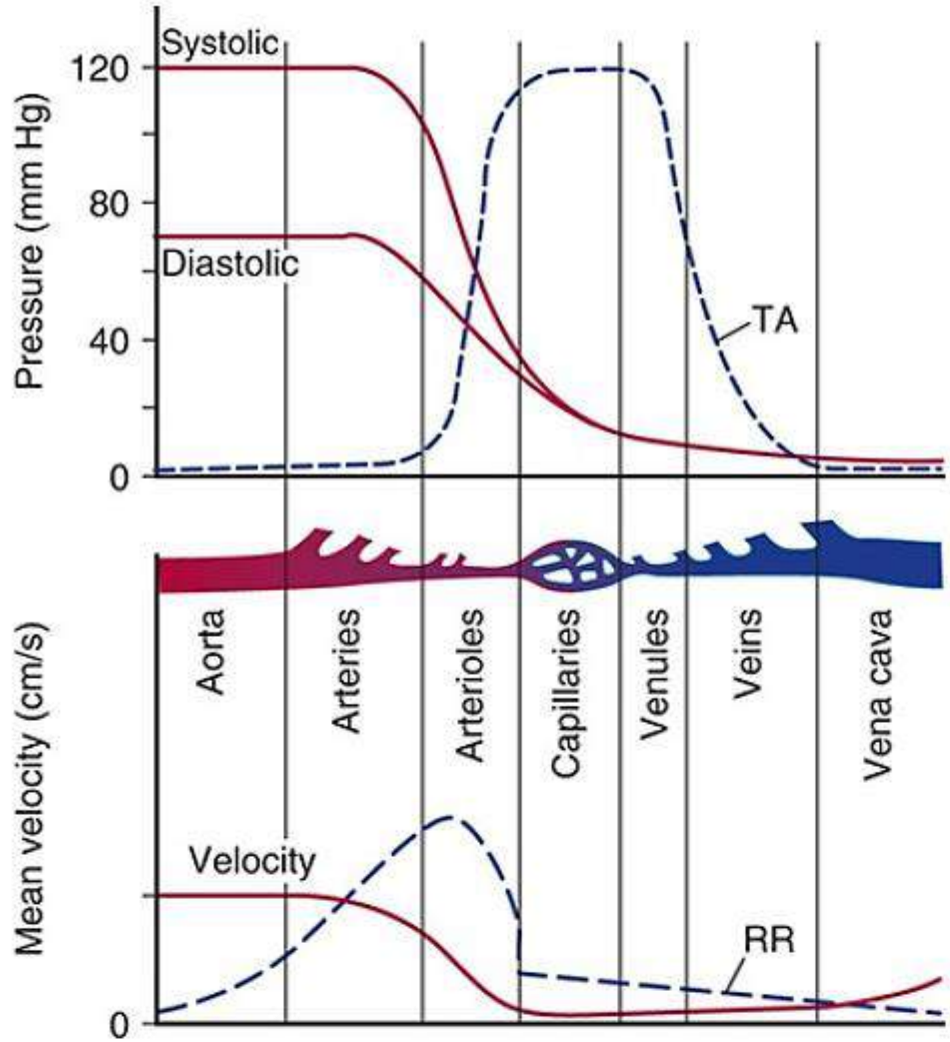
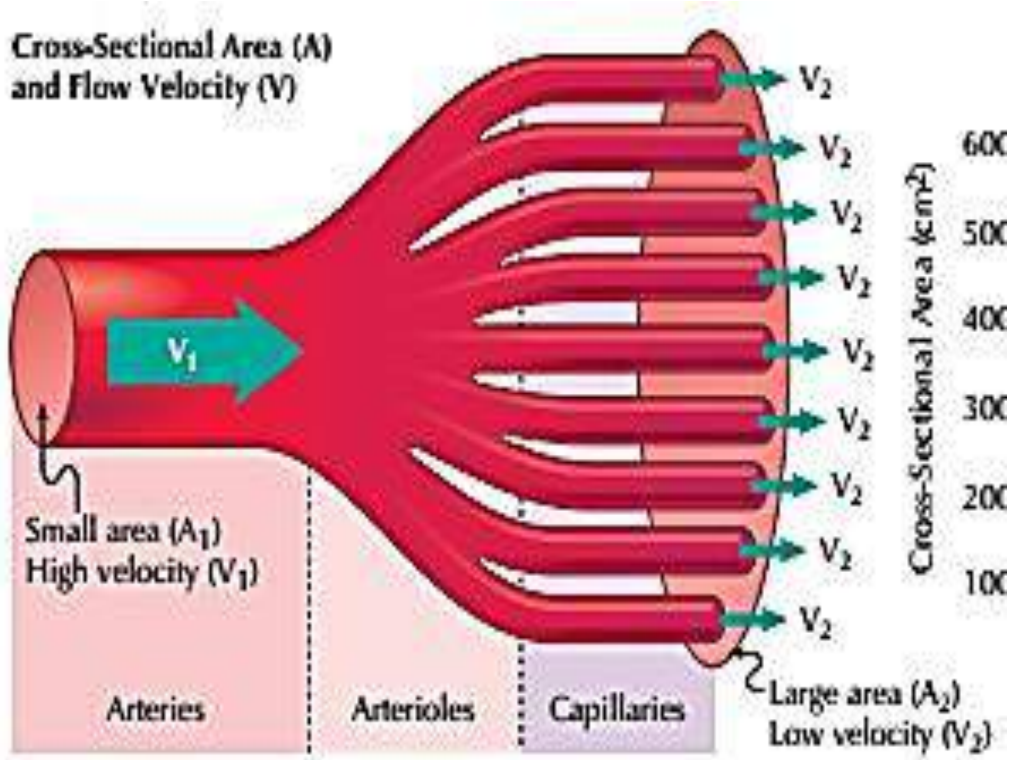


