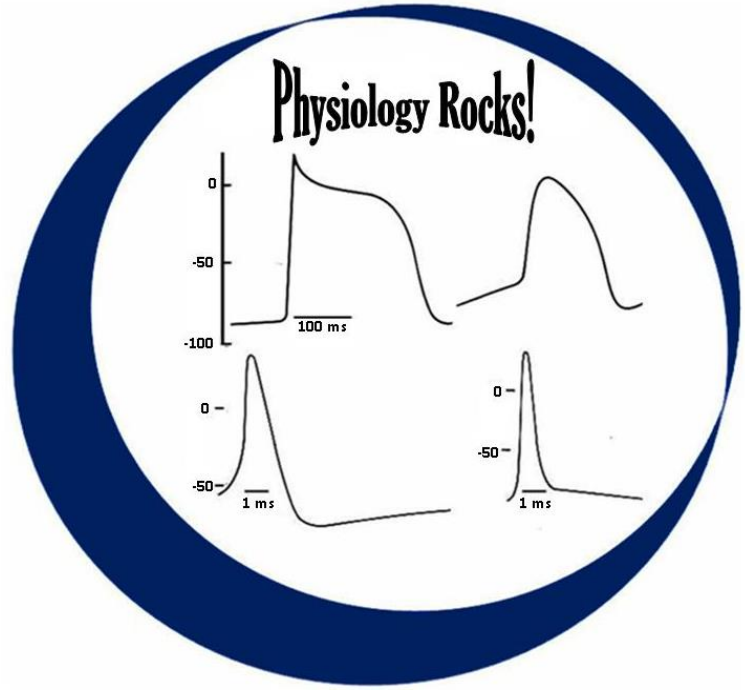
# Lecture 23
# Determinants of Cardiac Function

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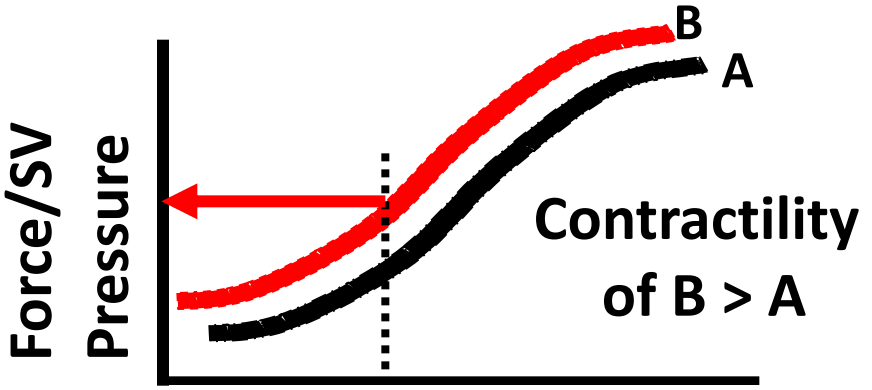
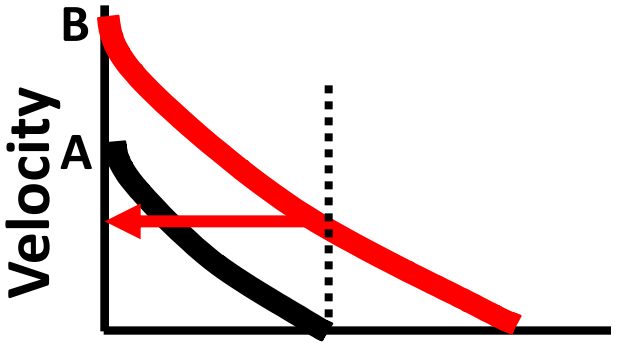
# Muscle Fiber Mechanics → Cardiac Pump Function



