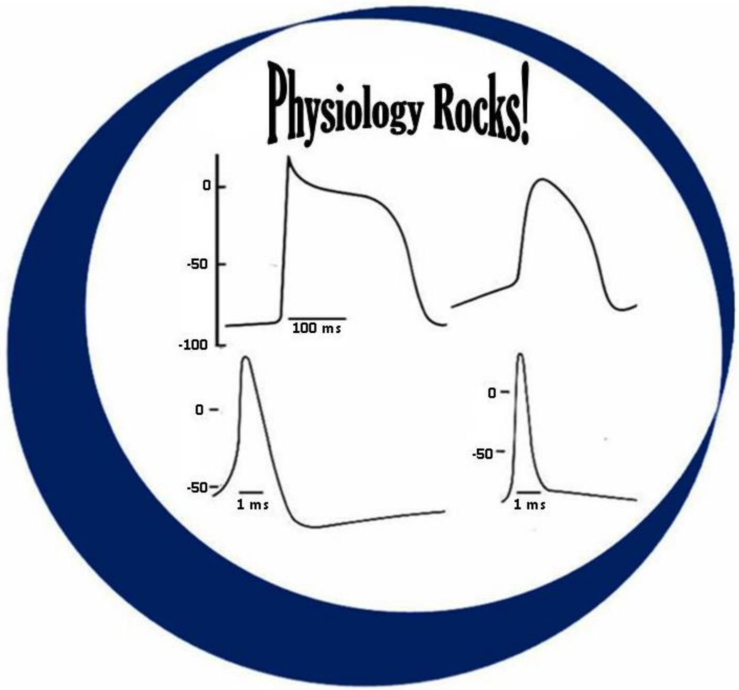
Lecture 6
Vascular and Cardiac Compliance



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Topics

- Wall properties affecting compliance
- Compliance definition and graphical representation
- Aging effects on compliance
- Effects of reduced compliance
- Volume and pressure effects on compliance
- Arterial vs. venous compliance
- Laplace's law and its modification and application
- Compliance and resistance as blood pressure determinants
- Gravity effects on compliance
- Interactive questions

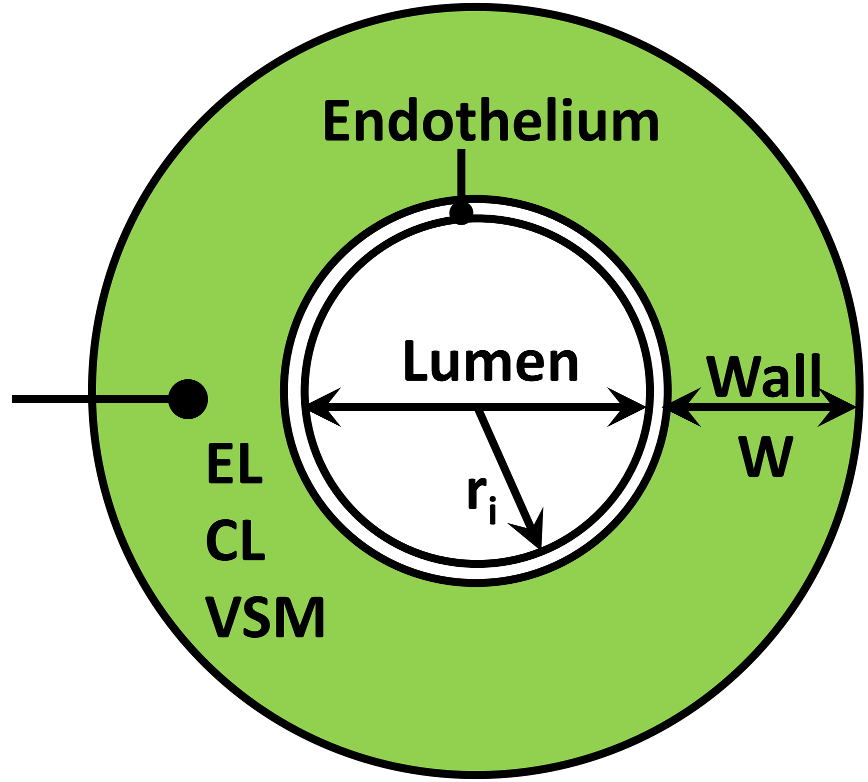
Vessel Structure and Components

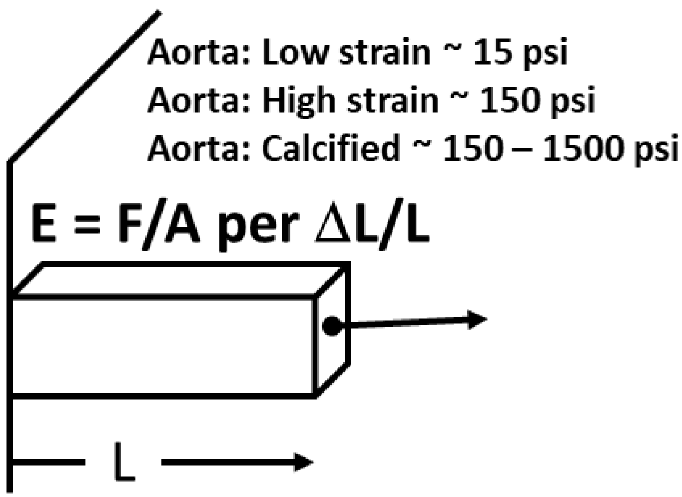
Amounts Vary by Vessel Type

Connective Tissues

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

Vascular Smooth Muscle (VSM)





E = Wall Elastic Modulus

Overall vessel "stiffness" depends on

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

Compliance (Vascular and Cardiac)

