Haemodynamics

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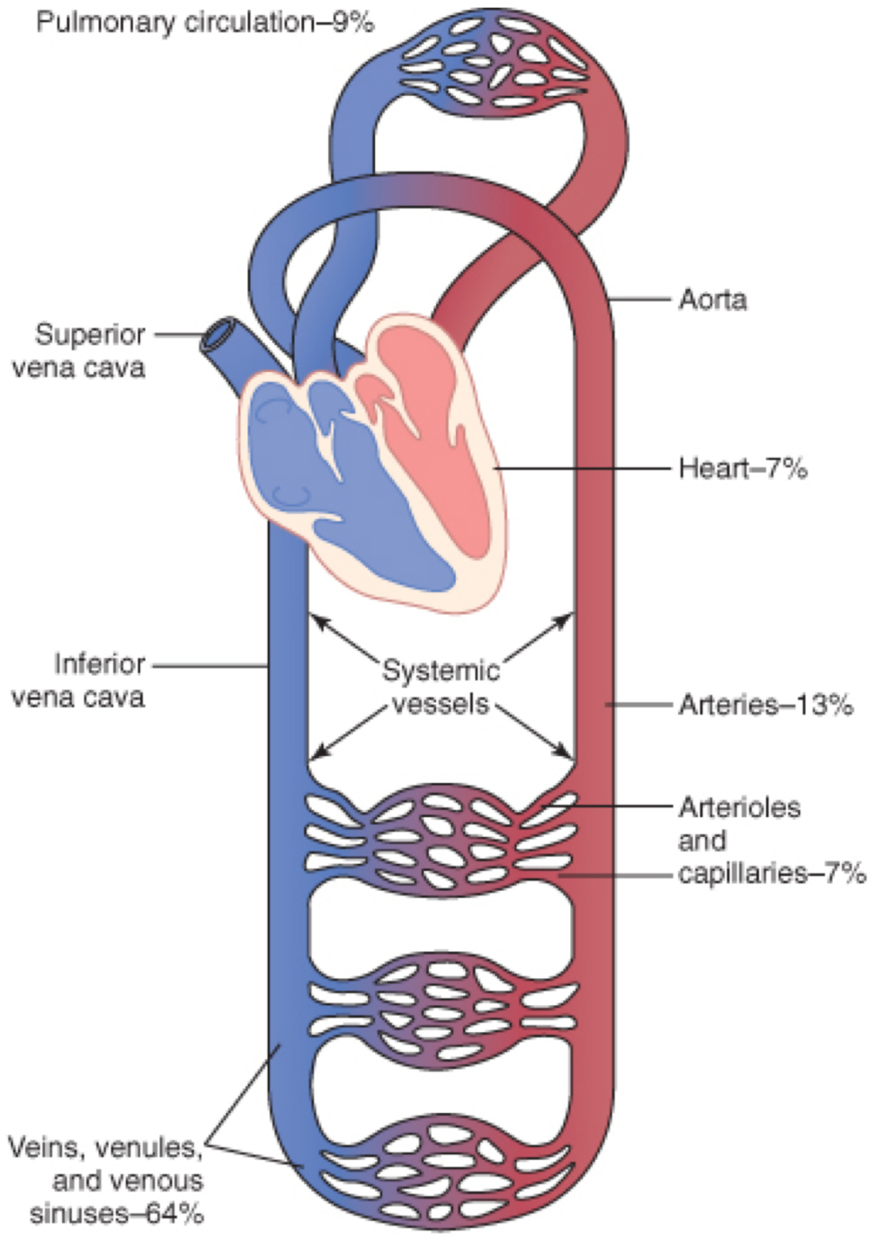
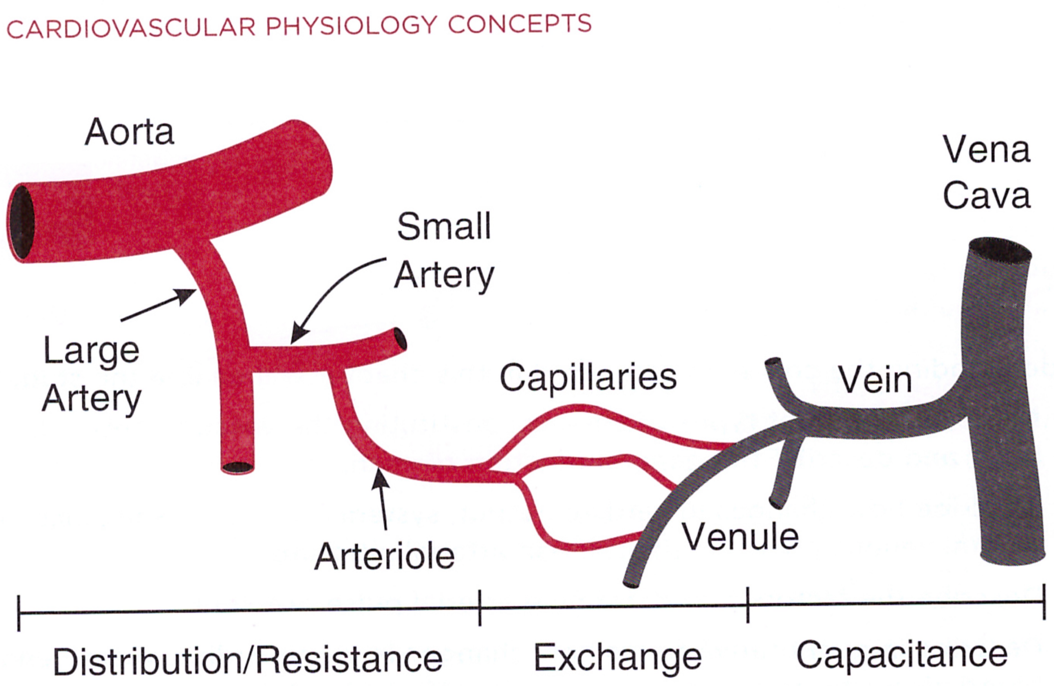
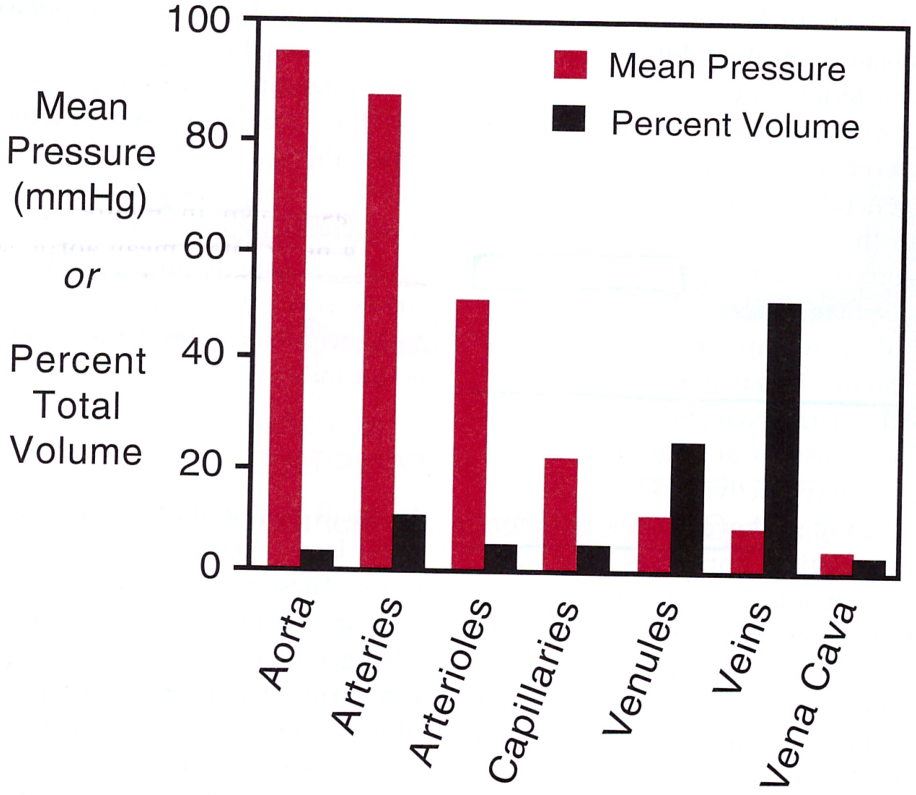

Pulmonary circulation–9%
Aorta
Superior vena cava
Heart–7%
Inferior vena cava
Systemic vessels
Arteries–13%
Arterioles and capillaries–7%
Veins, venules, and venous sinuses–64%

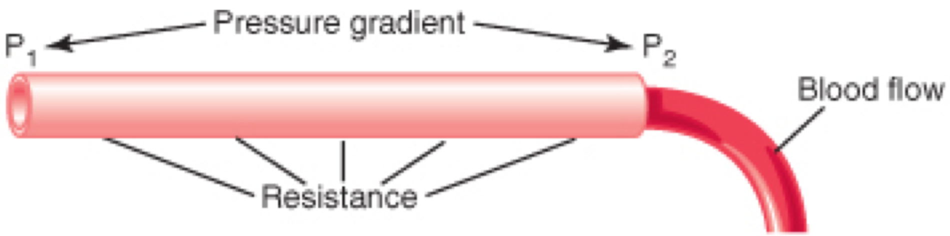
Major types of blood vessels



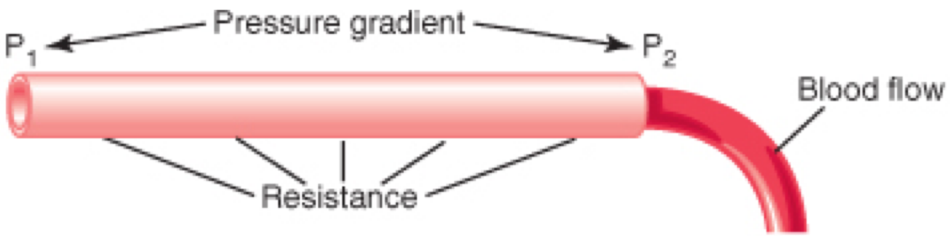


50cm/s 0.05cm/s

Flow, pressure, resistance



Flow, pressure, resistance



$$\Delta P = F \times R \quad \ldots \quad \Delta U = I \text{ x } R$$

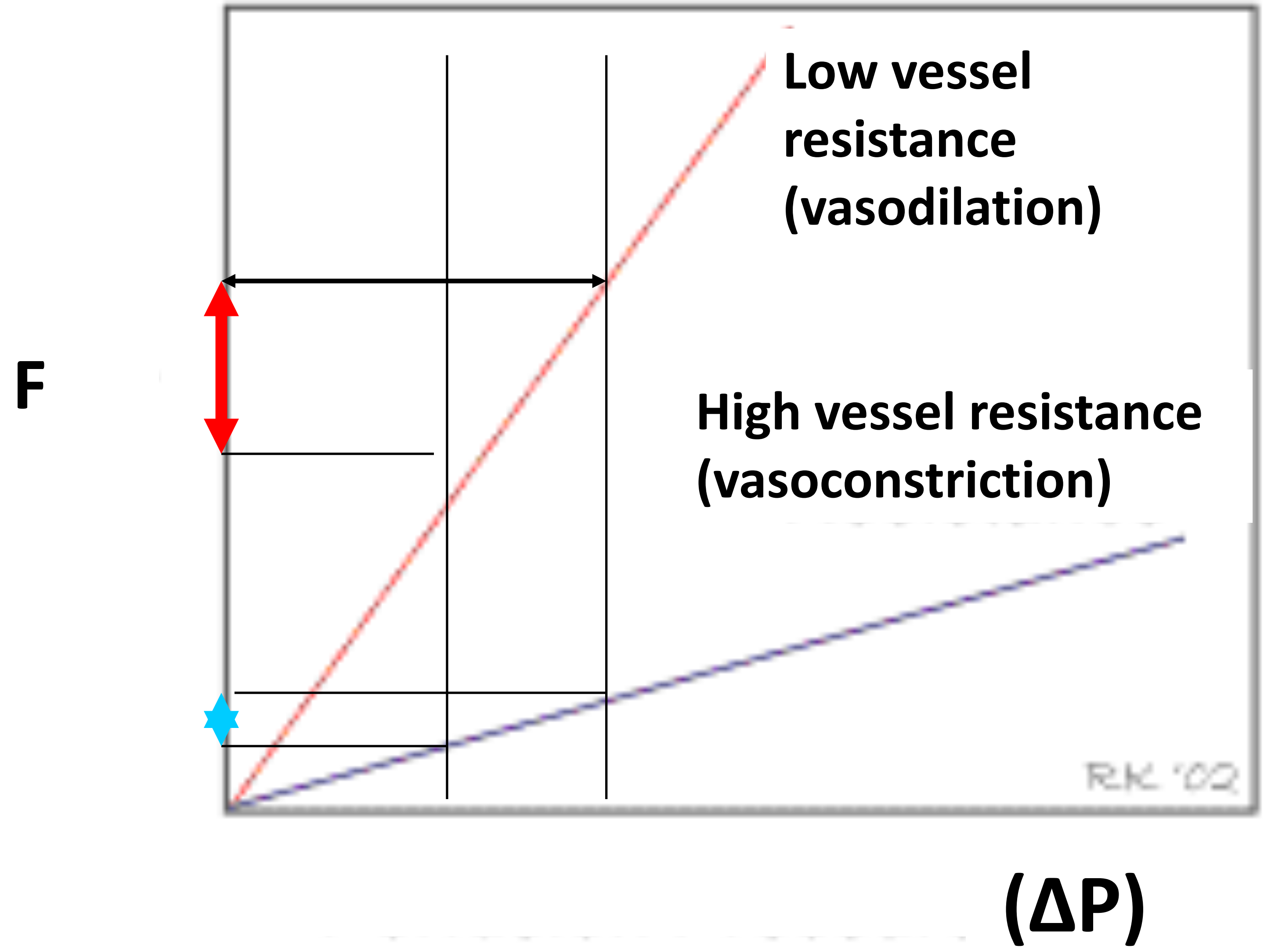
Blood and vessels are not rigidig tubes and ideal liquid!

