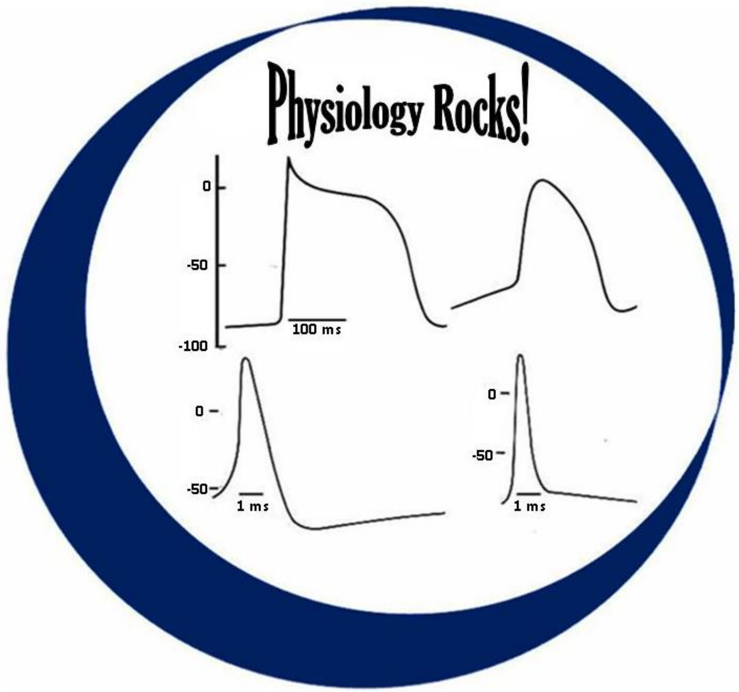
Lecture 20
Vascular and Cardiac Compliance and Mechanics



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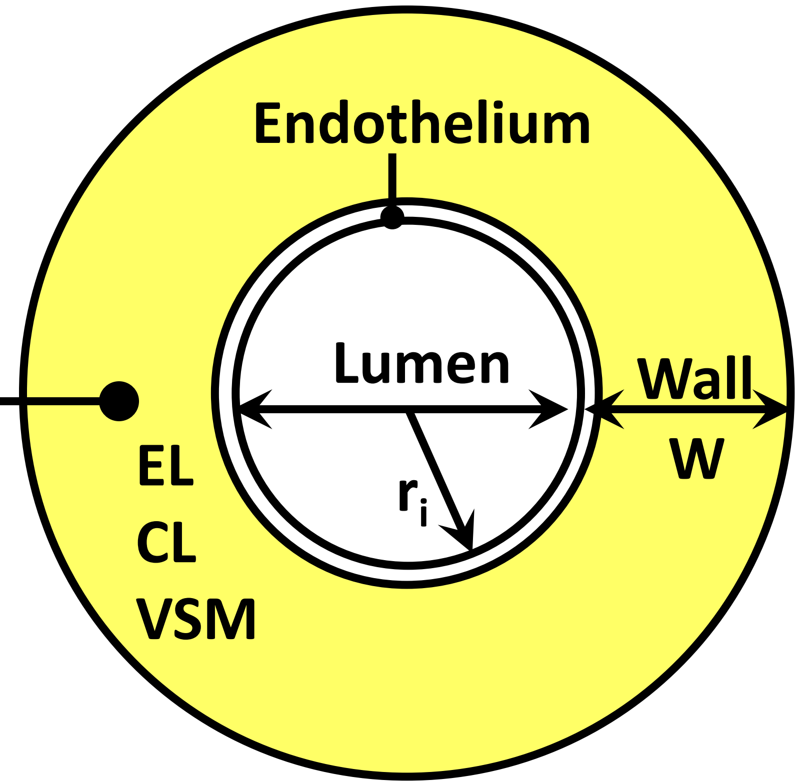
Vessel Structure and Components

Amounts Vary by Vessel Type

Connective Tissues

- **Elastin (EL) – "flexible"**
- **Collagen (CL)– "stiff"**

Vascular Smooth Muscle
(VSM)



Overall vessel "stiffness" depends on

- **Collagen/Elastin (Wall Material)**
- **W/r_i ratios (Geometry - Structure)**

Compliance (Vascular and Cardiac)

$$C \propto \frac{1}{E \times (W/D)}$$

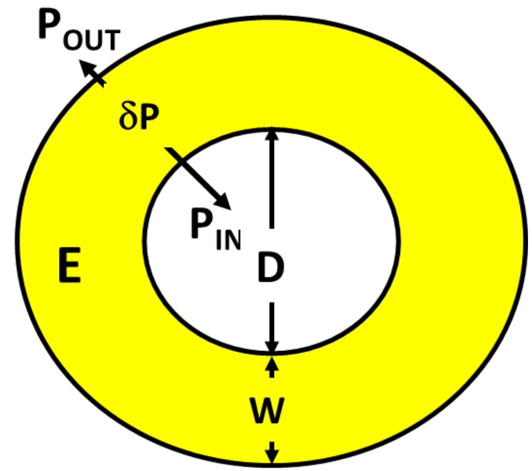
Elastic Modulus
E → Wall Material

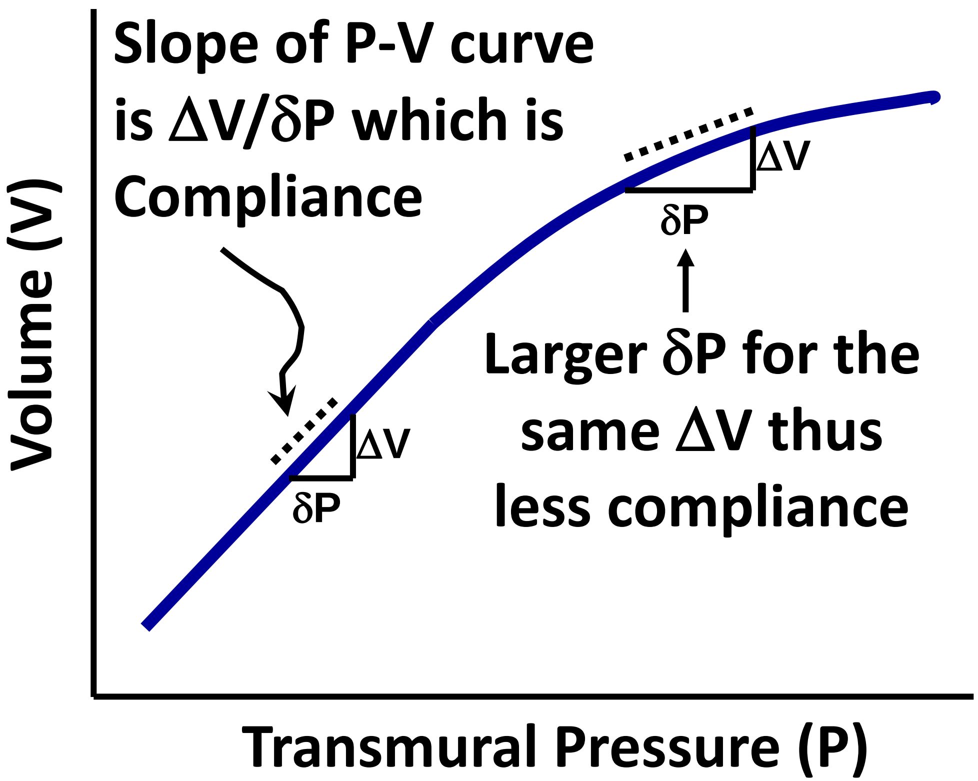
- Elastin Density and Structure
- Collagen Density and Structure