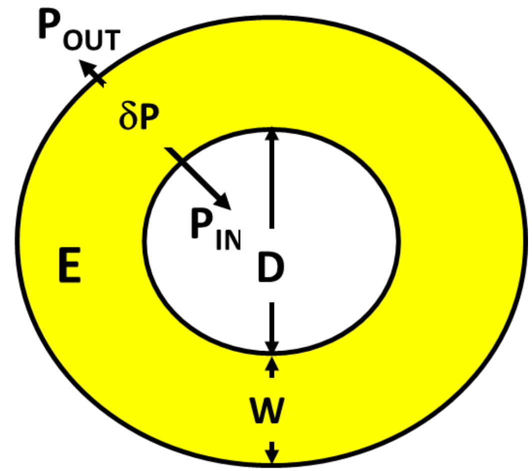
$$C \propto \frac{1}{E \times (W/D)}$$

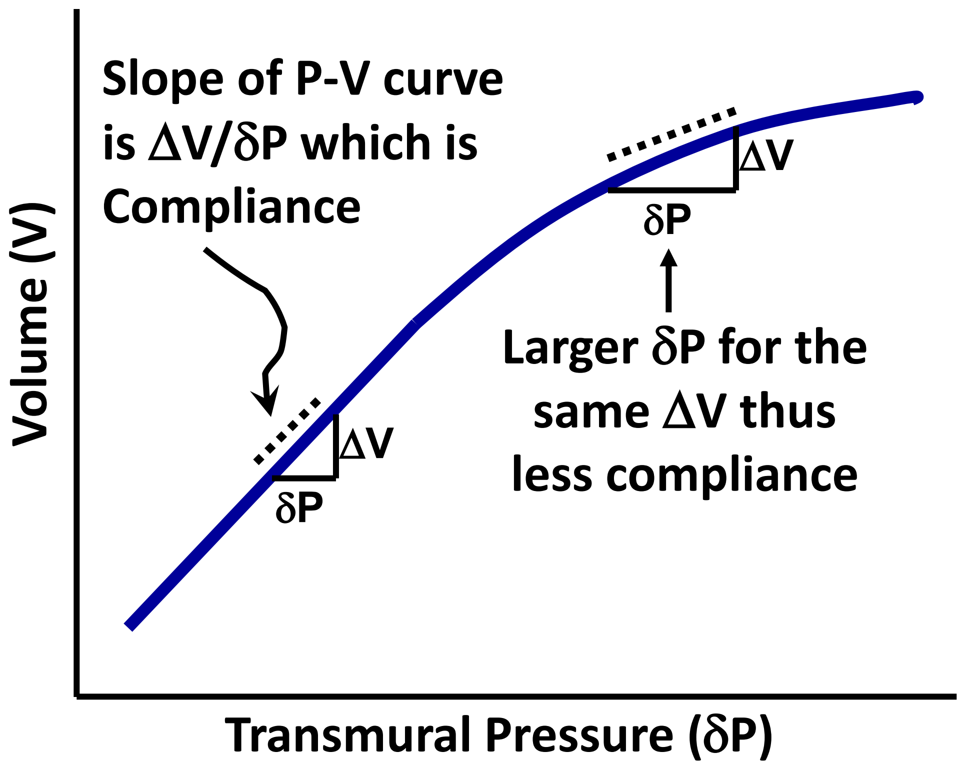
Elastic Modulus
E → Wall Material

W/D ~ Geometry

- **Elastin Density and Structure**
- **Collagen Density and Structure**

Age Related Changes

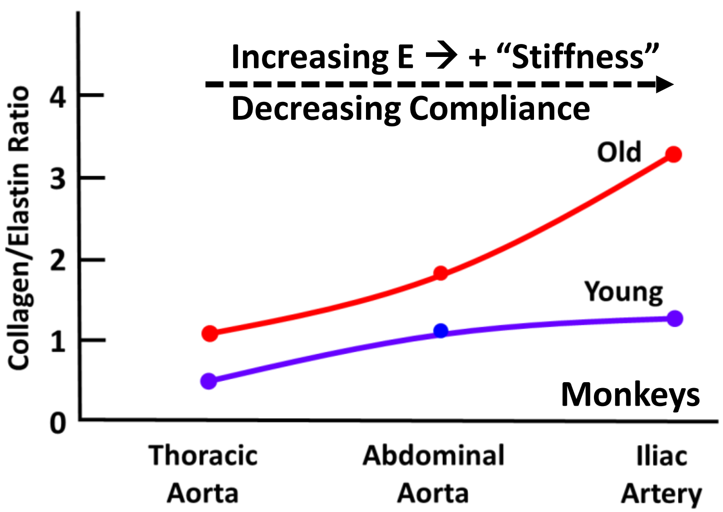




$$C = \frac{\Delta V}{\delta P}$$

$\delta P = P_{IN} - P_{OUT}$

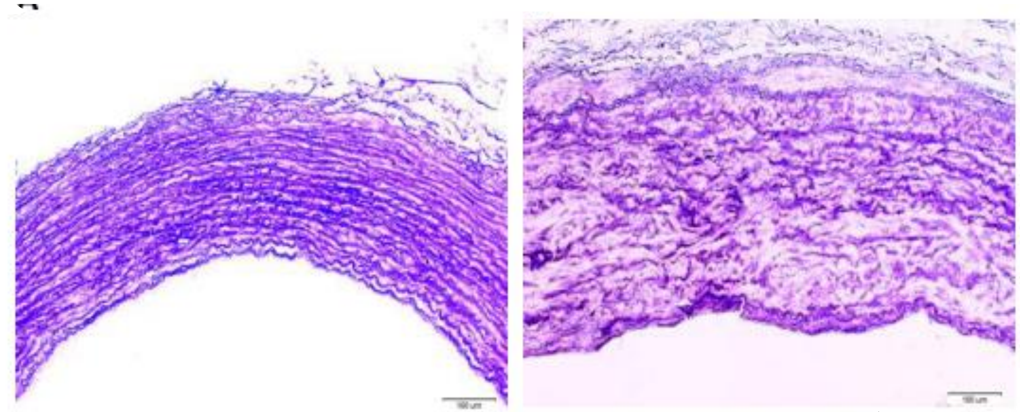
Abdominal Aorta Age-Related Changes



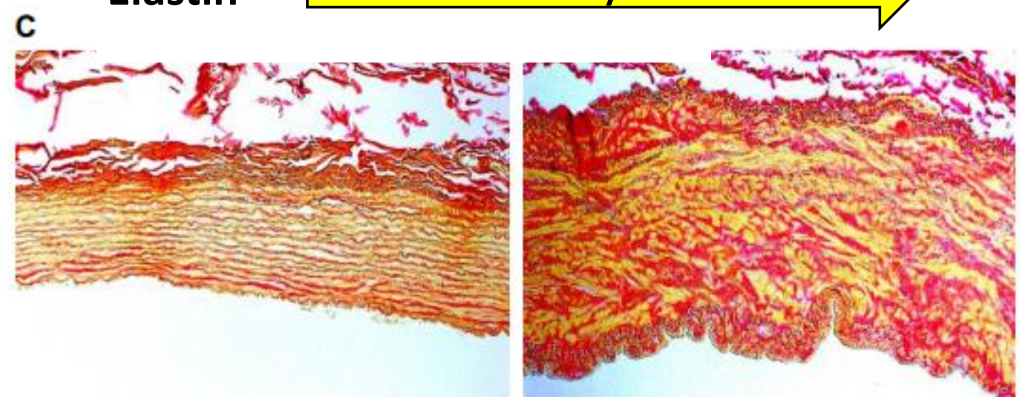
Female Monkeys (premenstrual)

Young 7 ± 0.7 years

Old 24 ± 0.7 years



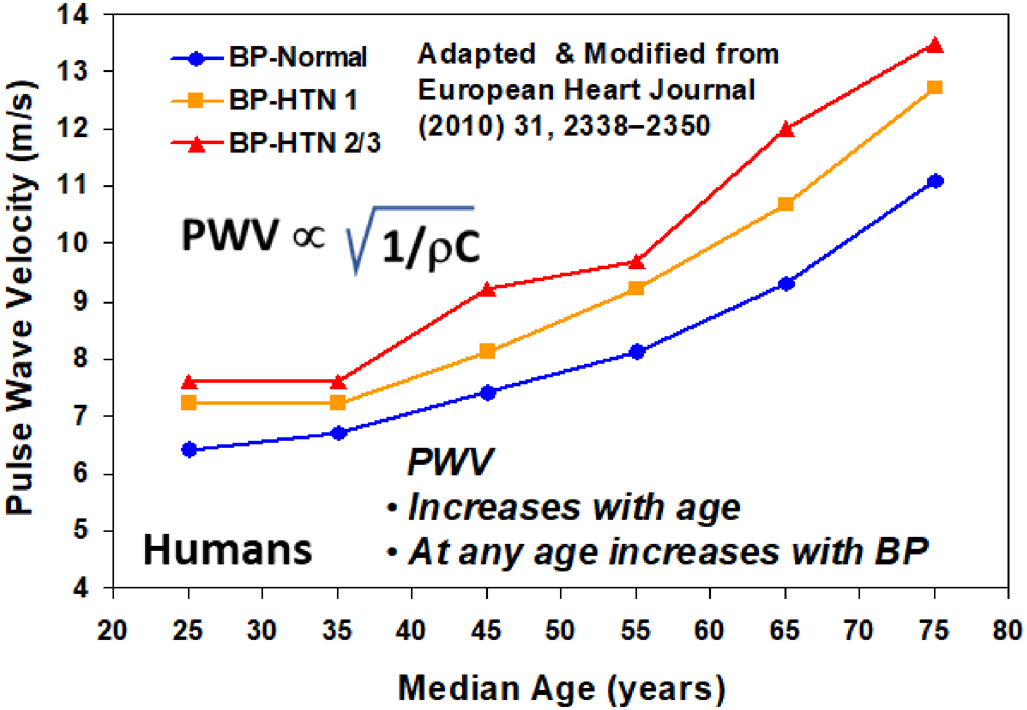
Elastin — Decreased Density and Δ structure