FIGURE 31–24 Diagram of the changes in pressure and velocity as blood flows through the systemic circulation. TA, total cross-sectional area of the vessels, which increases from 4.5 cm^2 in the aorta to 4500 cm^2 in the capillaries (Table 31–9). RR, relative resistance, which is highest in the arterioles.


Cross-Sectional Area (A)
and Flow Velocity (V)
V_1
V_2
Small area (A_1)
High velocity (V_1)
Large area (A_2)
Low velocity (V_2)
Arteries
Arterioles
Capillaries
Cross-Sectional Area (cm²)

Types of blood flow

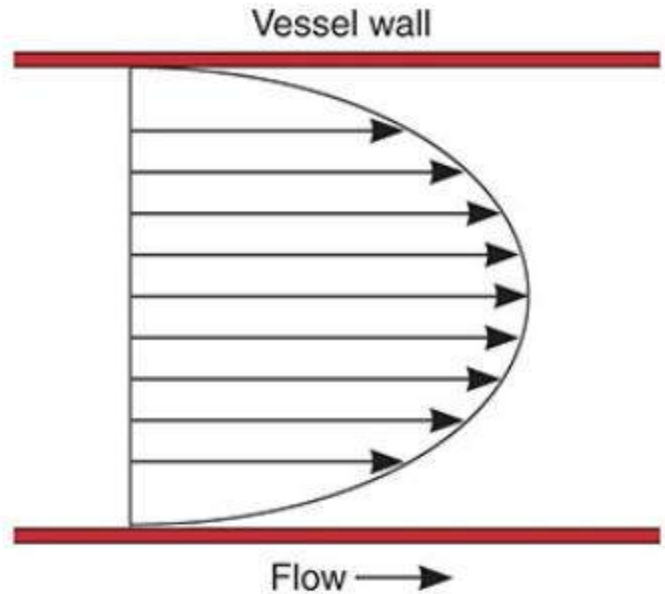
(1) Laminar (streamline):

