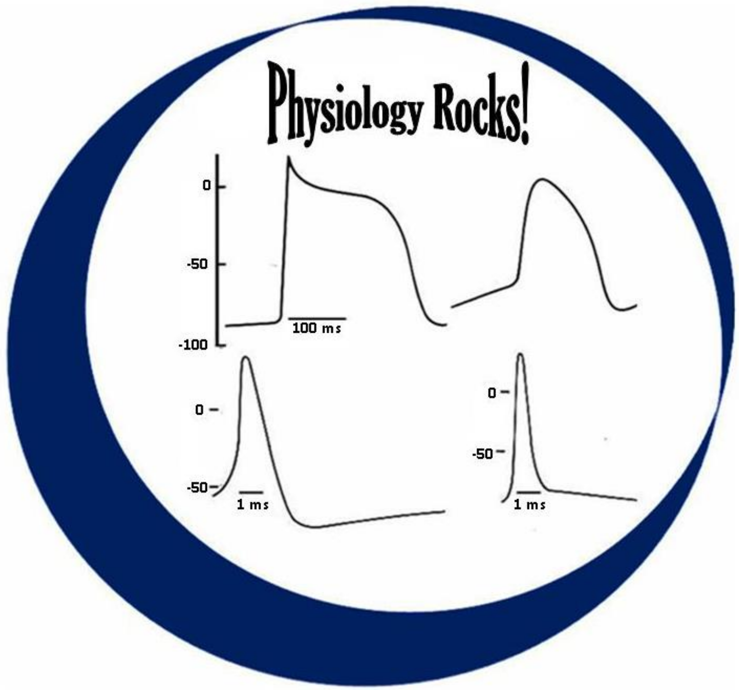
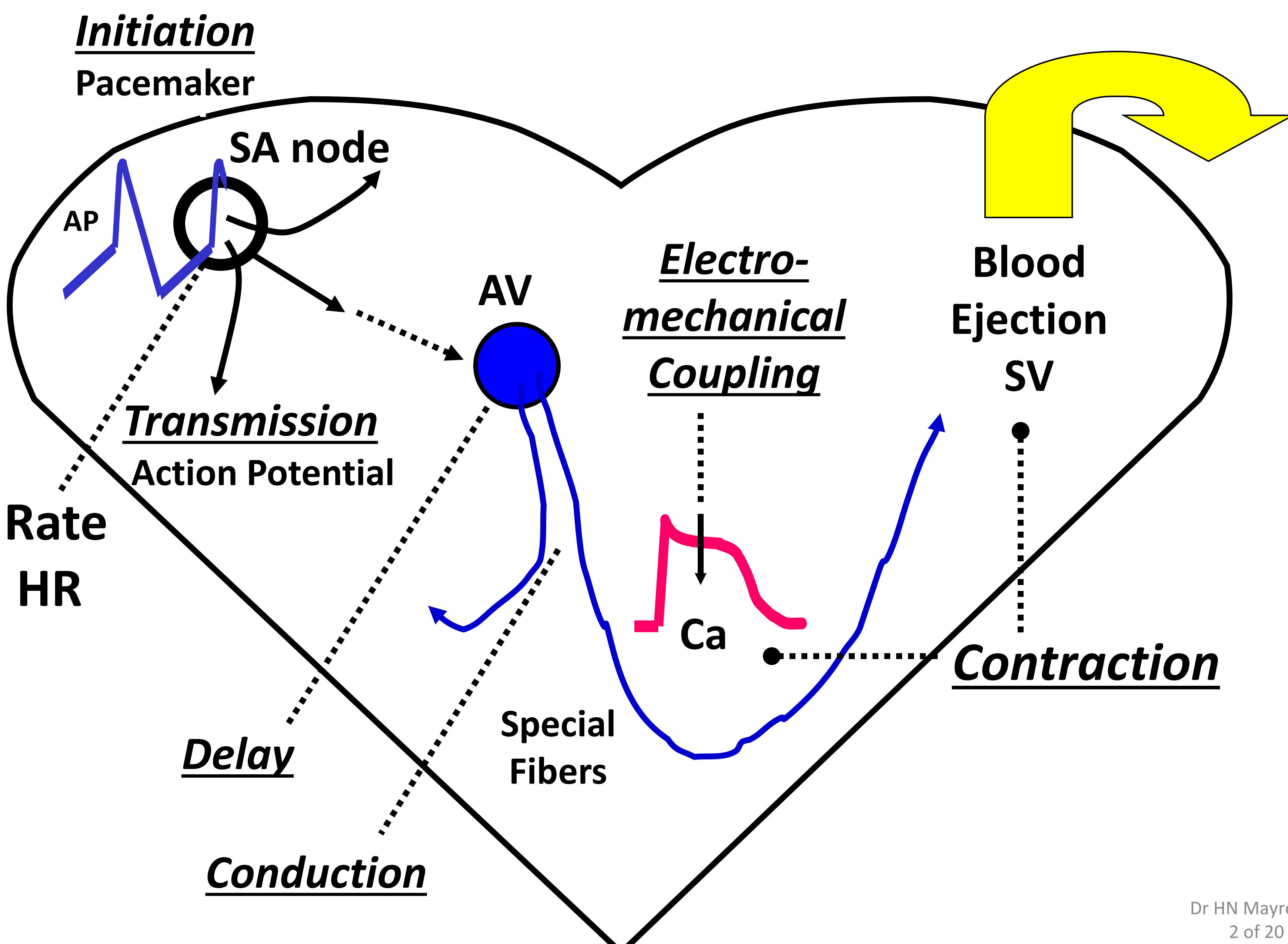
Lecture 18
Blood Flow, Pressure, Resistance – 1