Age Related Changes

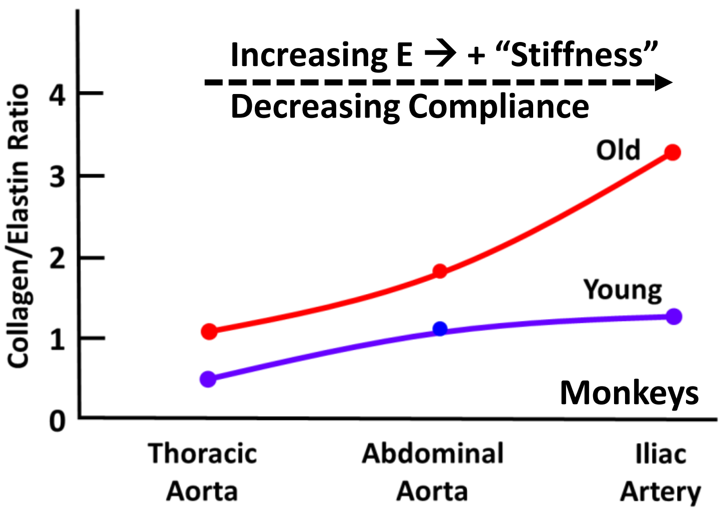
W/D ~ Geometry

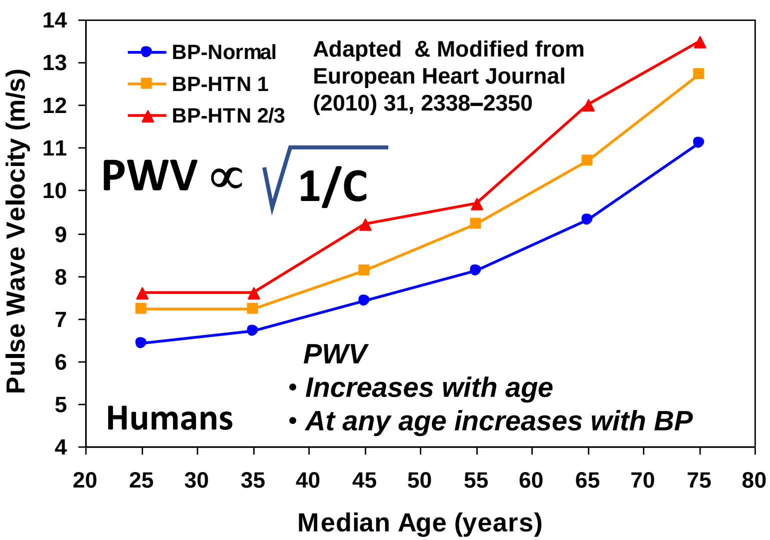
$$C = \frac{\Delta V}{\delta P}$$





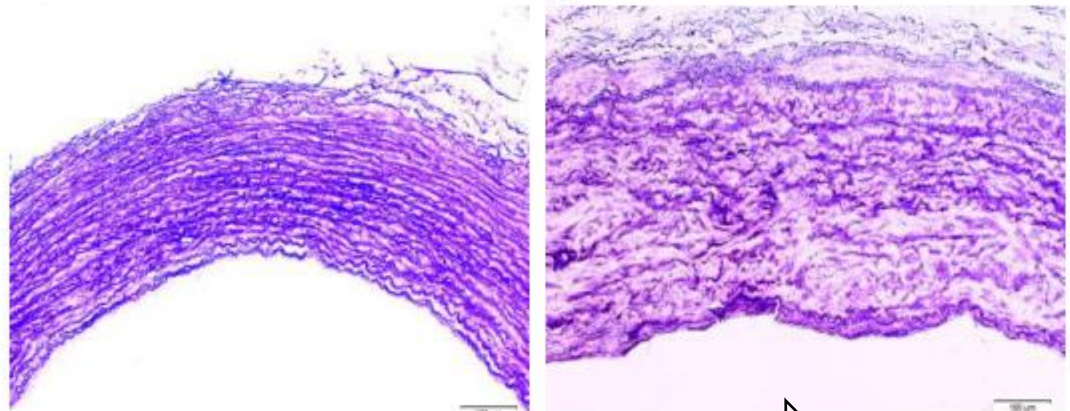
Abdominal Aorta Age-Related Changes



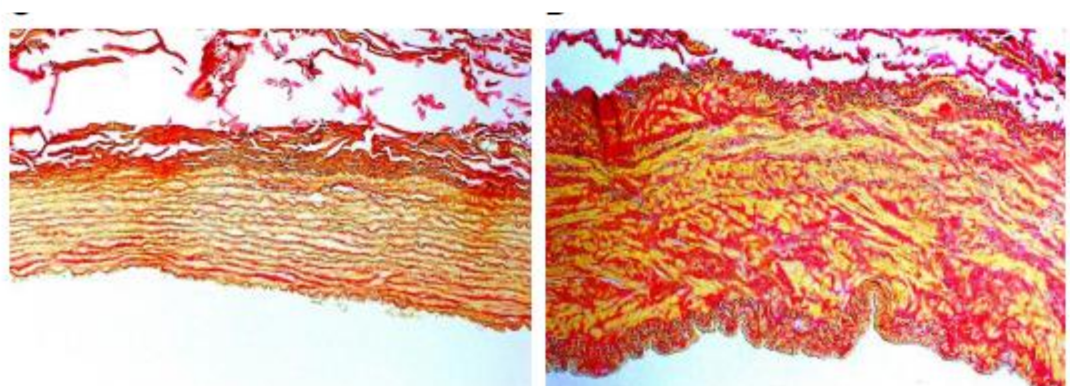


Female Monkeys (premenstrual)

Young 7 ± 0.7 years | **Old** 24 ± 0.7 years



Elastin — Decreased Density and Δ structure



Collagen — Increased Density and Δ structure

After Babici et al. AJP 2020;319: H222-H234

Interactive Question

If the compliance of an artery decreases, then to accommodate the same blood volume the intravascular pressure will ______________________

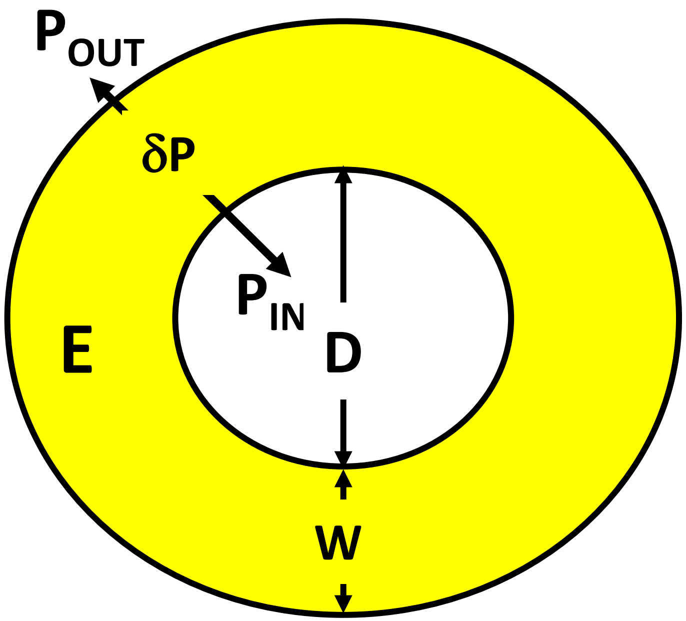
A. increase
B. decrease
C. be essentially unchanged
D. decrease a lot
E. increase a lot