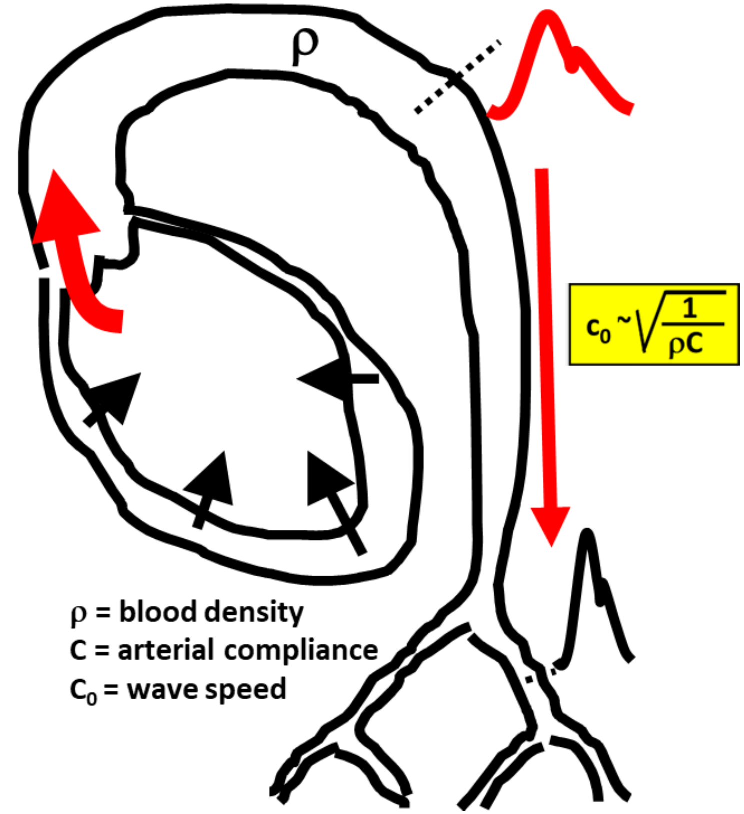


Collagen — Increased Density and Δ structure

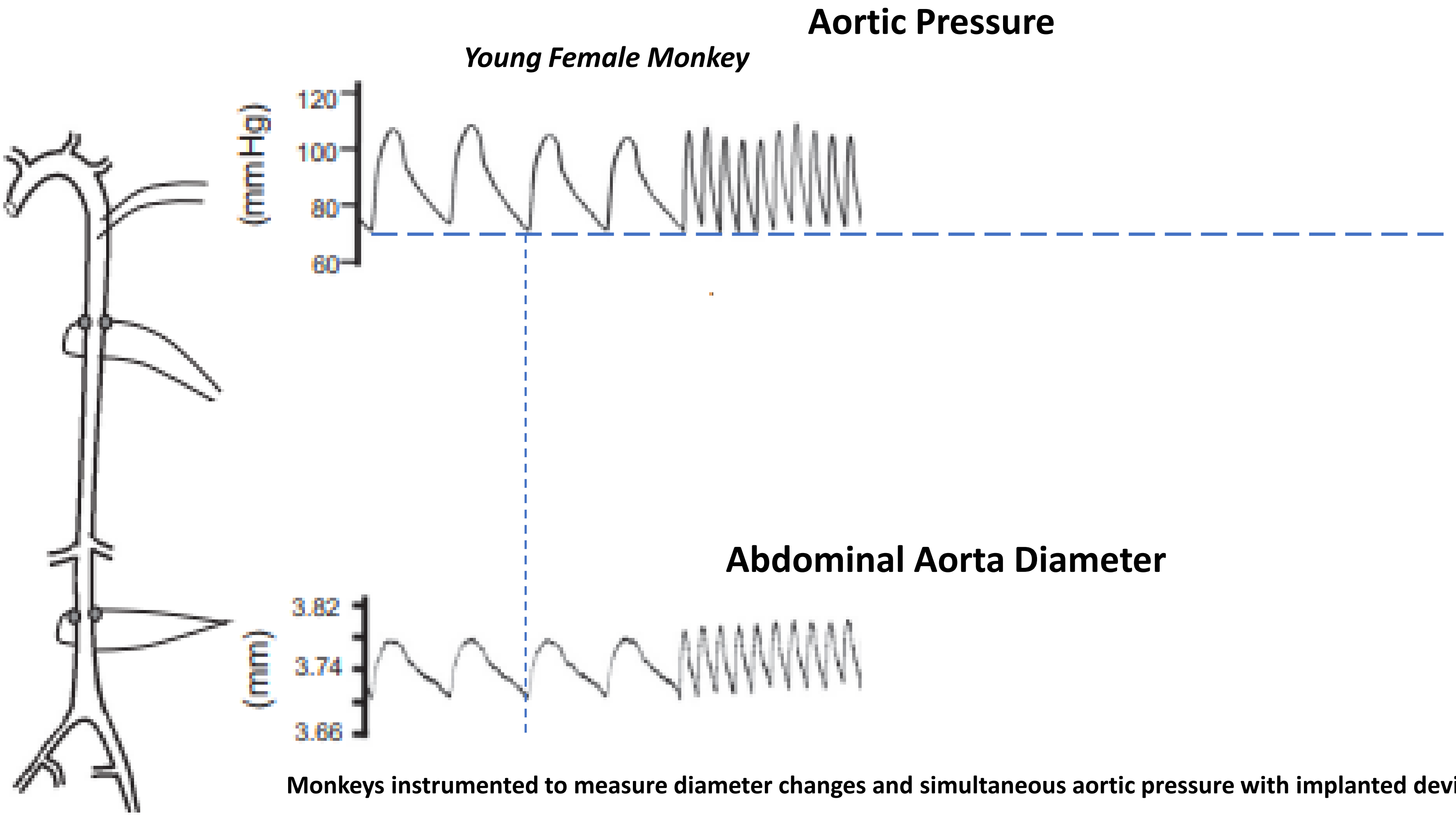
After Babici et al. AJP 2020;319: H222-H234

Compliance effects on pulse wave velocity



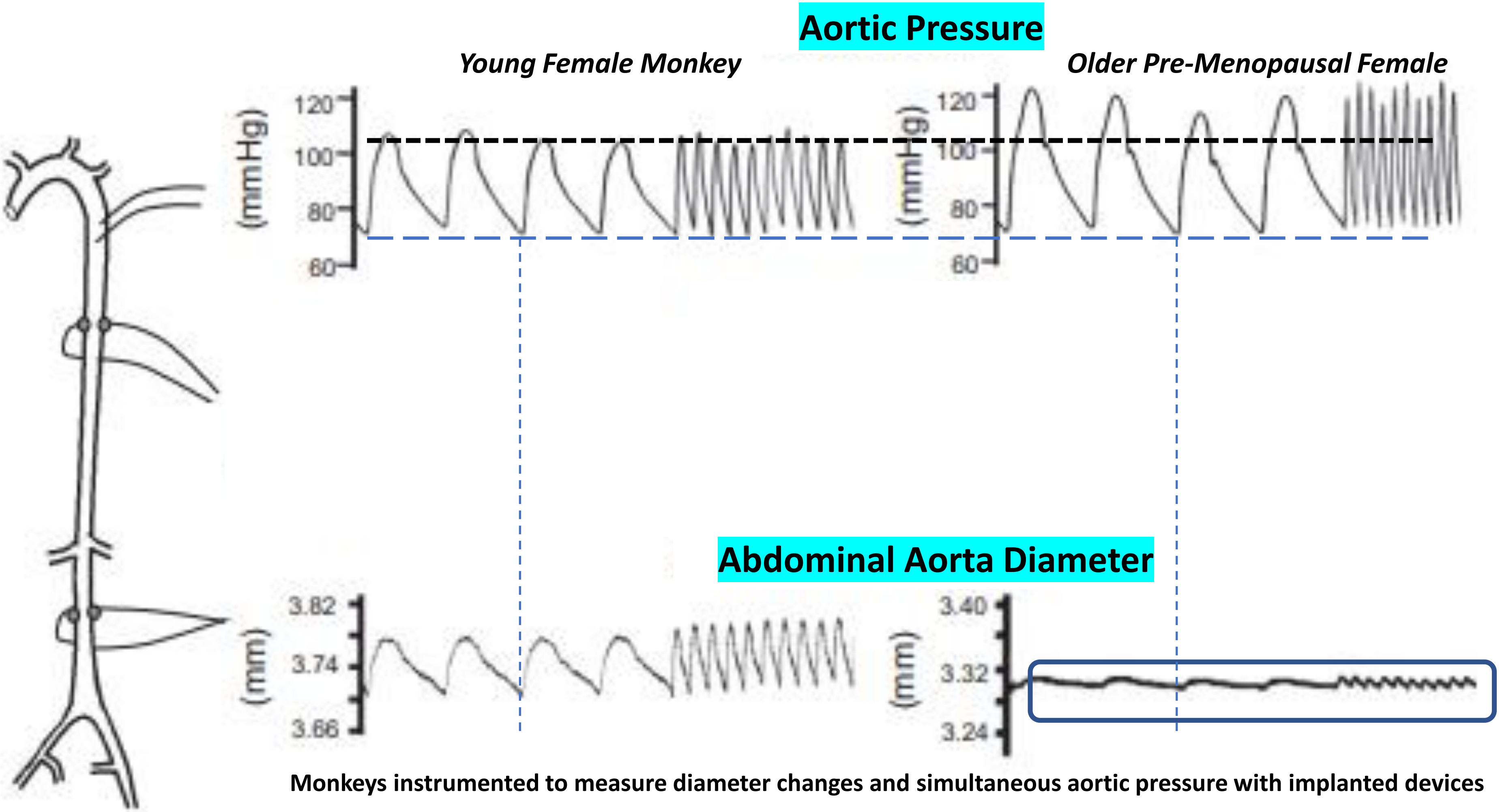


Example of Impact of Decreased Compliance



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 age change in aortic pressure?**
2. **What do you observe about the age change in abdominal aorta diameter?**
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**