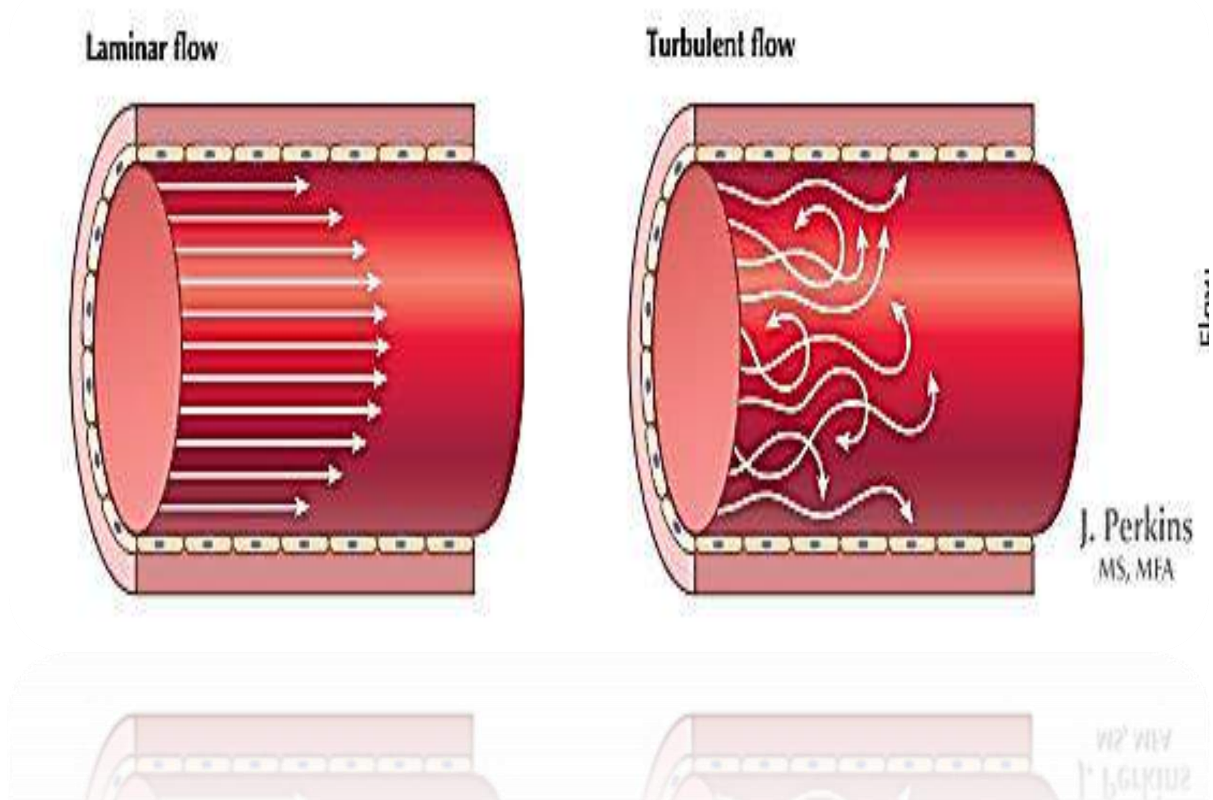
- **This is the normal smooth flow of blood.**
- **It is silent and laminar.**

The blood flows in several layers or laminae. The outermost layer of blood in contact with the vessel wall is almost completely static (wall stress; a type of shear stress) while the other layers move by velocities that increase gradually from out inwards till becoming maximal in the central layer of the stream. **Beyond a certain critical velocity, turbulence occurs.**

(2) Turbulent:

- **This is disturbed blood flow in the form of eddies in various directions.**
- **It produces sounds (= bruits or murmurs) which can be heard by stethoscope. It especially occurs when critical velocity exceeded.**