$$\delta P = \Delta V/C$$

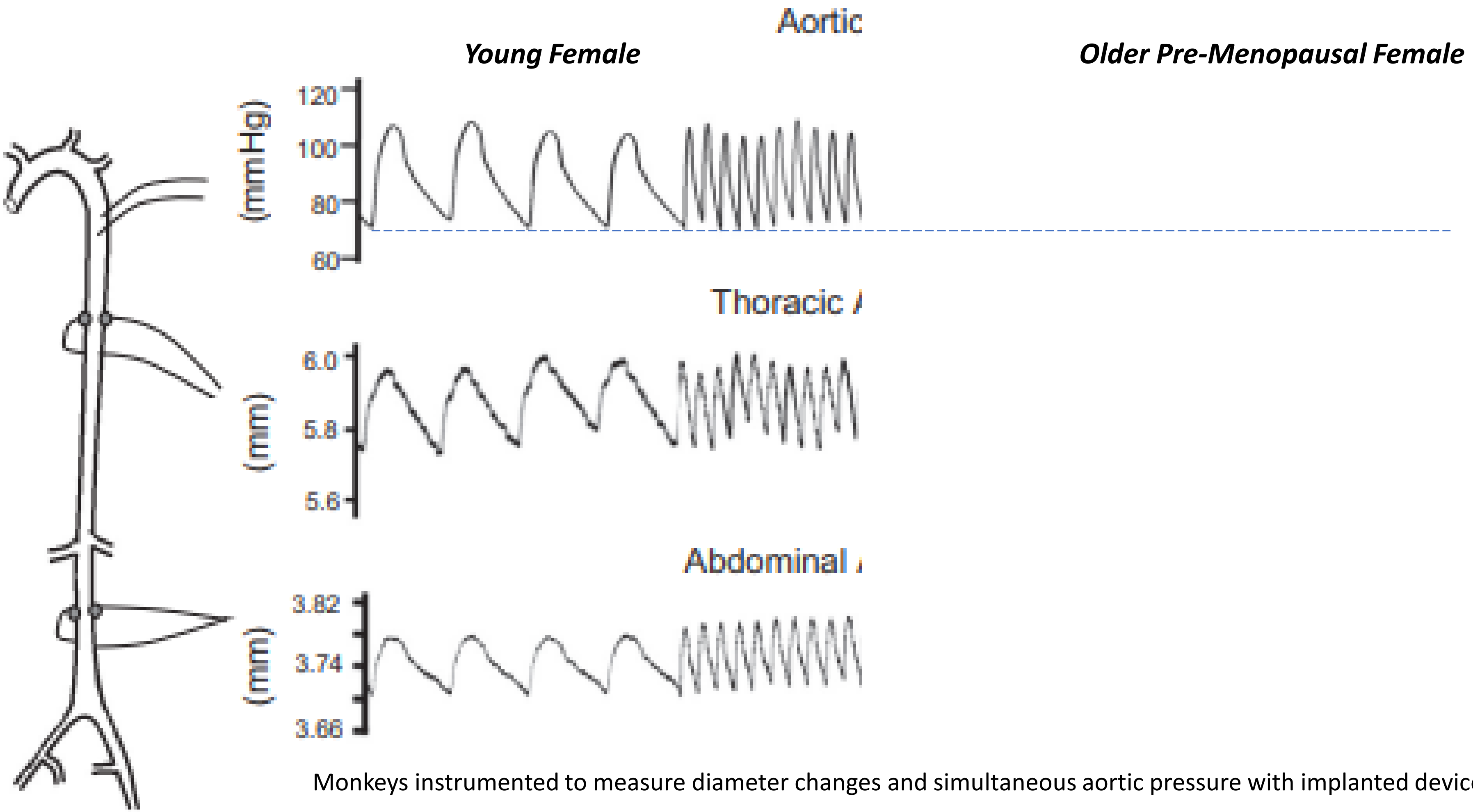
- **Increased E**
- **Increased W/D**

<u>**Reduced Compliance**</u>

A greater pressure change is needed to increase the vessel volume the same amount

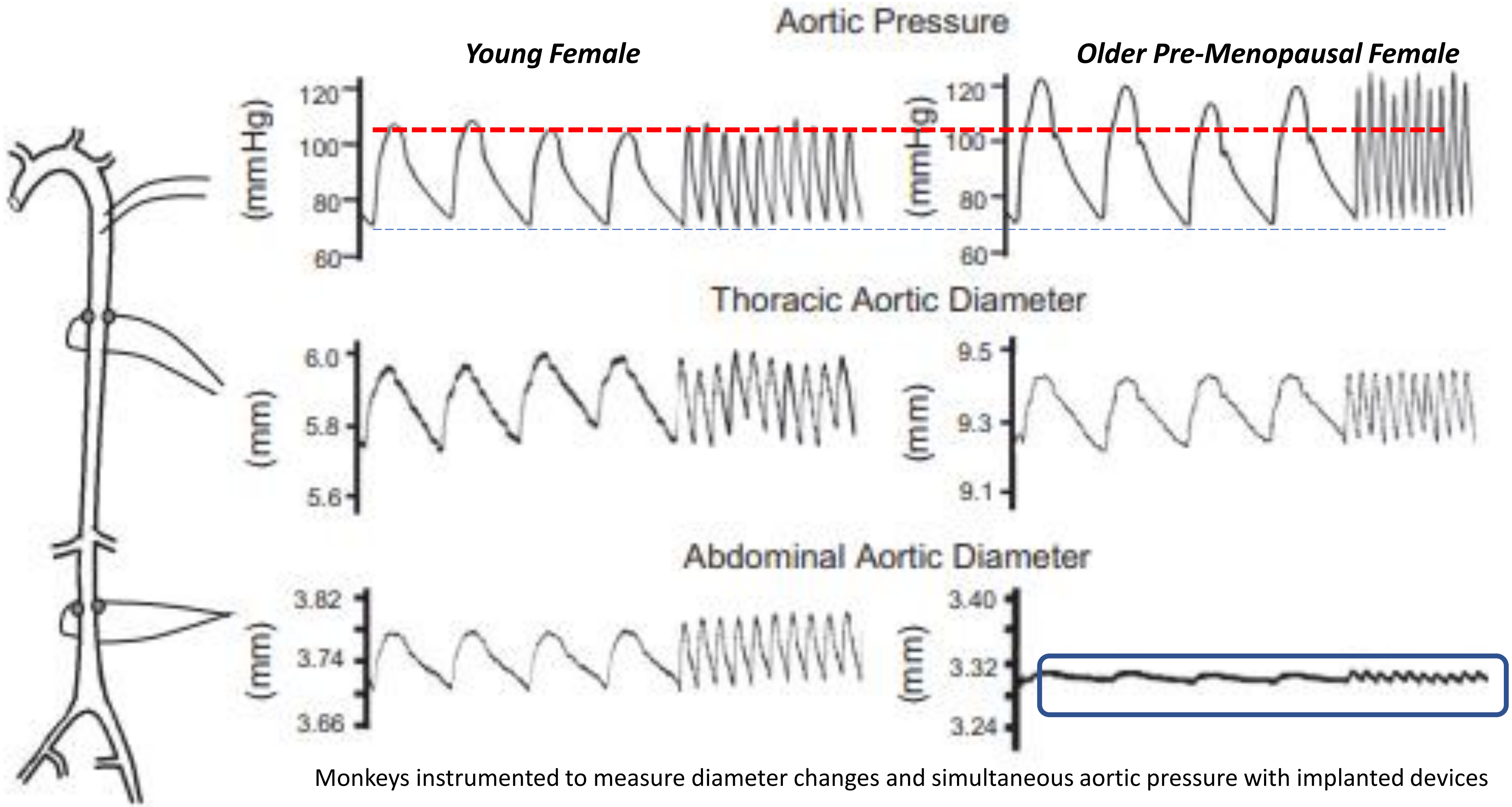


Example of Impact of Decreased Compliance



Monkeys instrumented to measure diameter changes and simultaneous aortic pressure with implanted devices

Example of Impact of Decreased Compliance



Monkeys instrumented to measure diameter changes and simultaneous aortic pressure with implanted devices

1. What do you observe about the change in aortic pressure? **Older → + Systolic → + PP**
2. What do you observe about the change in abdominal aorta diameter? **Older → much less expansion**
3. From the data could you estimate the compliance change with age?

Mechanisms of Age-Related Increasing Stiffness

Aging

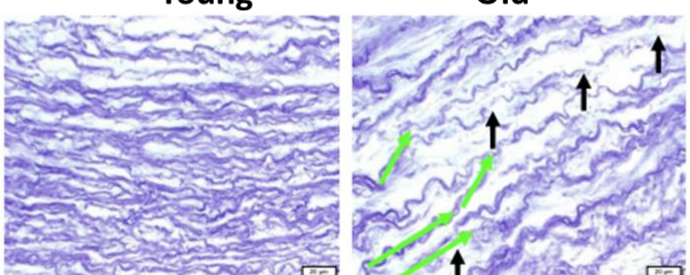
→ **Extracellular Matrix Mechanisms**
- Collagen/Elastin Ratio
- Collagen – Elastin "Disarray"
- Calcification

→ **Cellular Mechanisms**
- EC reduced vasodilatory function
- Increased VSM Stiffness
- Inflammation