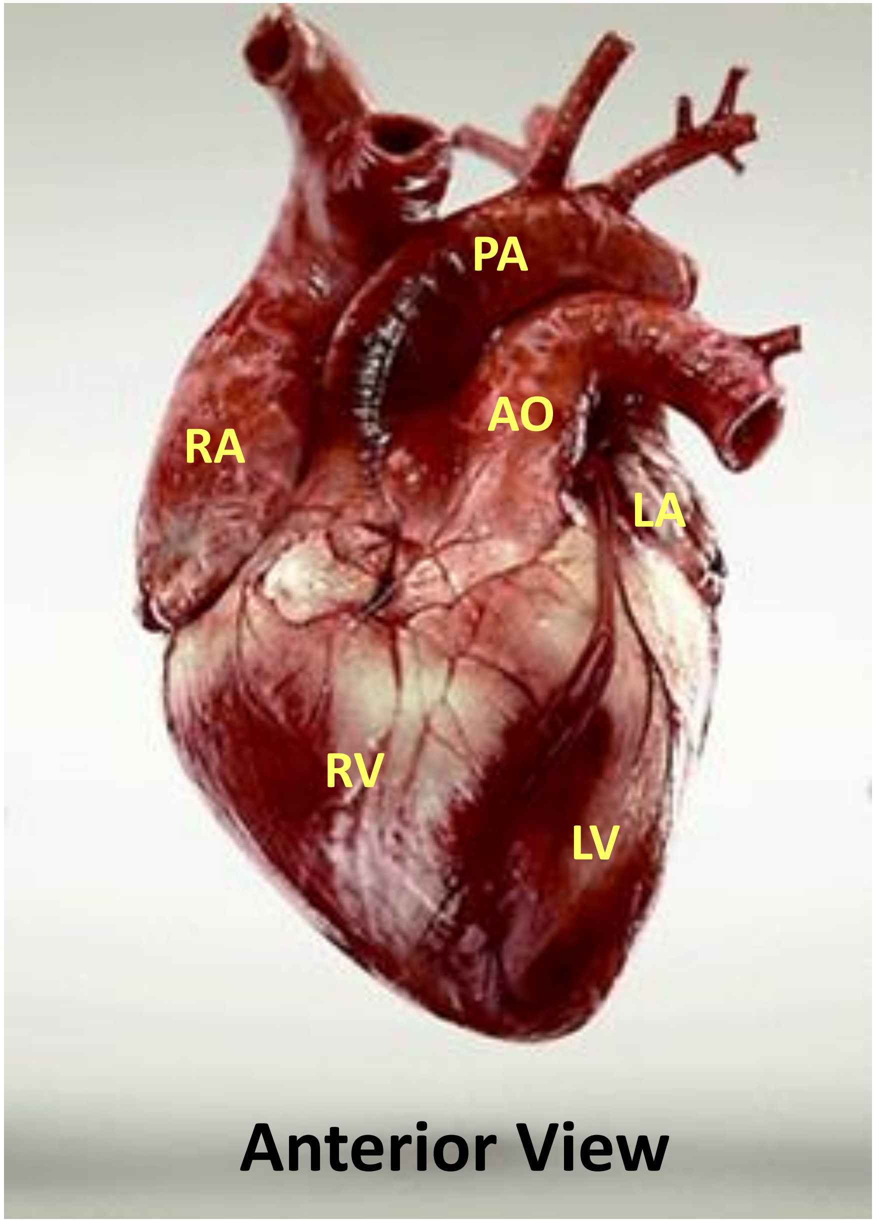


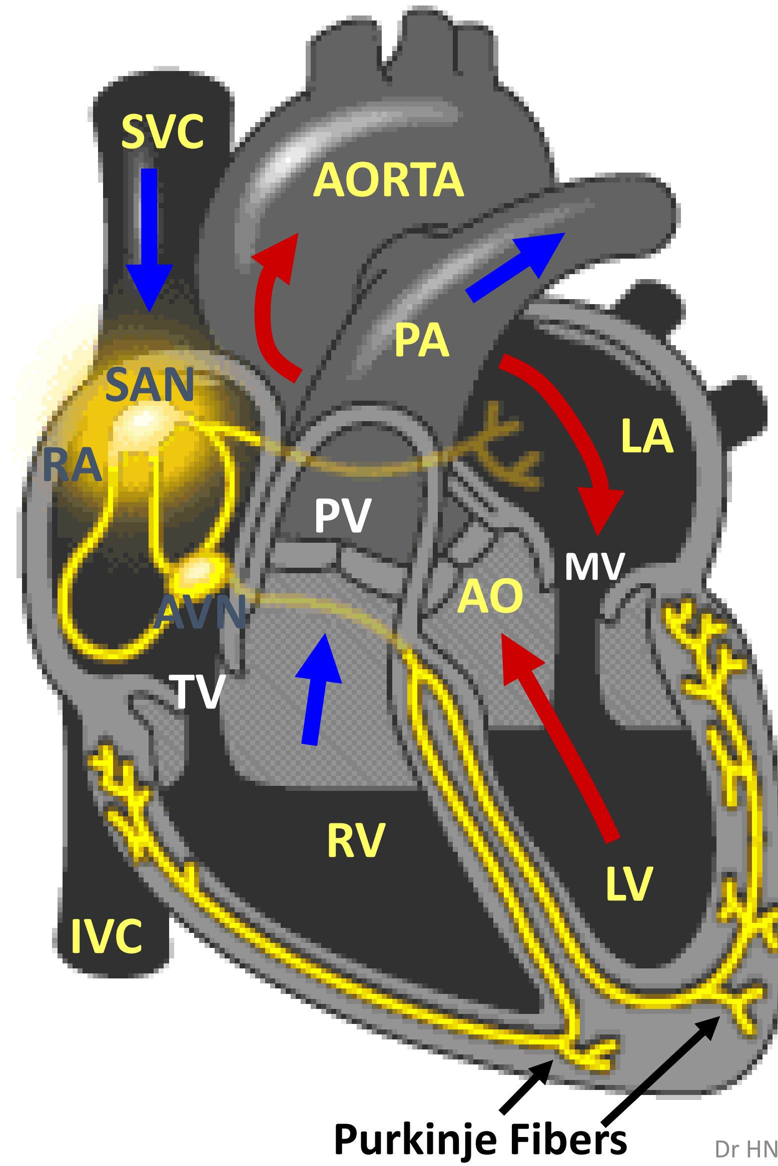
HN Mayrovitz PhD
mayrovit@nova.edu

Cardiac PUMP: Pressure and Flow "Generator"