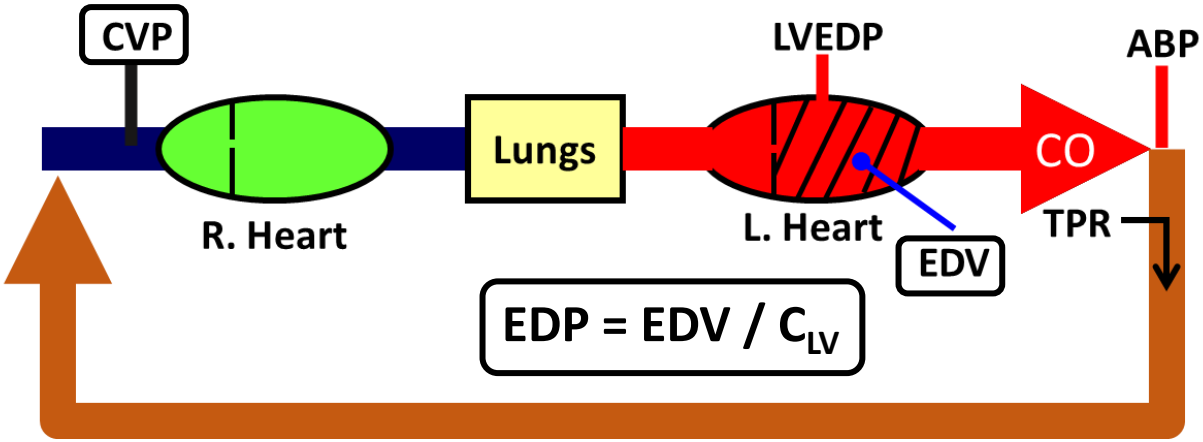

Preload

- *EDV*
- *EDP*
- *CVP*

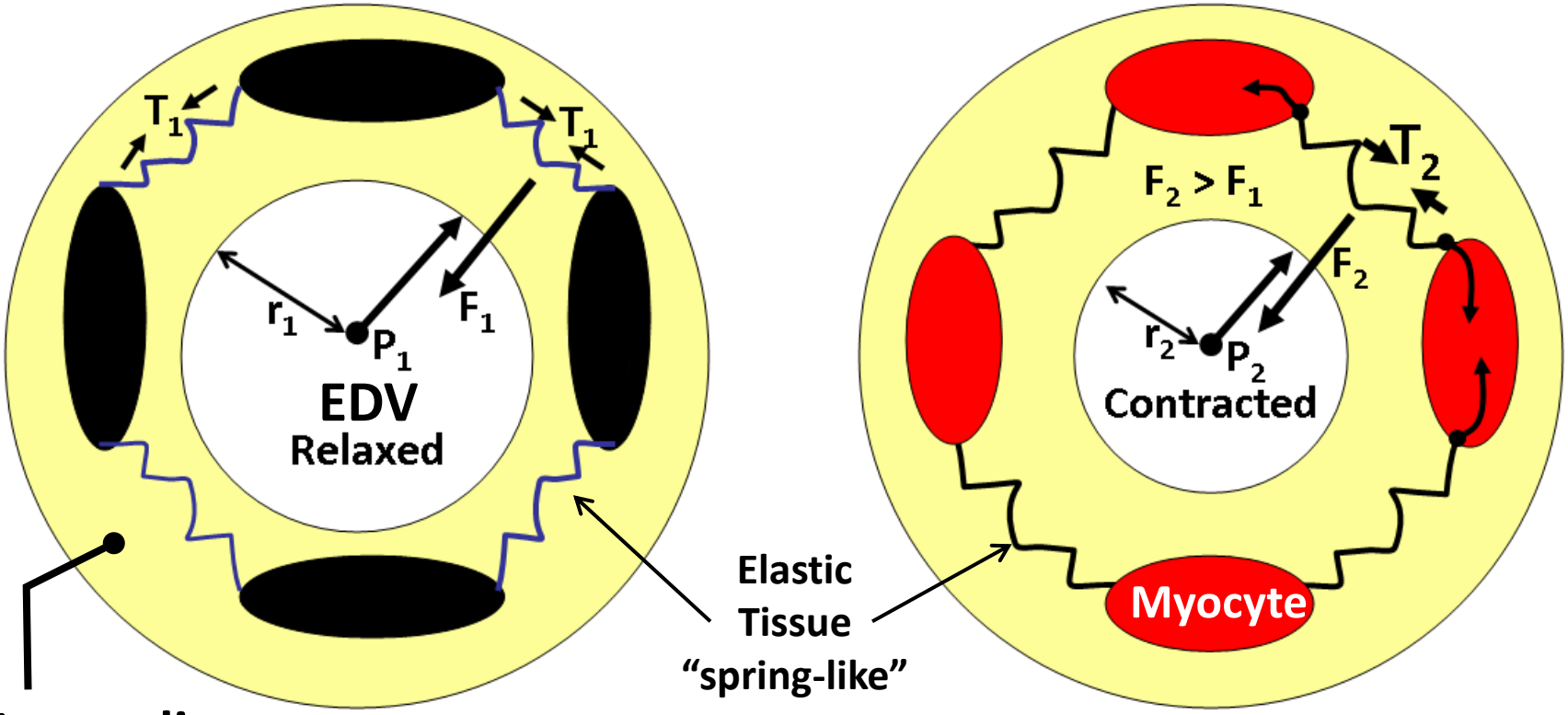



Afterload

- *Wall Stress (next slide)*
- *TPR*
- *Aortic/Ventricle Pressure*



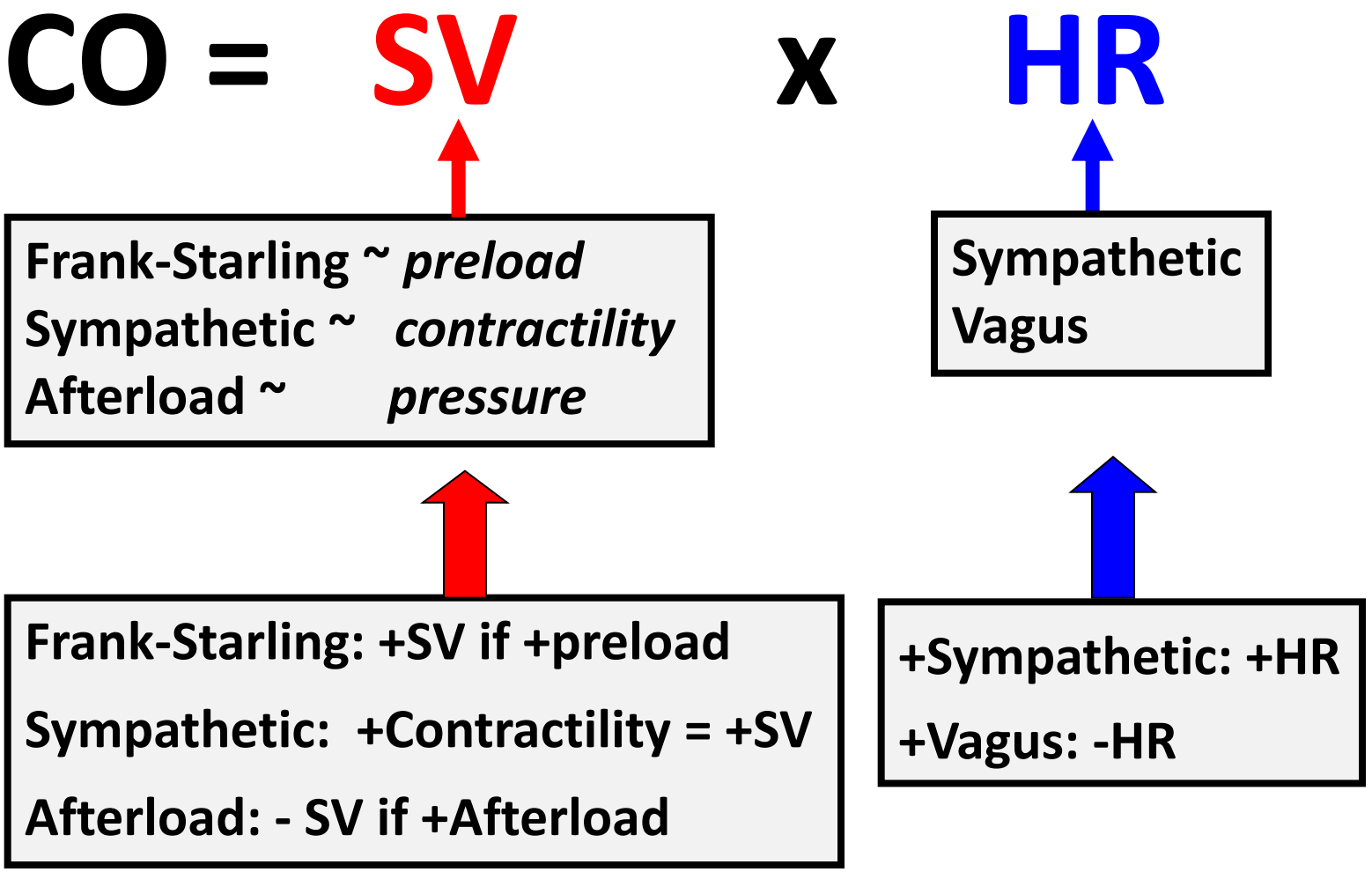
# Cardiac Muscle : Stress as Afterload



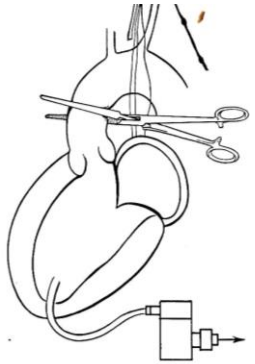

- Outward force due to $P_{TM}$
- Inward force due to wall T
- Equal and opposite at equilibrium

- Muscle contracts (systole)
- To shorten … myocyte must overcome tension (Wall Stress)
  AFTERLOAD
- Inward radial force increases ($F_2$)
- Chamber Radius decreases (r)
- LV Pressure increases
- Blood is ejected (Stroke Volume)

# Determinants of Cardiac Output



# Frank-Starling "Law" of the Heart



**Contraction force increases as EDV increases**
**Translates to increased SV as EDV increases**

**Peak Isovolumic Pressures achievable increases directly with increases in preload**

- ***Isolated Heart***
- ***Ejection prevented***
- ***Contractions are isovolumic***