Vessel wall
Flow

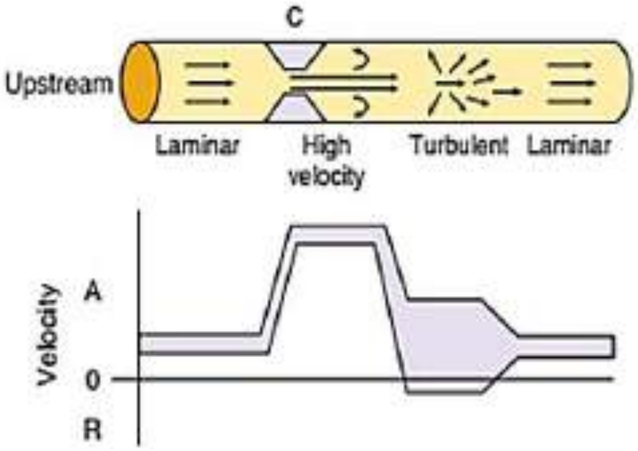

Laminar flow
Turbulent flow
J. Perkins
MS, MFA

- **In addition to blood velocity, blood viscosity as well as diameter of the vessel are also contributing factors in producing turbulence**.

- Turbulence occurs pathologically due to increased blood velocity in the following conditions:

✓ Beyond points of constriction in arteries. This produces abnormal sounds (e.g. the bruits heard over arterial areas constricted by atherosclerotic plaques and the sounds of Korotkoff heard when measuring blood pressure).

✓ In severe anemia (in which blood velocity increases due to reduction of its viscosity). In such cases, turbulence may produce systolic murmurs.



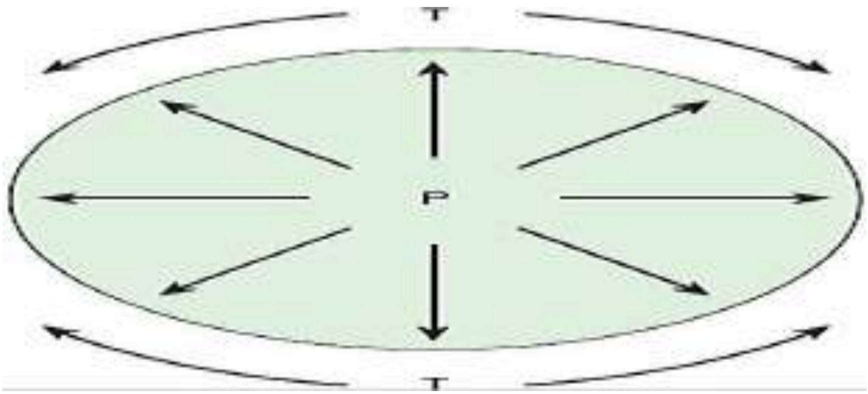
LAW OF LAPLACE

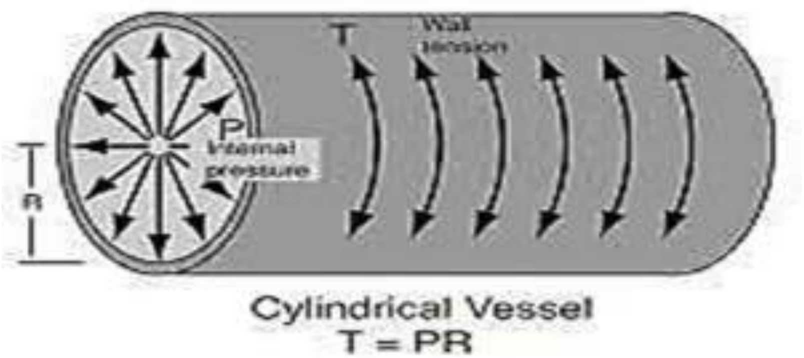
This law states that tension (T) in the wall of a cylinder (as blood vessels) is equal to the product of the transmural pressure (P_t) and the radius (r)

The tension (T) = distending pressure (P_t) x radius (r)

$T = P \times r$

It also applies to hollow viscus e.g. the urinary bladder, lung alveoli and stomach.






Thank you