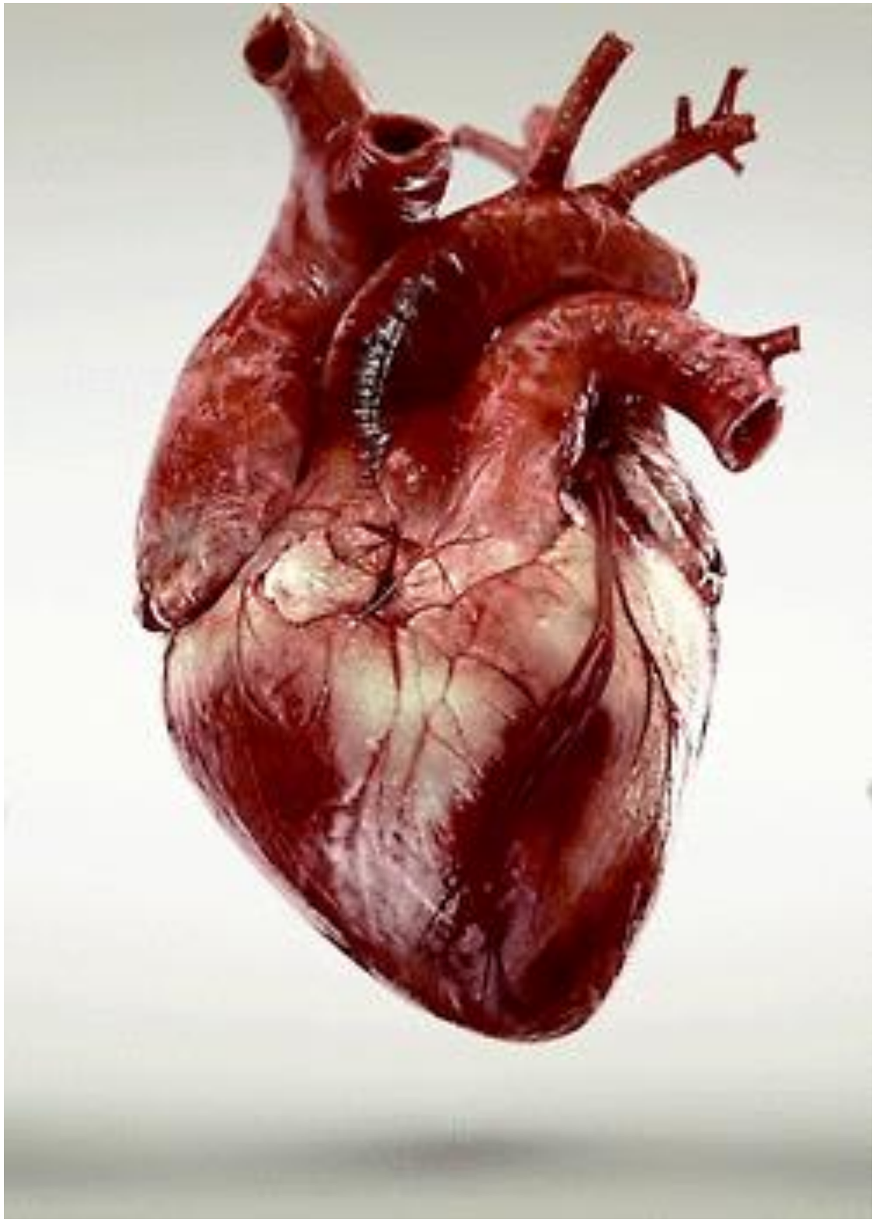


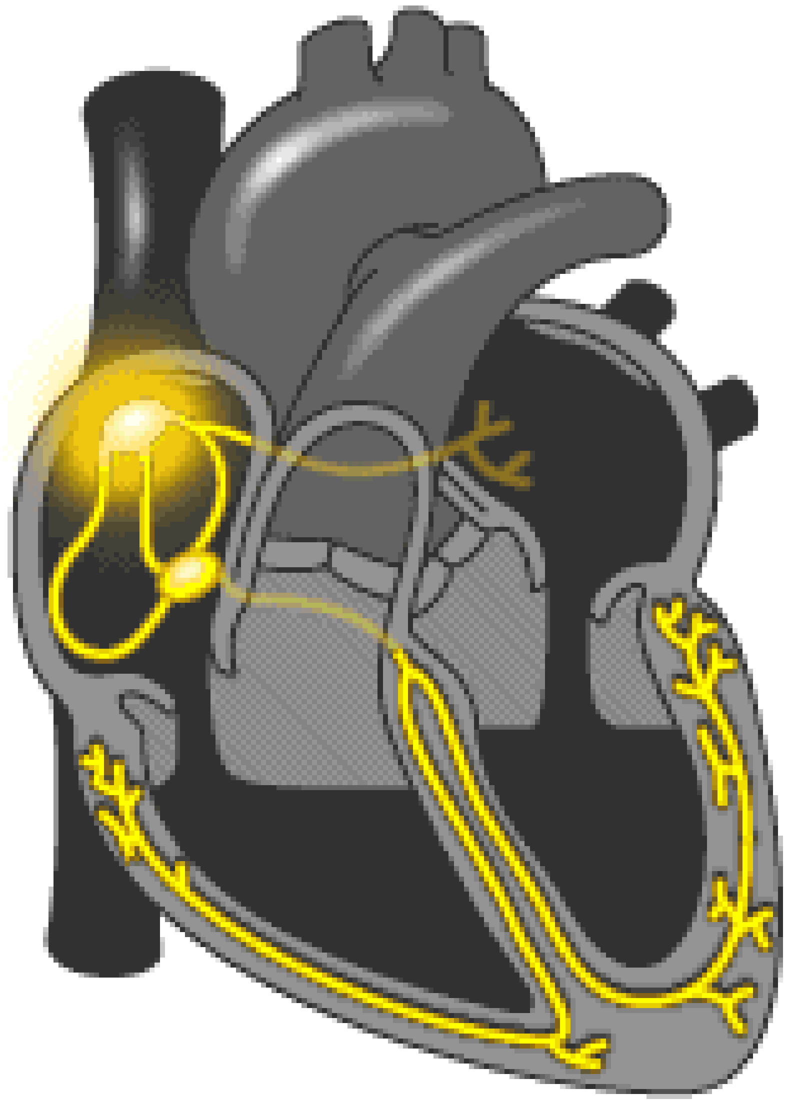
The Beating Heart: Functional Anatomy



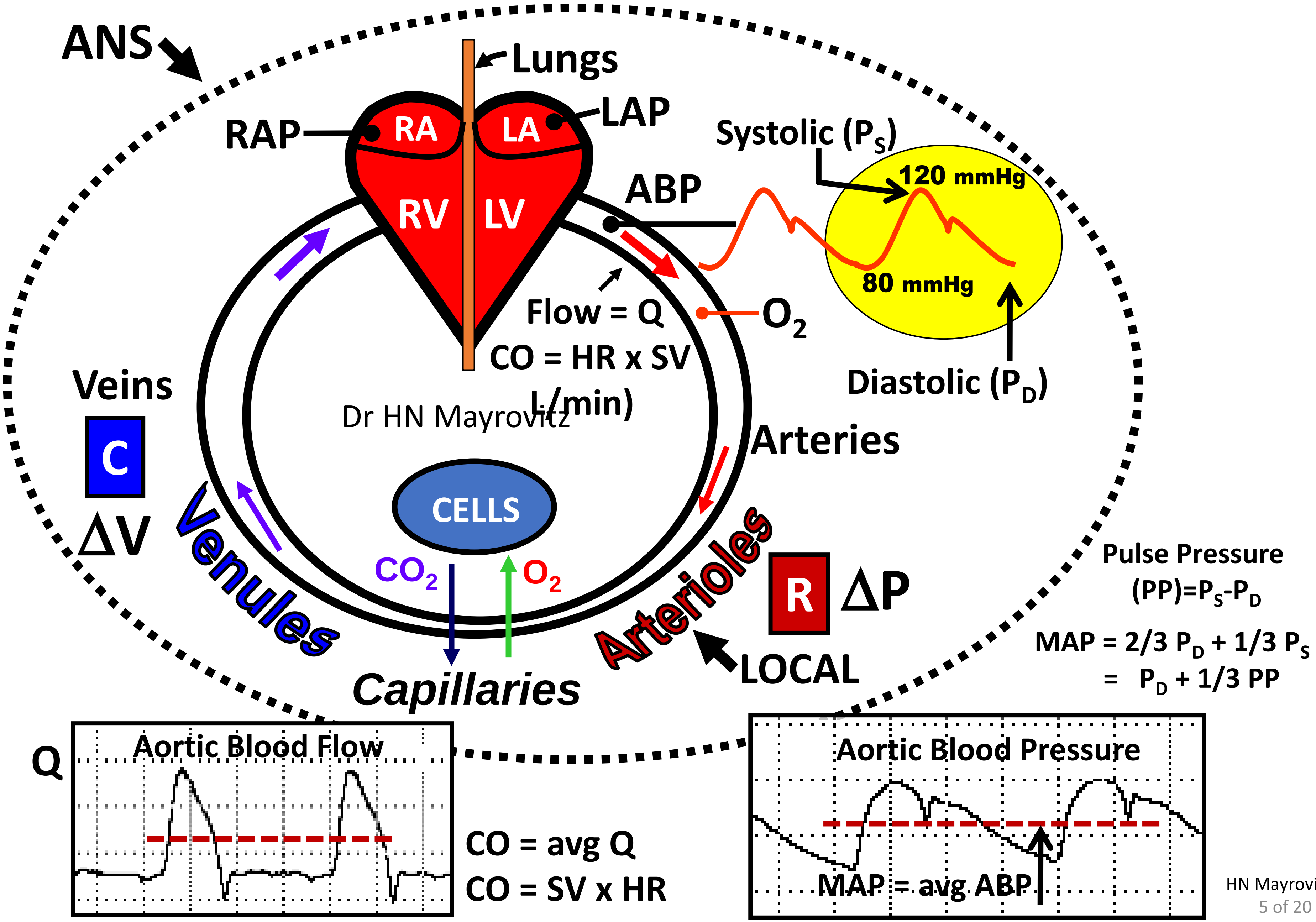


The Beating Heart: Functional ACTIONS

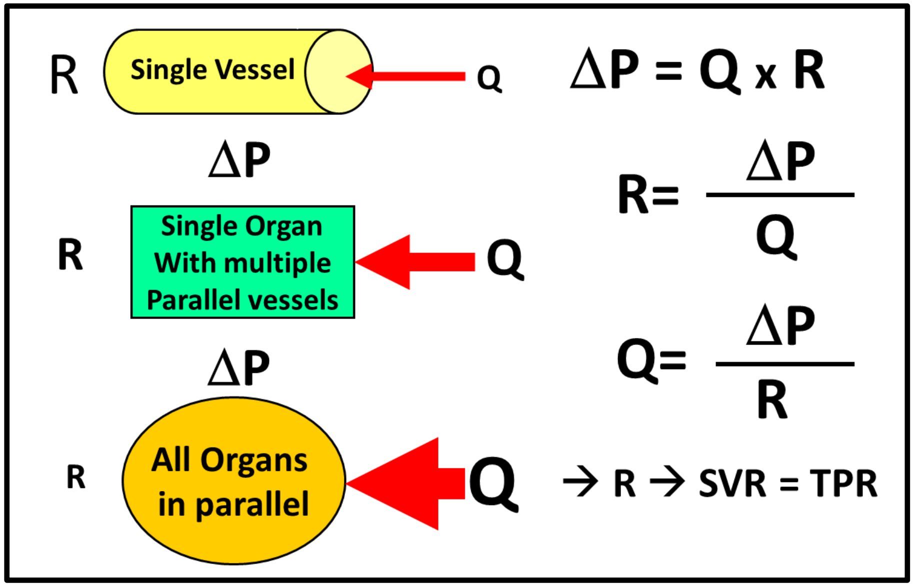




Vascular Circuit with Pressures and Flows Defined



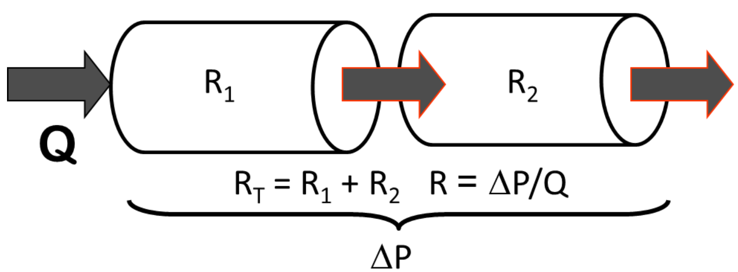
Vascular Resistance Concept

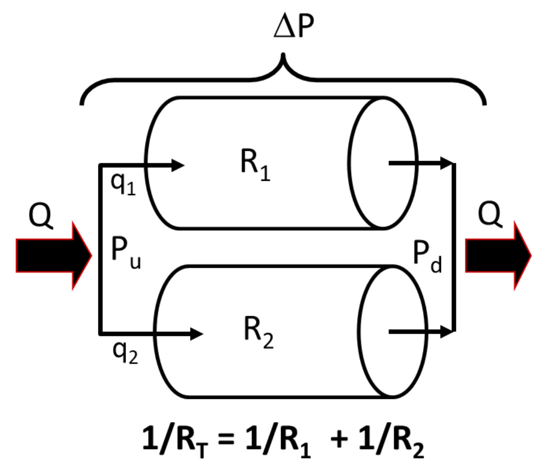


SVR = Systemic Vascular Resistance
TPR = Total Peripheral Resistance

SVR = TPR = mmHg/(L/min) = Wood Unit
If mmHg/ml/min = PRU = Wood Unit/1000

"Normal" values 15-20 Wood units
→ 0.015-0.020 PRU

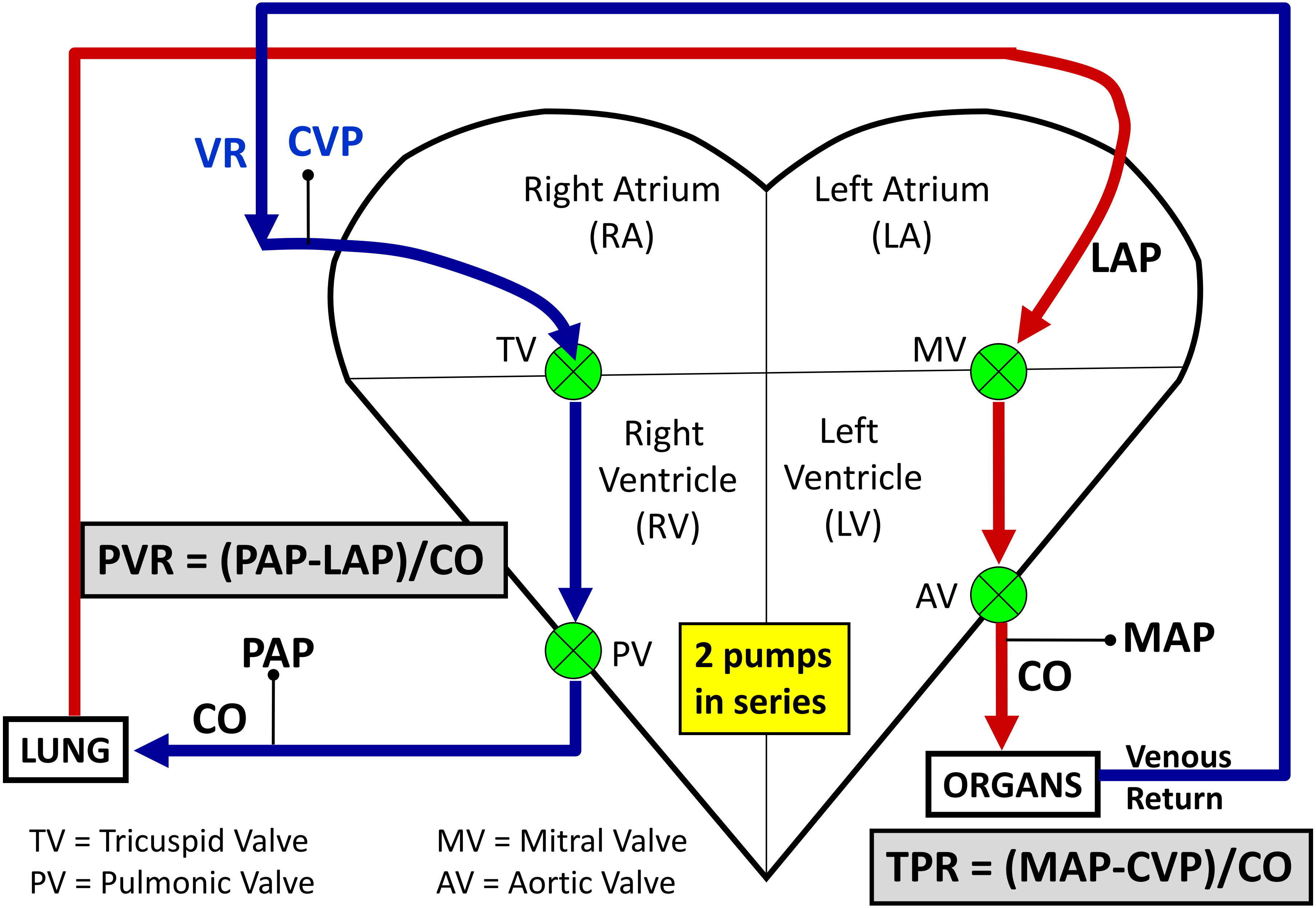




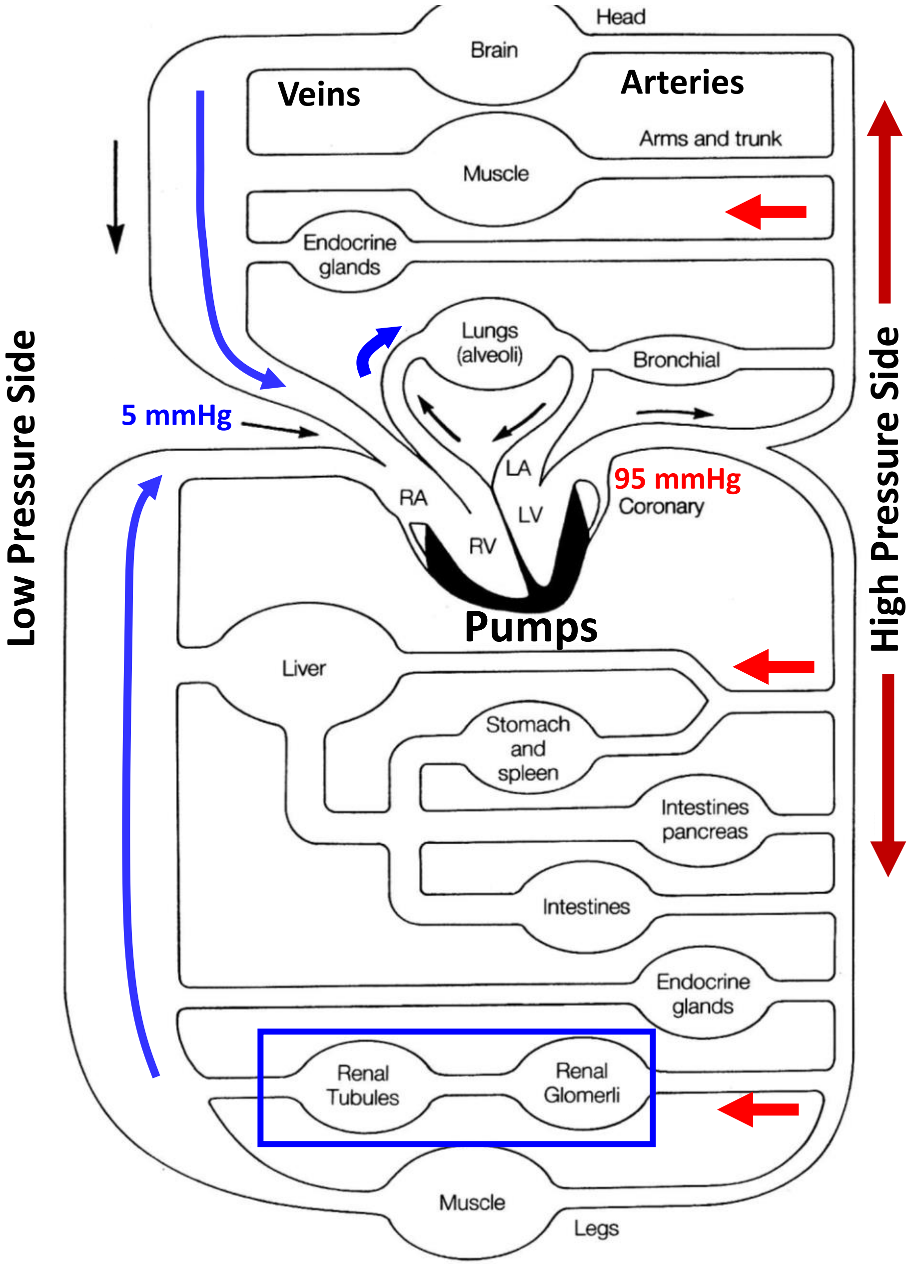
Organs or Vasculatures in SERIES
- Flow same in series-coupled parts
