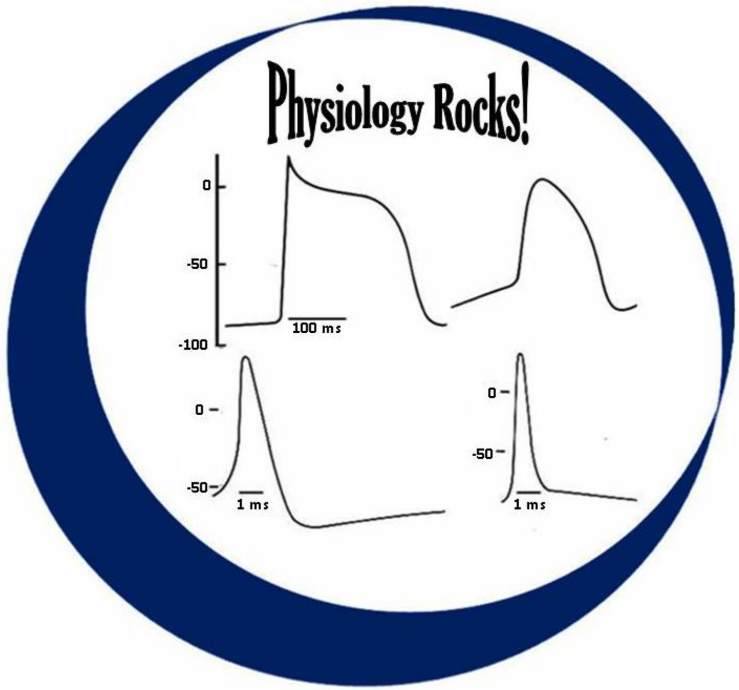
Lectures 10 -11

Pump Failure and Hemodynamics



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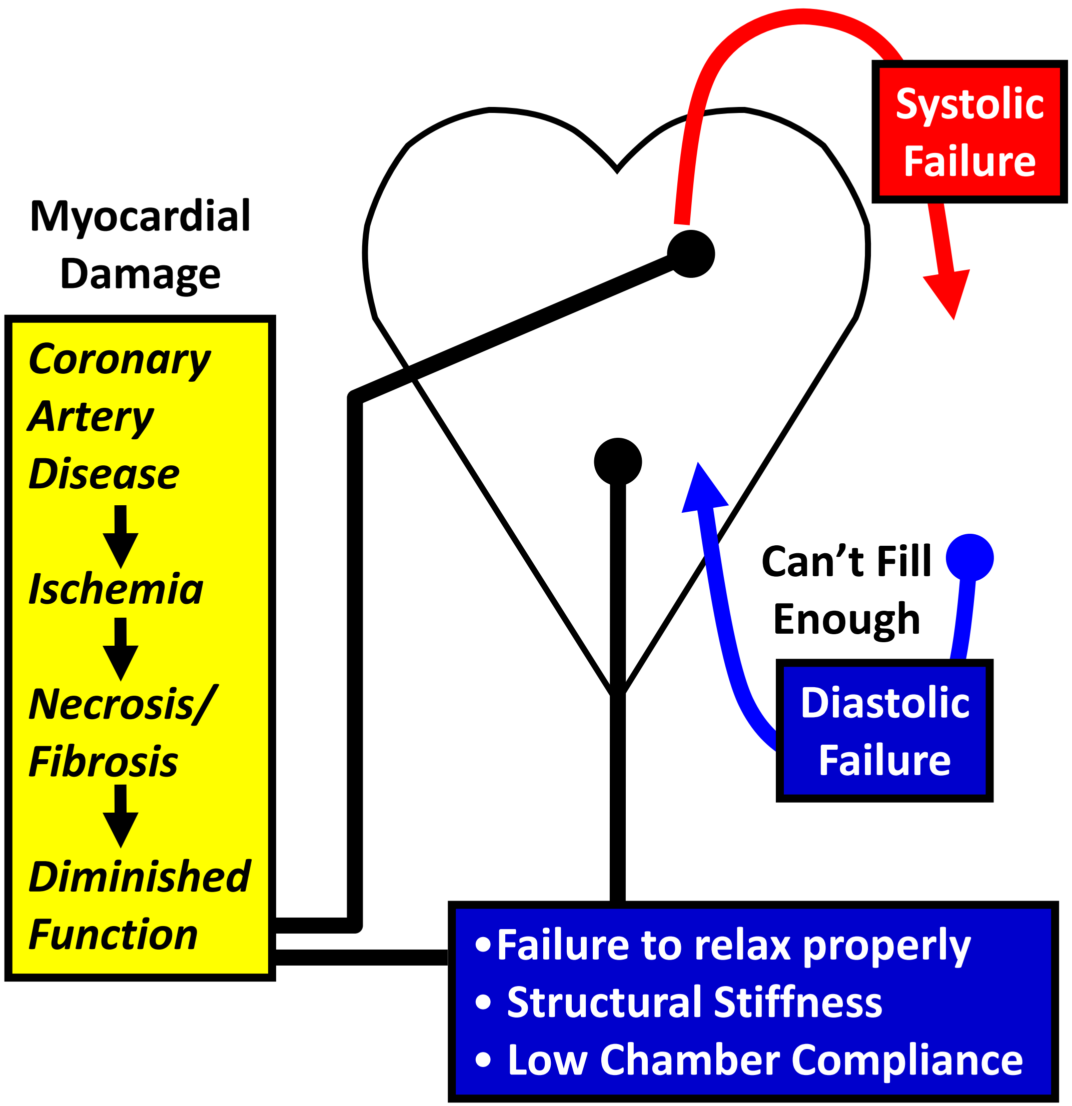
Topics