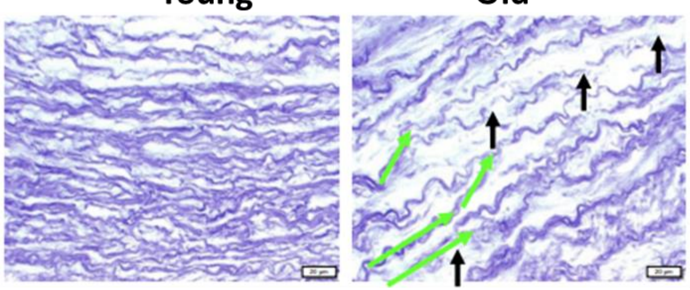
Cellular Mechanisms

- **EC reduced vasodilatory function**
- **Increased VSM Stiffness**
- **Inflammation**

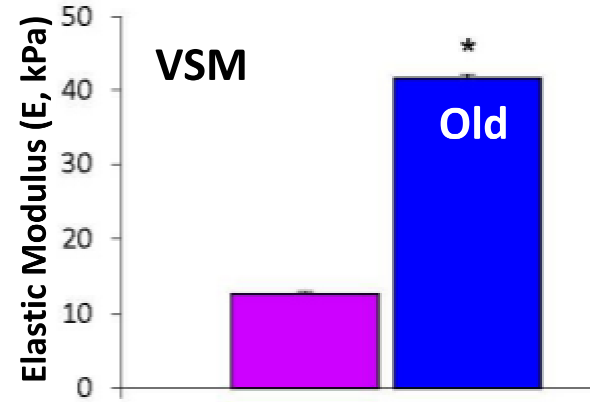
Decreased Vascular Compliance

Elastin: Abdominal Aorta

Young **Old**



Arrows: Fiber Breaks Green: Fiber Shifts

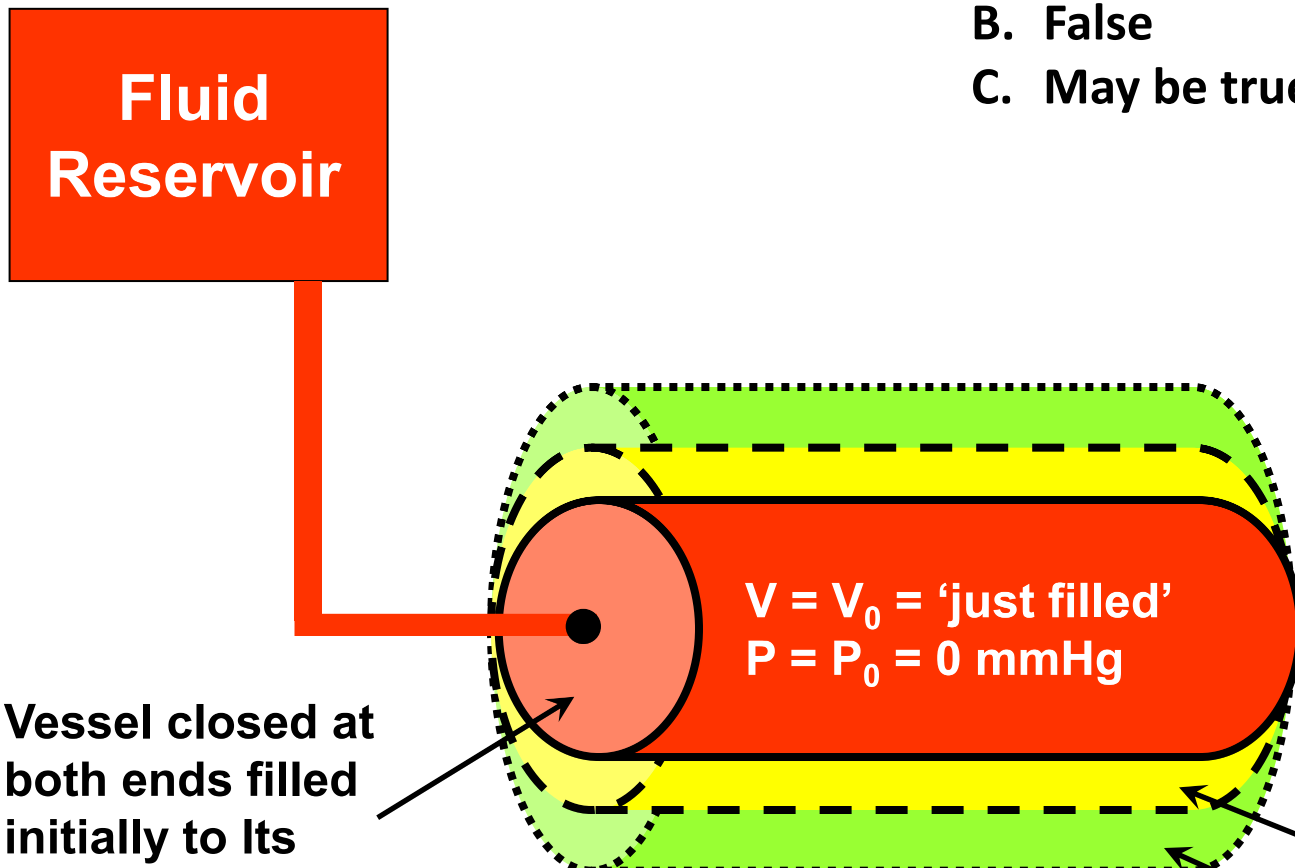


After Vatner et al.Front. Physiol. 12:762437.
doi: 10.3389/fphys.2021.762437

“Stressed” vs “Unstressed” Volume

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

A. True
B. False
C. May be true



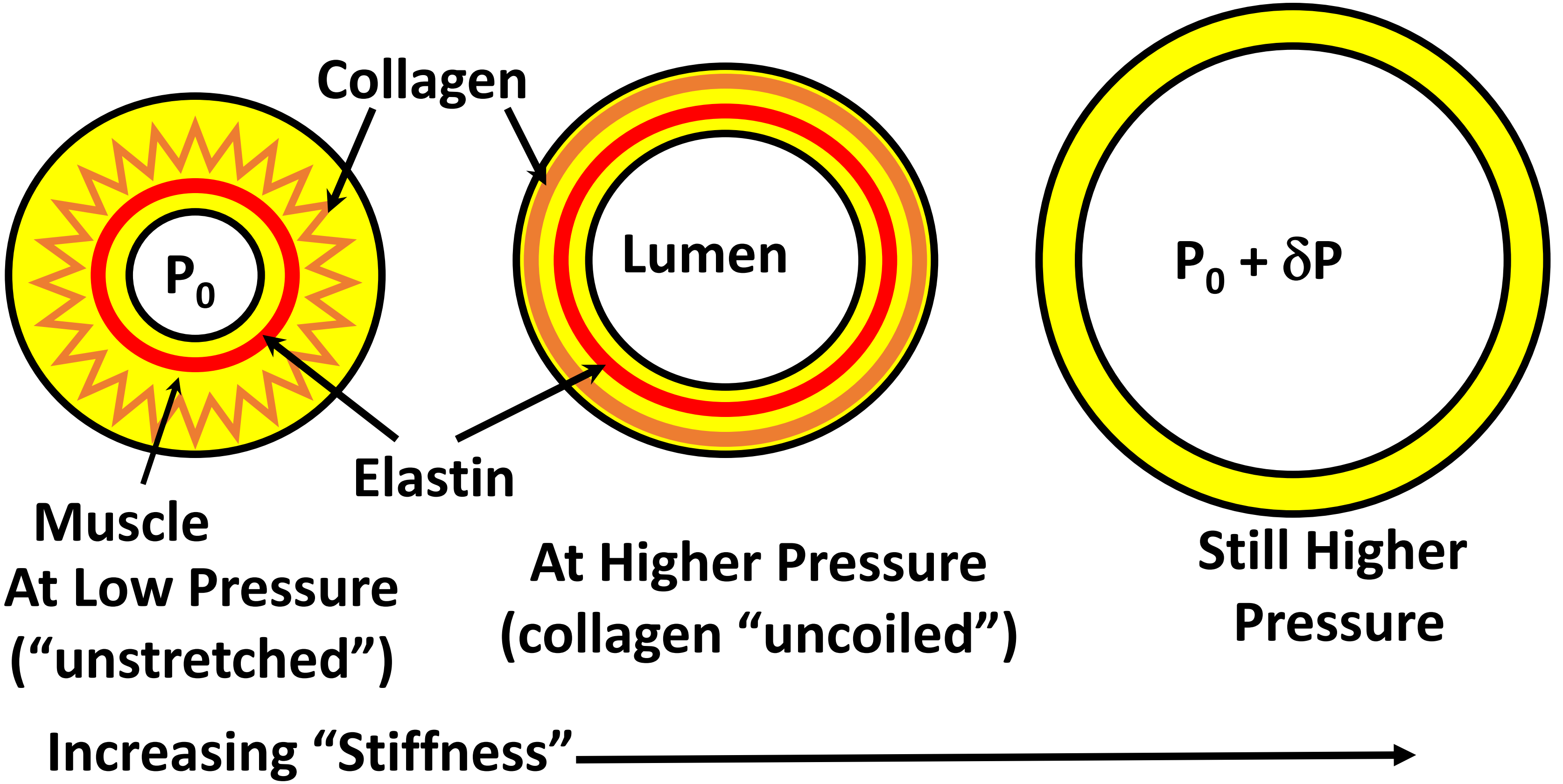
Vessel closed at both ends filled initially to Its Internal volume (V_0). Pressure is zero at V_0 → “Unstressed Volume”