**LV Pressure**

**Active Max-Systolic P-V Curve**

**Peak Isovolumic Pressure Line**

**Developed Pressure**

**Onset of systole**

**EDP**

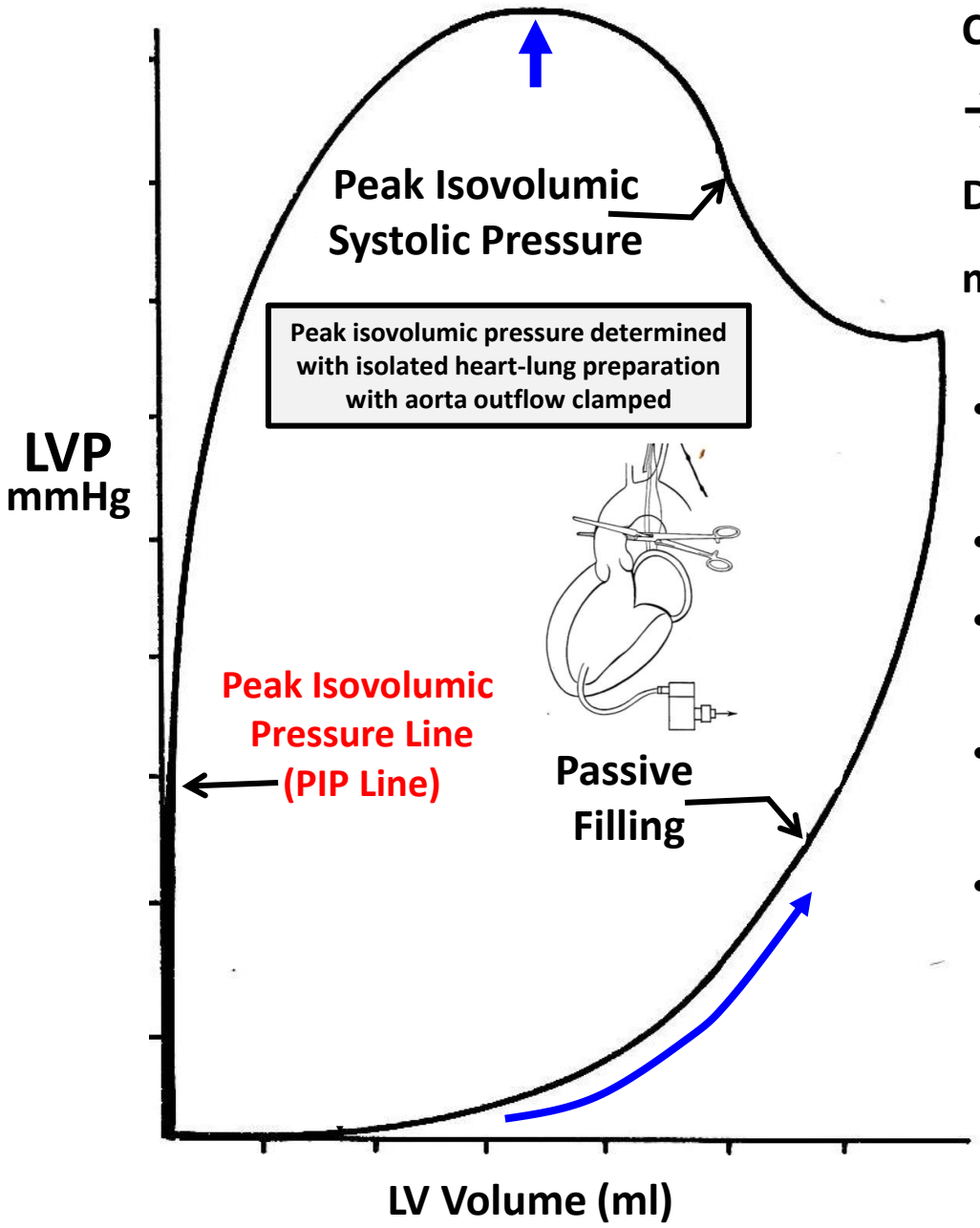
**Isovolumic Contraction**

1 2 3

**Passive Filling**

**LV Volume**

# Max Peak Isovolumic Left Ventricular Pressure (LVP)




**Clamped aorta with ventricle contracting**

**→ isovolumic contraction**

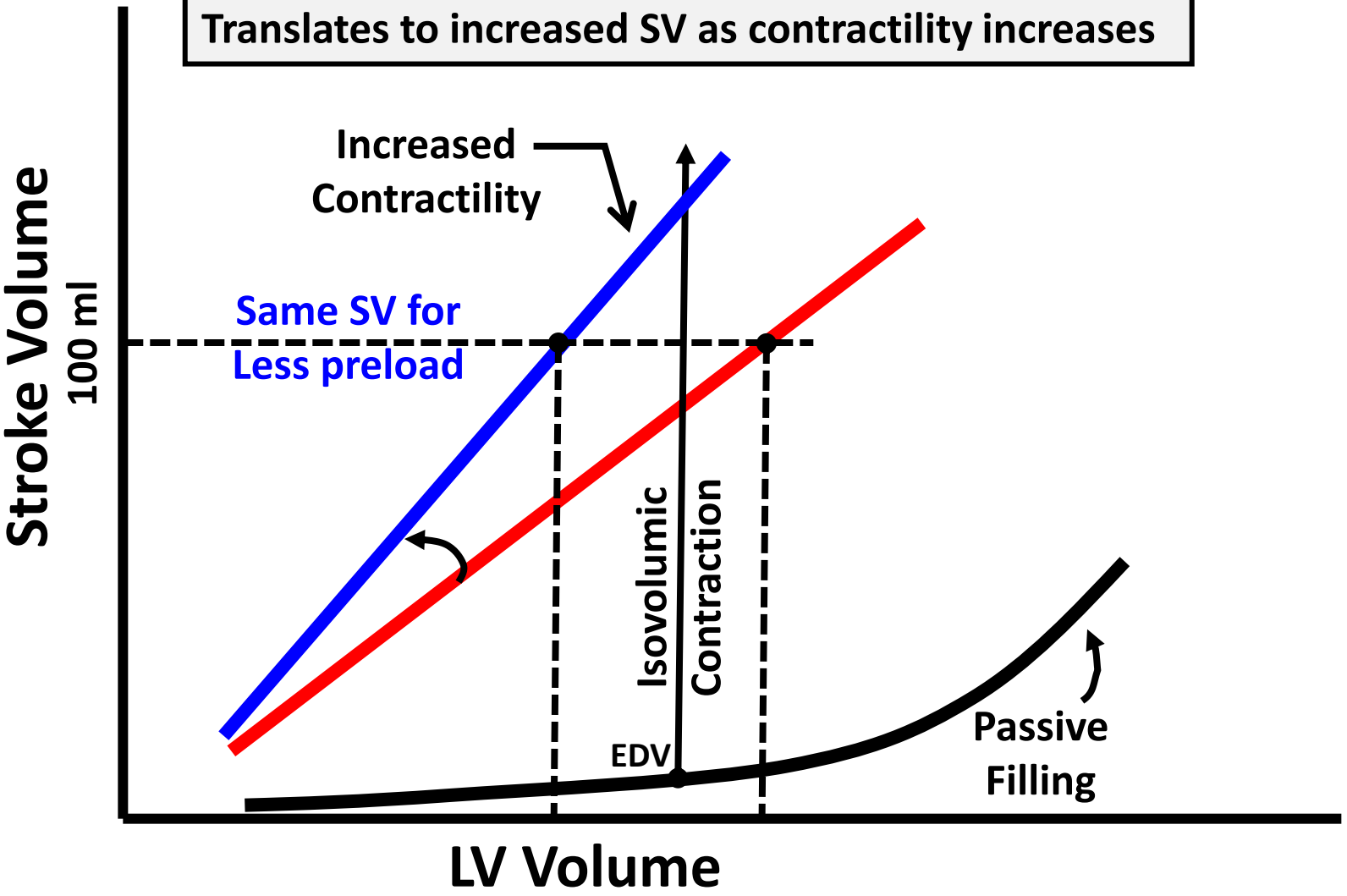
**Developed ventricular pressure is**

**maximum for its state of activation**

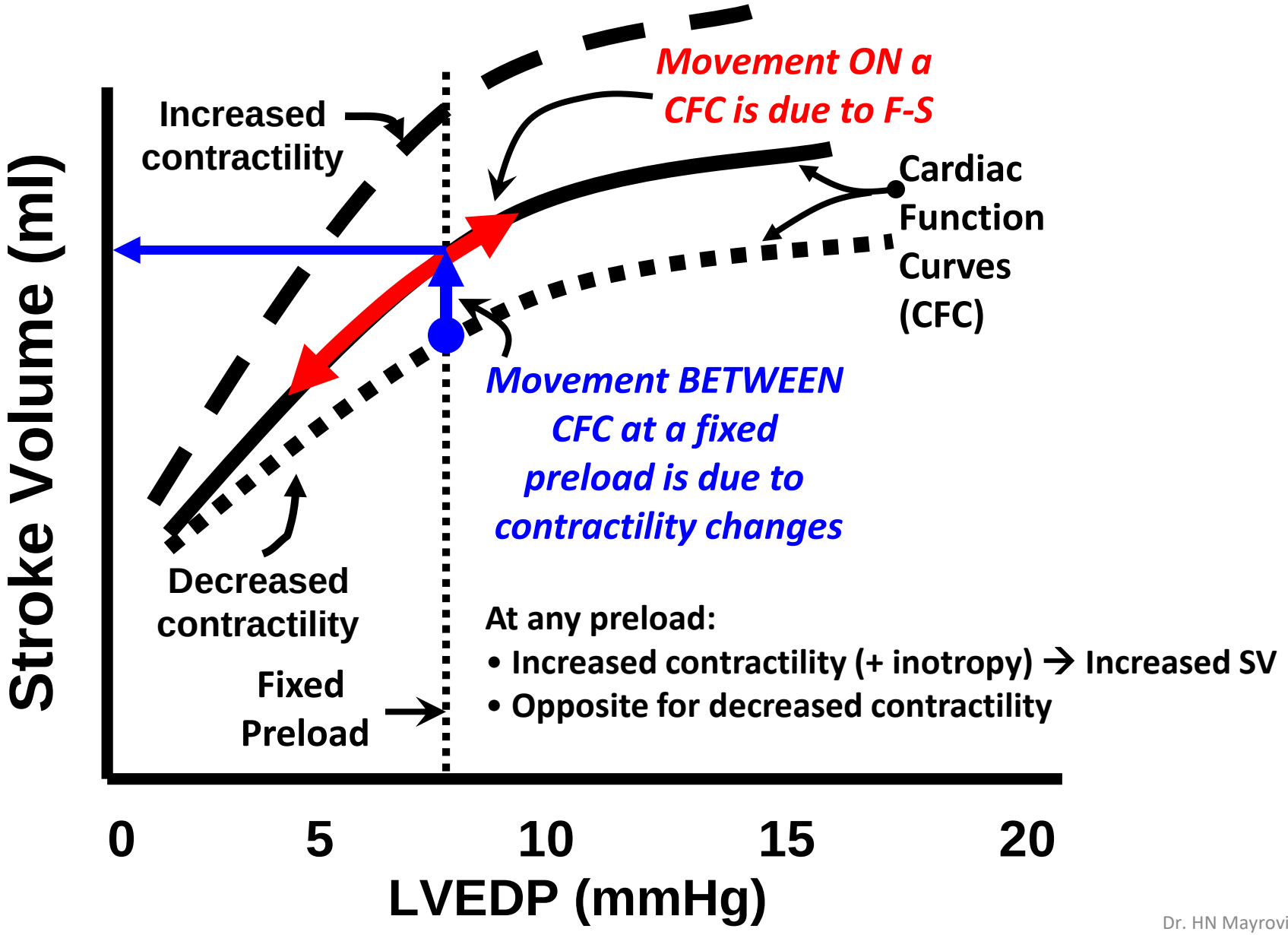
- **Heart contracts at different amounts of LV filling volume**
- **Peak LVP increases with EDV**
- **At a certain EDV peak and developed LVP starts to decline**
- **Occurs due to actin-myosin overlap less efficient at this stretch amount**
- **Ascending part of the peak isovolumic curve is a consequence of the Frank-Starling mechanism**