- Heart failure overview
- PV loops for systolic and diastolic dysfunction
- Cardiac valve conditions affecting cardiac function
- Aortic stenosis
- Mitral stenosis
- Aortic regurgitation
- Mitral regurgitation
- PV loops for cardiac valve conditions
- Cardiac adaptations to volume and pressure overloads
- PV loops associated with cardiac remodeling
- Murmurs of cardiac valve conditions
- Valsalva hemodynamic responses
- Interactive questions at various insertions

Pump Failure → Heart Failure: Overview



PUMP FAILURE

May develops rapidly ('Acute')

- **M.I.**
- **Infection**
- **Post bypass surgery**

May develop over Time ('Chronic')

- **Pressure overload as with:**
  hypertension (HTN)
  aortic stenosis (AS)
- **Volume Overload as with:**
  aortic regurgitation (AR)
  mitral regurgitation (MR)

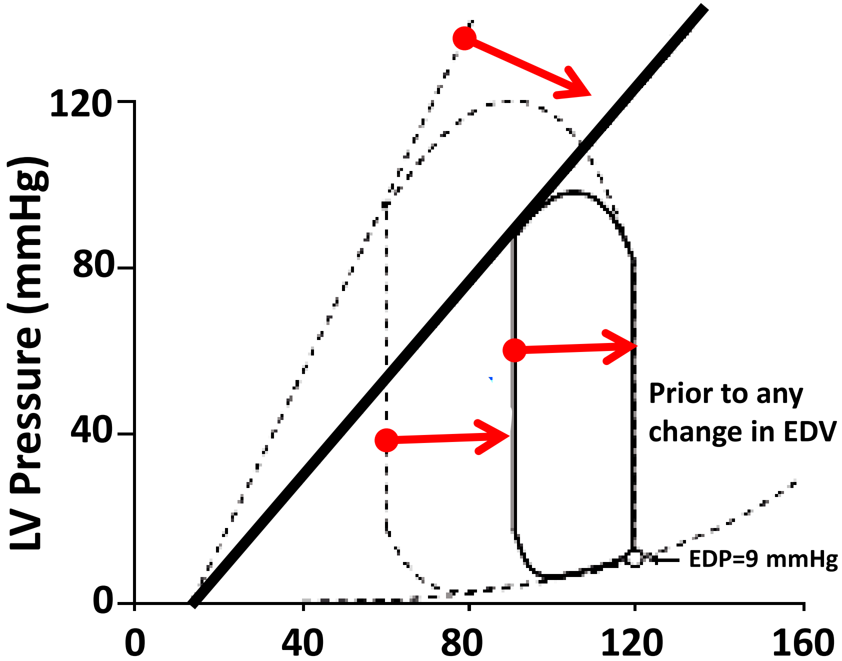
- **Adaptive Remodeling**
  Ventricular Hypertrophy
  Chamber Dilation