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

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

Q = (Pa – Pv)/R

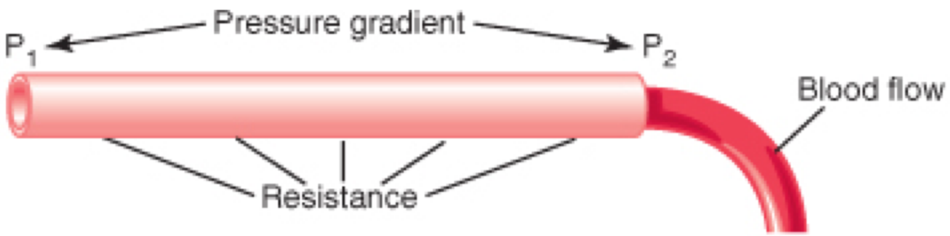
$$F = \frac{\Delta P}{R}$$



Vasodilation = increased blood flow, **more blood** in organ…

Vasoconstriction = decreased blood flow, **less blood** in organ…

Flow, pressure, resistance



$$\Delta P = F \times R$$

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

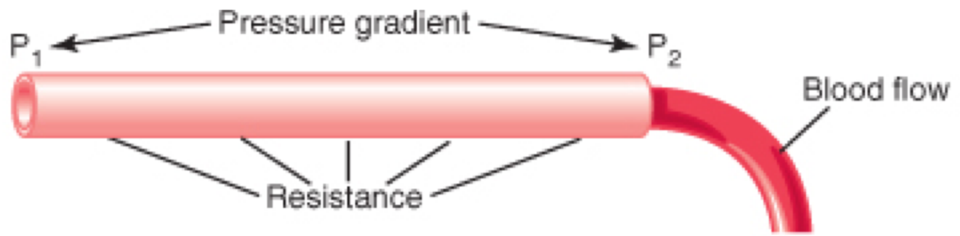
$$F = \frac{\Delta P}{R}$$

Hagen - Poiseuille law

$$R \propto \frac{\eta \cdot L}{r^4}$$

η – viskosity
L – vessel lenght
r – radius

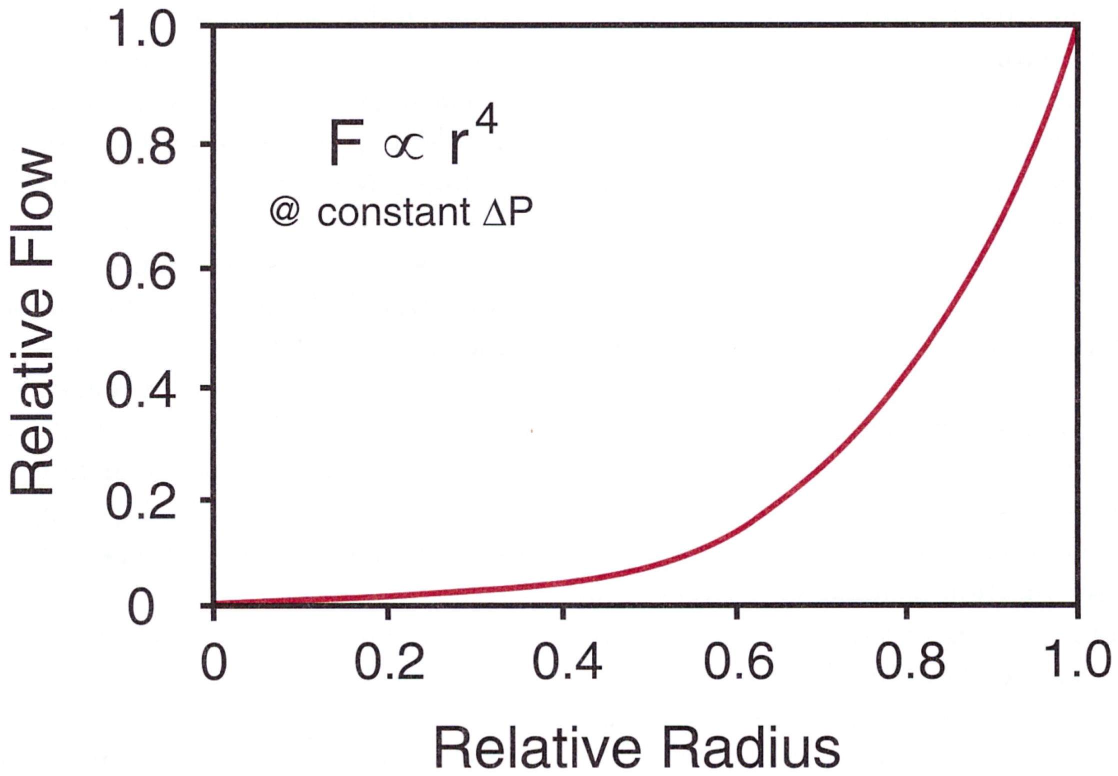
Flow, pressure, resistance



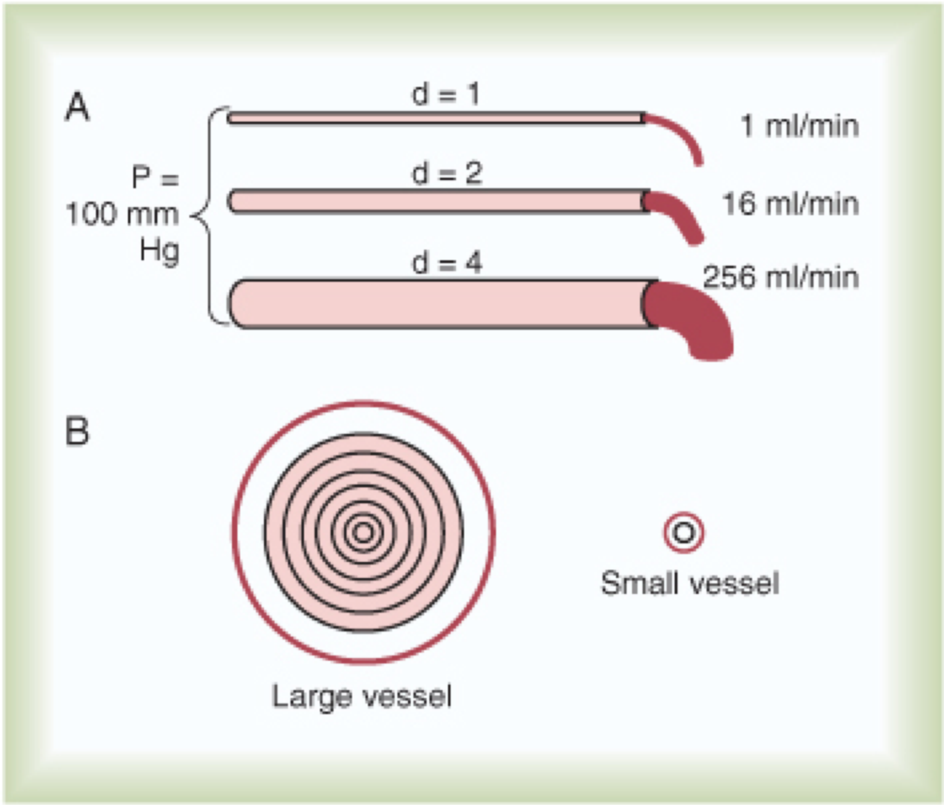
$$\Delta P = F \times R$$

$$R = \frac{\Delta P}{F} \qquad R \propto \frac{\eta \cdot L}{r^4}$$

$$F = \frac{\Delta P}{R} \qquad F \propto \frac{\Delta P \cdot r^4}{\eta \cdot L} \qquad \ldots\ \mathbf{F \simeq r^4}$$

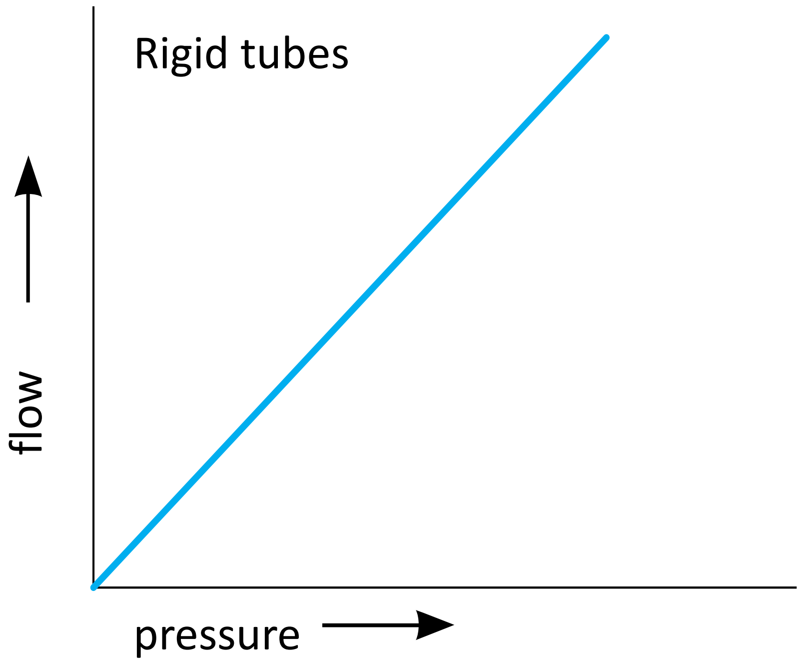


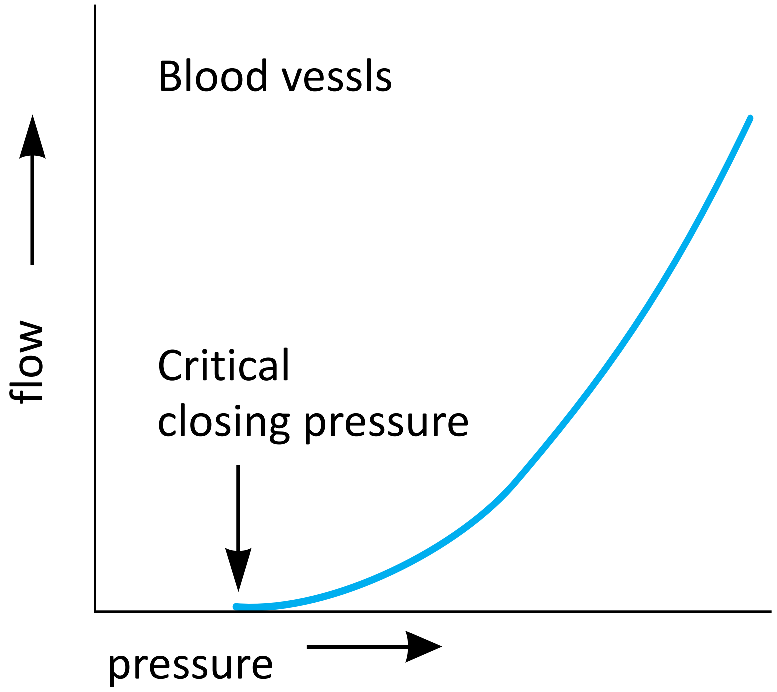
1.0
0.8
0.6
0.4
0.2
0
Relative Flow
F ∝ r4
@ constant ΔP
0
0.2
0.4
0.6
0.8
1.0
Relative Radius

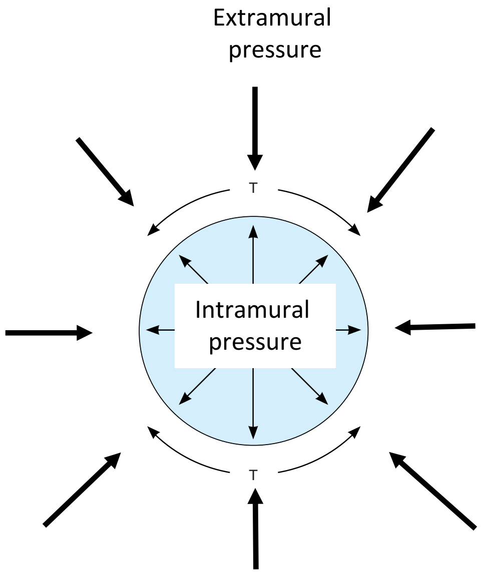


A
d = 1
1 ml/min
P =
100 mm
Hg
d = 2
16 ml/min
d = 4
256 ml/min
B
Small vessel
Large vessel