# Effects of Contractility on PIP Line

**Increased contractility increases PIP line slope**
**Translates to increased SV as contractility increases**



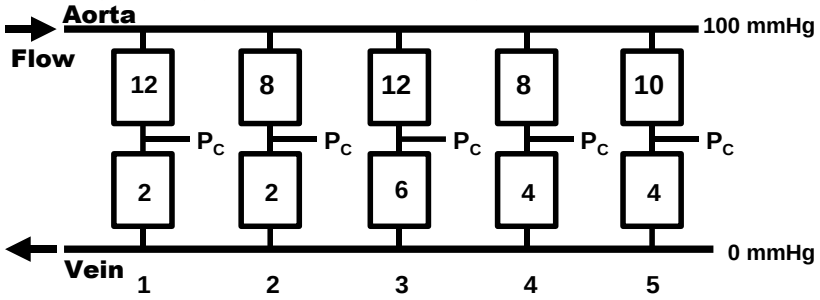
# Frank-Starling vs. Contractility



# Interactive "Review" Questions

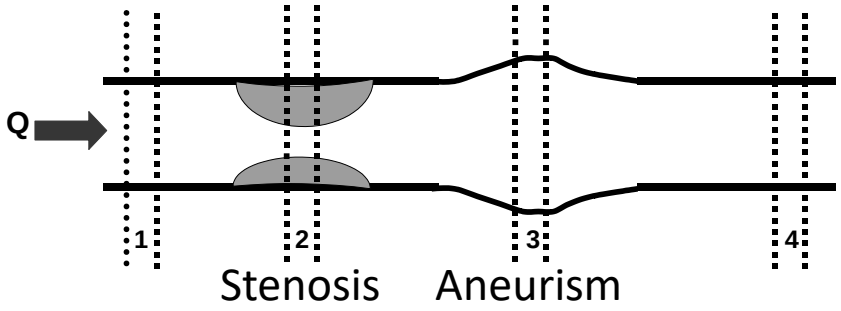
In which organ is capillary pressure 20 mmHg?

A. 1
B. 2
C. 3
D. 4
E. 5

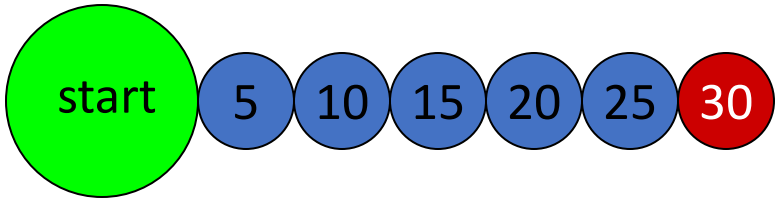



For the figure below, which one of the following statements is true?

A. Blood flow (Q) is greater in section 1 than in section 2
B. Average blood velocity is greater in section 1 than in section 3
C. Reynolds number is greater in section 1 than in section 2
D. Pressure loss across section 4 is greater than across section 1
E. Resistance of section 3 is greater than that of section 2