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

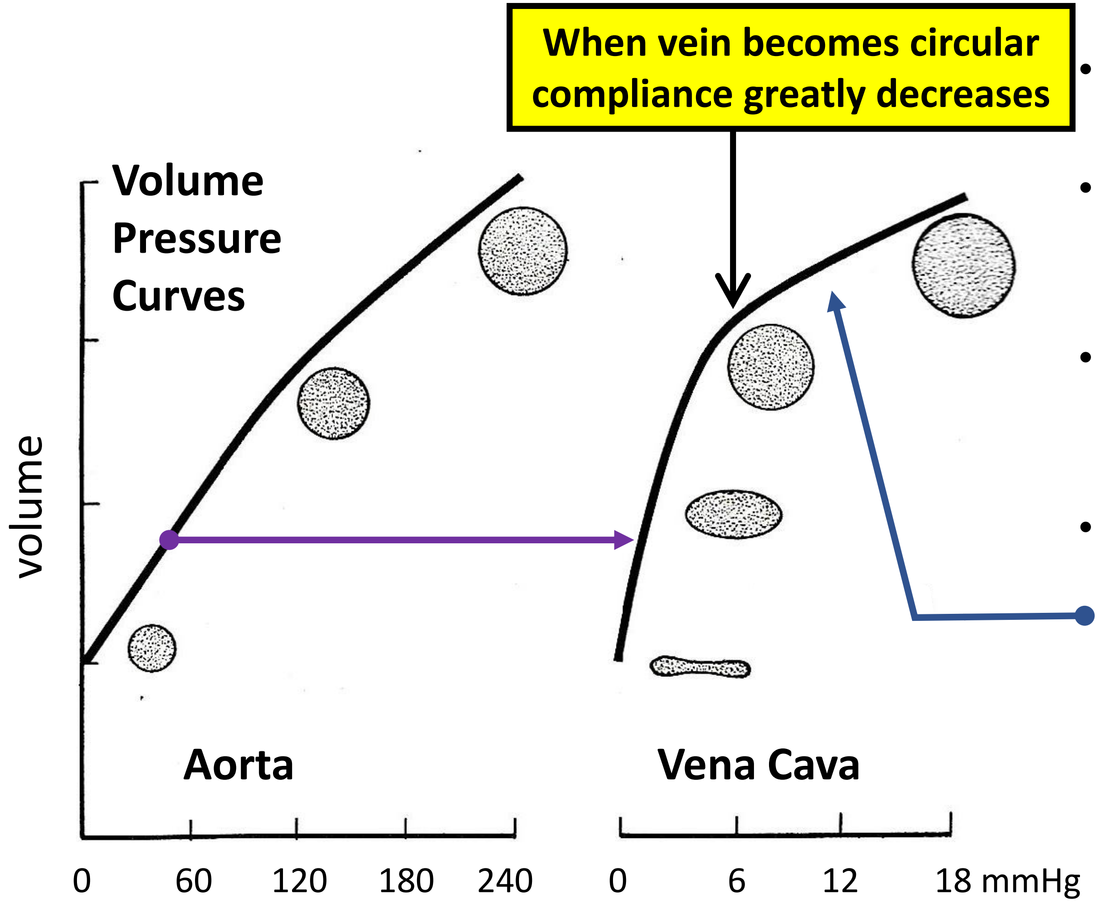
Transmural Pressure Effects

Increasing transmural pressure generally __________________ vascular compliance

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

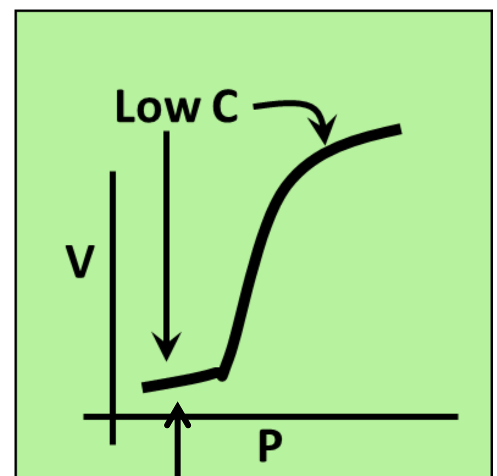


Arterial vs. Venous Compliance

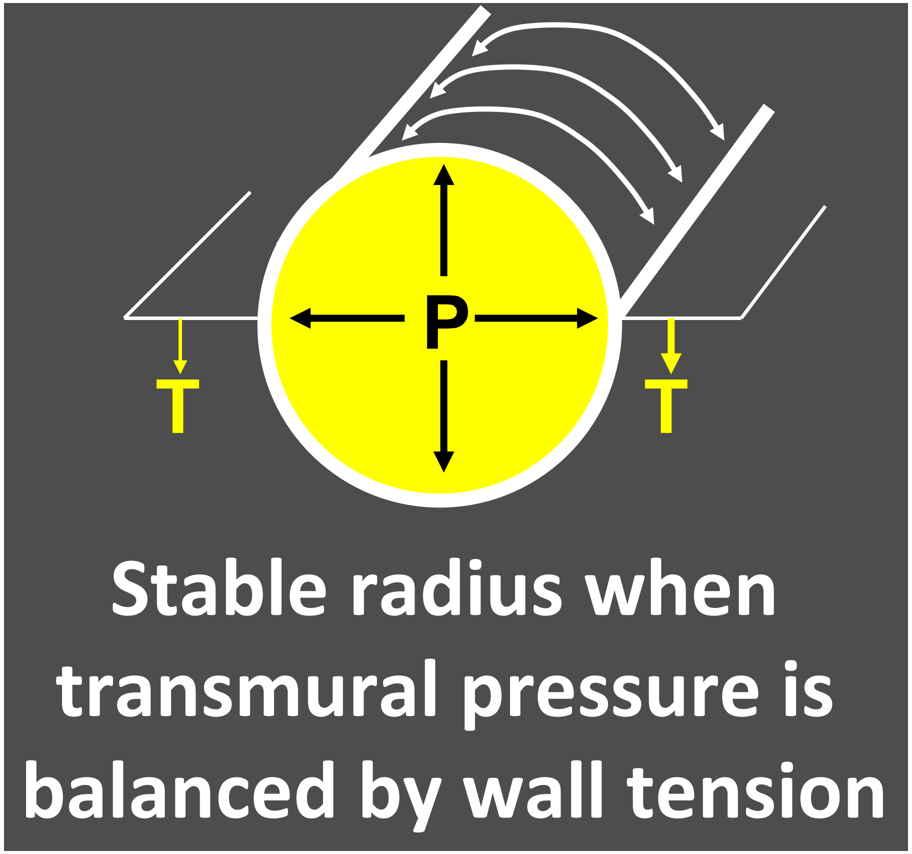


- At normal pressures venous compliance is greater than arterial
- This is shown by the greater slope of the volume-pressure curve for veins until they become circular
- With higher pressure expansion of veins must be done by engaging the stiffer collagen in the vein wall
- For large venous pressure 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