Critical closing flow pressure





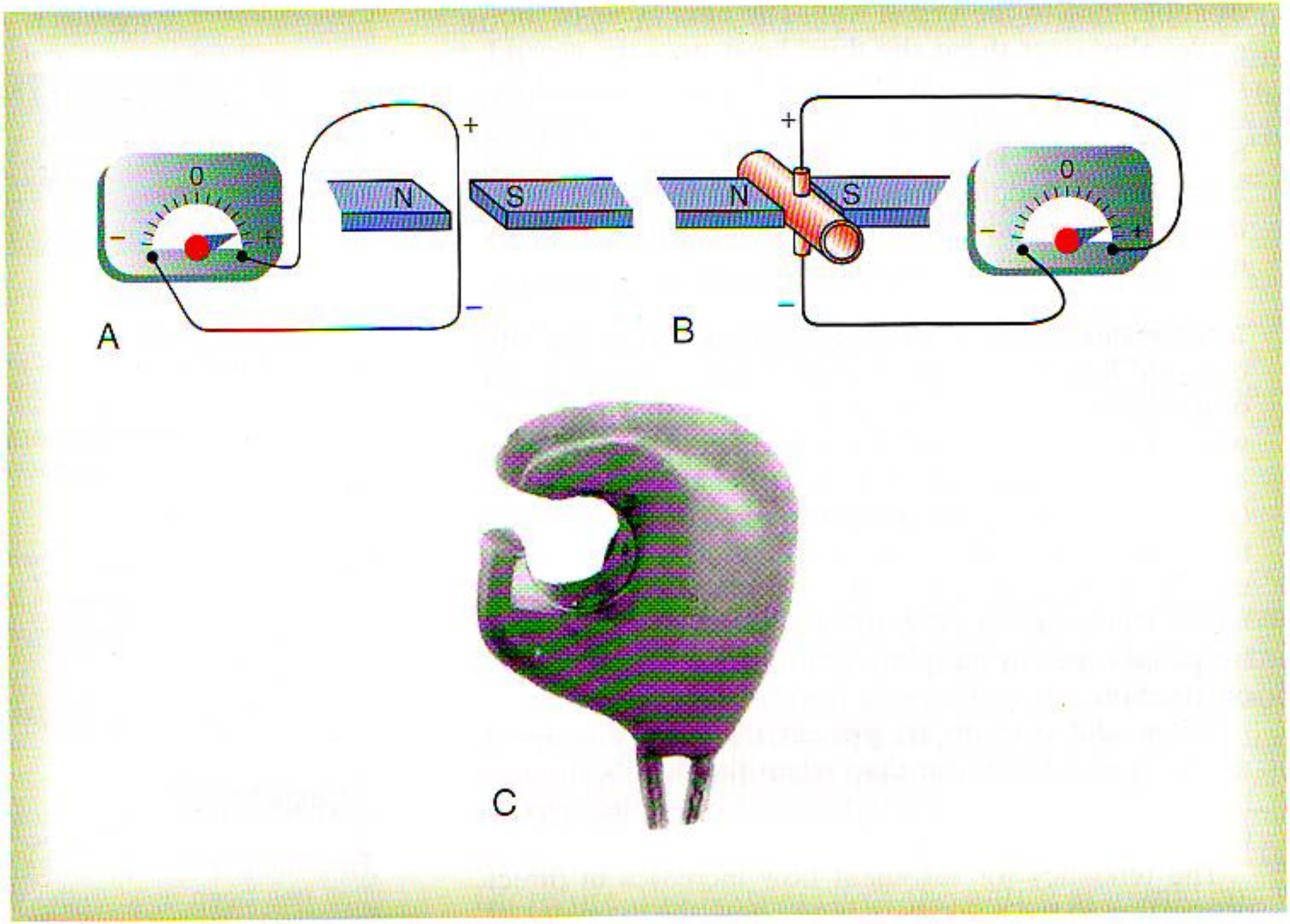


Flow in the vessels starts when intramural pressure exceed extramural pressure

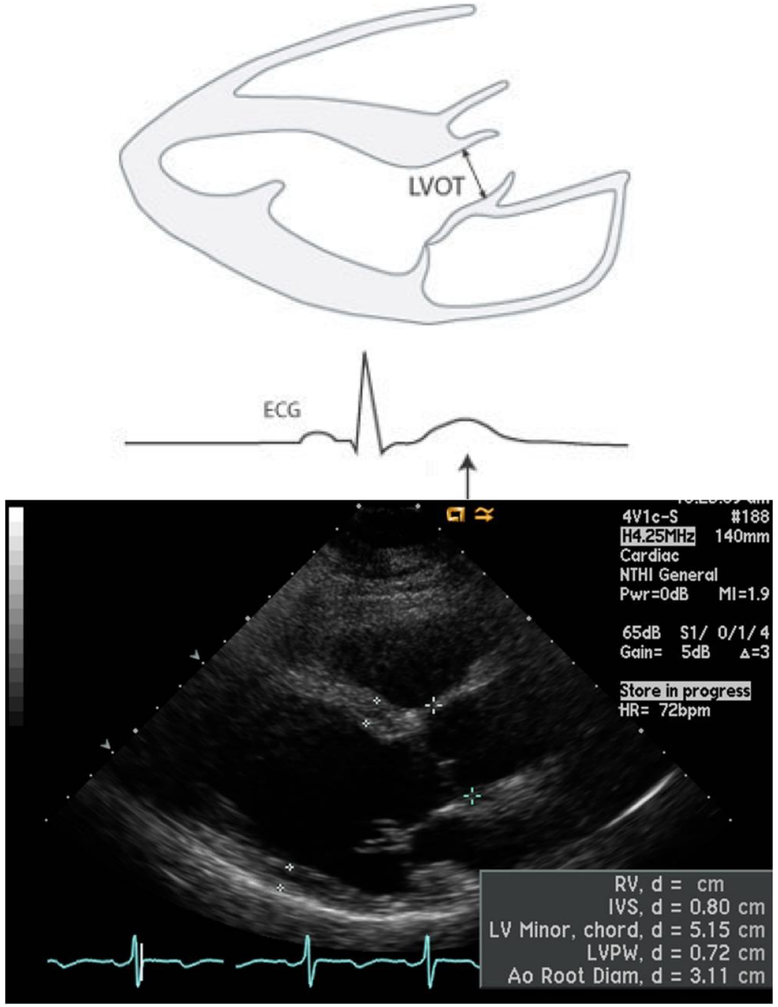
Flow measurement

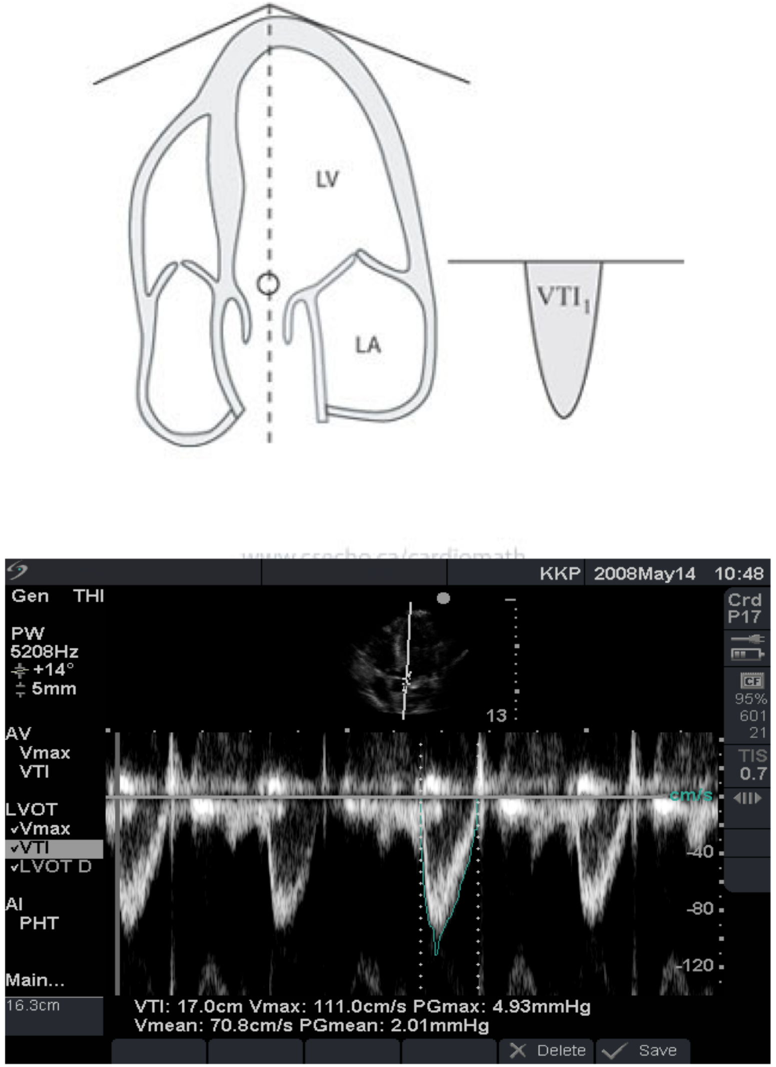
- Electromagnetic method
- Ultrasound (doppler effect)
- The dye dilution methods
- Fick priciple

Electromagnetic flowmeter



Ultrasound – dopple effect (echo)

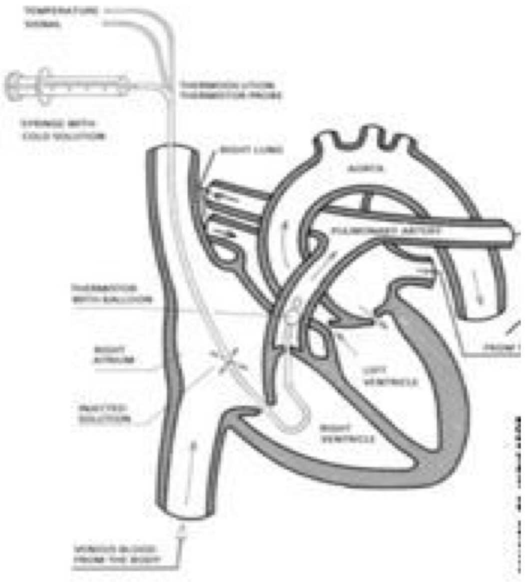


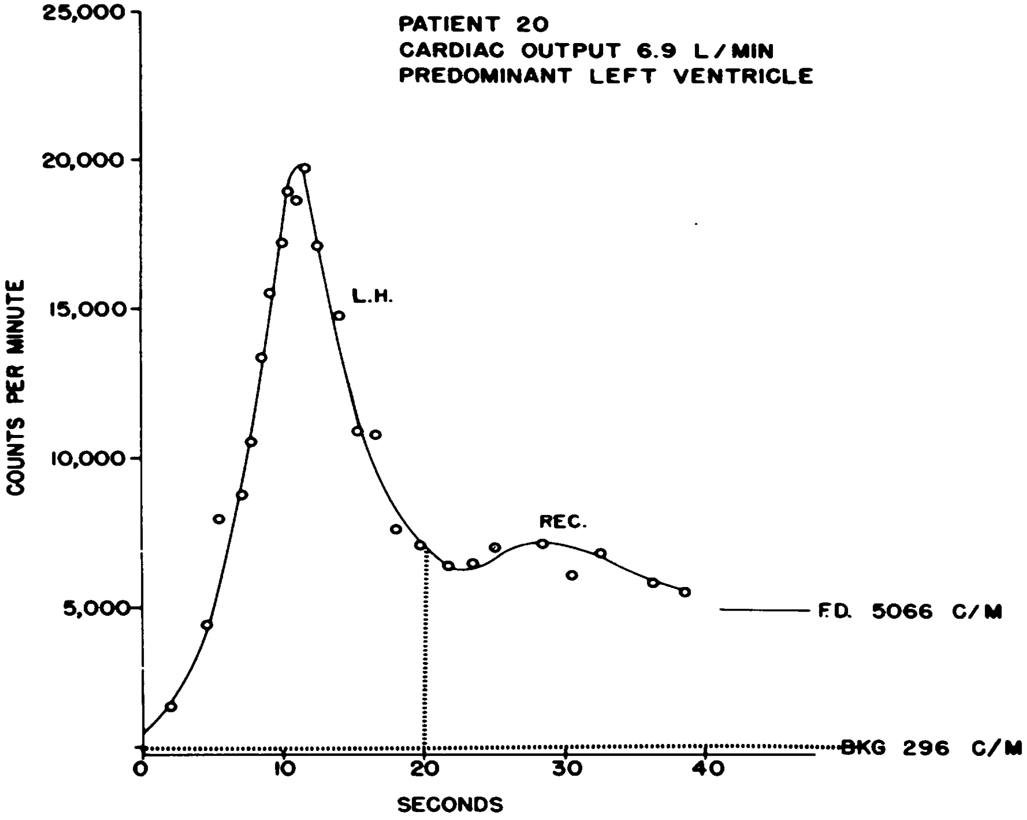


The dilution methods

- **Dye dilution:** methylene green, Evans blue…
  AUC represents the value of CO

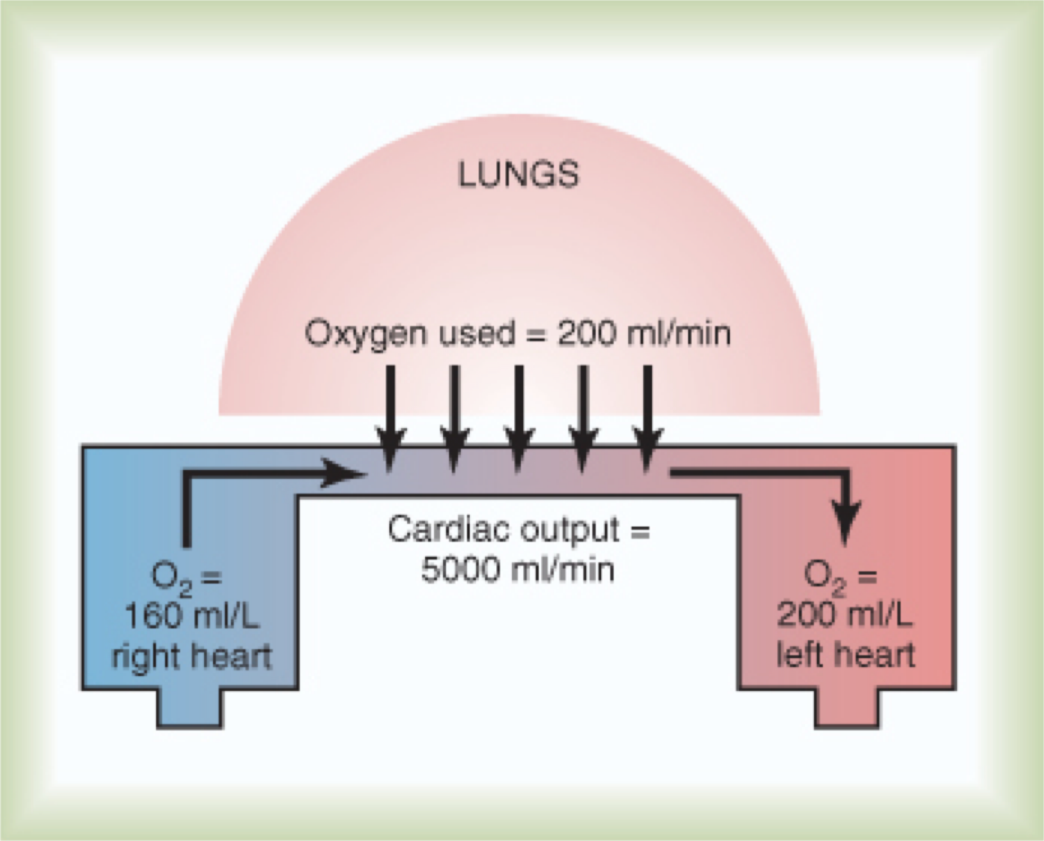
- **Thermodilution:** cold salt solution