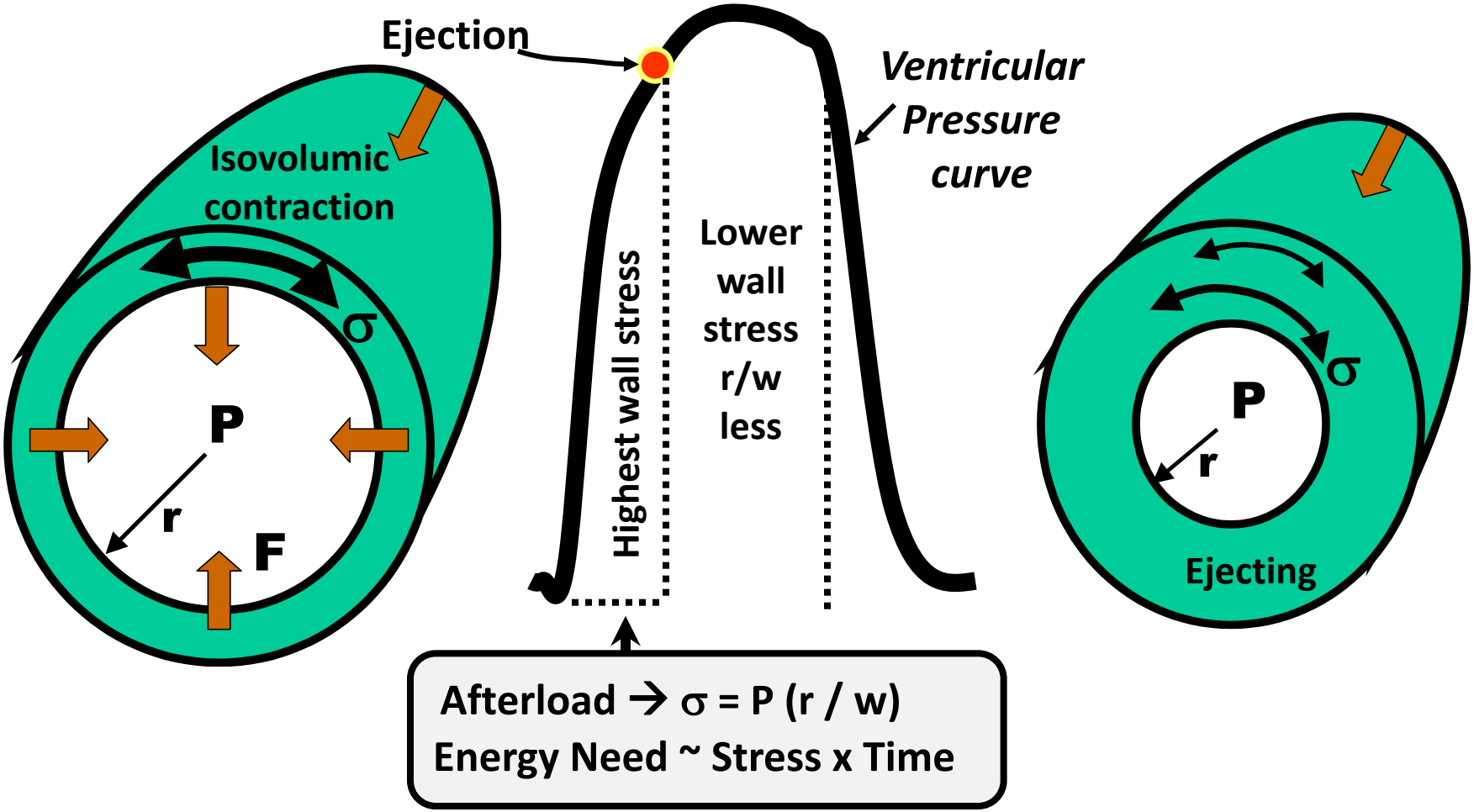
# Interactive "Review" Question




Maximum velocity of shortening ($V_{max}$) of myocardial fibers is mainly affected by changes in:

A. Preload
B. Afterload
C. End diastolic volume
D. Contractility
E. Diastolic blood pressure

# Ventricular Muscle's Load and Energy Demand



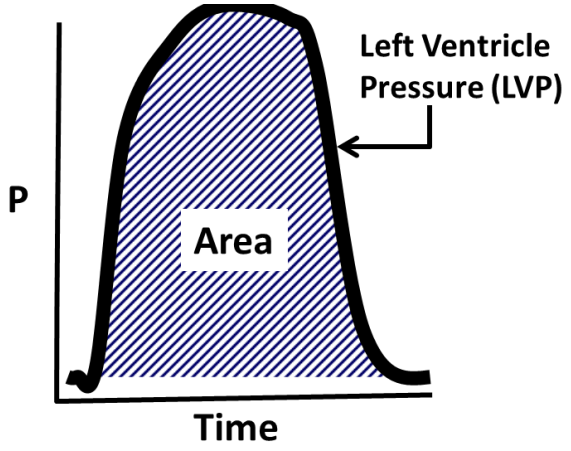

- Large $O_2$ demand during isovolumic contraction (large P and large r)
- Increased in conditions with elevated P (Aortic stenosis or Hypertension)
- $O_2$ demand during ejection also increased in conditions with elevated P

# Measures of Ventricle Energy Demand

- **Area under the P – T curve**

  **Increased P**

  **Increased duration**




- **Tension Time Integral (TTI)**

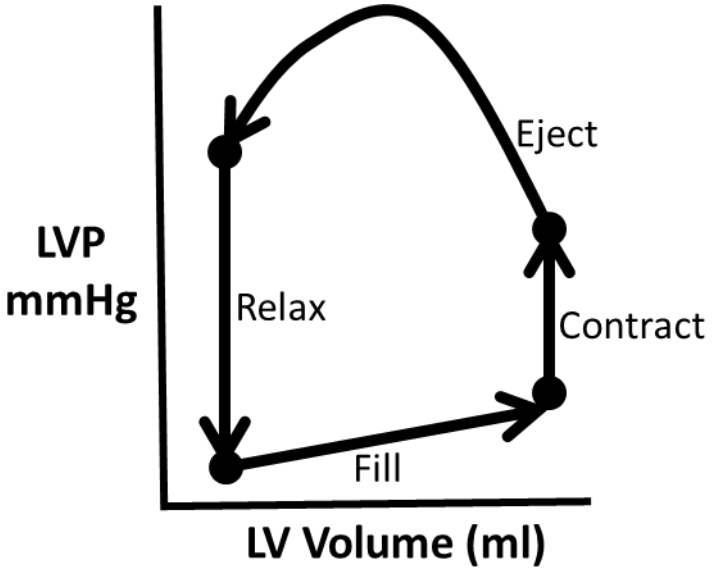
$$\int \sigma(t) = \int [P(t) \times r(t) / w(t)]$$