- Resistances sum directly
- Total R greater than individual R

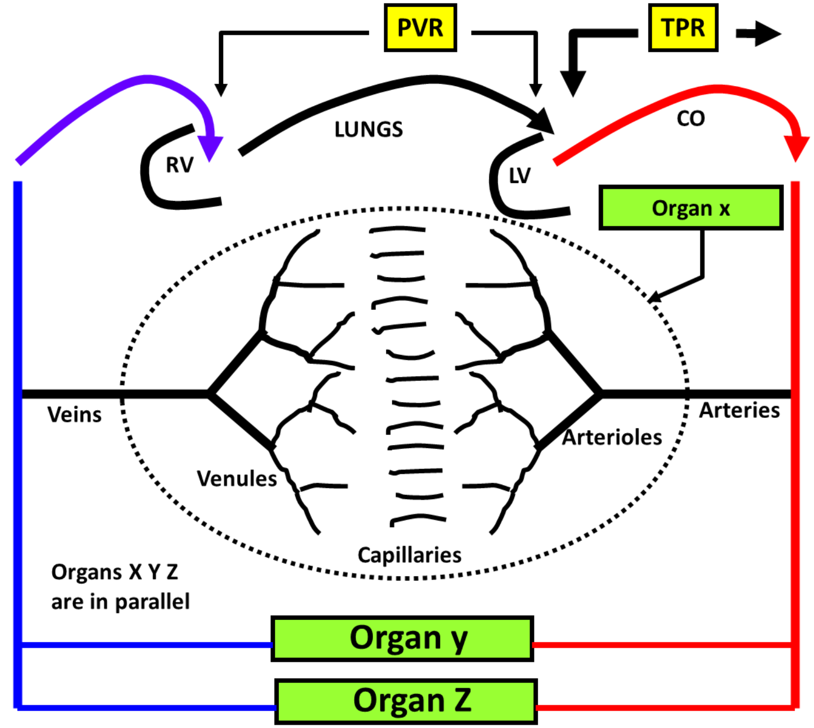
Organs or Vasculatures in PARALLEL
- Perfusion Pressures are the same
- Resistances sum reciprocally
- Total R is LESS than any individual R

Circulation Pathways and Definitions



Cardiovascular Patterns and Arrangements





- Organs are in parallel with other organs
- So, flow to each organ depends on its vascular resistance since all have equal perfusion pressure

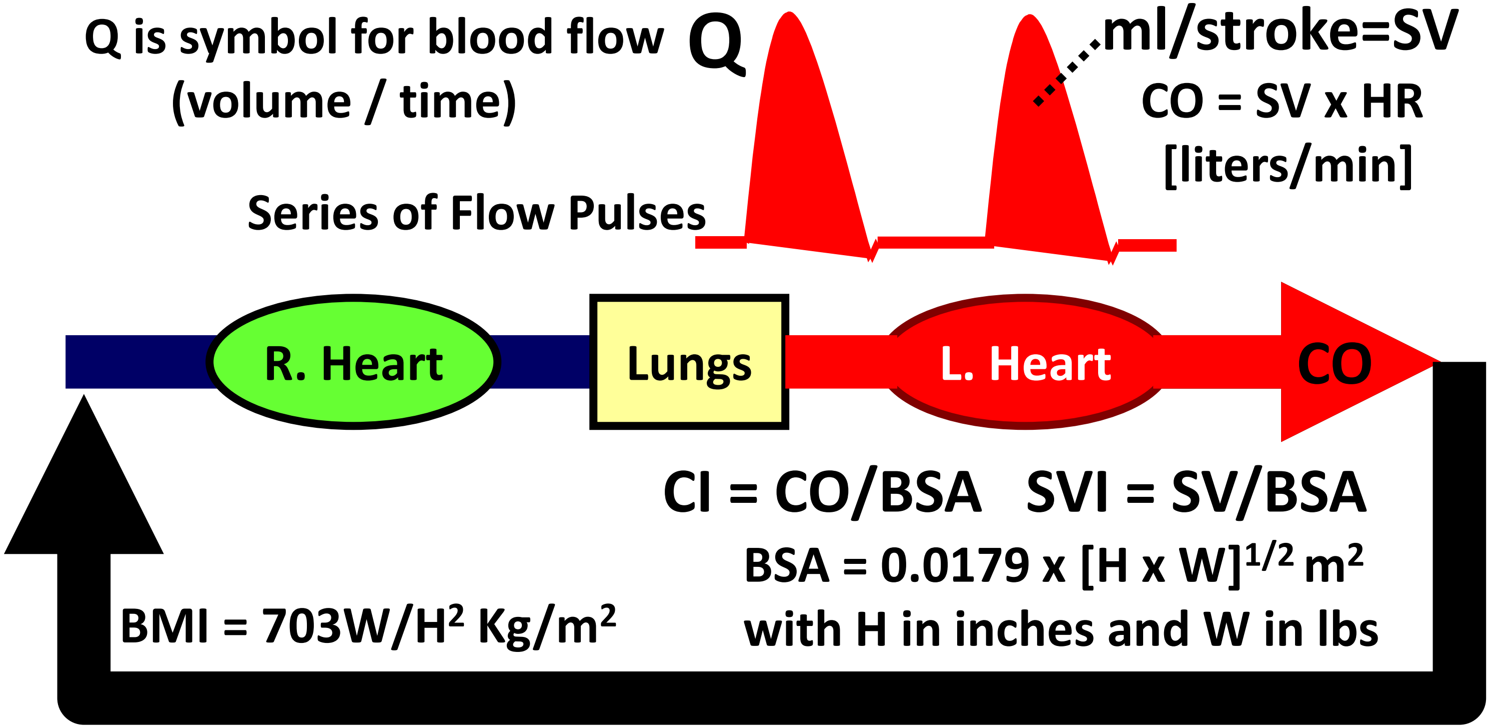
Within Organs

- Arterioles are in parallel with arterioles
- Capillaries are in parallel with capillaries

BUT

- Segments are in series with the other segments
- Since in series pressure is lost across each segment