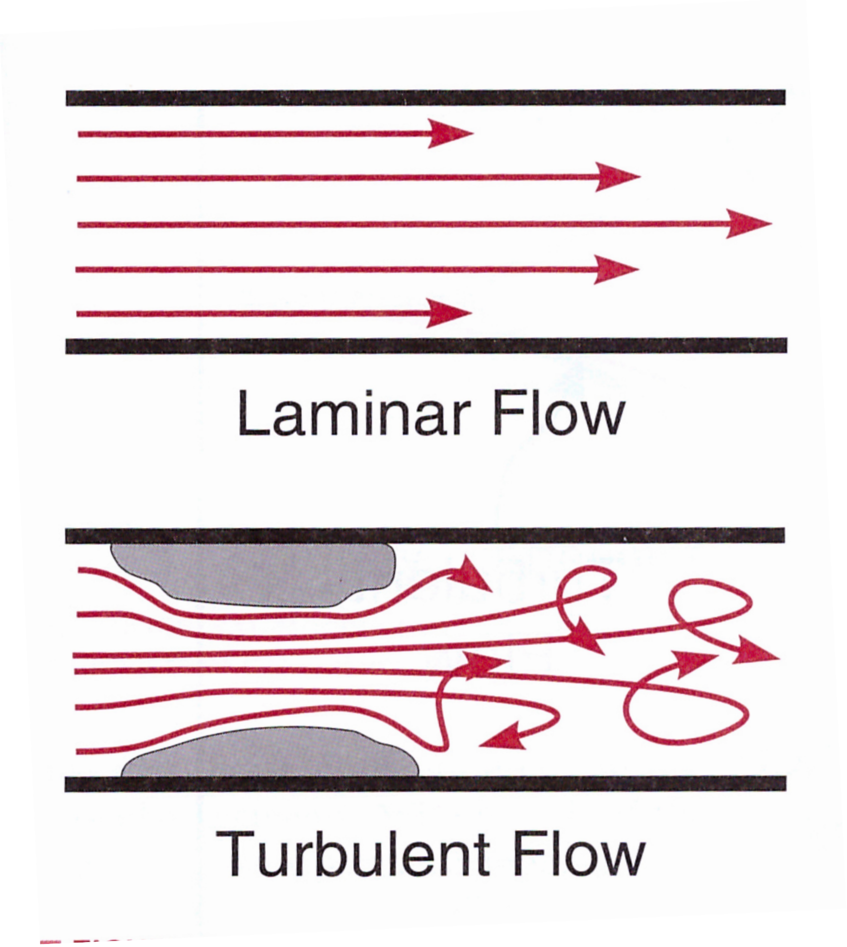


MacIntyre et al, Circulation 1958

Fick principle



The types of blood flow: laminar vs. turbulent

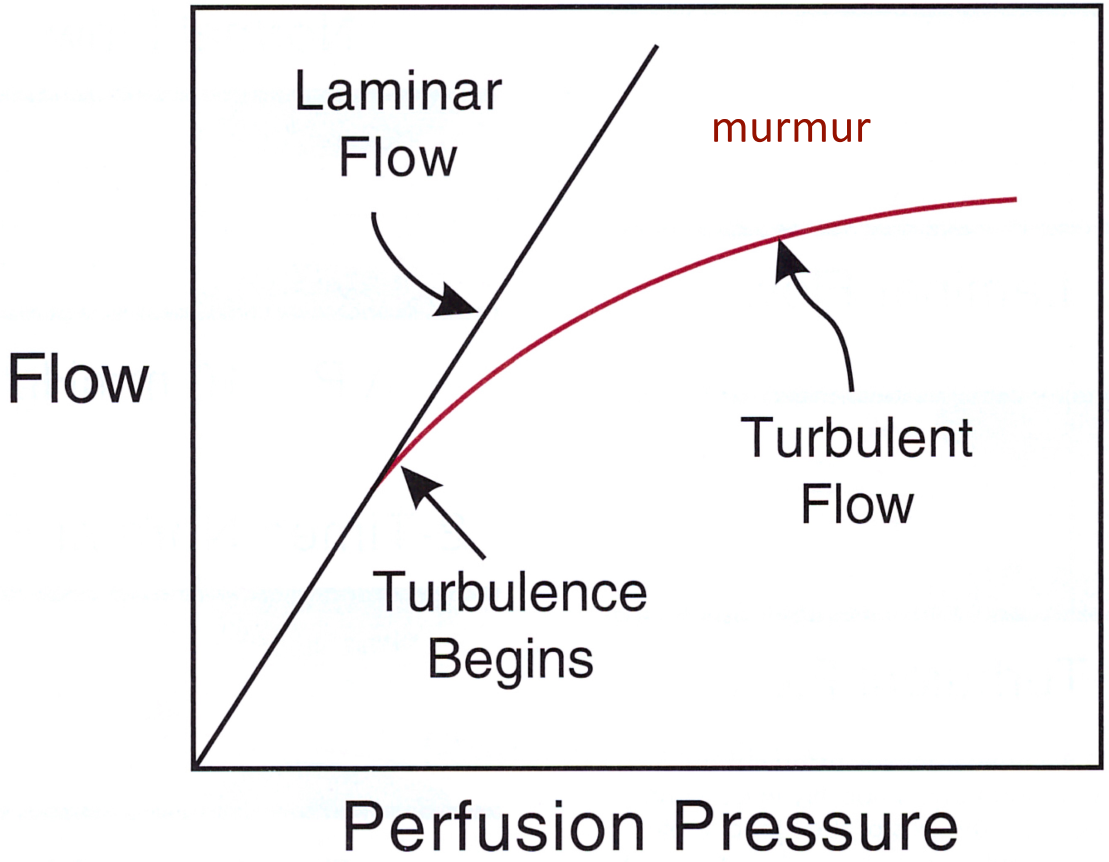


- a normal blood flow in majority of vessels
- Energically the most effective
- The smallest loose of energy
- inaudible

- Energetically less effective
- Přítomné při vysoké rychlosti průtoku po překročení „hranice“
- Present in high flow velocity above „critical point
- Audible - murmur
- Able to injure the vessel wall

- Stenosis, aterosclerosis….

Changing from laminar to turbulent flow



Reynolds number

$$Re = \frac{\rho D \dot{V}}{\eta}$$

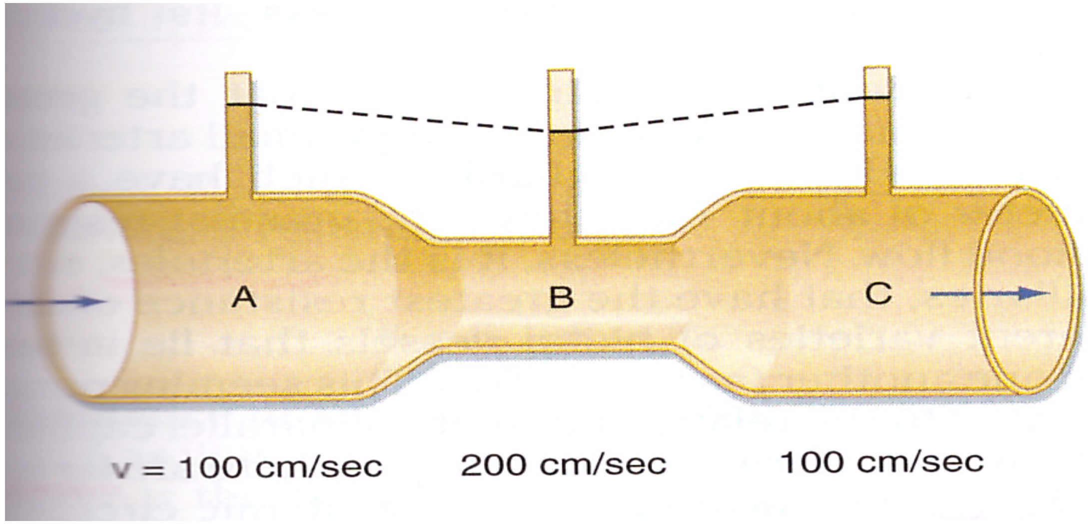
ρ - density
η - viskosity
D – diameter
V – velocity

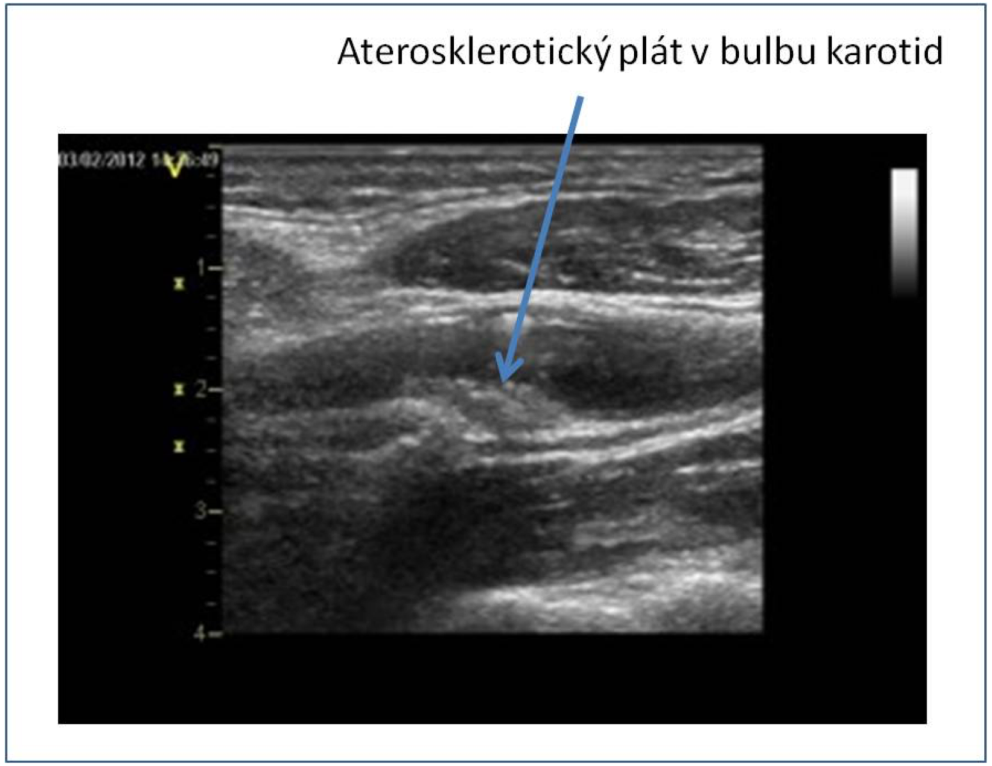
Relationship between vessel‘s kinetic and potential energy – Bernouli law

- Serial connection = flow is constant in all segments
- Energy of the blood is constant
- Sum of the flow velocity and pressure is constant
- **Increasing** flow **velocity** leads to **decreasing** of the flow **pressure** and vice versa

$$P + v = const.$$

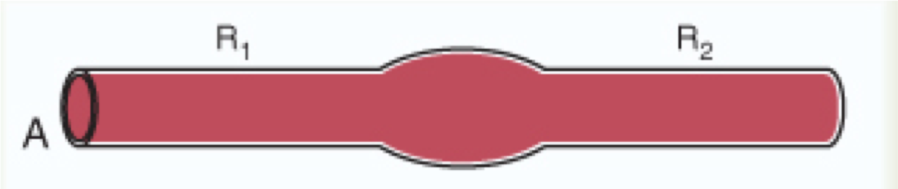
- Stenosis, suction, spray, airplane wings, ….





Serial and Parallel arragement of the vasculature

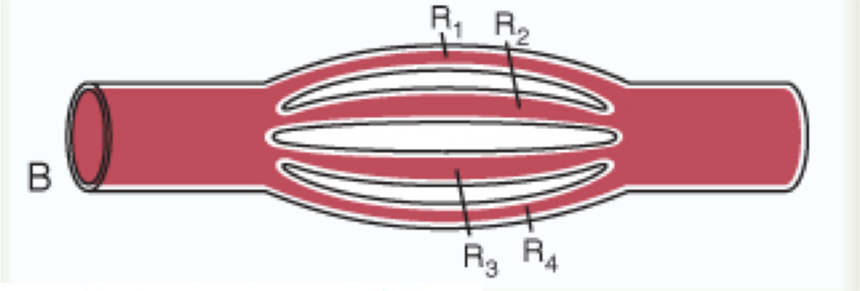
Serial



$$R_T = R_1 + R_2 + R_3 + R_4 + R_5 \ldots$$

- e.g. Systemic and pulmonary circulation
- The total resistace equals the sum of the individual segmental resistances
- $R_T = R_A + R_a + R_c + R_v + R_V$
  1% + 70% + 20% + 8% + 1% = 100%
- depends on which vessel region is affected…

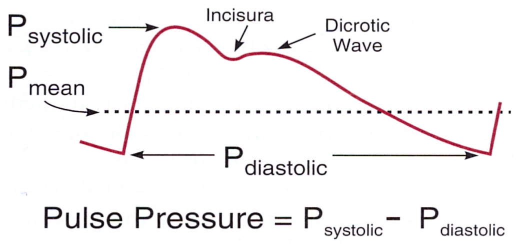
Parallel



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

- Parallel vessels decrease total vascular resistance
- The total resistance of a network of parallel resistances is less than the resistance of the single lowest resistance
- An example: $R_1 = 5$, $R_2 = 10$, $R_3 = 20$
  $R_T = 1/0.2+0.1+0.05 = 1/0.35 =$ **2.86**

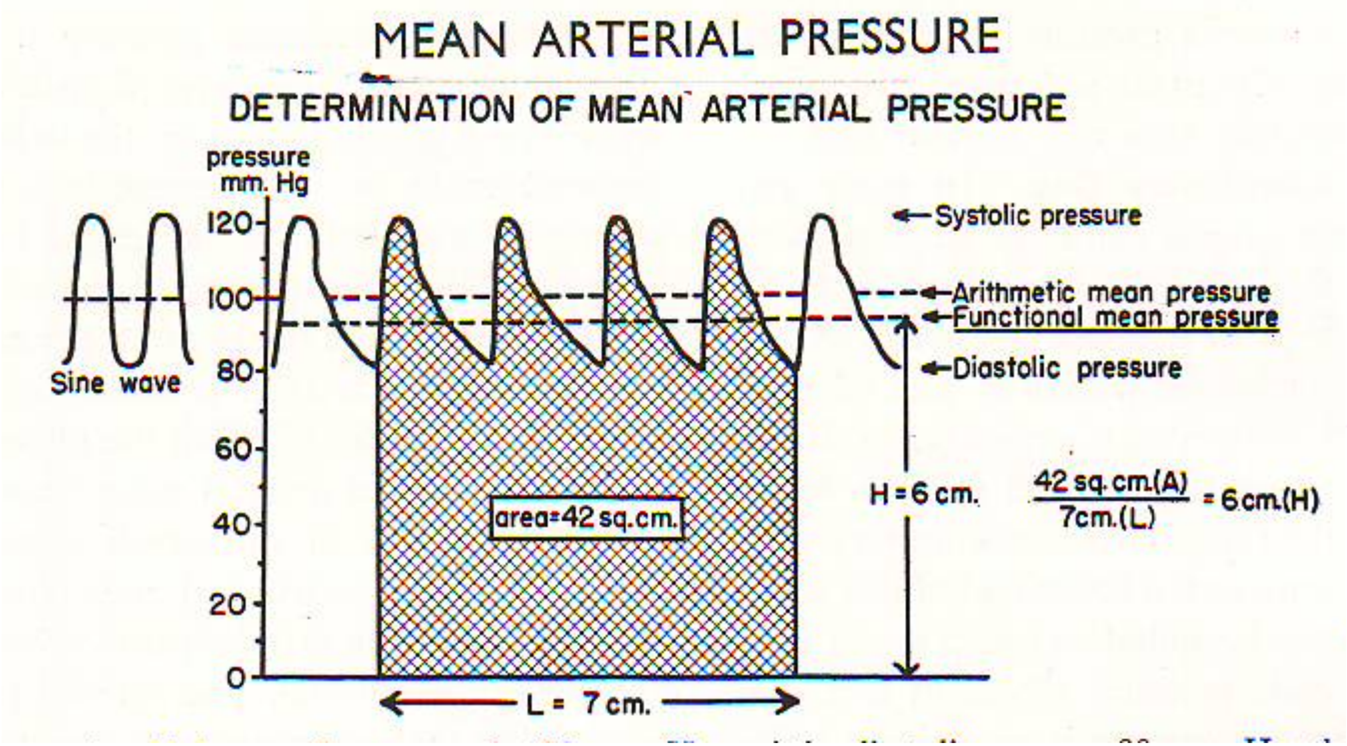
Arterial blood pressure



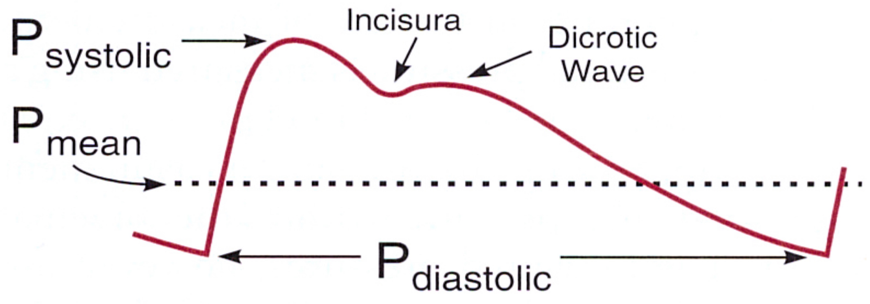
- Arterial pressures:
  - Systolic: end of the systole, approx. 120mmHg
  - Diastolic: end of the diastole, approx. 80mmHg
  - Pulse – pressure amplitude: difference between systolic and diastolic pr., approx. 40-45mmHg
  - **Mean** – geometric mean: is less than arithmetical mean (systole is shorter than diastole)
    - influences of the organ blood flow