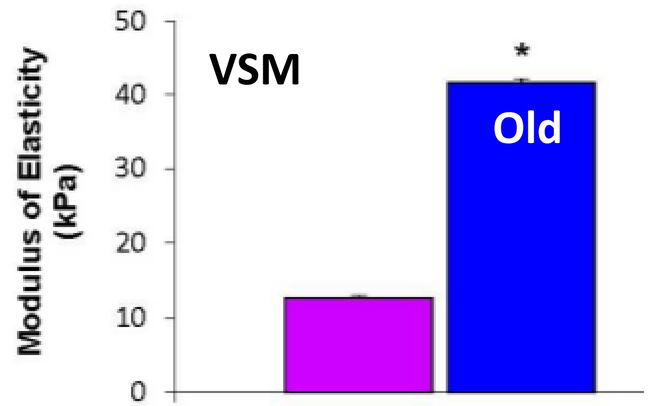
→ **Decreased Vascular Compliance**

Elastin: Abdominal Aorta

Young **Old**



Arrows: Fiber Breaks Green: Fiber Shifts

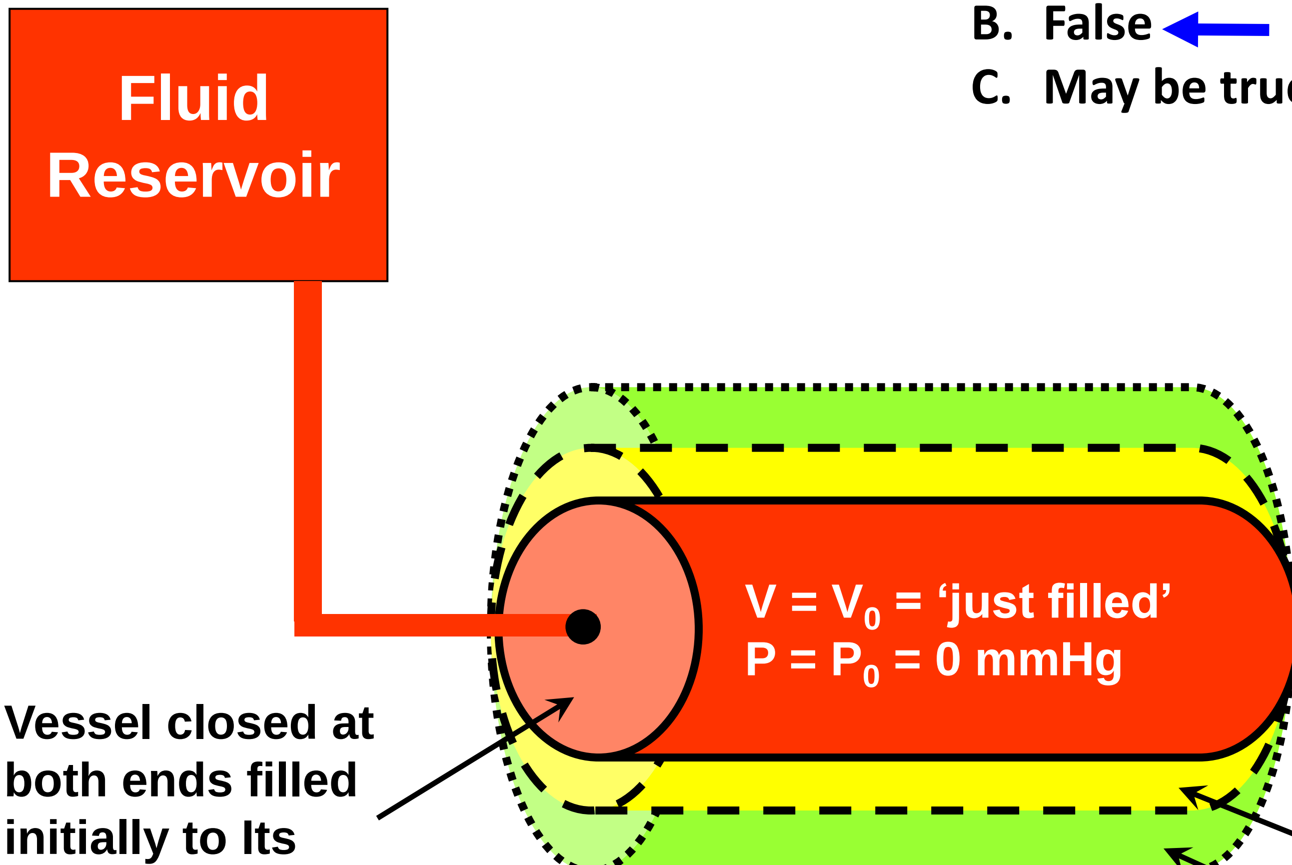


After Vatner et al.Front. Physiol. 12:762437.
doi: 10.3389/fphys.2021.762437

“Stressed” vs “Unstressed” Volume

“Unstressed” volume is a term defined as the blood volume in a relaxed vessel

A. True
B. False
C. May be true

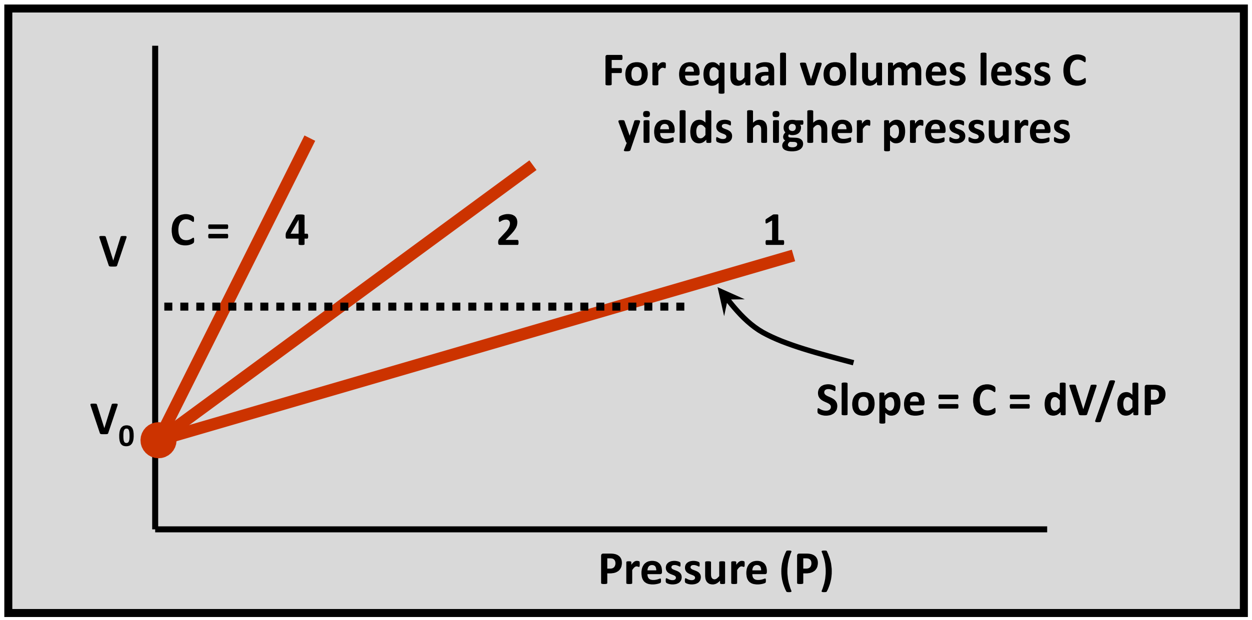


Vessel closed at both ends filled initially to Its Internal volume (V_0). Pressure is zero at V_0 → “Unstressed Volume”

Increasing amounts of volume added. P increase depends on ‘stiffness’ of the vessel wall “Stressed Volume”