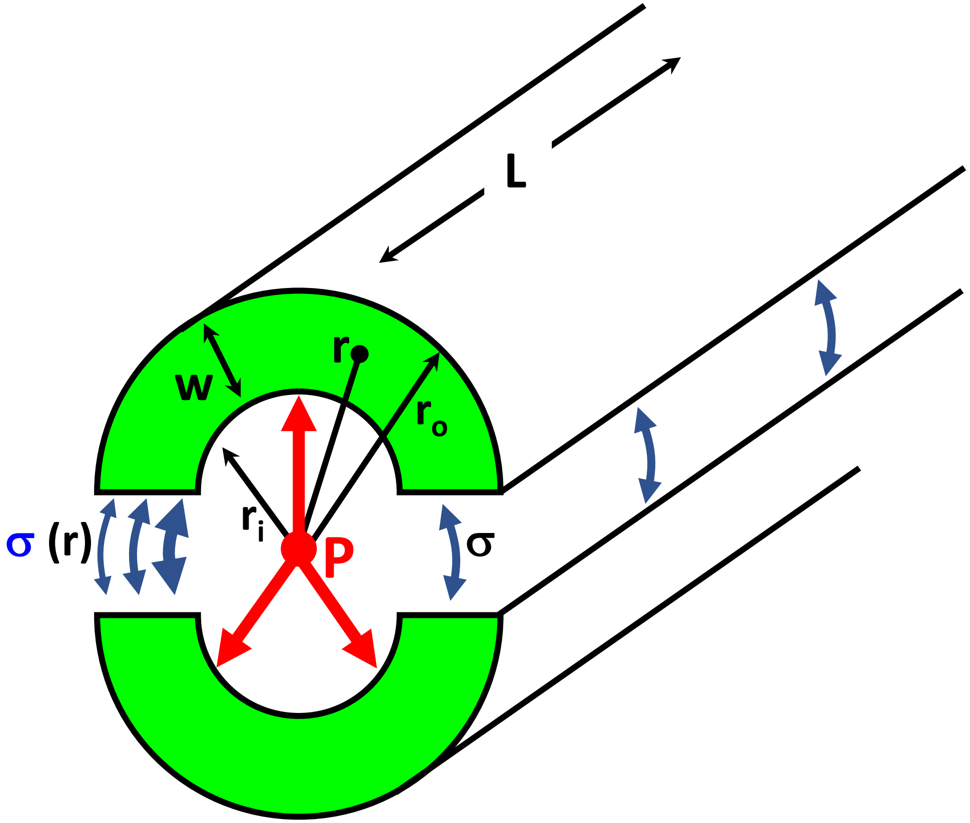
Simple Statement of Laplace's Law



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: Details



Laplace's "modified" Law for blood vessels
Wall stress in balance with distending force for equilibrium radius
$\sigma = P r / w$ → 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).

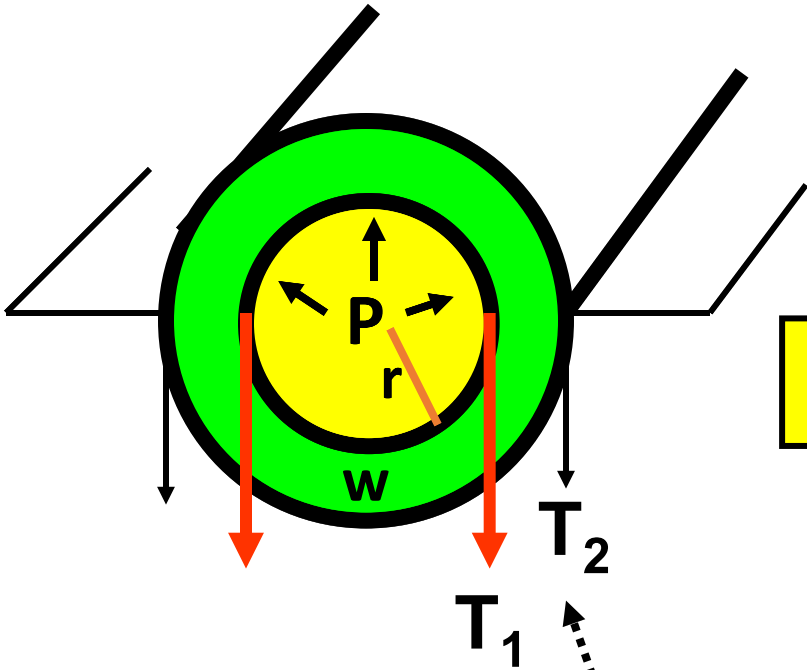
- To hold the two halves together there is a stress (σ) in the vessel wall acting in opposition to the distending force

The distending force/L = $P \times \pi r_i^2$
The restoring force/L = $\sigma \times \pi r_i w$

- Equating these yields $\sigma = (P \times r_i) / w$ which is the Modified Laplace's Law
  σ is the average stress in the wall

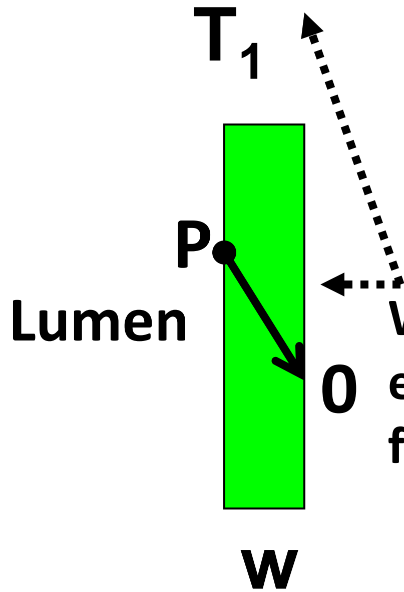
- The radial distribution of stress σ(r) is greatest at r_i and diminishes through the wall becoming least at r_o

Modified Laplace's Law: Summary for a blood vessel



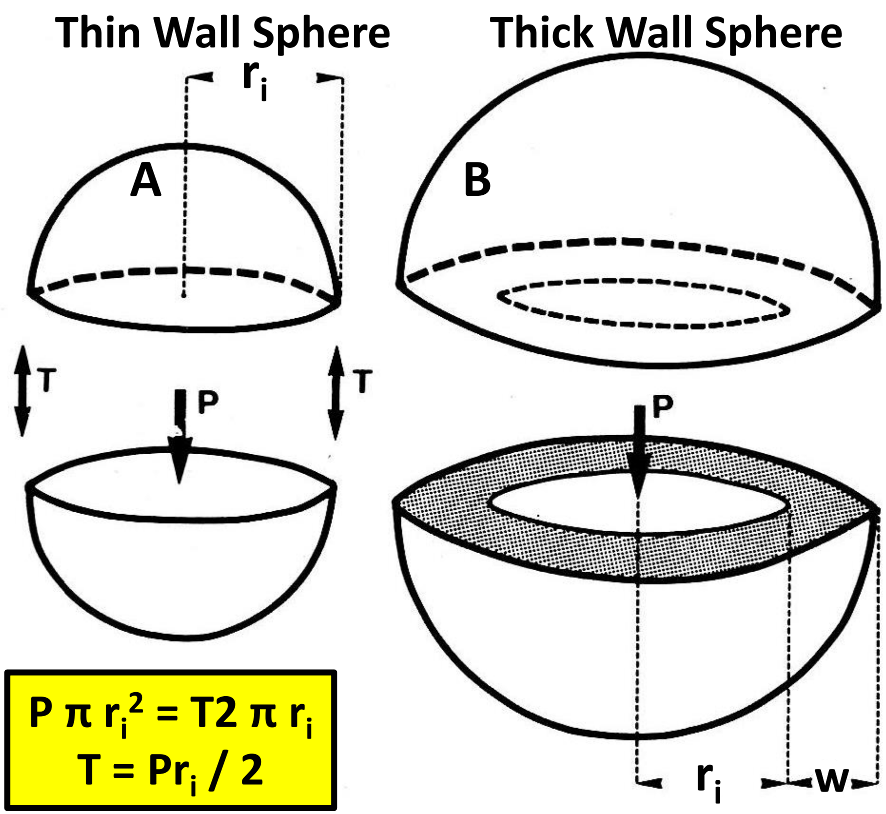
$\sigma = Pr/w = \langle S_\theta \rangle =$ "avg Tension"

Wall stress (σ) is more appropriate then tension



Wall tension needed for equilibrium decreases from inner to outer wall

Laplace's Law: "Heart"