Cardiac Output & Stroke Volume: Absolute & Indices

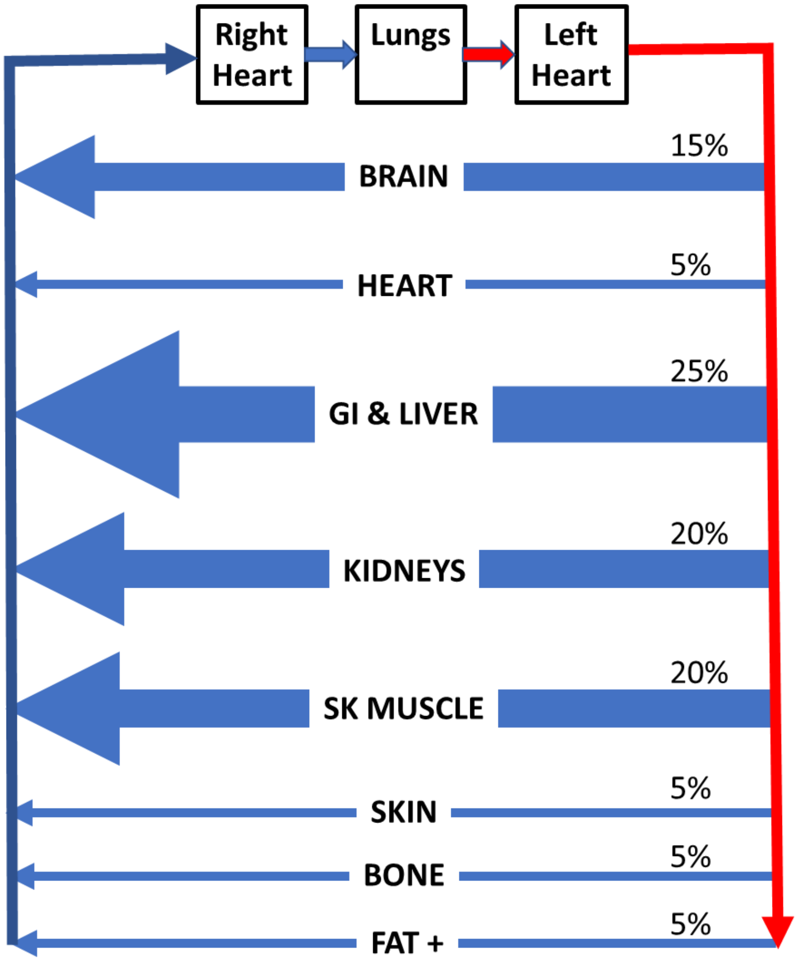


Organ blood flow through multiple parallel pathways

Summation and some take-homes

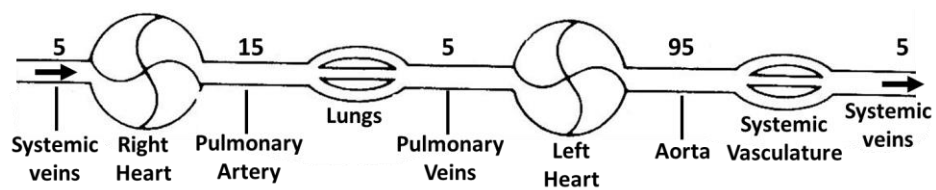
- SV → amount ejected / beat (ml)
- CO → flow output / time (ml/sec or l/min)
- Indices normalize among patients with BSA
- No need to memorize BMI or BSA formulas

Resting Cardiac Output Distribution



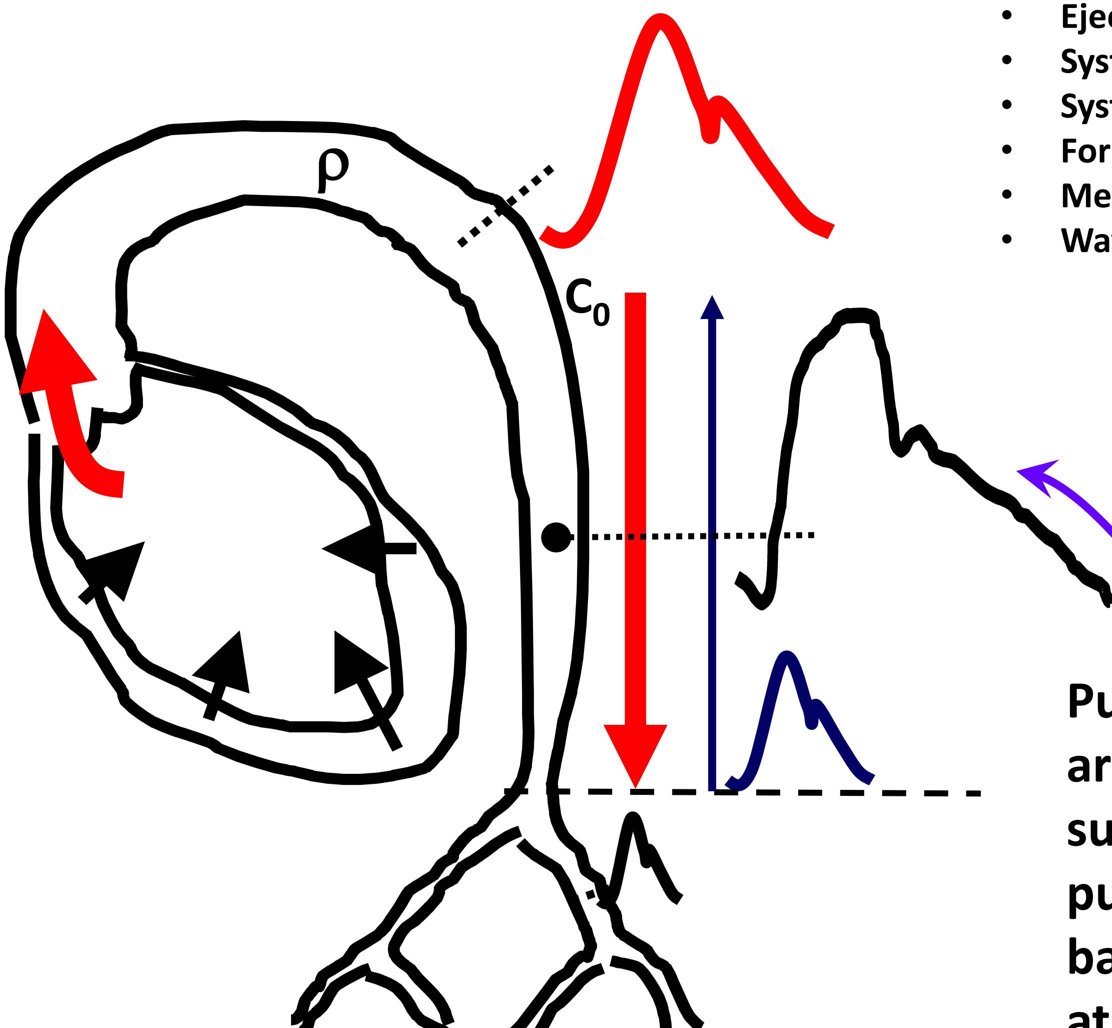
The above figure shows approximate percentages of cardiac output distribution. If CO were 6 L/min then absolute flow to the kidneys would be 1.2 L/min.

- Percentages are approximate; vary by person
- **Absolute cardiac output** (CO, L/min) varies by age, gender, weight and other
- **Cardiac Index** (CO/BSA, L/min/m^2) helps minimize variance also (**SVI = SV/BSA**)
- For a fixed perfusion pressure, flow (Q) distribution to organs depends on its vascular resistance; **Q = ΔP/R**
- The diagram below shows pressures in mmHg and illustrates normal average values at the different locations



Perfusion pressure = ΔP = 95-5 = 90 mmHg
If cardiac output were 6 L/min then
TPR = 90/6 = 15 Wood units and
PVR = 10/6 = 1.67 Wood units

Arterial Pressure Pulse



Summation and some take-homes

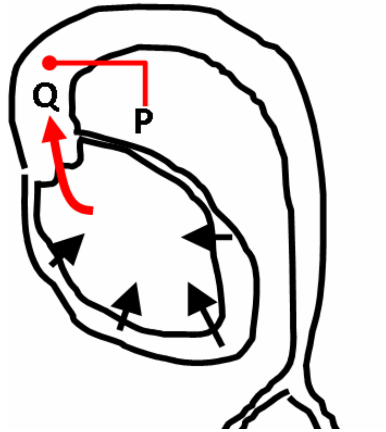
- Ejected blood raises aortic BP
- Systolic peak & Diastolic minimum
- Systolic-Diastolic = Pulse Pressure
- Forward and reflected pulse waves
- Measured pressure depends on both
- Wave speed varies with vessel conditions

$$\boxed{c_0 \sim \sqrt{\frac{1}{\rho C}}}$$

Pulses at any point in the artery are the algebraic sum of forward transmitted pulses and reflected backward pulses each moving at a speed of C_0 m/sec

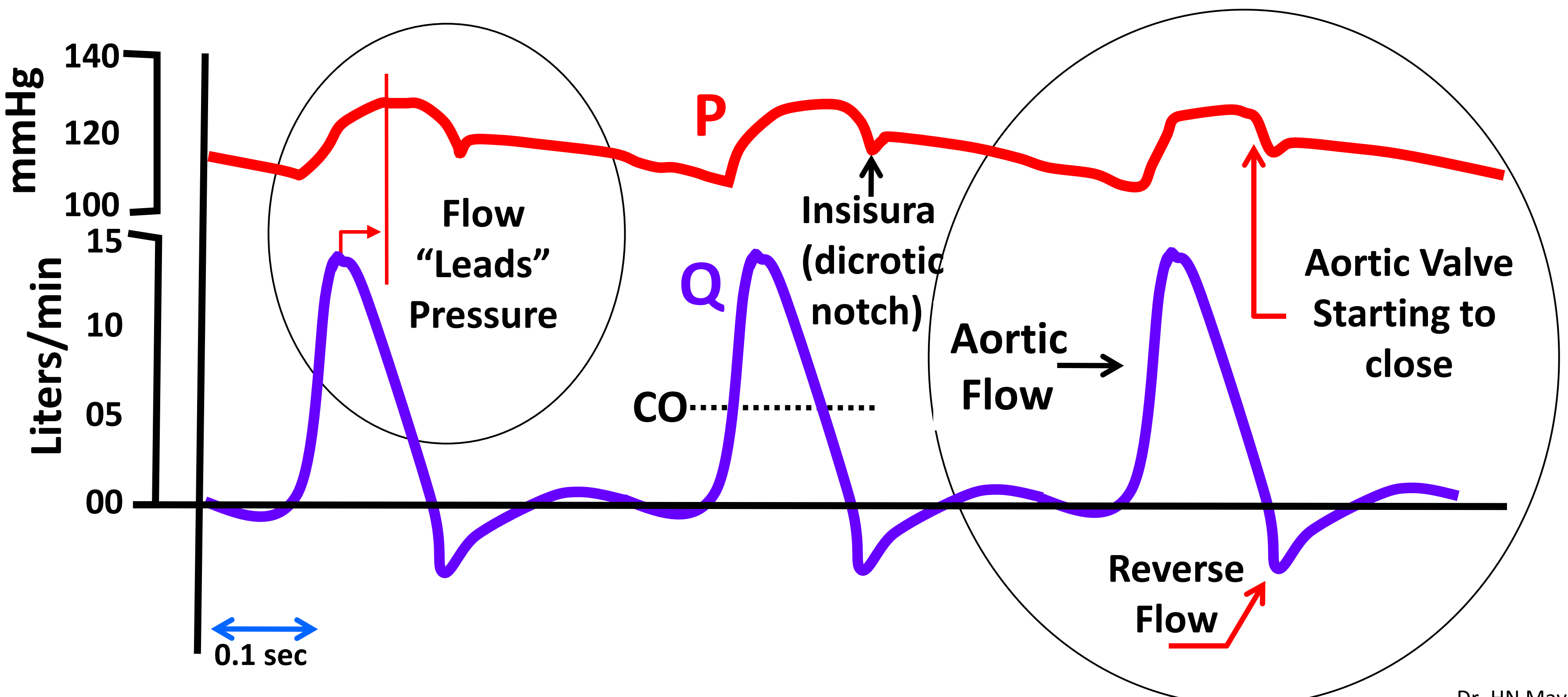
ρ = blood density
C = arterial compliance