“Stressed” vs “Unstressed” Volume

Volumes greater than the “unstressed“ volume cause increased pressure



A. True
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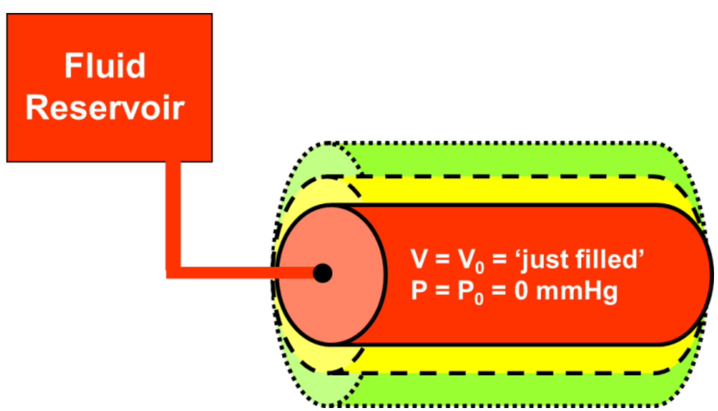
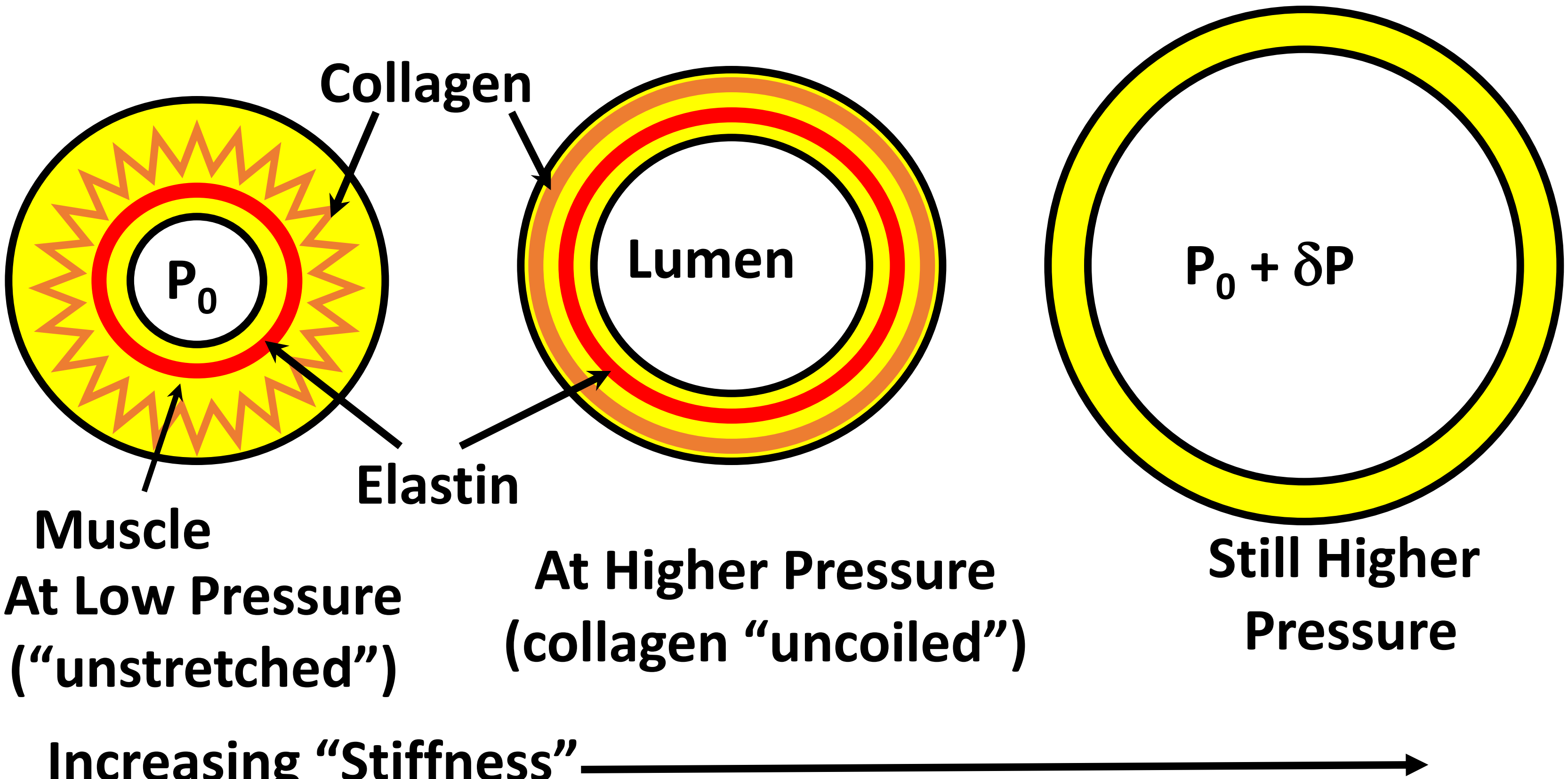