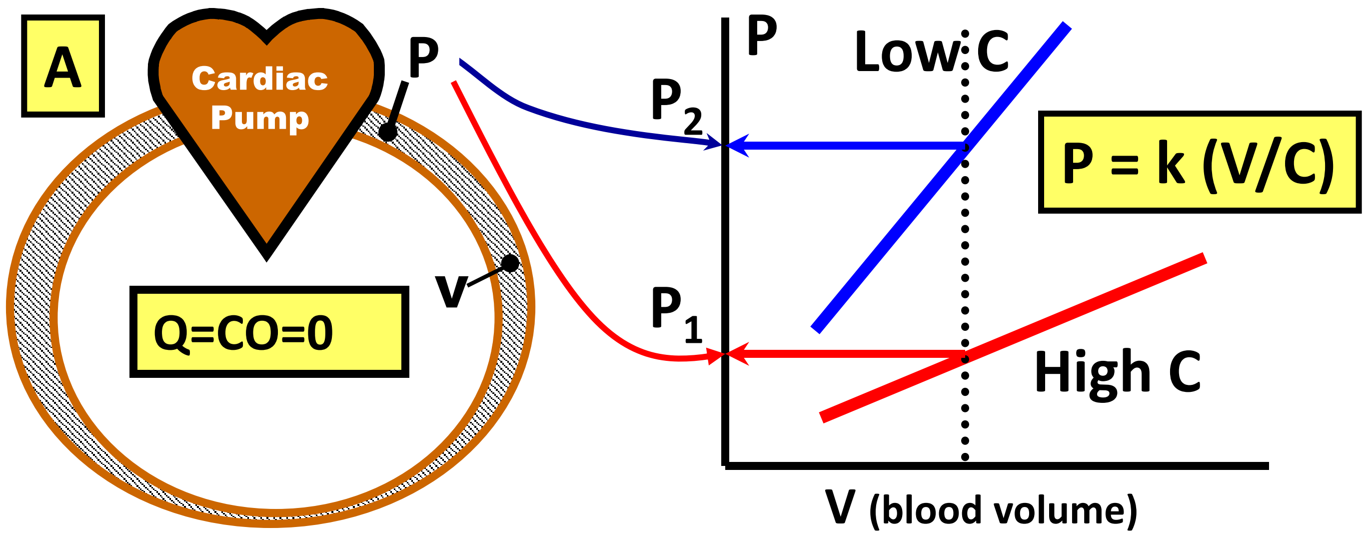
$P \pi r_i^2 = T 2 \pi r_i$
$T = P r_i / 2$

- 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
- $\sigma = Pr/2w$

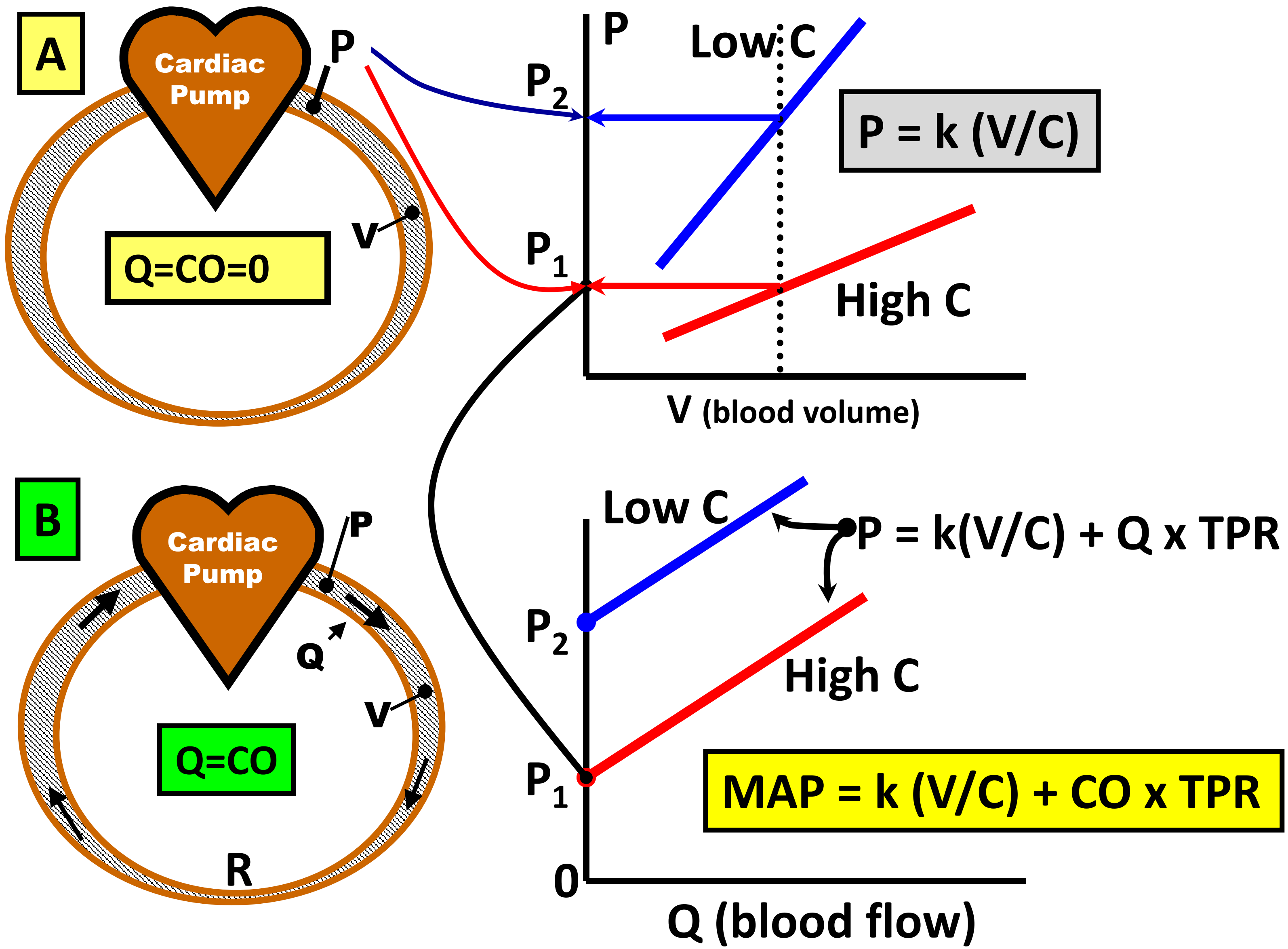
Laplace's "modified" Law for heart
Wall stress is in balance with distending force for equilibrium radius
$\sigma = P r / 2w$ → **Modified form for sphere**
P = transmural pressure
r = internal radius

Beware → Heart is not a sphere!