Aortic Pressure and Flow Pulse Patterns



Summation and some take-homes

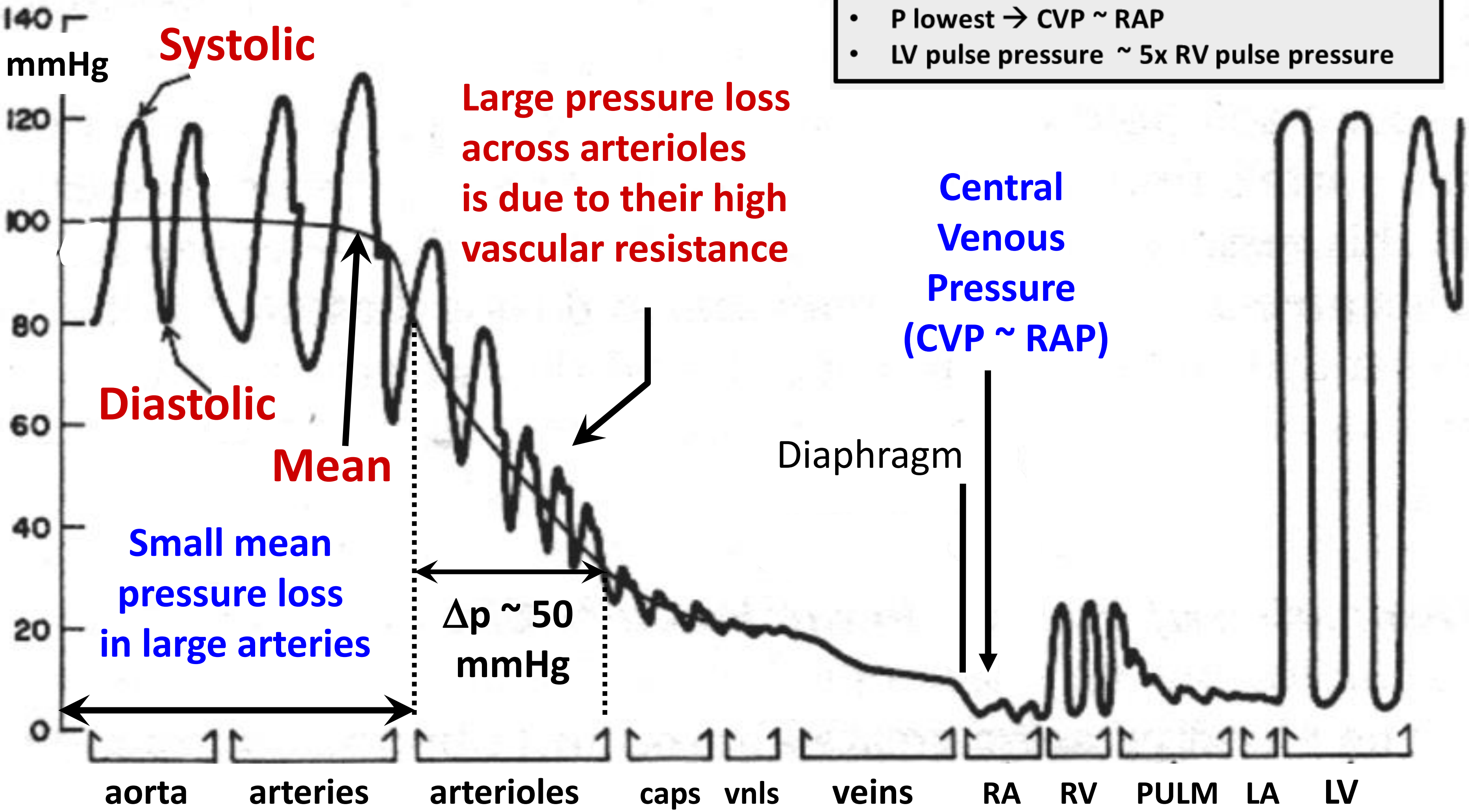
- Pressure and Flow are Pulsatile
- Closing aortic valve → Pressure Incisura
- Closing aortic valve → Flow reversal
- Flow rises before rise in pressure
- CO = average of aortic blood flow



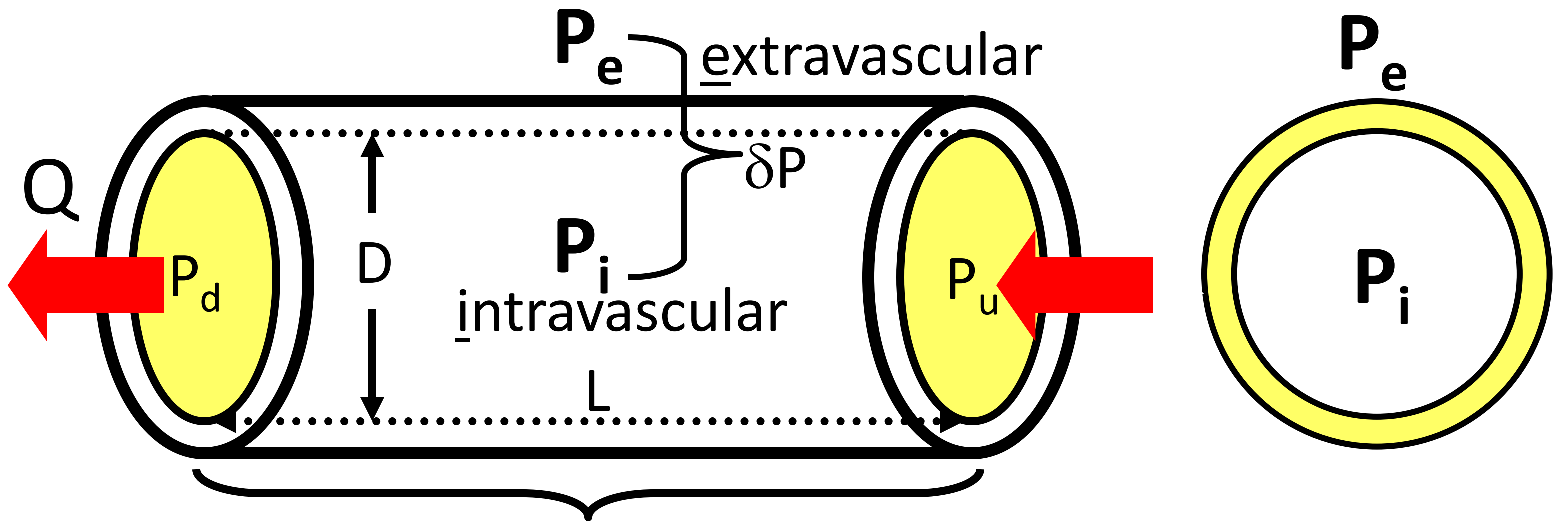
Cardiovascular Pressure Variations

Summation and some take-homes

- MAP decreases little in large arteries
- P decreases most across arterioles
- Most pulsations reduced toward capillaries
- P lowest → CVP ~ RAP
- LV pulse pressure ~ 5x RV pulse pressure



Pressures



ΔP = Perfusion Pressure

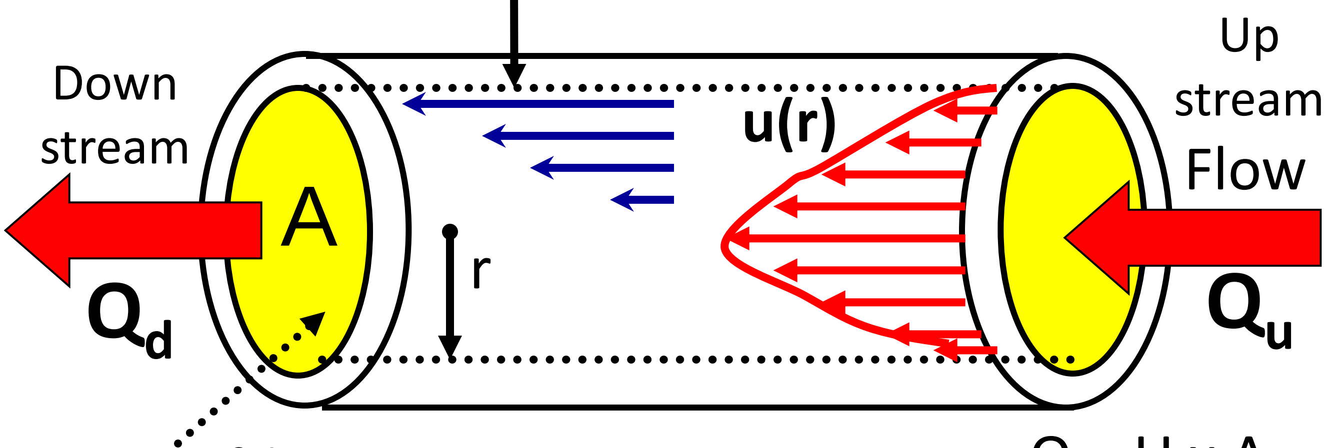
Pressure = Force/Area = Energy/Volume
[dynes/cm^2 or mmHg]