- **Double product (MAP X HR)**

  **Clinically Measurable**

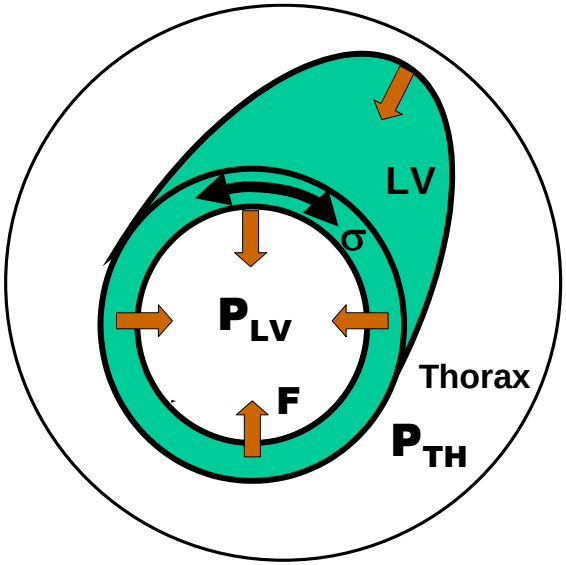
  **Clinically Useful**

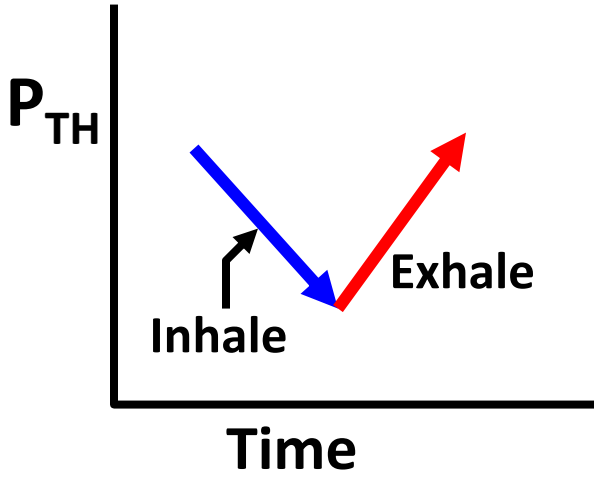
  **Does not include SV component**




**Stroke Work = loop area = $\int PdV$**

# + Intra-thoracic Pressure → + 'Afterload' Effect

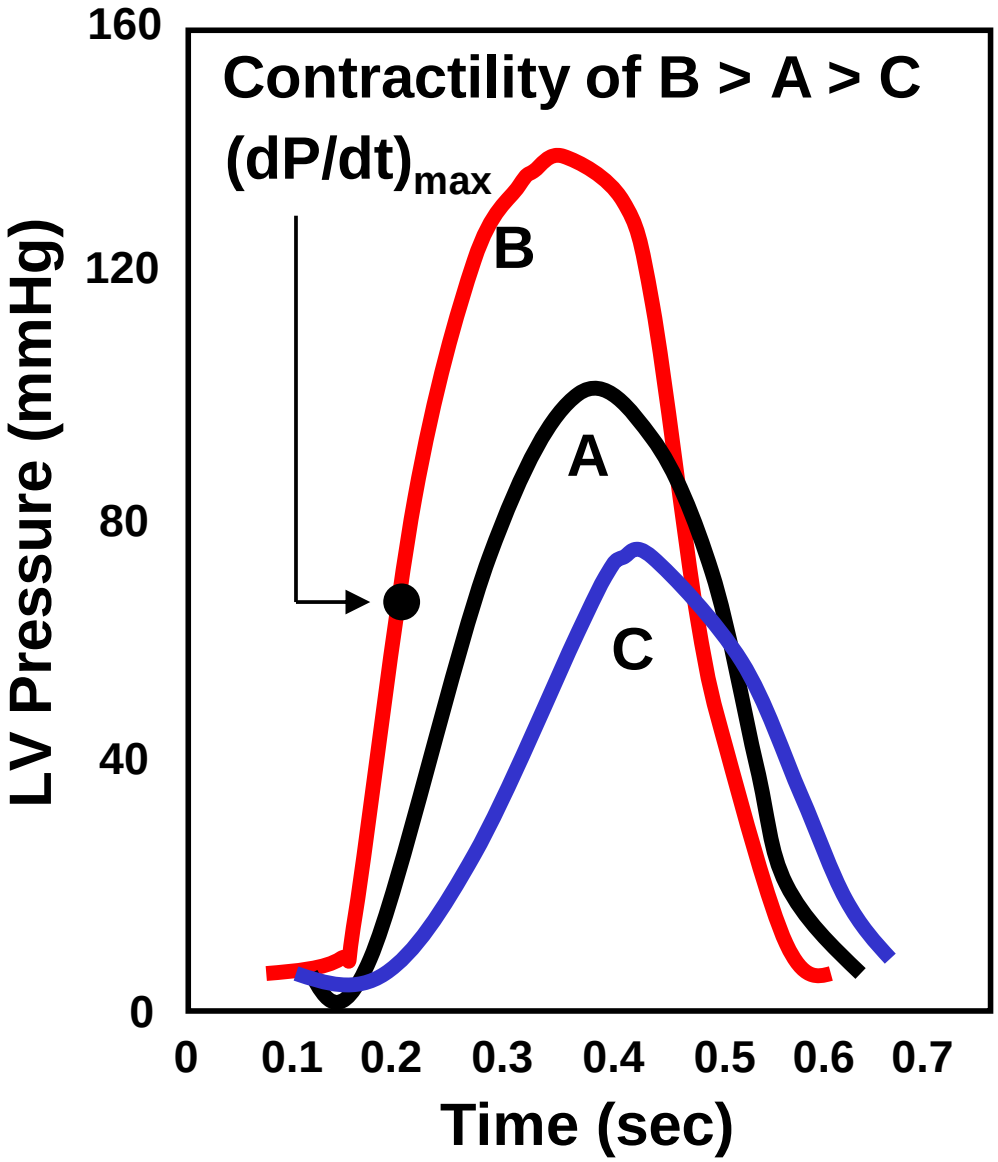


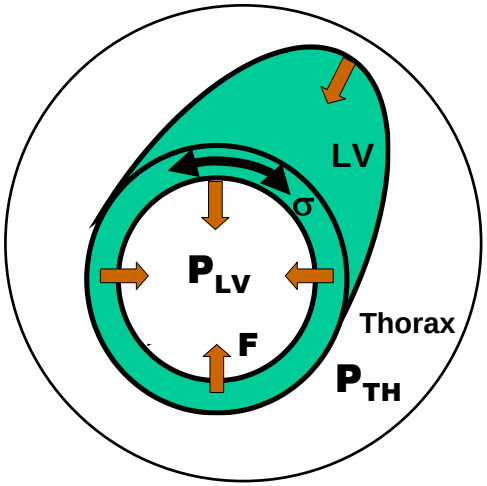

**Afterload → $\sigma = P\ r / w = (P_{LV} - P_{TH})\ (r/w)$**

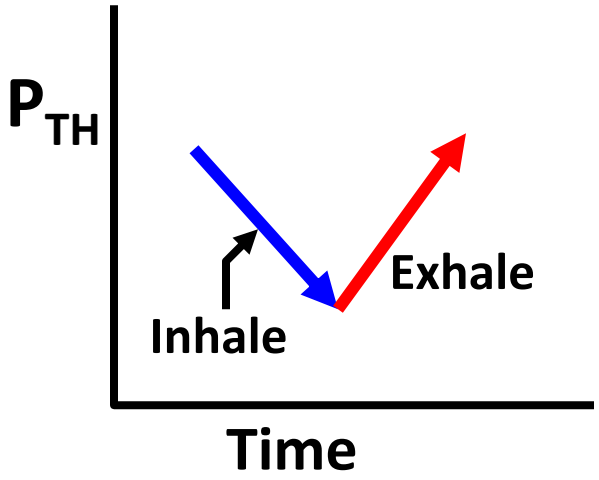
**During a deep inspiration against a closed glottis $P_{TH}$ can decrease substantially causing a substantial increase in the LV transmural pressure. This increases the effective afterload and may reduce SV**

# Contractility Effect on LVP



# If Large decrease in intrathoracic Pressure → + 'Afterload' Effect



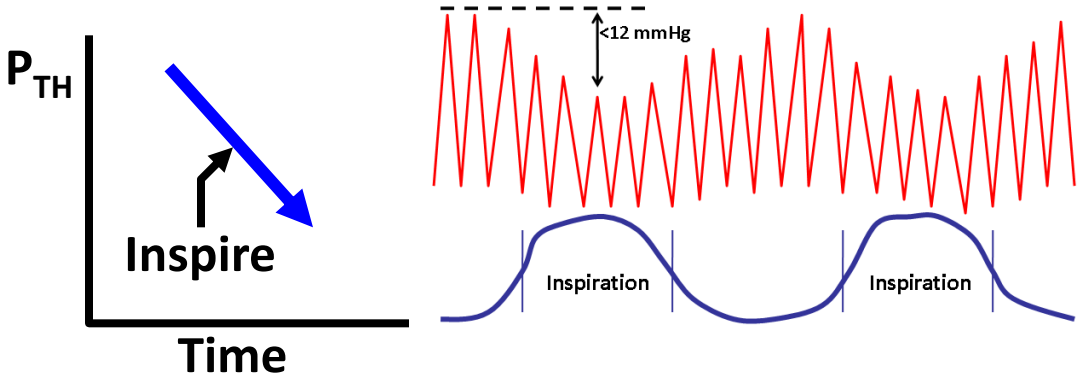




$$P_{TM} = P_{LV} - P_{TH}$$

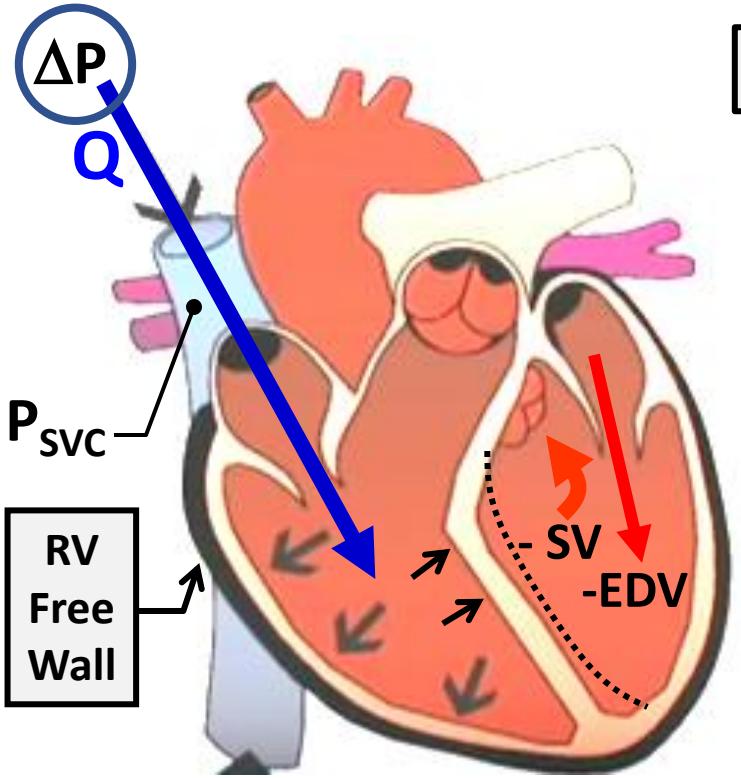
During a deep inspiration against a closed glottis $P_{TH}$ can decrease substantially causing a substantial increase in the LV transmural pressure. This increases the effective afterload and may reduce SV