$$MAP = P_{diast} + 1/3\ (P_{syst} - P_{diast})$$

Mean arterial pressure



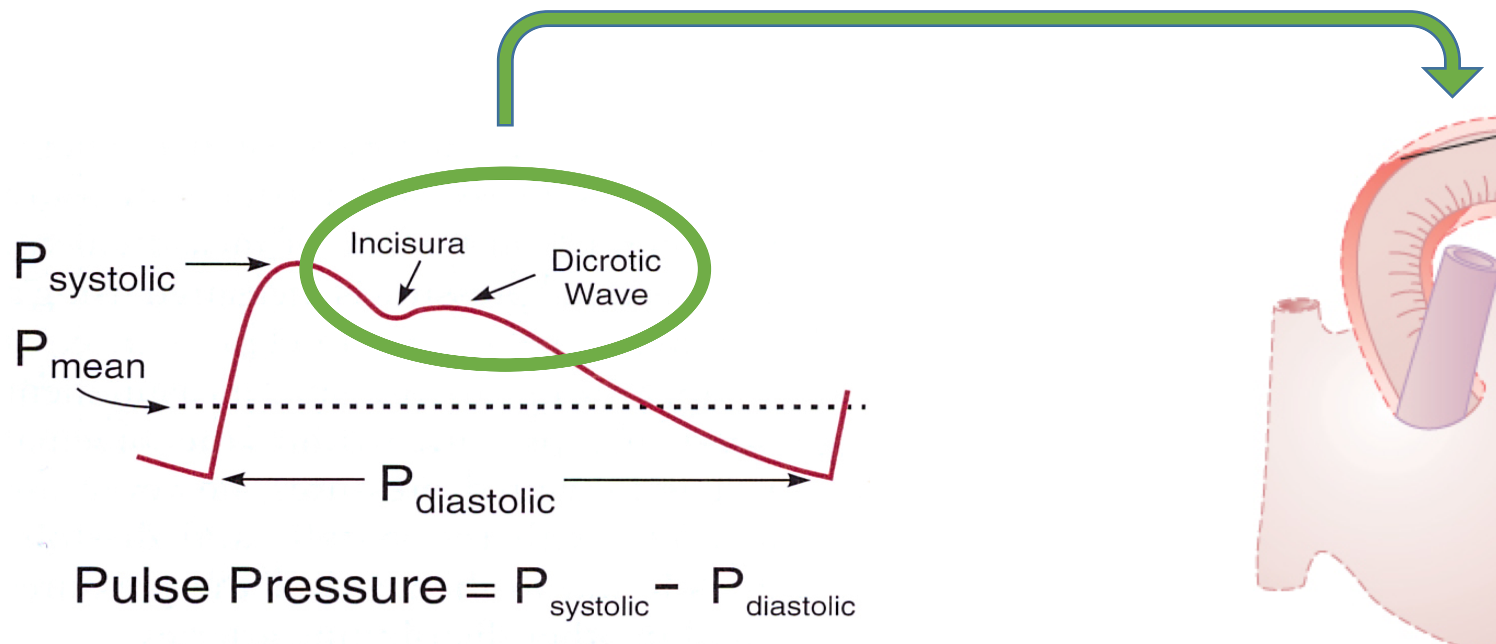
Measurement of the MAP by integration of AUC

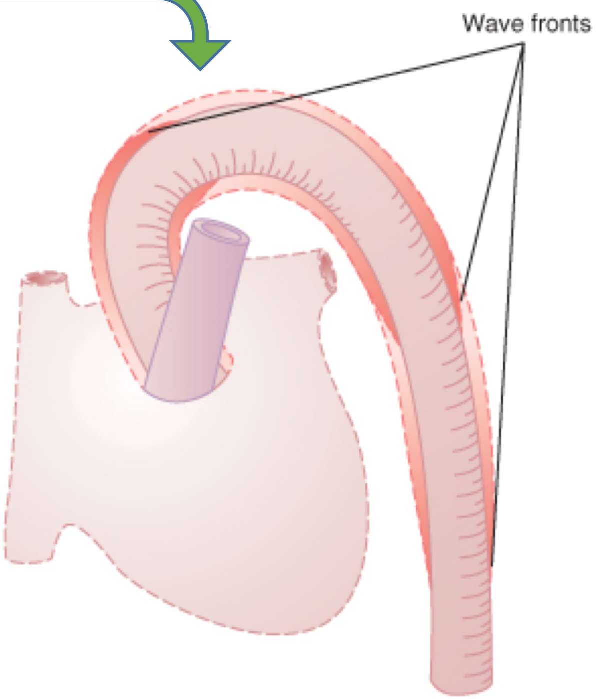


$$\text{Pulse Pressure} = P_{systolic} - P_{diastolic}$$

$$MAP \cong P_{dias} + \frac{1}{3}(P_{sys} - P_{dias})$$

Mean arterial pressure



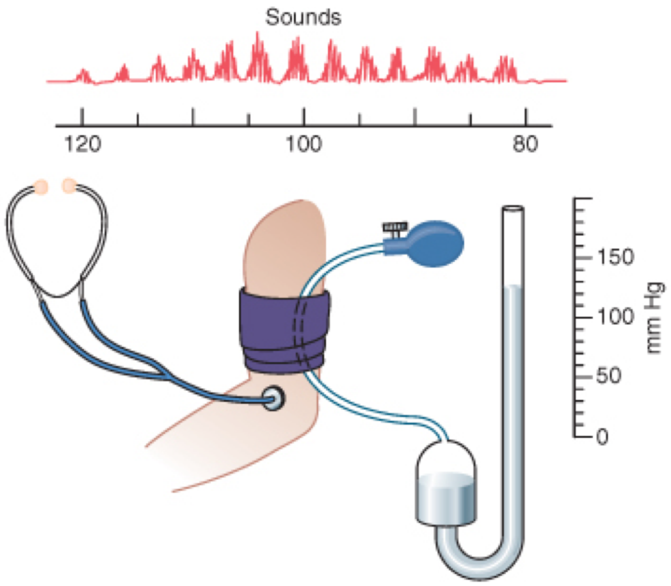


Transmission of the pressure pulse along the aorta – reduction of the blood pressure and flow fluctuation

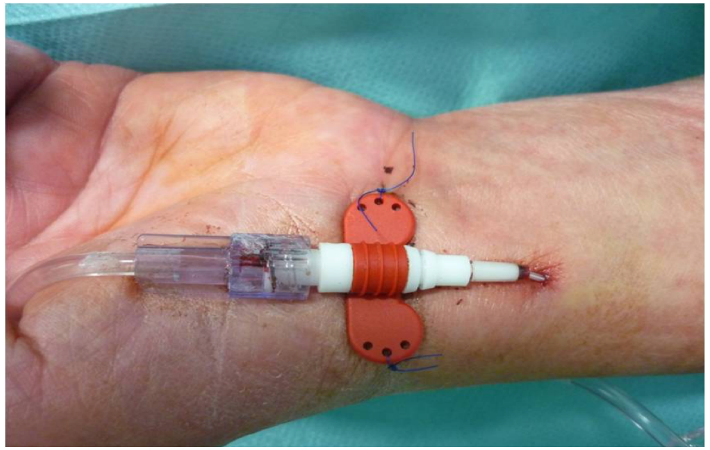
Pathology: atherosclerosis…

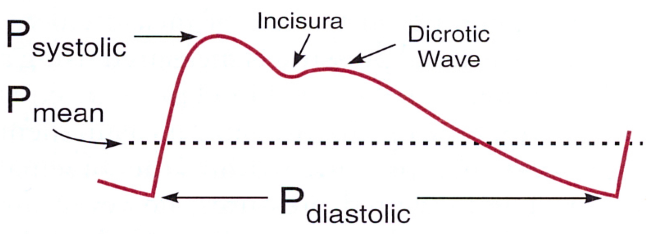
Blood pressure measurement

Non-invasive: ausculatory method



Invasive:





$$\text{Pulse Pressure} = P_{systolic} - P_{diastolic}$$

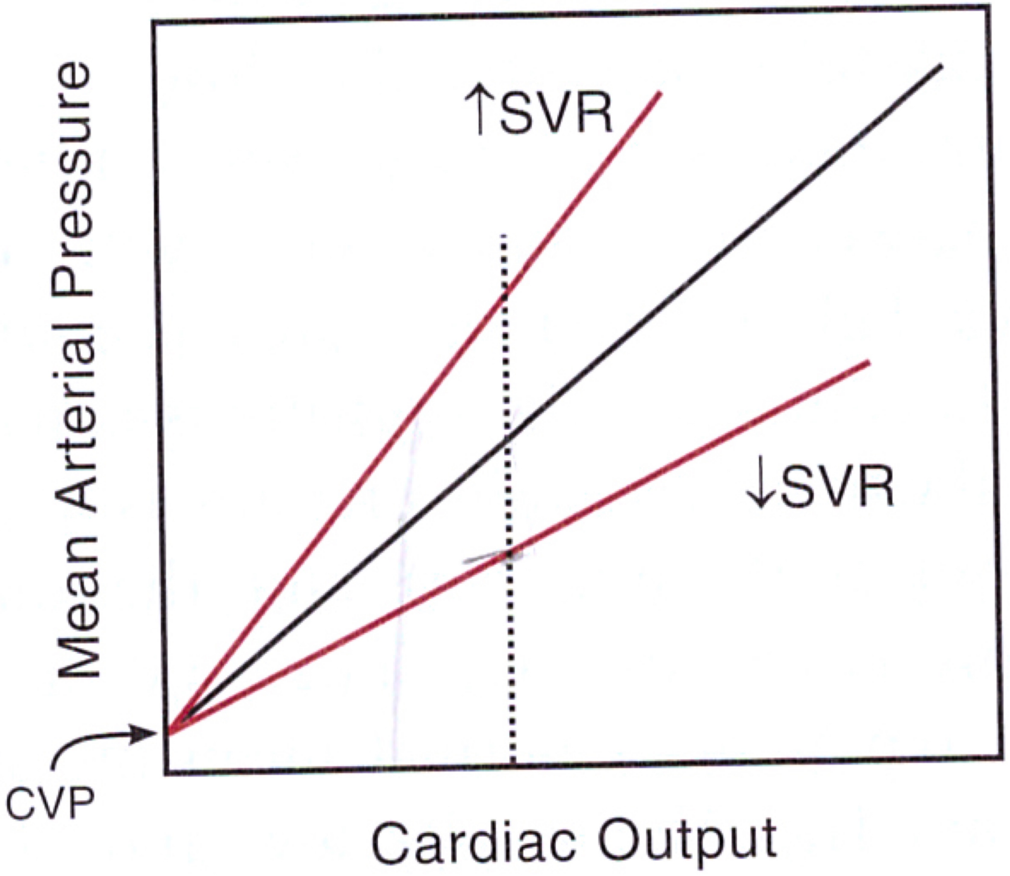
Systemic vascular resistance (SVR)

- Resistance to blood flow offered by all of the systemic vasculature
- SVR is determined by changes in: vascular diameters, viscosity, (Hagen - Poiseuille law)
- SVR represents resistance for left ventricle (AFTERLOAD)
- Vasoconstriction = increase SVR
- Vasodilation = decrease SVR

$$SVR = \frac{(MAP - CVP)}{CO}$$

- **<u>Small arteries + arterioles = resistent vessels</u>**

MAP – mean arterial pressure
CVP – central venous pressure
CO – cardiac output



SVR: systemic vascular resistance

CVP: central venous pressure (pressure in IVC)

Vascular tone

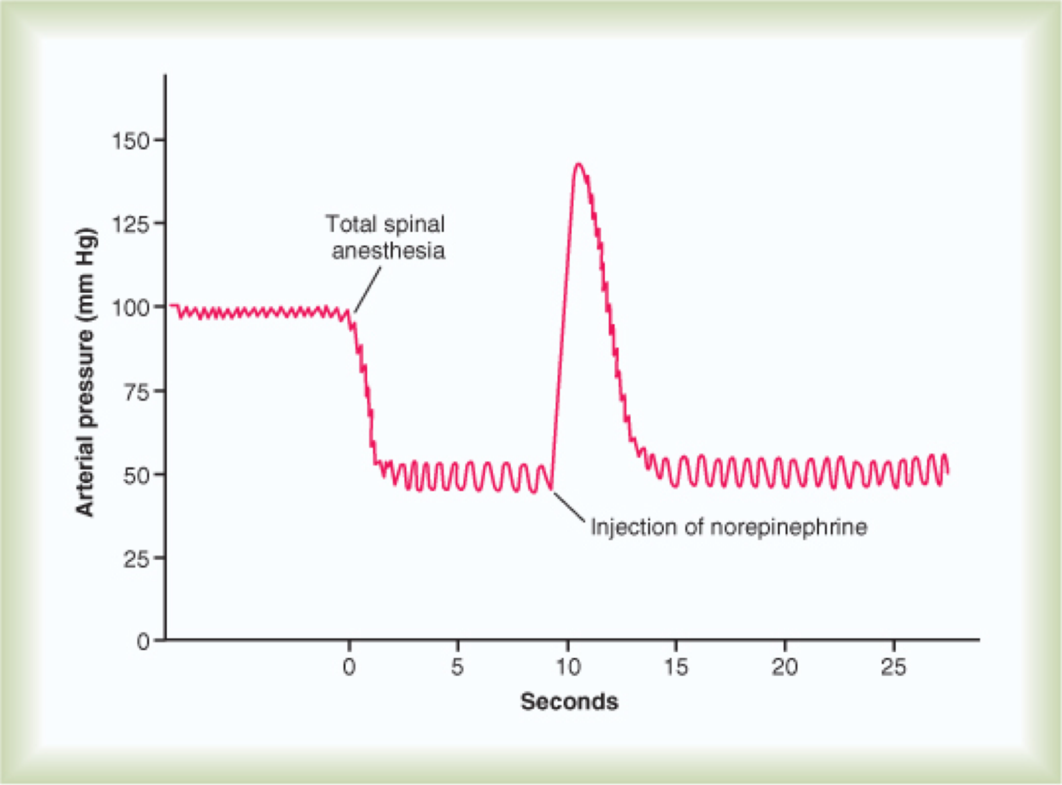
- Resistance vessels (small arteries and arterioles) are normaly in a partially constricted state – vascular tone.