- **Perfusion Pressure = $P_u - P_d = \Delta P$**
- **Transmural Pressure = $P_i - P_e = \delta P$**

- **Resistance $R = (128/\pi) \times \eta \times (L/D^4)$**

Blood Flow vs. Blood Velocity

Shear Stress = τ = Max at wall ~ $\eta Q/D^3$



$A=\pi D^2/4$
cm^2

Velocity = U = avg u(r)
cm/sec

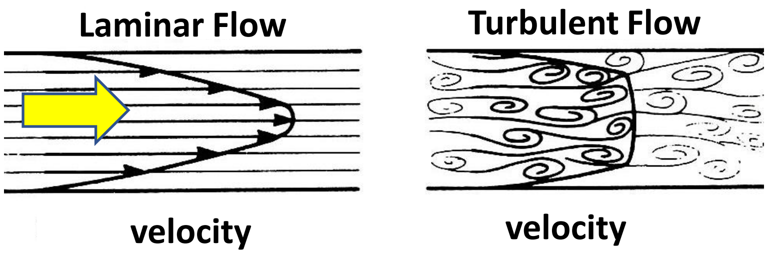
Q = U x A
cm^3/sec

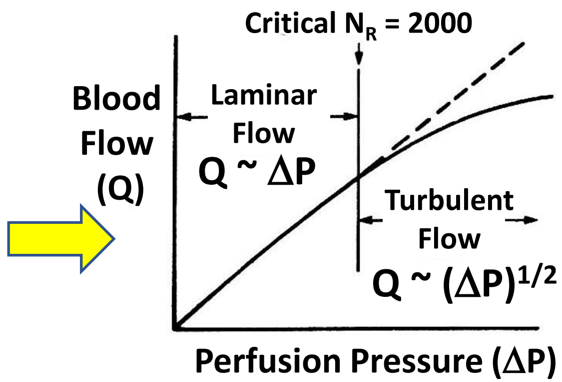
For a given Flow, Velocity is *<u>inverse</u>* to Area $\quad \mathbf{U = \frac{Q}{A}}$

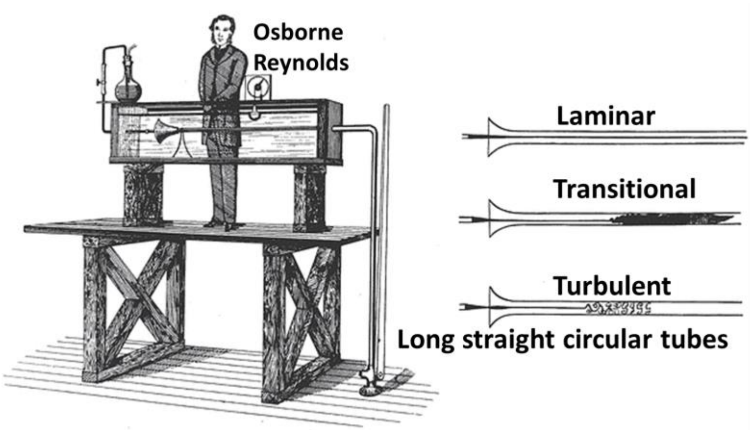
shear stress = viscosity x shear Rate = η x du/dr

du/dr = velocity gradient = shear rate

Laminar vs. Turbulent Blood Flow







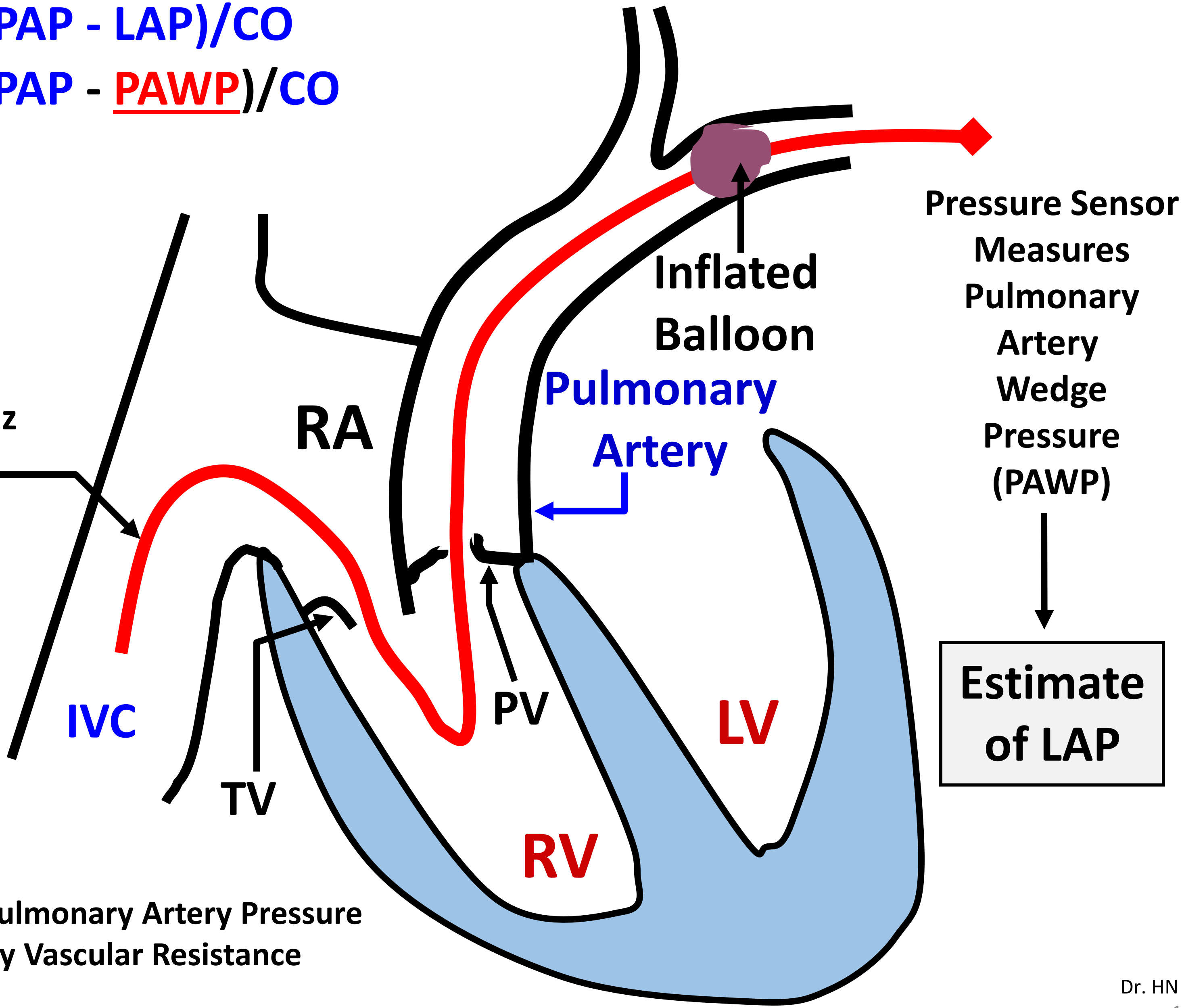
- **Laminar** flow has **steady streamlines** with no crossover and flow (Q) vs. perfusion pressure (ΔP) is linear
- **Turbulent** flow has **chaotic stream lines** that cross each other causing additional energy loss
- Added energy loss increases resistance to flow requiring more perfusion pressure so **Q not ~ ΔP** as in laminar flow but is **$Q \sim (\Delta P)^{1/2}$** for turbulent flow
- Transition from laminar to turbulent occurs at a critical value of **Reynolds number** (N_R) that depends on blood's density (ρ) , viscosity (η) and velocity (U) and vessel diameter (D) as: **$N_R = U \times D \times (\rho/\eta)$**
- The **critical Reynolds number (N_{RC})** has a value of **2000**
- An alternate form, useful when Q is known is

  $N_R = (4/pi) \times Q/D^2 \times (\rho/\eta)$
- Turbulence: more likely at **high blood flow** or velocity and **reduced blood viscosity**
- For fixed blood flow, turbulence is more likely at areas of diameter reduction (vascular or valvular **stenoses**).
- If turbulence occurs sounds it generates are **murmurs**