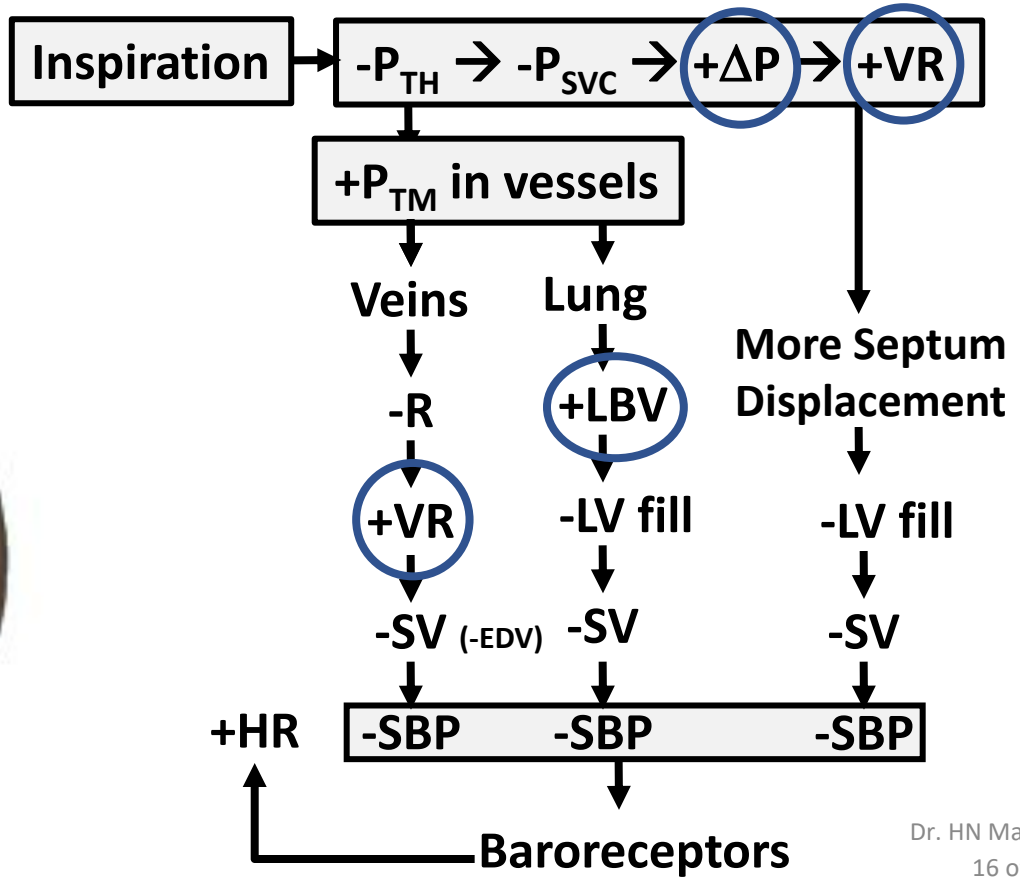
***Pulsus Paradoxus*** → Abnormally decreased systolic pressure (peripheral pulse) during inspiration

# Normal Variation is Systolic BP with Respiration

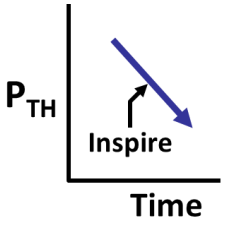


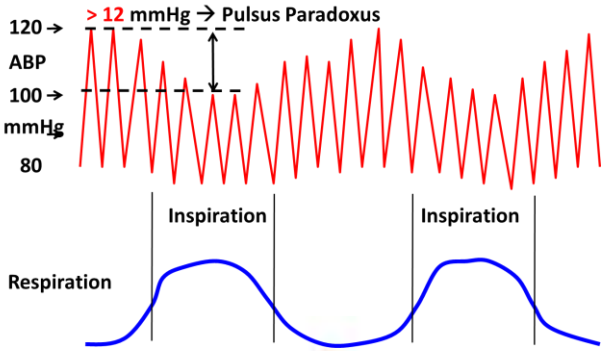

- During inspiration
  - small septum shift & + Lung BV (LBV)
  - small Left Ventricle SV decrease
- Causes small decrease in systolic BP (<12 mmHg)
- Increased venous return (VR) to RH can cause similar effects
- If > 12 mmHg then Pulsus Paradoxus



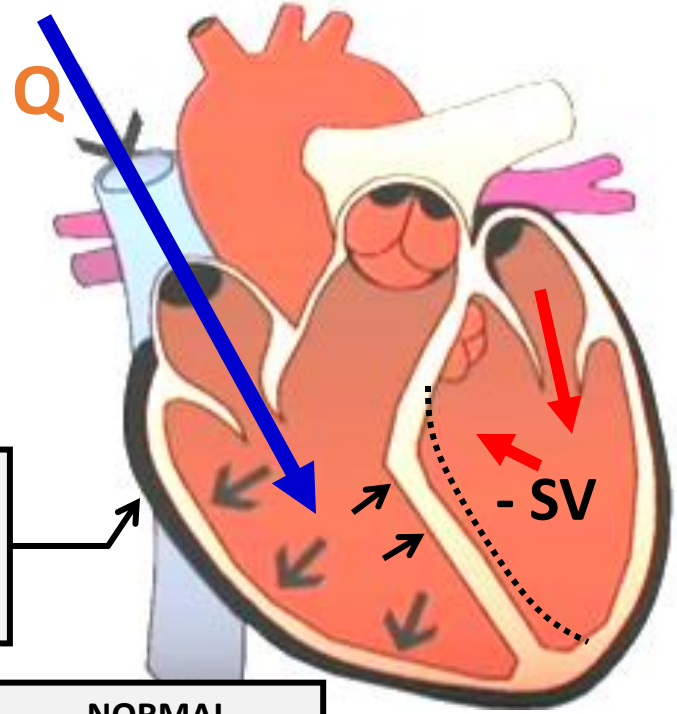
# Abnormal Variation is Systolic BP with Respiration