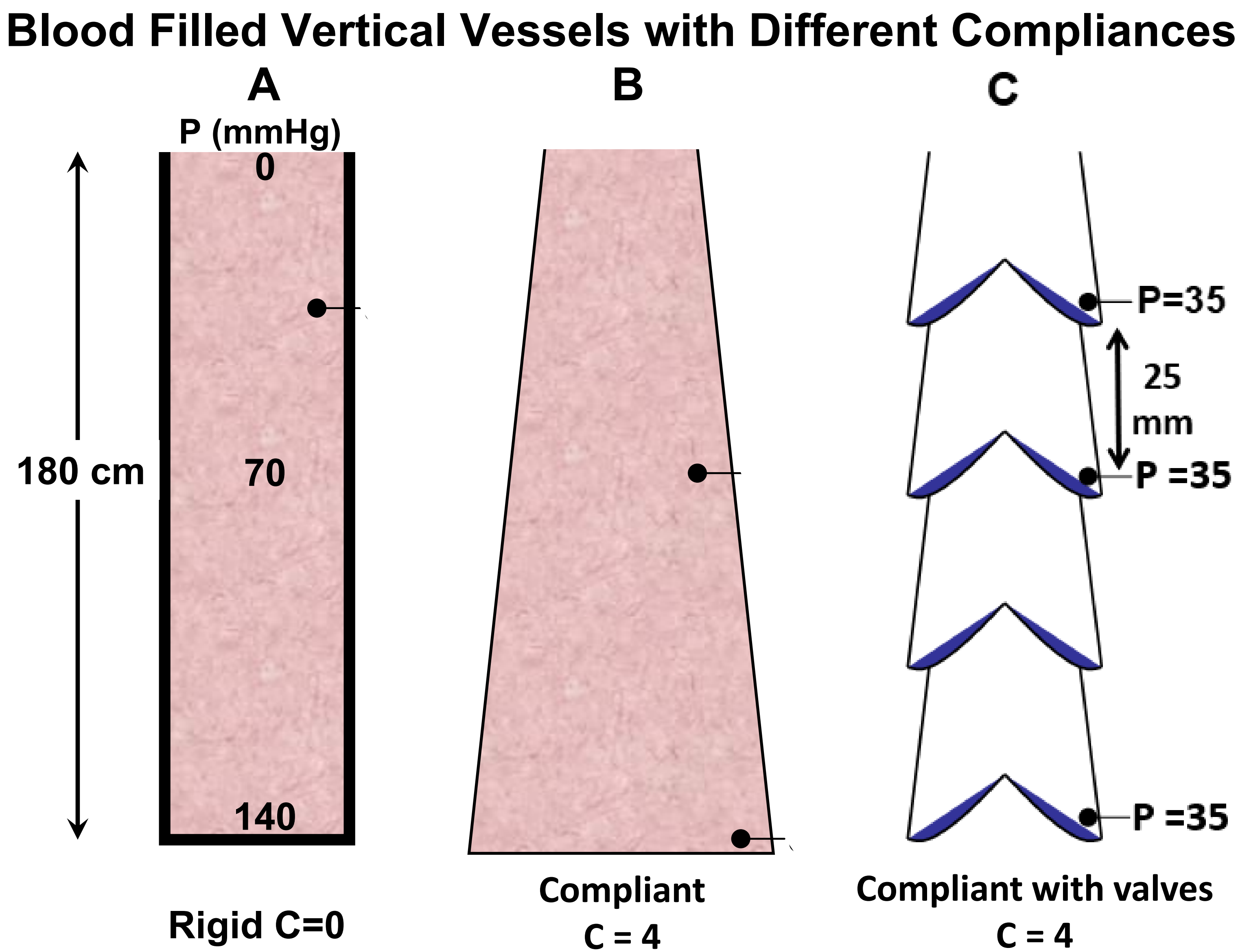
Compliance & Resistance are both BP Determinants



Resistance & Compliance are BOTH BP Determinants



Gravity – Compliance - Valves



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

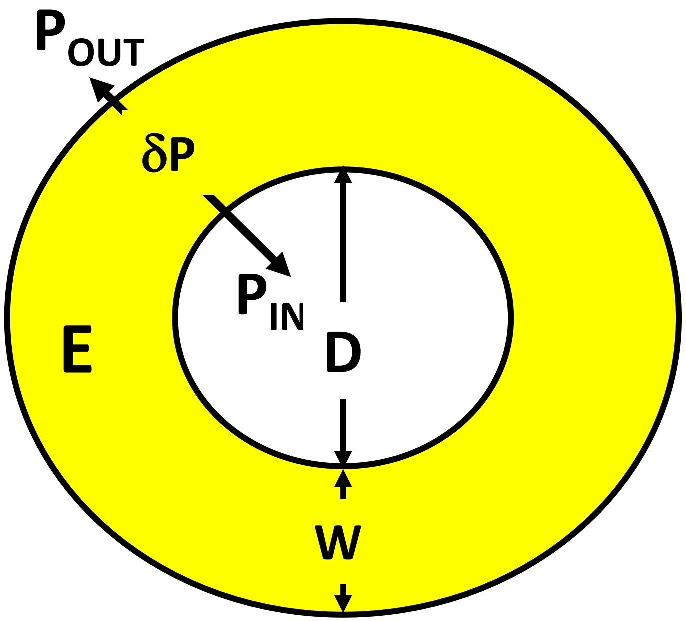
$$\delta P = \Delta V / C$$

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

↓

<u>Reduced Compliance</u>

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



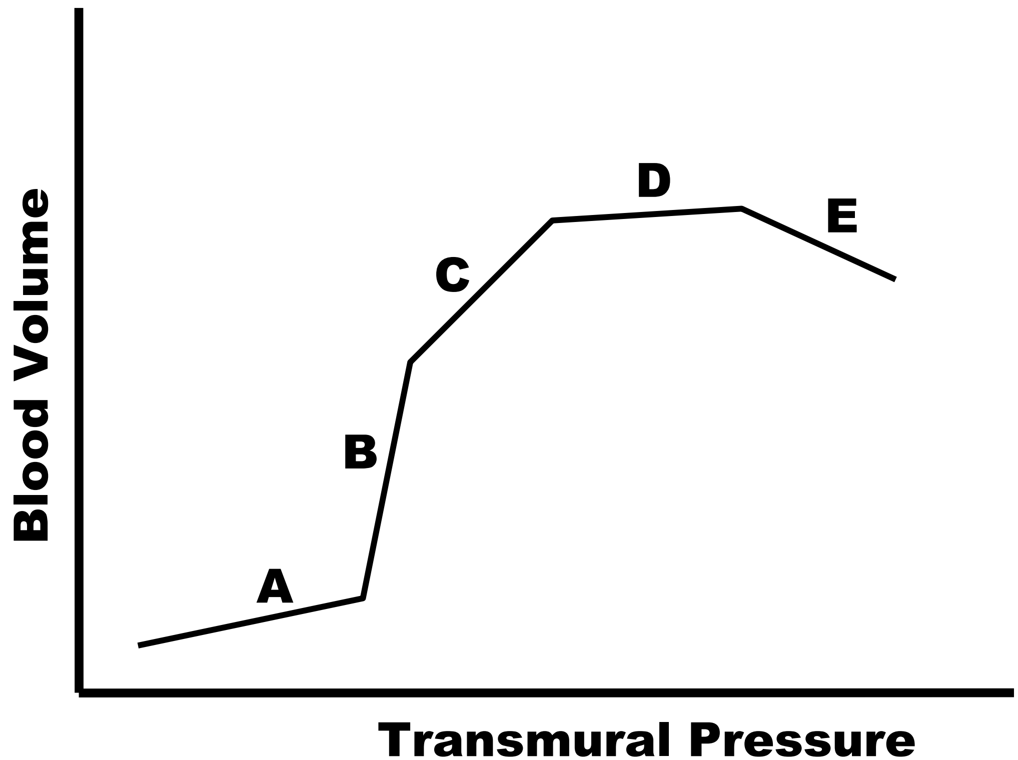
Interactive Question

start 5 10 15 20 25 30 **30 sec**

Which segment of the cardiac pressure-volume curve shows the greatest compliance?

A. A
B. B
C. C
D. D
E. E

Solution?



Interactive Review Question

start 5 10 15 20 25 30 35 40 45 50 55 60

The figure is a model of a standing child's circulatory system.

The resistance of each of the segments (A → E) = 0.02 pru.

P_0 ~ MAP = 120 mmHg and P_5 ~ CVP =20 mmHg.

If a 2 m blood column has 160 mmHg pressure at its bottom,

what is the value of the pressure P_2? 60 sec

A. 80 mmHg

B. 100 mmHg

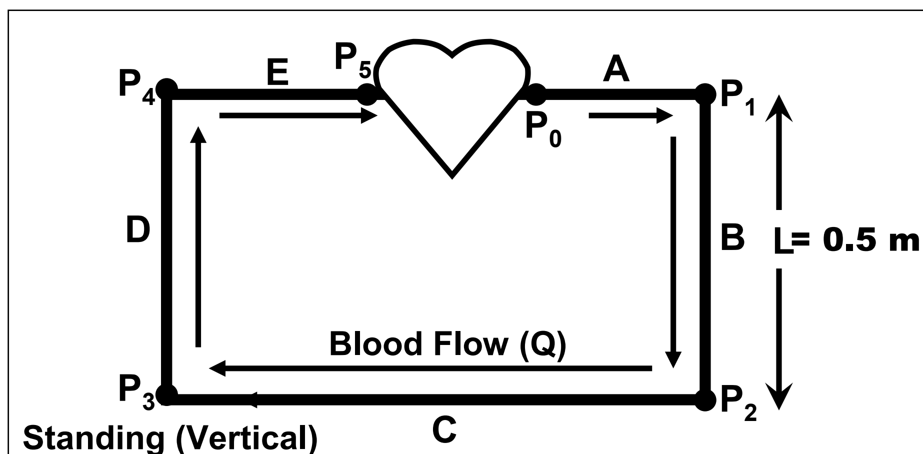
C. 120 mmHg ←

D. 140 mmHg

E. 240 mmHg

Solution?

Young child standing



End CV Physiology Lecture 6