- **Functional Decline**

Pump Failure → Systolic vs. Diastolic Dysfunction

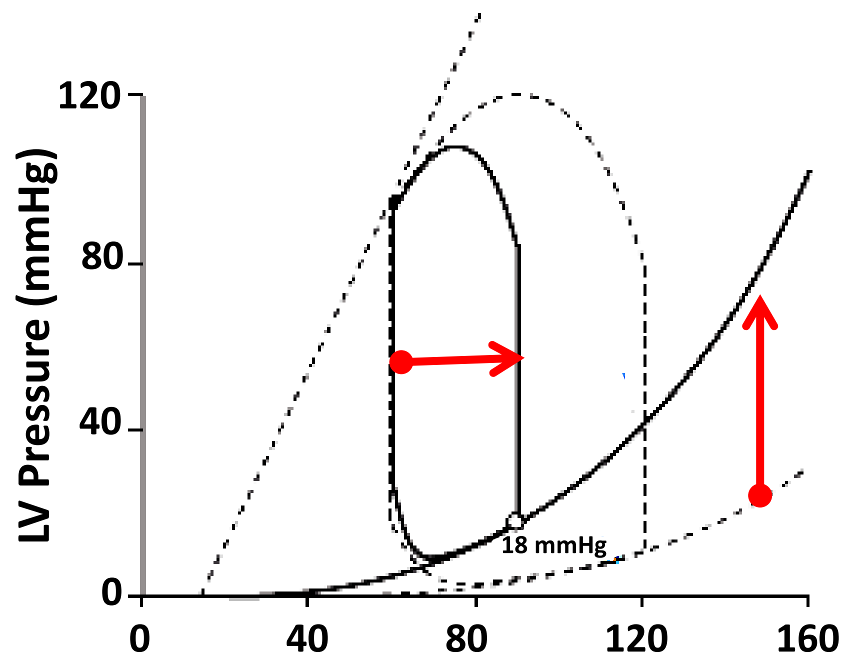
Acute Initial Changes

Systolic Dysfunction



- Contractility is reduced
- ESV is increased
- Stroke volume is reduced

Diastolic Dysfunction



- Contractility is unchanged
- EDP is increased
- Stroke volume is reduced

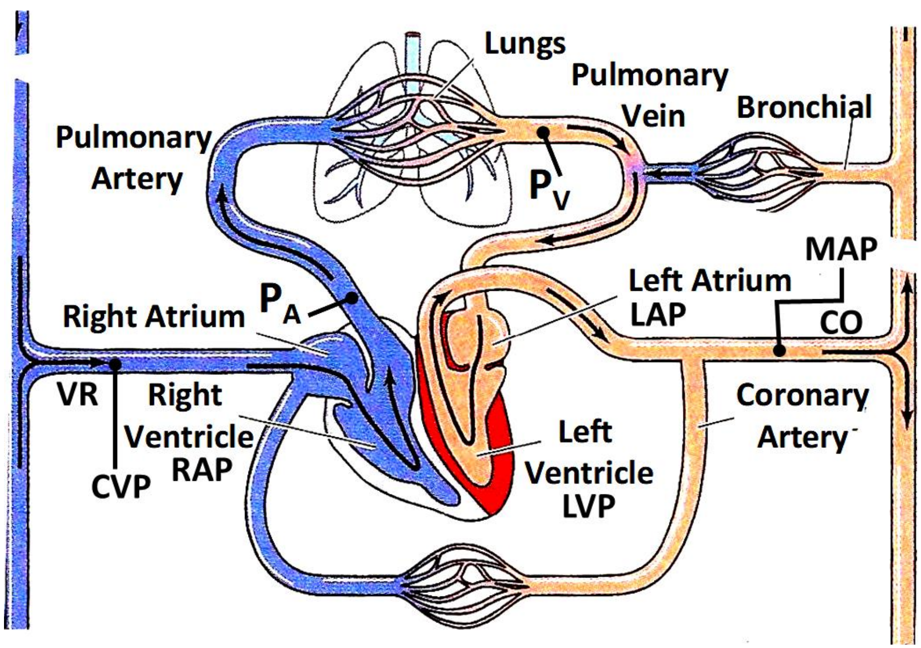
Cardiac Valve Conditions Affecting Pump Function

- Aortic Stenosis
- Mitral Stenosis

→ Pressure "overload"
- LVP
- LAP

- Aortic Insufficiency (Regurgitation)
- Mitral Insufficiency (Regurgitation)

→ Volume "overload"
- LV
- LA



P_A = Pulmonary artery pressure
P_V = Pulmonary vein pressure
MAP = Mean aortic pressure