- A partially constricted state of resistace vessels could:
  - Increase vasoconstriction – increase SVR, increase BP
  - decrease vasoconstriction (vasodilation) – decrease SVR, decrease BP

- A regulation of vascular tone:
  - Inner: products of the endothelial cells, autocrinne substances, local metabolites (O_2, CO_2, lactate, teplota, pH…)
  - Outer: hormones (ATII, ET), sympathetic nerves

- Mechanisms of vasoconstriction: maintain of MAP
- Mechanisms of vasodilation: regulation of blood flow in particular organs

Arthur Guyton‘s experiments on vascular tone



Venous blood pressure – central venous pressure (CVP)

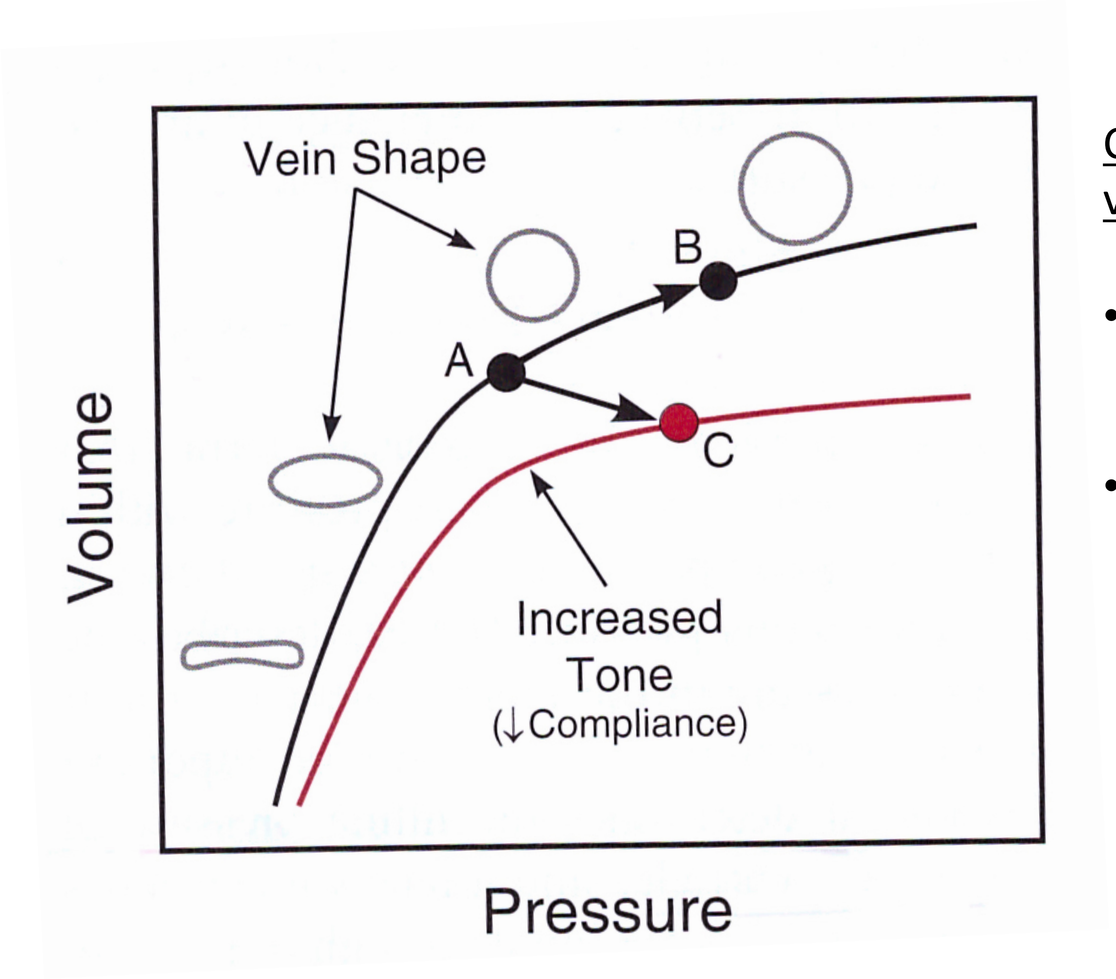
- Blood pressure within venous compartment

- CVP determines the filling pressure of the right ventricle (PRELOAD) and affects cardiac output (Frank-Starling mechanism)

- Factors affecting CVP:
    - Cardiac output*
    - Sympathetic activation*
    - Respiratory activity
    - Skeletal muscle pump
    - gravity

$$\Delta P_V \propto \frac{\Delta V_V}{C_V}$$

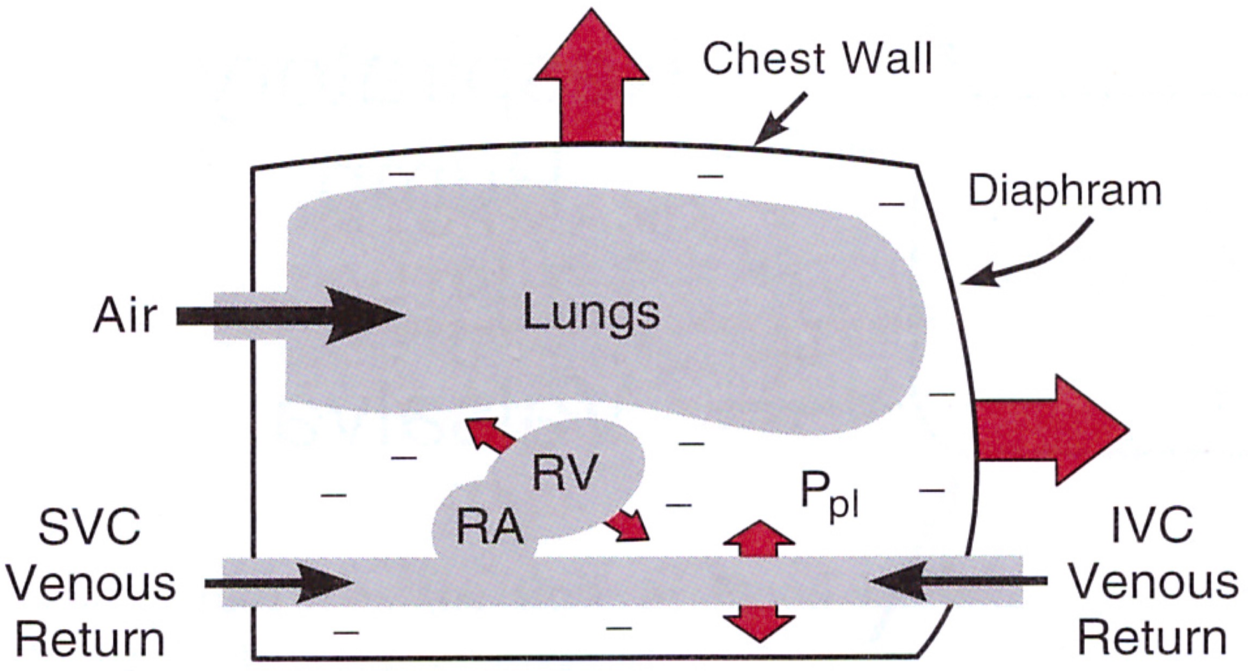
Cetral venous pressure

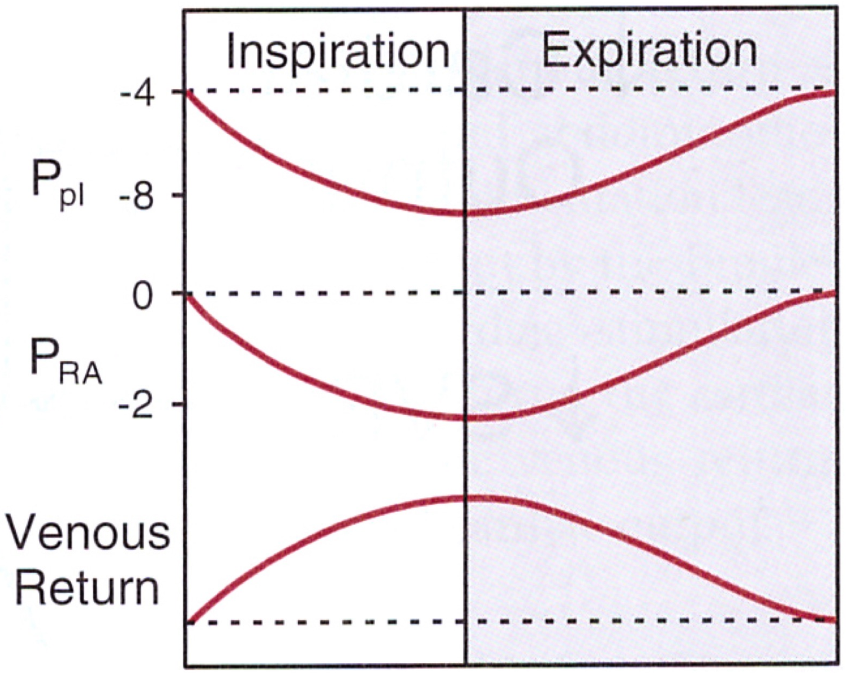


<u>Changes of CVP are determined by changes of venous volume nad tone/compliance:</u>

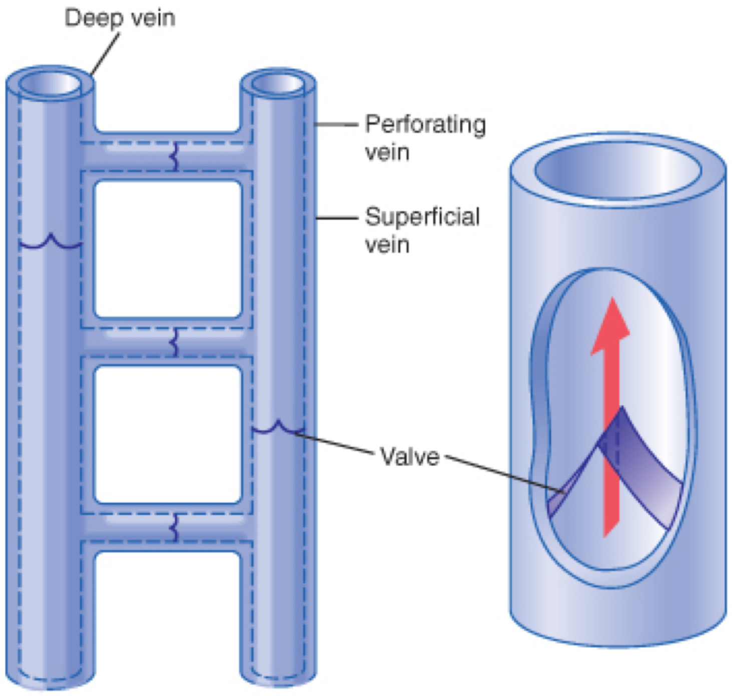
- Increase of venous volume leads to increase of venous pressure
- Increase of venous pressure is determined by venous tone/compliance