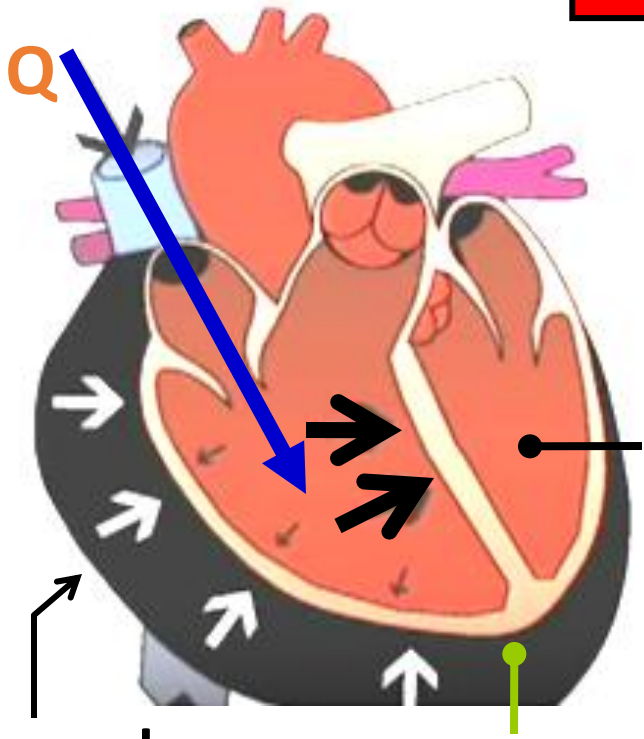




**Pulsus Paradoxus**

**ABNORMAL**
**LARGE decrease**
**In Systolic BP**



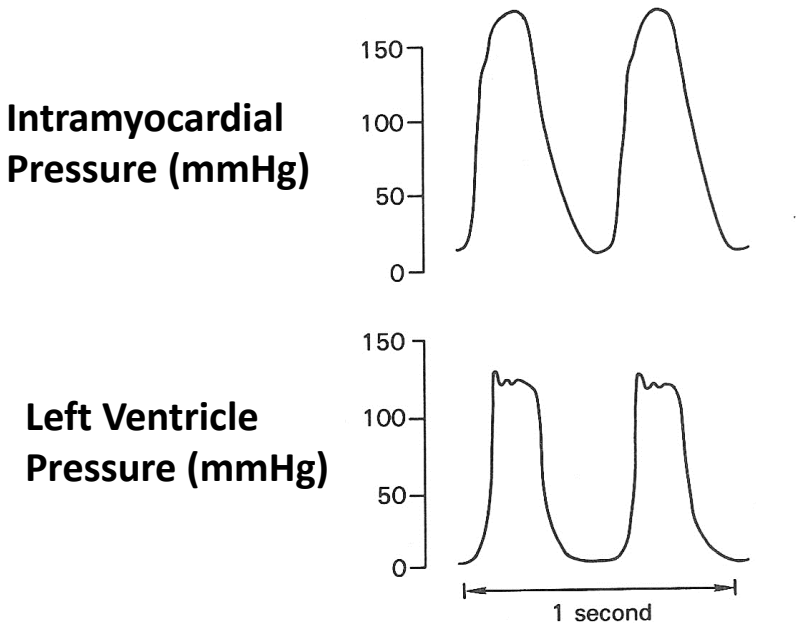

**NORMAL**
**Small decrease**
**In Systolic BP**

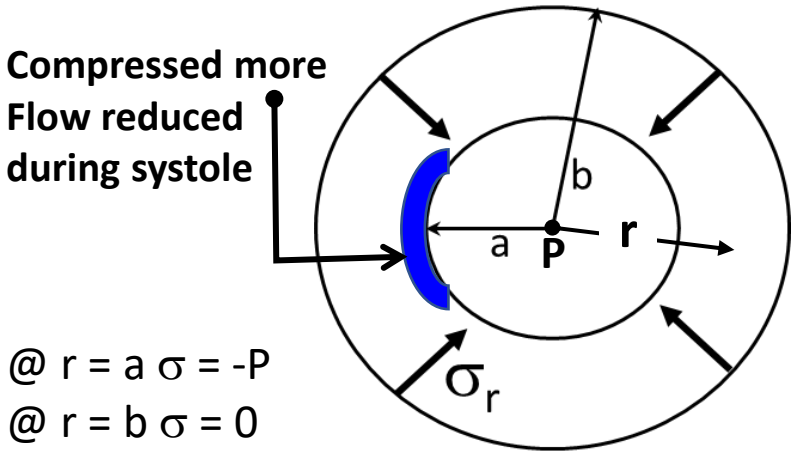



**Tamponade** — **Fluid in pericardial sac**

- **RV free wall can't easily expand during filling**
- **RV pressure rises and further displaces (bows) the septum inward**

# *Intra*-Myocardial Pressures




@ r = a $\sigma$ = -P

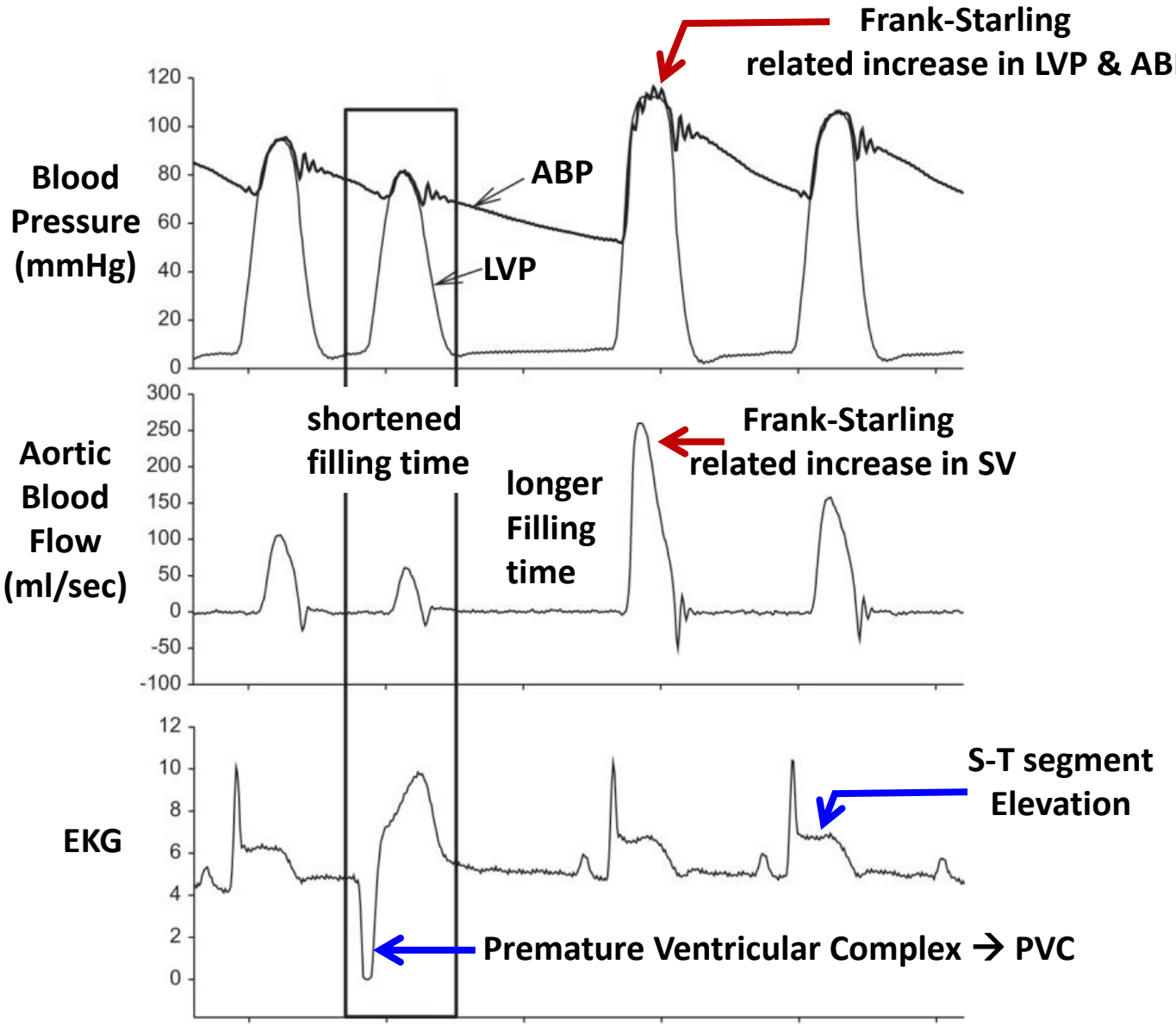
@ r = b $\sigma$ = 0

$$\sigma_r = [a^2P/(b^2-a^2)] \times (1 - b^2/r^2)$$

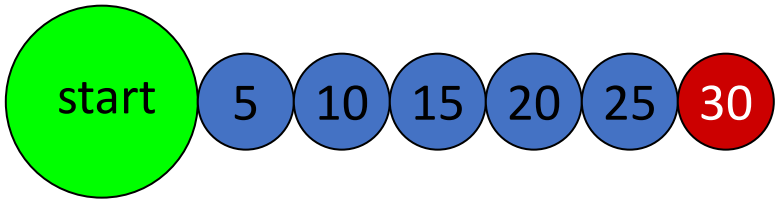
- Contraction increases ventricular pressure and intra-myocardial pressure
- Stress in myocardial wall (radial and tangential) with contraction is greater towards endocardial vs. epicardial surfaces
- Consequence is that during contraction the blood vessels toward the endocardial surface (subendocardial) are compressed more and blood flow is compromised more
- This contributes to the increased vulnerability of the endocardial part of the ventricle wall to ischemia and injury when perfusion pressure is reduced
- Also explains why most of subendocardial blood flow occurs during diastole

After: Pfluegers Arch 1963;278:181 cp196

# Clinical Correlation: Patient with MI and PVC



# Interactive Question




Which of the following, if increased, would most likely increase blood pressure If the change was the only change?
Note on this question there can be more than one choice!

a) arteriolar diameters
b) vascular resistance
c) stroke volume
d) cardiac output
e) blood viscosity
f) blood volume

End Lecture 21
MCQs as time permits