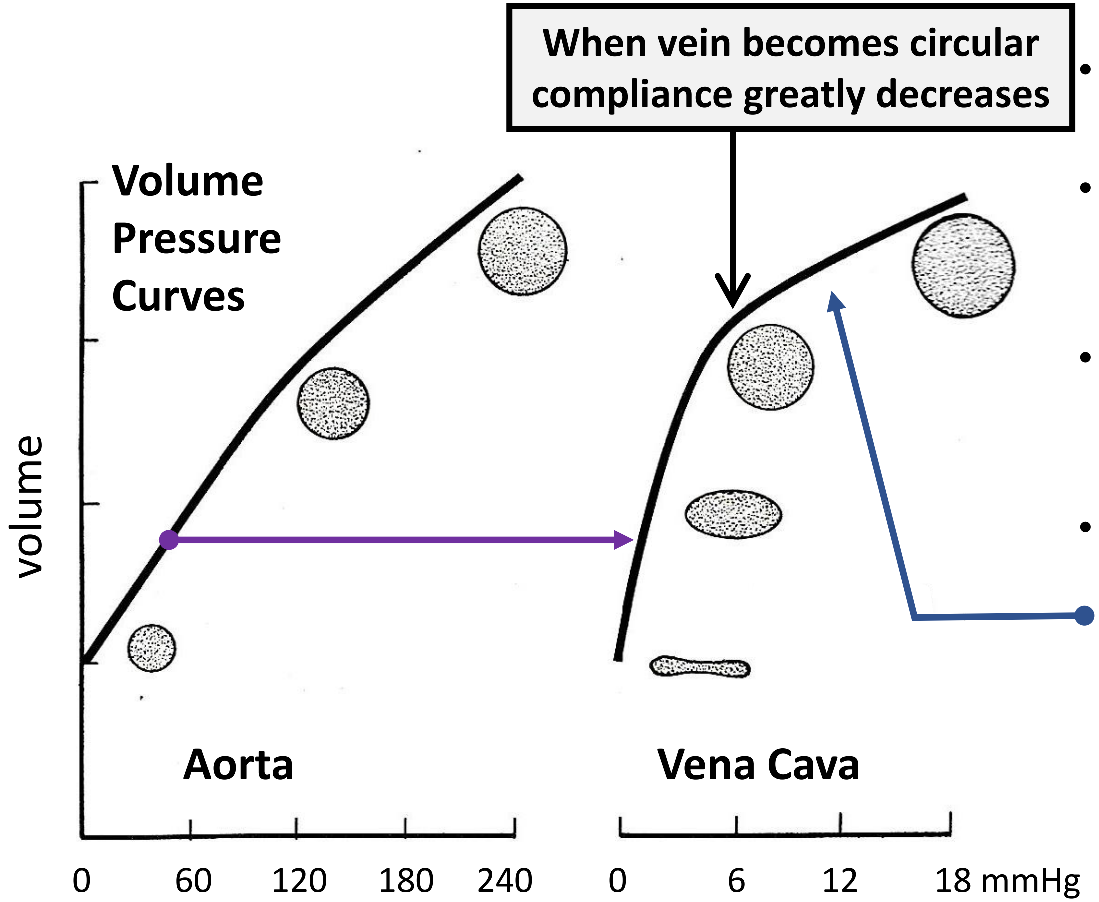
Transmural Pressure Effects

Increasing transmural pressure generally ________________ vascular compliance

A. Increases
B. Decreases
C. Has no effect on

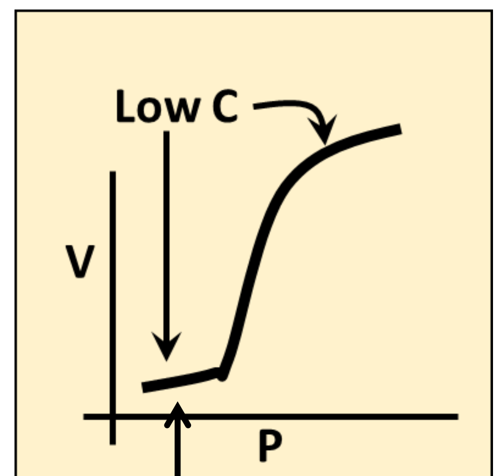


Arterial vs. Venous Compliance

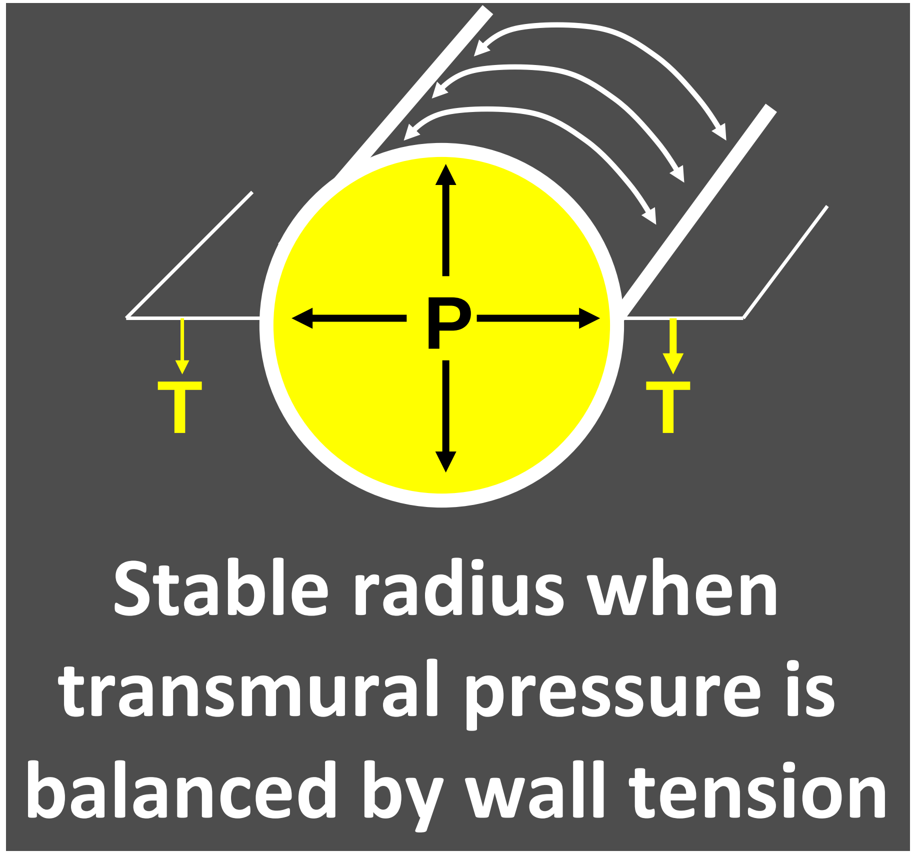


- At normal pressures venous compliance is greater than arterial
- This is shown by the greater slope of the volume-pressure curve for veins until they become circular
- With higher pressure expansion of veins must be done by engaging the stiffer collagen in the vein wall
- For large venous pressure and wall stretch, vein compliance is similar to arteries as shown by a near parallel volume-pressure curve

- Compliance = change in volume (dV) / change in transmural pressure (dP)
- The quantity dV/dP corresponds to the slope of the volume-pressure curve
- At very low transmural pressures veins tend to buckle and need greater P to expand thus the low compliance in this region



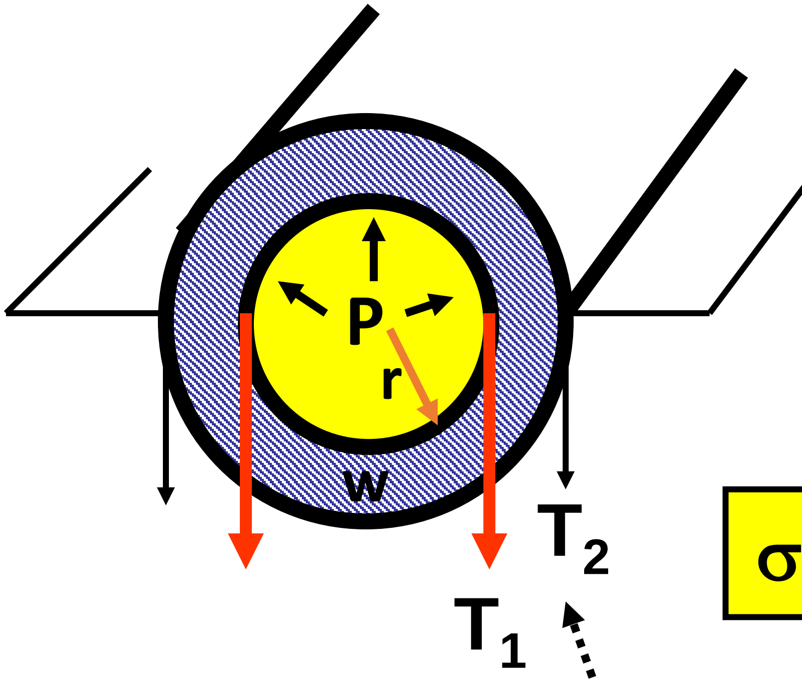
Simple Statement of Laplace's Law



Blood vessel experiences an outward transmural pressure force that is balanced by tension T in the thin wall resulting in a stable radius, r.

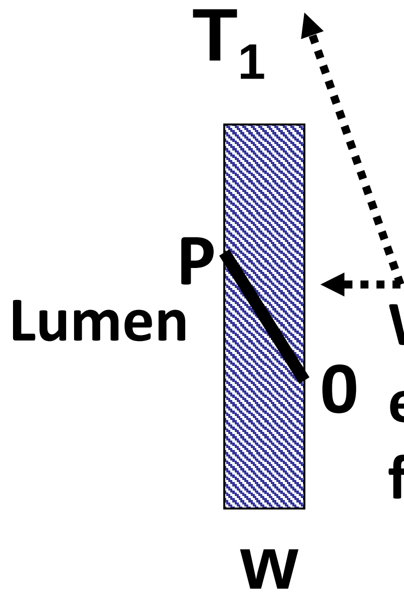
$$T = P \times r$$

Modified Laplace's Law



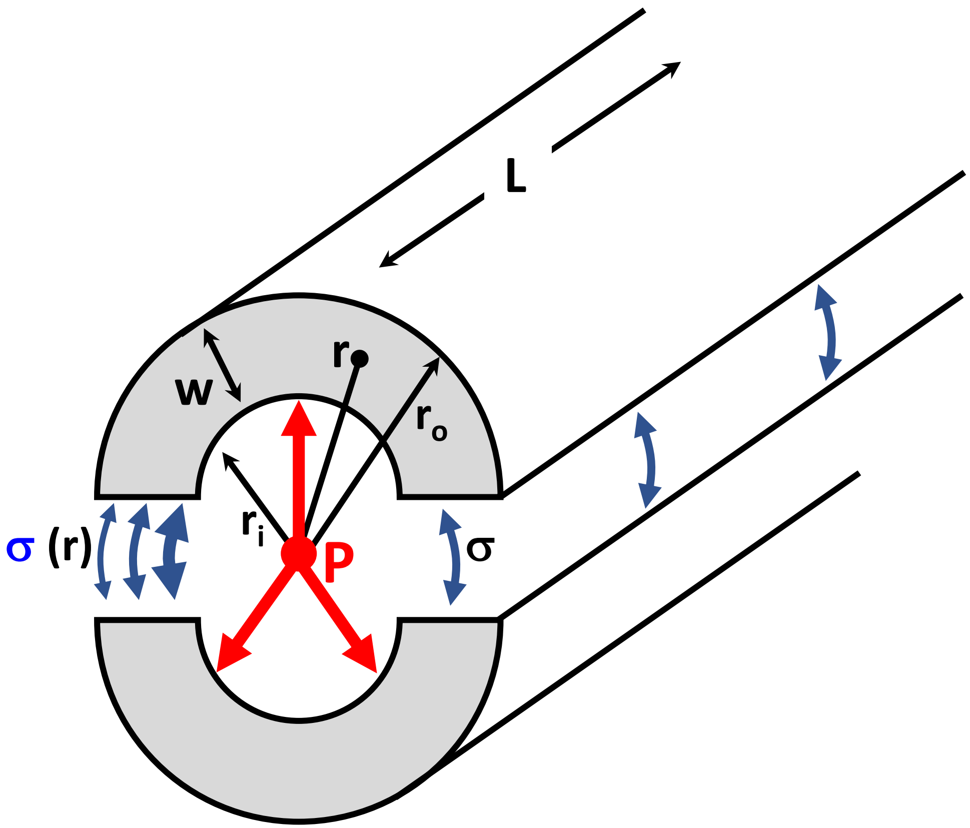
$\sigma = Pr/w = \langle S_\theta \rangle$ = "avg Tension"