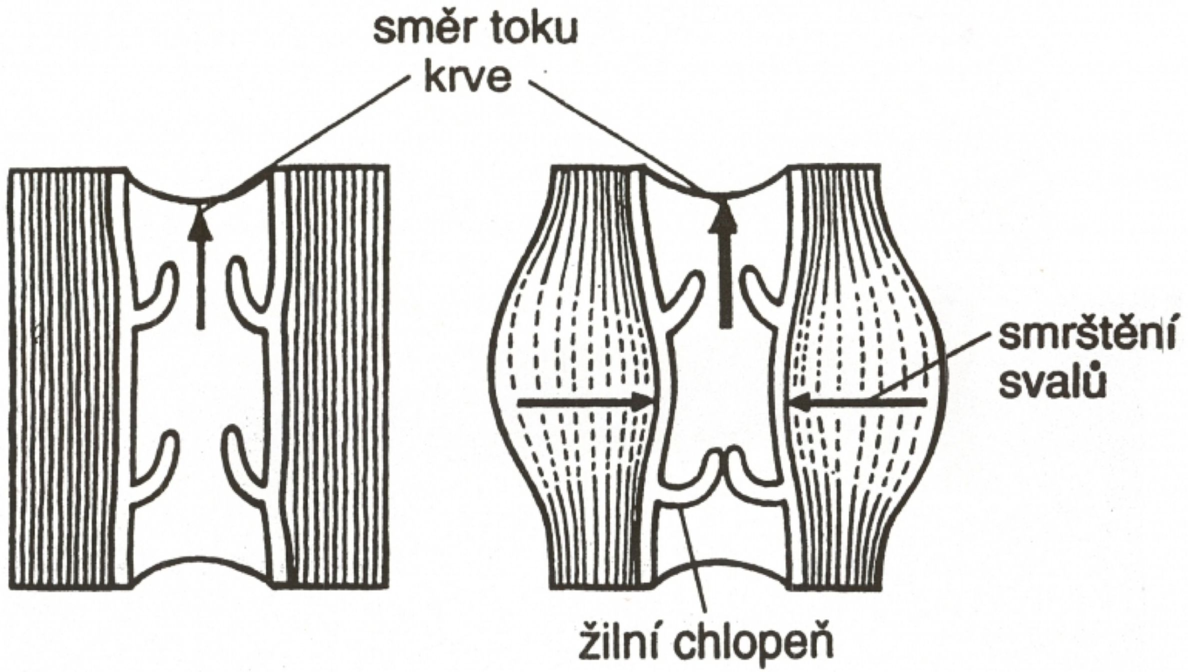
Respiratory activity and CVP



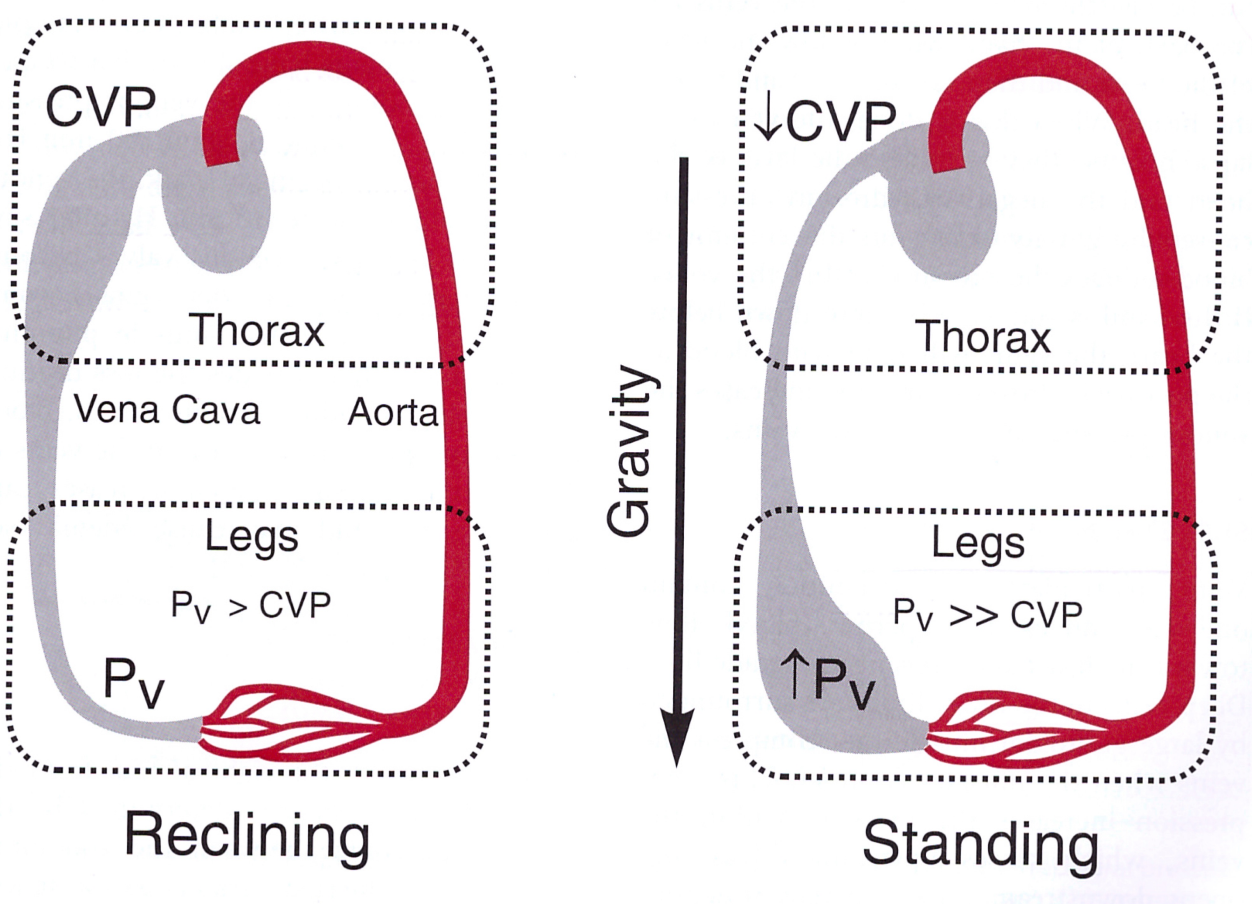


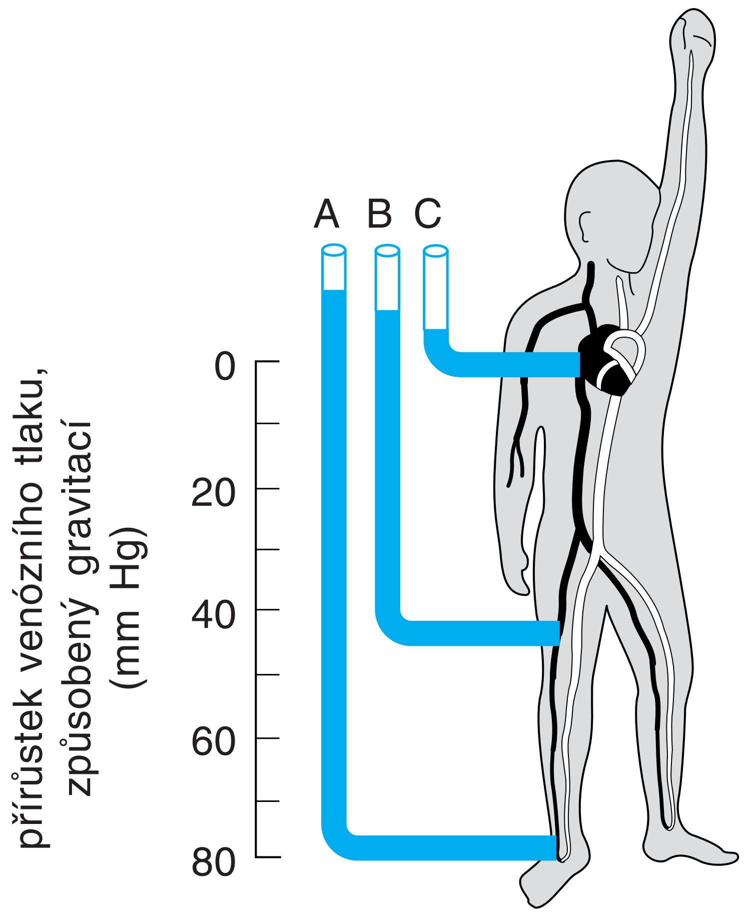
Skeletal muscle pump and CVP





Gravity and CVP



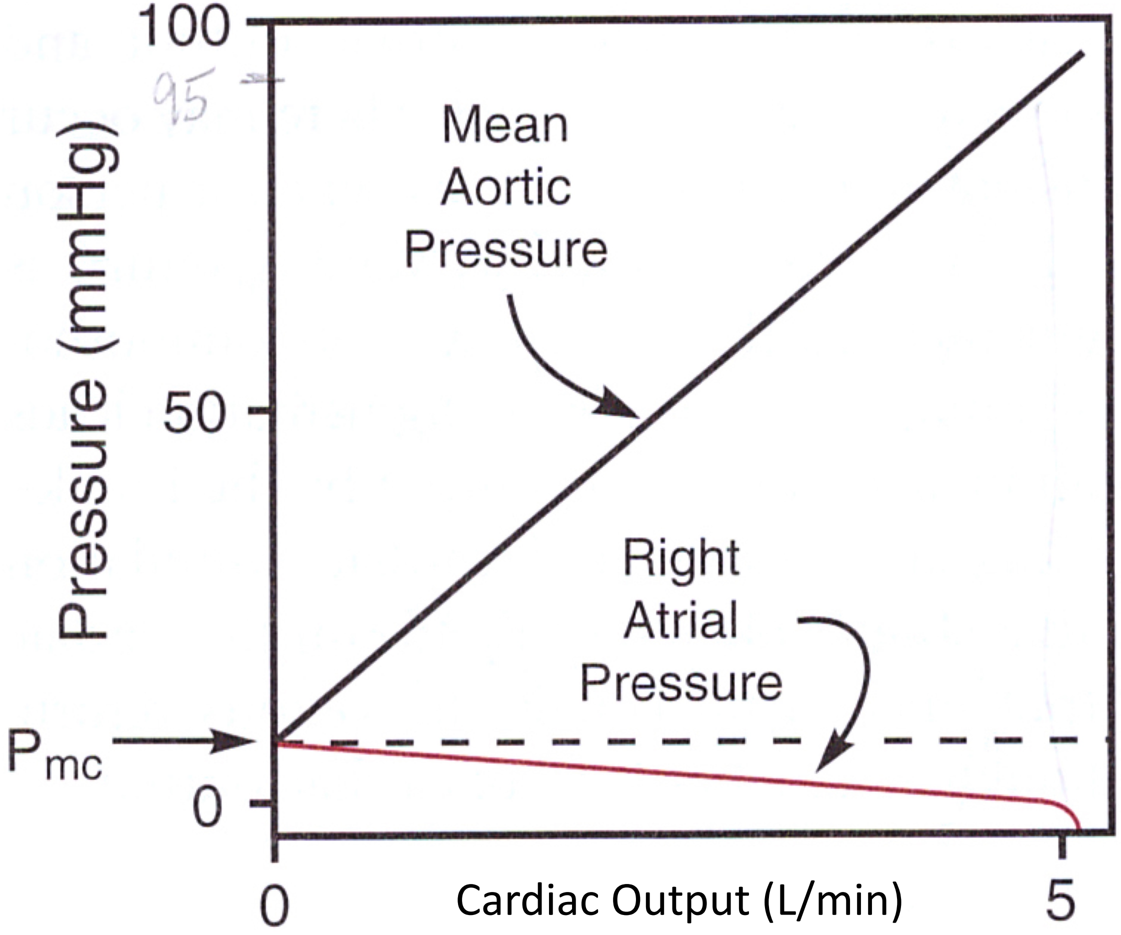


Valsalva maneuver (external compression of IVC) = increases of CVP

Cardiac output vs. Venous return

- Cardiovascular system – closed system. Amount of blood left of the heart have to return back to the heart.
- Cardiac output = venous return
- Transitional imbalance (beginning of run, stand up....) is very fast repaired by regulation mechanisms
- Vascular system significantly affects cardiac output and venous return (relationship among CO, MAP and CVP)

Relationship among CO, MAP and RAP



Decrease of CO = decrease MAP and increase of RAP

= less amount of blood is moved from veins to the aorta

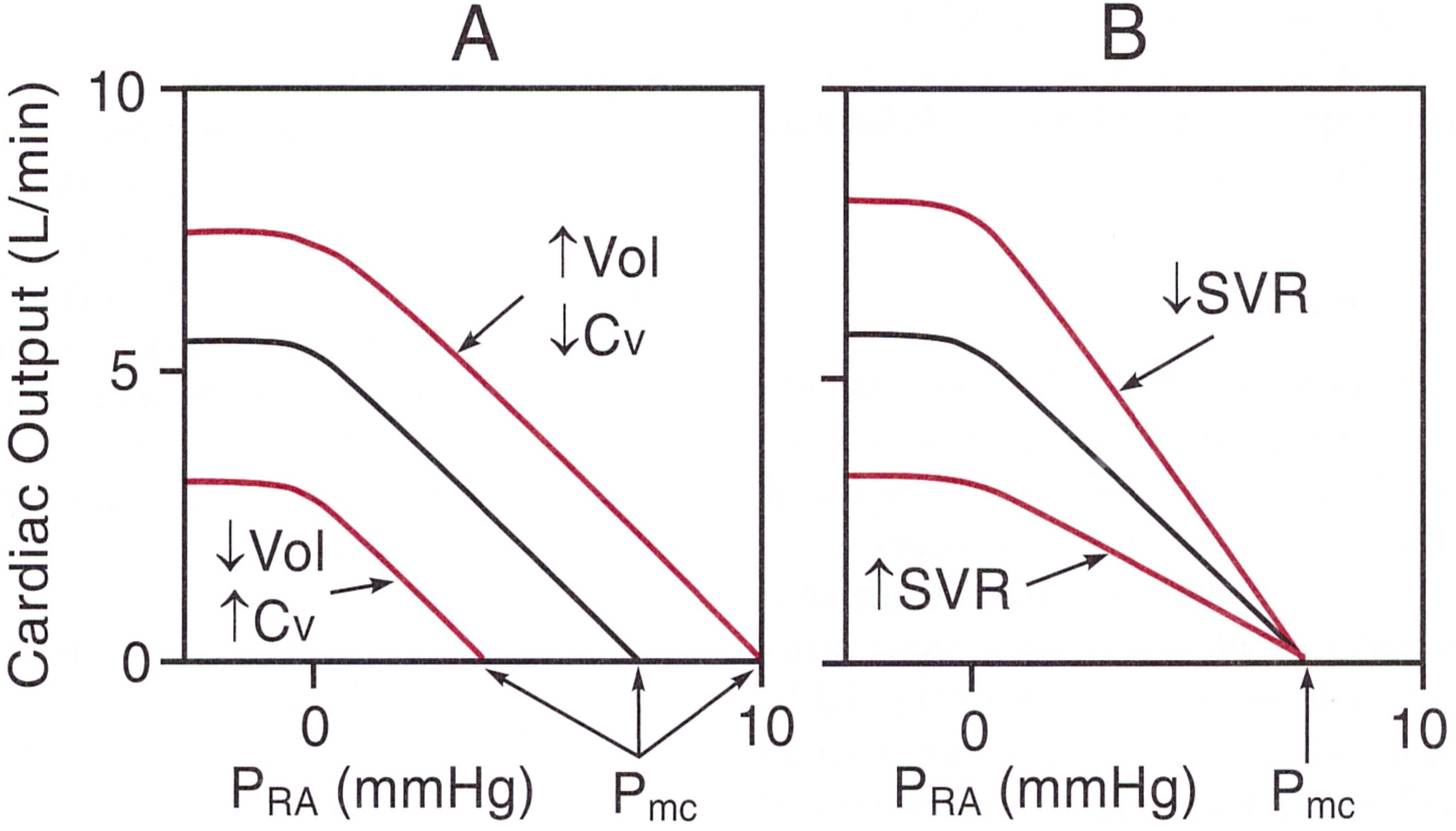
If CO = 0, then RAP=MAP = Pmc

Pmc – mean filling pressure

- BP in venous system when flow is zero
- depends on **blood volume** nad **venous compiance**

Relathioship between CO and RAP

Vascular functional curves



Increase blood volume/decrease venous compliance leads to increase Pmc and increase of RAP

Changes of SVR (arterioles) does not change of Pmc

Increasing of SVR leads to increase of RAP but not Pmc

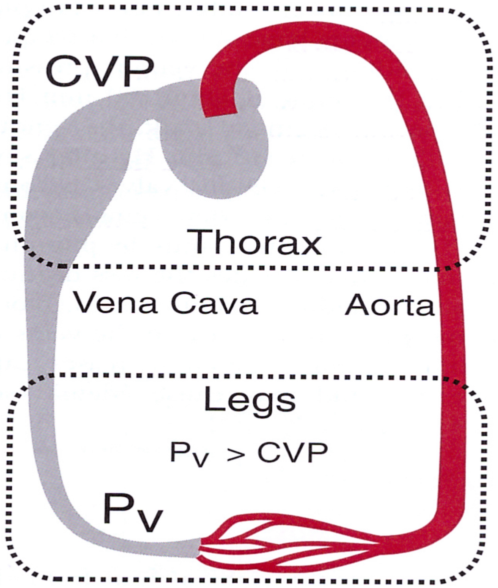
P_{RA} – right atrium pressure
P_{mc} – mean filling pressure, depends on volume and compliance of the veins
Vol – blood volume
Cv – venous compliance
SVR – systemic vascular compliance

Arteriolar dilation – decreasing of SVR (constant CO) – moving blood from arteries to capilaries and veins – more blood leave arteries than will flow into them (constant CO) …

….increased pressure in veins + decreased pressure in arteries….