Determining Pulmonary Artery Wedge Pressure

PVR = (MPAP - LAP)/CO

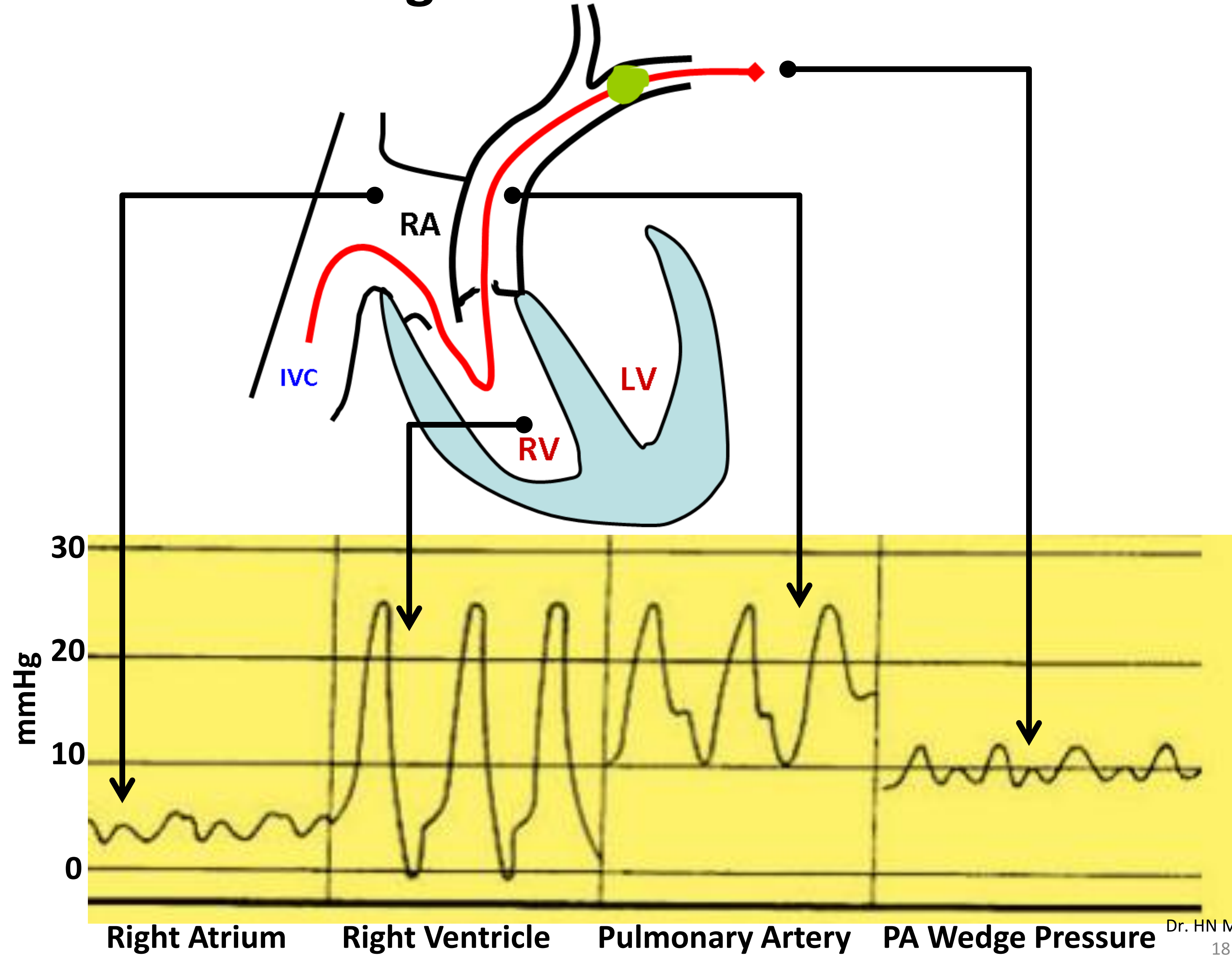
PVR = (MPAP - PAWP)/CO



MPAP = Mean Pulmonary Artery Pressure

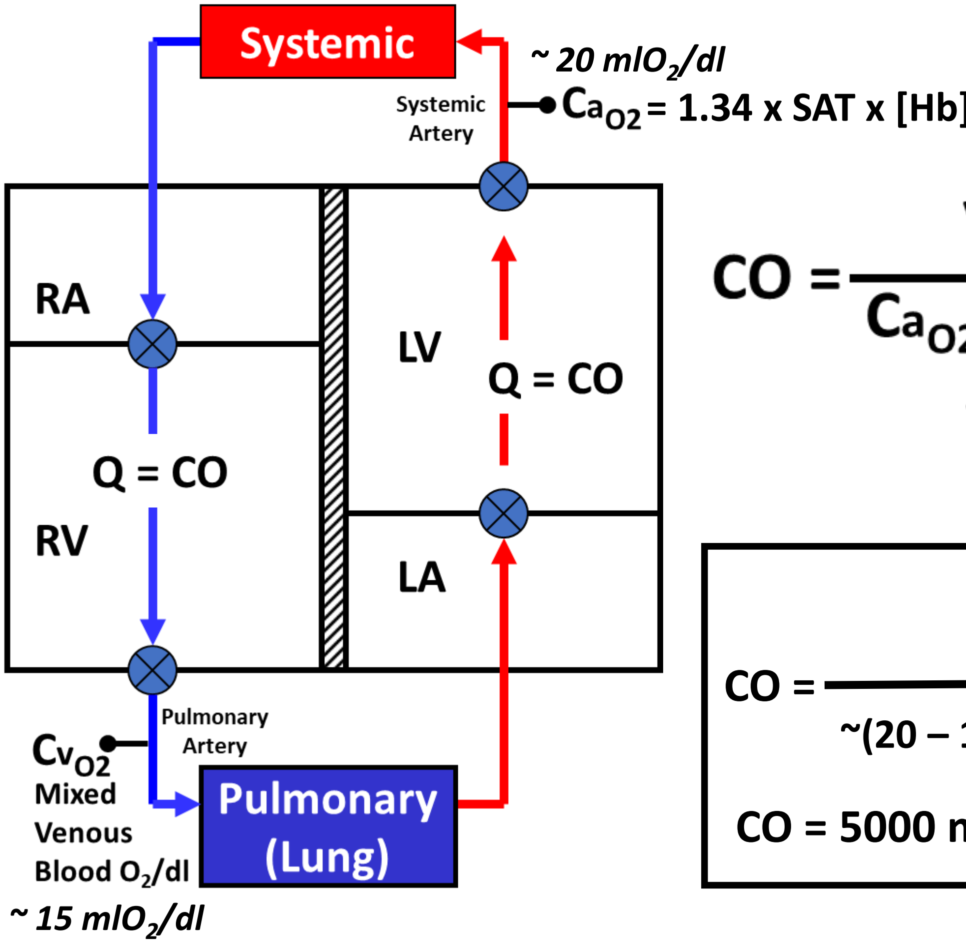
PVR = Pulmonary Vascular Resistance

Right Sided Pressures



Dr. HN Mayrovitz

Determining Cardiac Output (CO): Fick



$$CO = \frac{\dot{V}_{O_2}}{Ca_{O2} - Cv_{O2}}$$ Fick's Equation

$\dot{V}_{O_2}$ = Oxygen Utilization

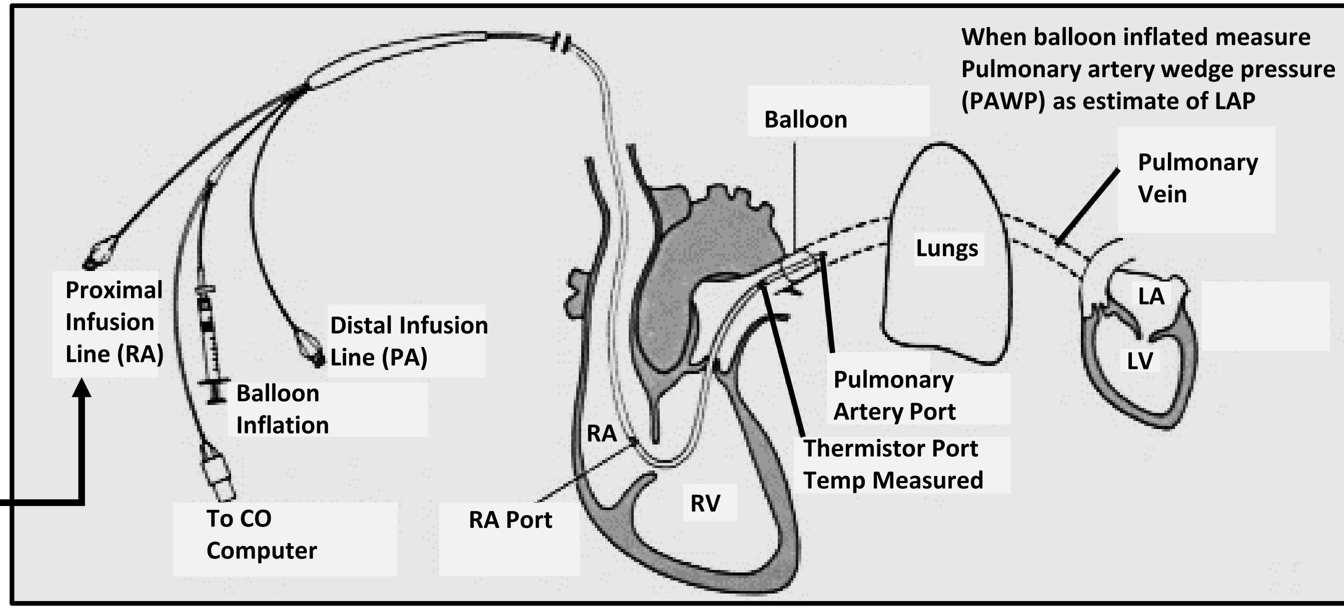
Example

$$CO = \frac{250\ mlO_2/min}{\sim(20 - 15)\ mlO_2/100ml = 0.05\ mlO_2/ml\ blood}$$

CO = 5000 ml/min

Determining CO via Thermodilution Method

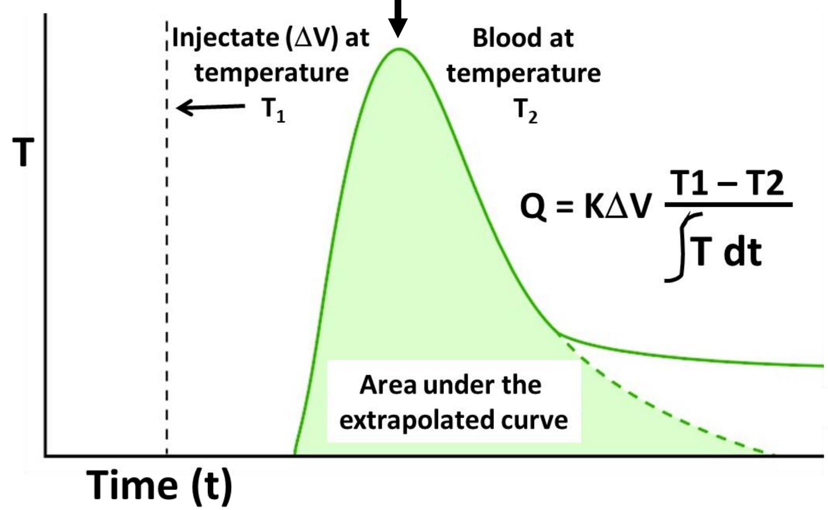
Thermodilution
Swan-Ganz catheter with thermistor placed into pulmonary artery via peripheral vein insertion



- Cold saline injected into right atrium at end of expiration

- Temperature changes at thermistor sensed and recorded

- Blood flow (cardiac output, CO) is determined from temperature profile



$$Q = K\Delta V \frac{T1 - T2}{\int T\,dt}$$

ΔV = volume injected
K – calibration constant

End Lecture 18
or If time
Interactive Questions