Wall stress (σ) is more appropriate then tension



Wall tension needed for equilibrium decreases from inner to outer wall

Modified Laplace's Law: "Blood Vessels"



Laplace's "modified" Law for blood vessels
Wall stress in balance with distending force for equilibrium radius
σ = P r / w → Modified form for vessel
P = transmural pressure
r = internal radius

- Pressure (P) causes an outward force (F) tending to expand the vessel. The force acts over the length of the vessel (L).
- To hold the two halves together there is a stress (σ) in the vessel wall acting in opposition to the distending force

  The distending force/L = P x π r_i^2

  The restoring force/L = σ x π r_iw
- Equating these yields σ = (P x r_i) /w which is the Modified Laplace's Law

  σ is the average stress in the wall
- The radial distribution of stress σ(r) is greatest at r_i and diminishes through the wall becoming least at r_o

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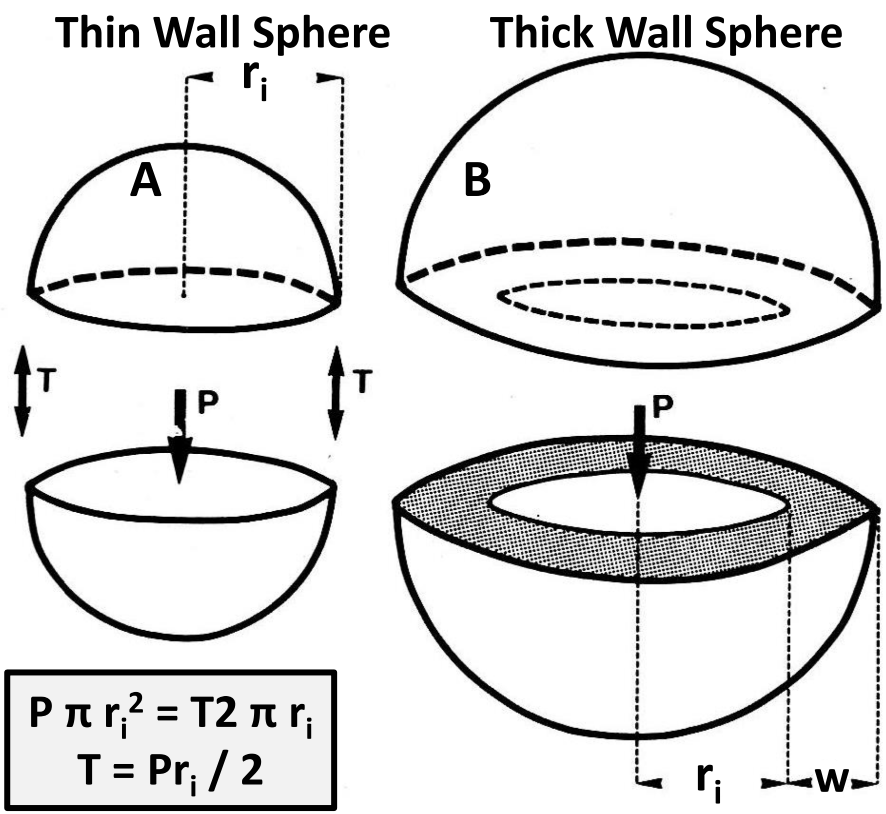
Laplace's Law: "Heart"



$P \pi r_i^2 = T 2 \pi r_i$
$T = P r_i / 2$

Laplace's "modified" Law for heart
Wall stress is in balance with distending force for equilibrium radius
σ = P r / 2w → Modified form for sphere
P = transmural pressure
r = internal radius

- Heart viewed as sphere with a thin wall as in A and with a thick wall as in B
- In A, Tension (T) force ($2\pi rT$) opposes pressure (P) force ($\pi r^2 P$)
- Equating forces yields the "pure" Laplace's equation $T = Pr/2$
- In B, the presence of non-zero wall thickness (w), requires that average wall stress (σ) oppose and balance pressure force $P\pi r_i^2 = \sigma \pi w(2r_i + w)$
- This leads to the so-called thick-walled modification and results in the modified Laplace equation as $\sigma = Pr/2w$

Beware → Heart is not a sphere!