Increased venous volume and pressure (PRELOAD) – increased heart filling – increased CO (Frank-Starling mechanism changes CO)

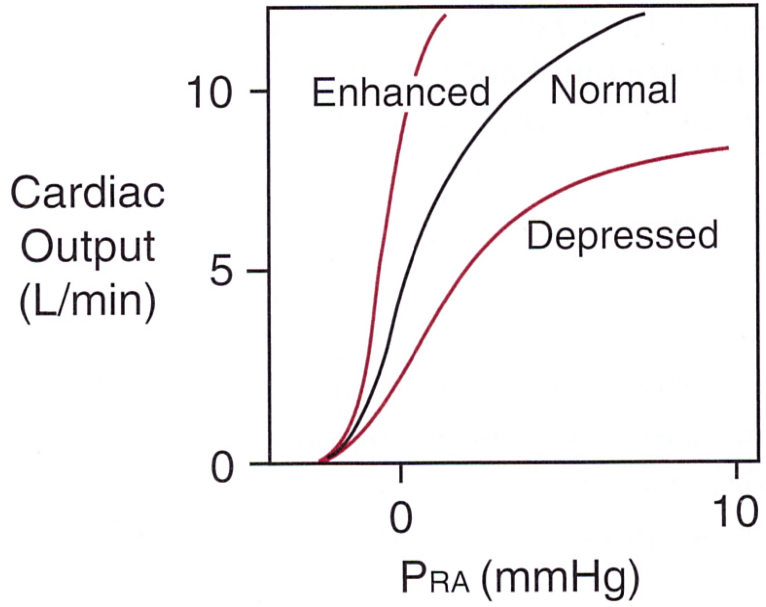
= equilibrium



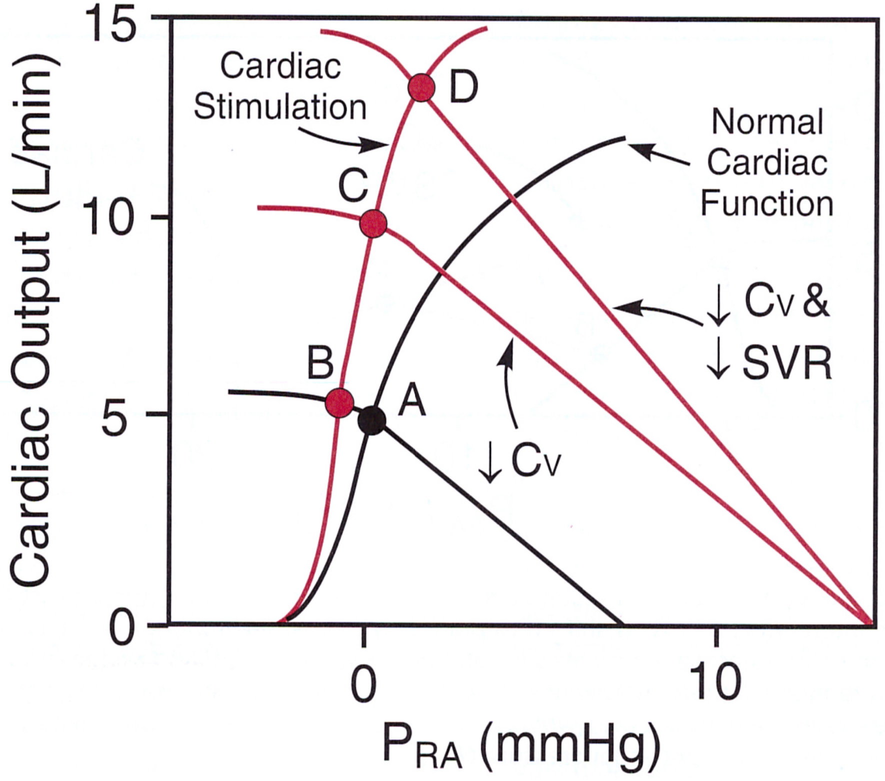
Increased sympathetic activity

(increased heart stimulation + veanous splanchnic vasoconstriction + arteriolar vasodilation)

The heart functions curve



Combination of the heart and the vascular curves

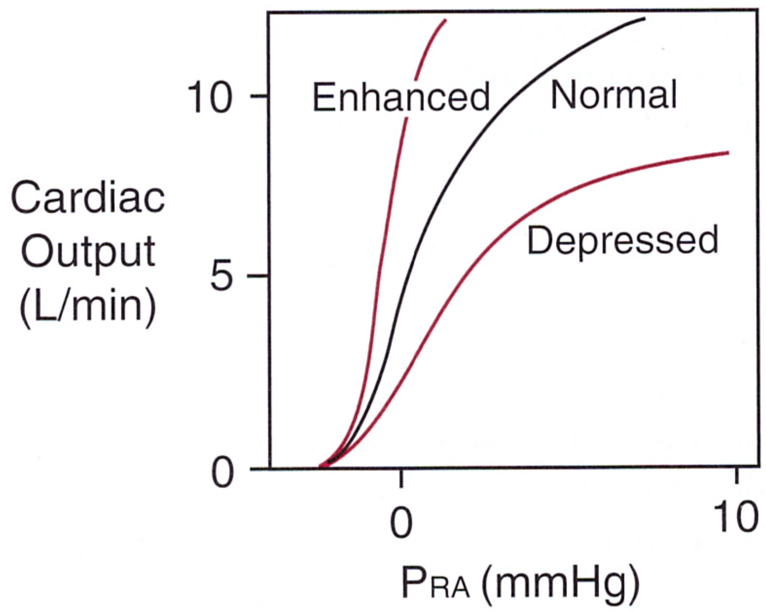


A – equilibrium between CO and venous return

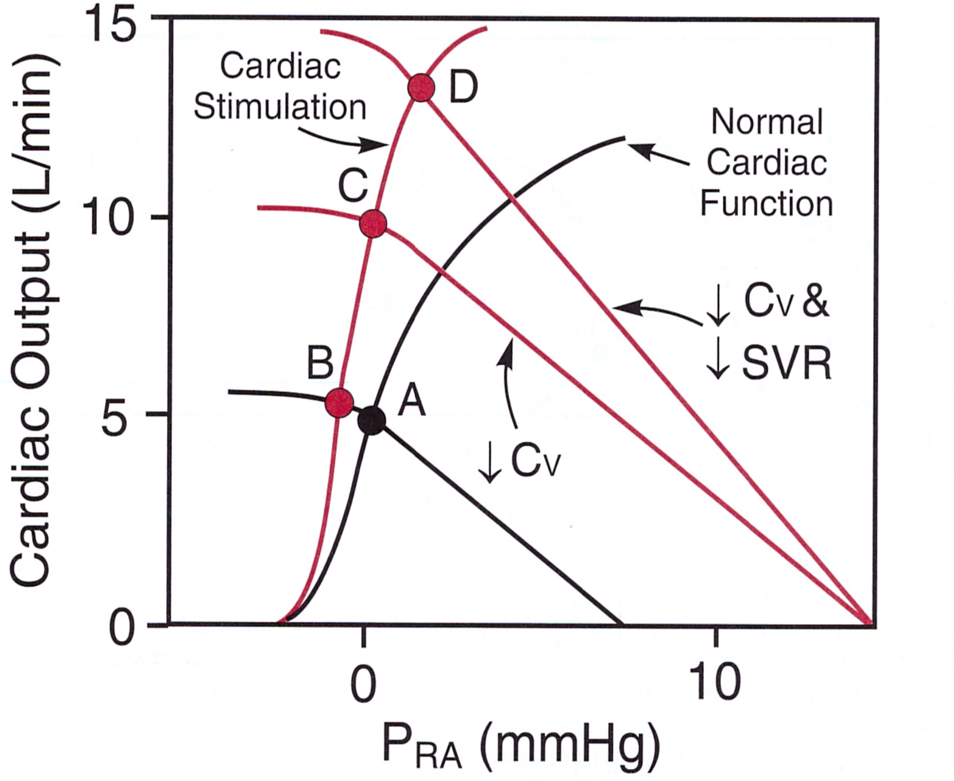
Increased sympathetic activity

(increased heart stimulation + veanous splanchnic vasoconstriction + arteriolar vasodilation)

The heart functions curve

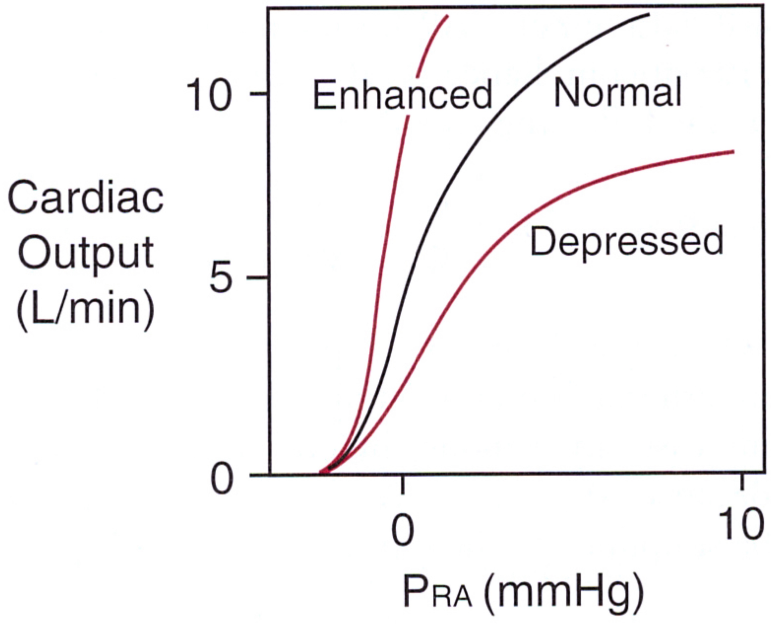


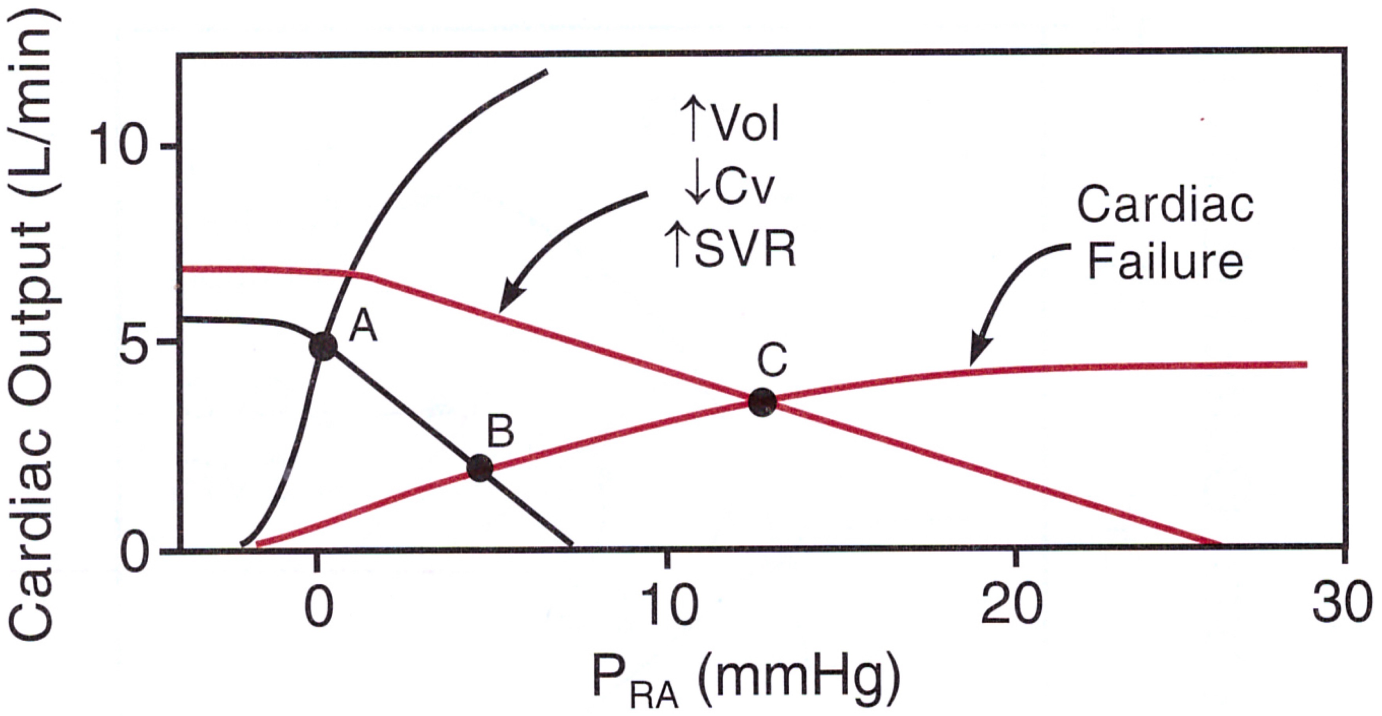
Combination of the heart and the vascular curves



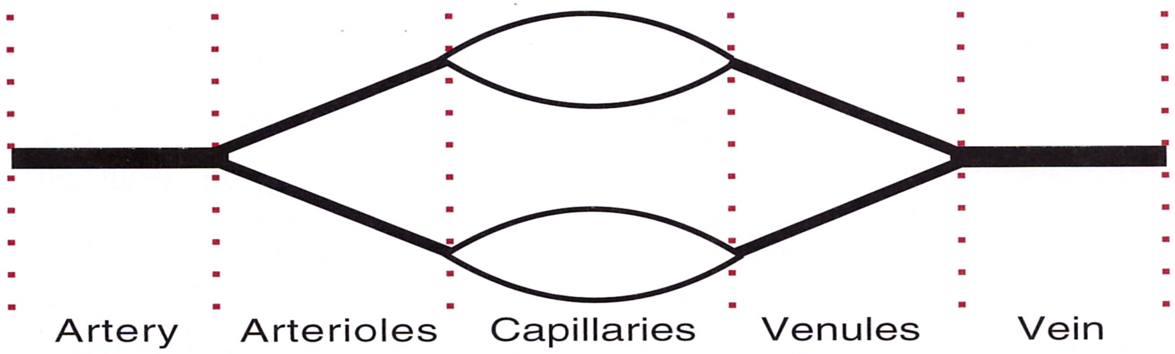
A – equilibrium between CO and venous return

Heart failure





$$C = \frac{\Delta V}{\Delta P} \quad \text{or,} \quad \Delta V = C \cdot \Delta P$$



$$\frac{C_V}{C_A} \propto \frac{\Delta P_A}{\Delta P_V}$$

15:1mmHg

$$R_T = R_A + R_a + R_c + R_v + R_V = 1 + 70 + 20 + 8 + 1 = 100$$

$$SVR = \frac{(MAP - CVP)}{CO}$$

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