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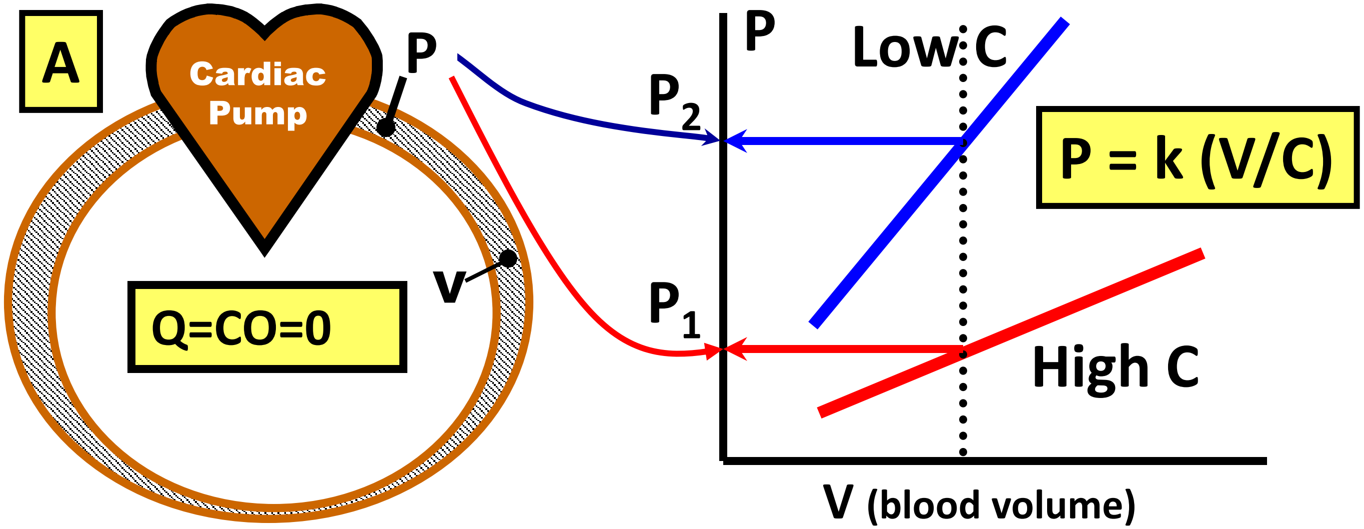
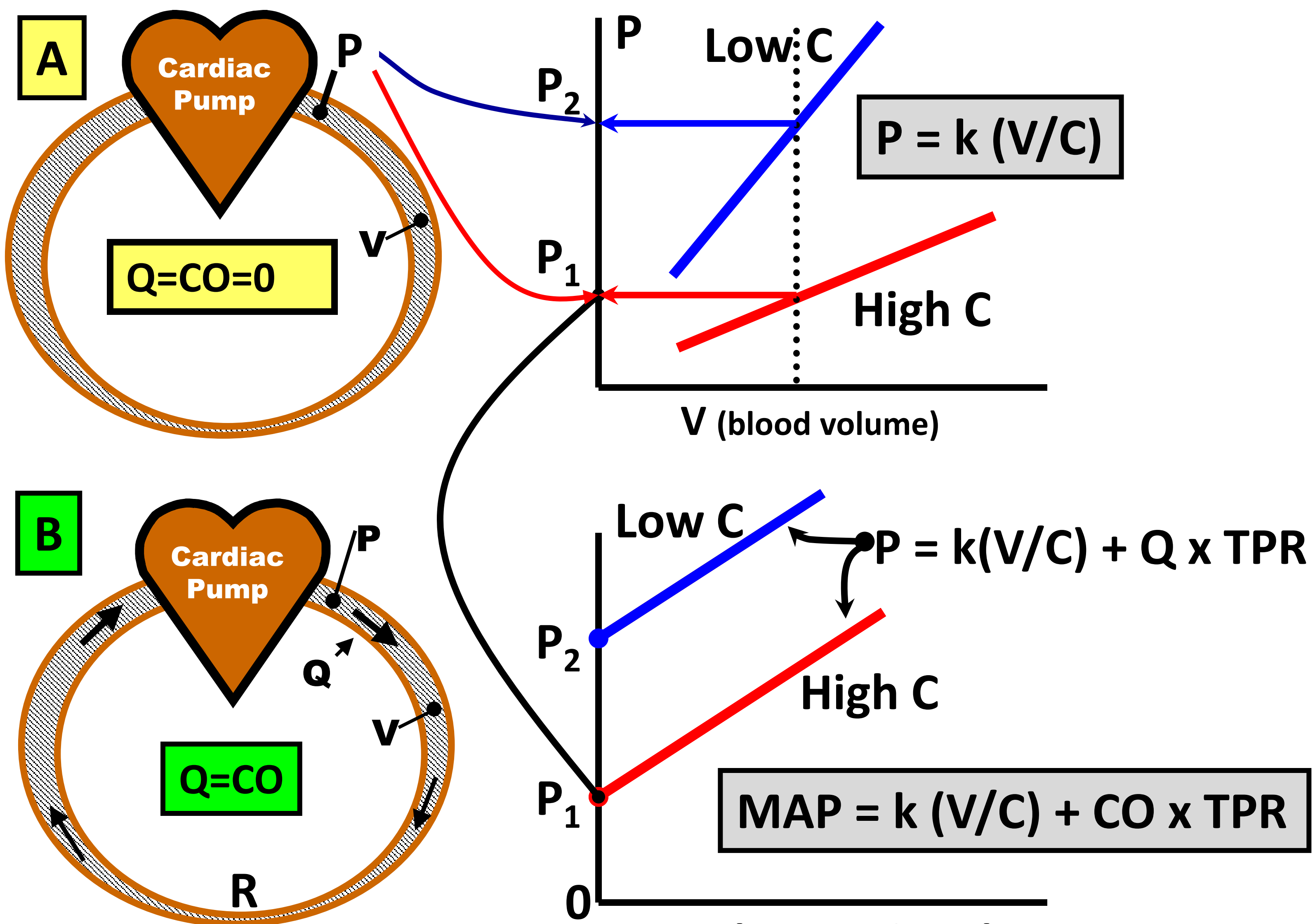
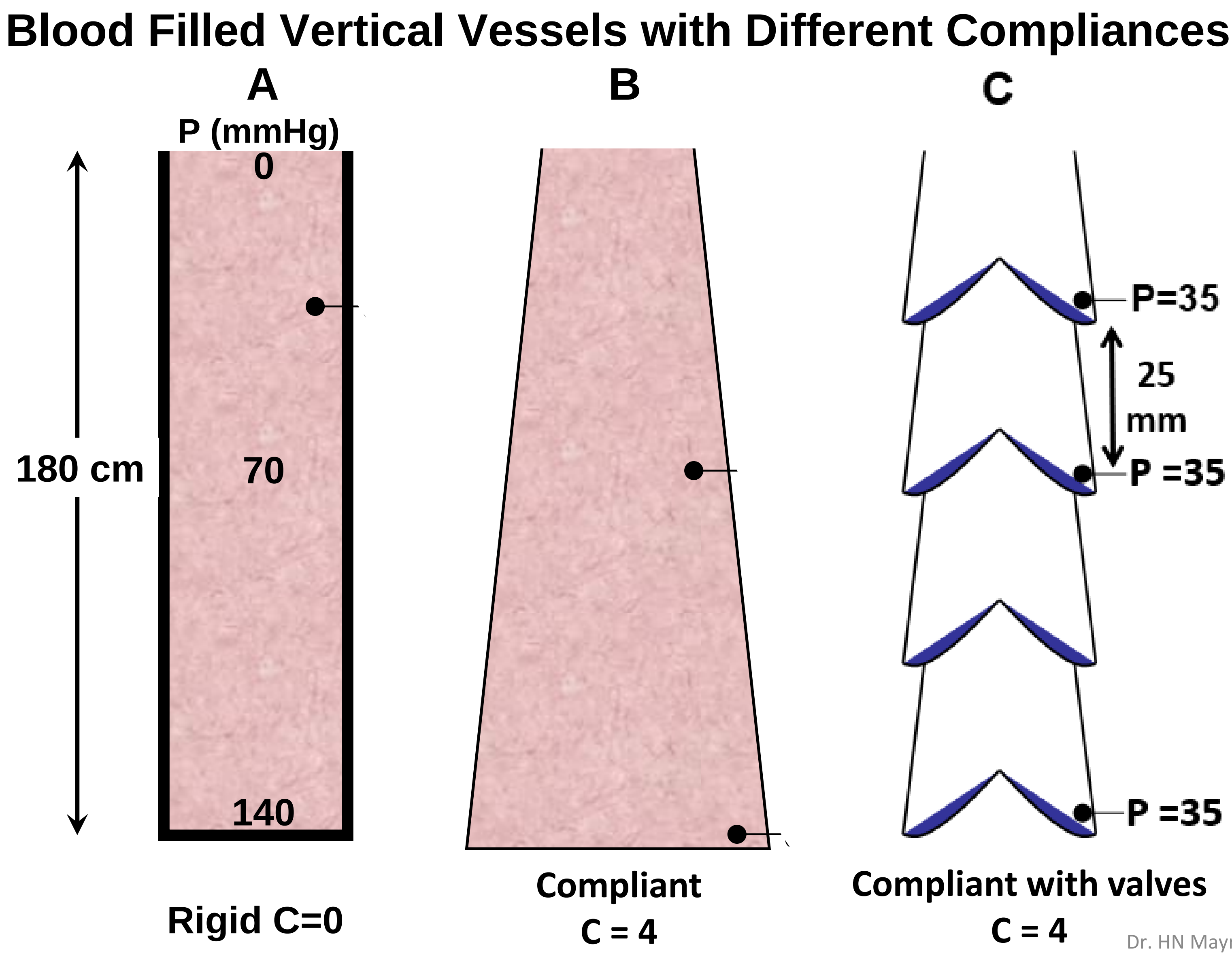
Compliance & Resistance are both BP Determinants



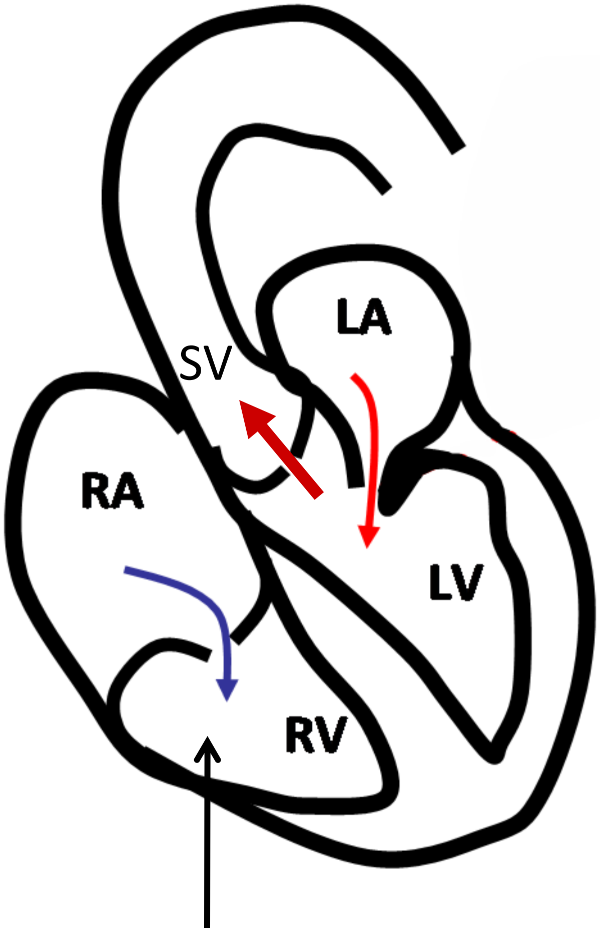
Resistance & Compliance are BOTH BP Determinants



Gravity – Compliance - Valves



Interactive Questions



Same is true for Right Ventricle

What is the effect on LV compliance if Ca^{++} re-uptake during (ϕ3) is reduced?

What is the effect of decreased LV compliance on LV filling volume at the onset of ϕ0?

What is the effect of decreased EDV on cardiac stroke volume (SV)?

What is the effect of increased LV wall thickness on LV Compliance?

End Lecture 20
MCQs as time permits