CVP = Central venous pressure
RAP = Right atrial pressure
LAP = Left atrial pressure
LVP = Left ventricular pressure
RVP = Right ventricular pressure

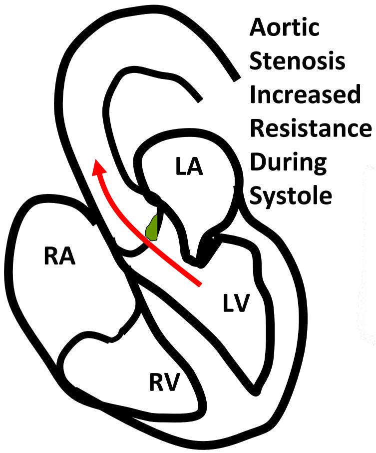
Aortic Stenosis

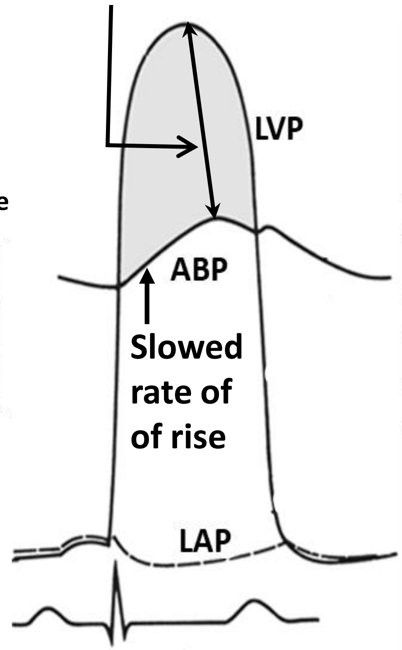
Outflow obstruction → Systolic Velocity Increase → **Systolic Murmur**

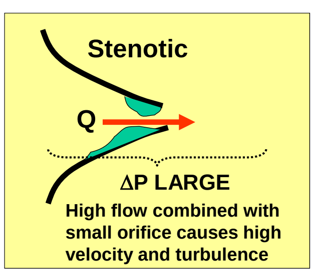
+ Ventricle Pressure
+ Pressure Loss

Gradient=LVP-ABP

Decreased Stroke Volume







Outflow obstruction summary

- (+) Valve Resistance and (+) LVP
- (-) SV and (-) SBP and (-) d(ABP)/dt
- + LVP predisposes to LVH
- Peripheral pulse weak and non-crisp on palpation
- Reduced valve area with high flow (CO) causes high Reynold's number → systolic murmur

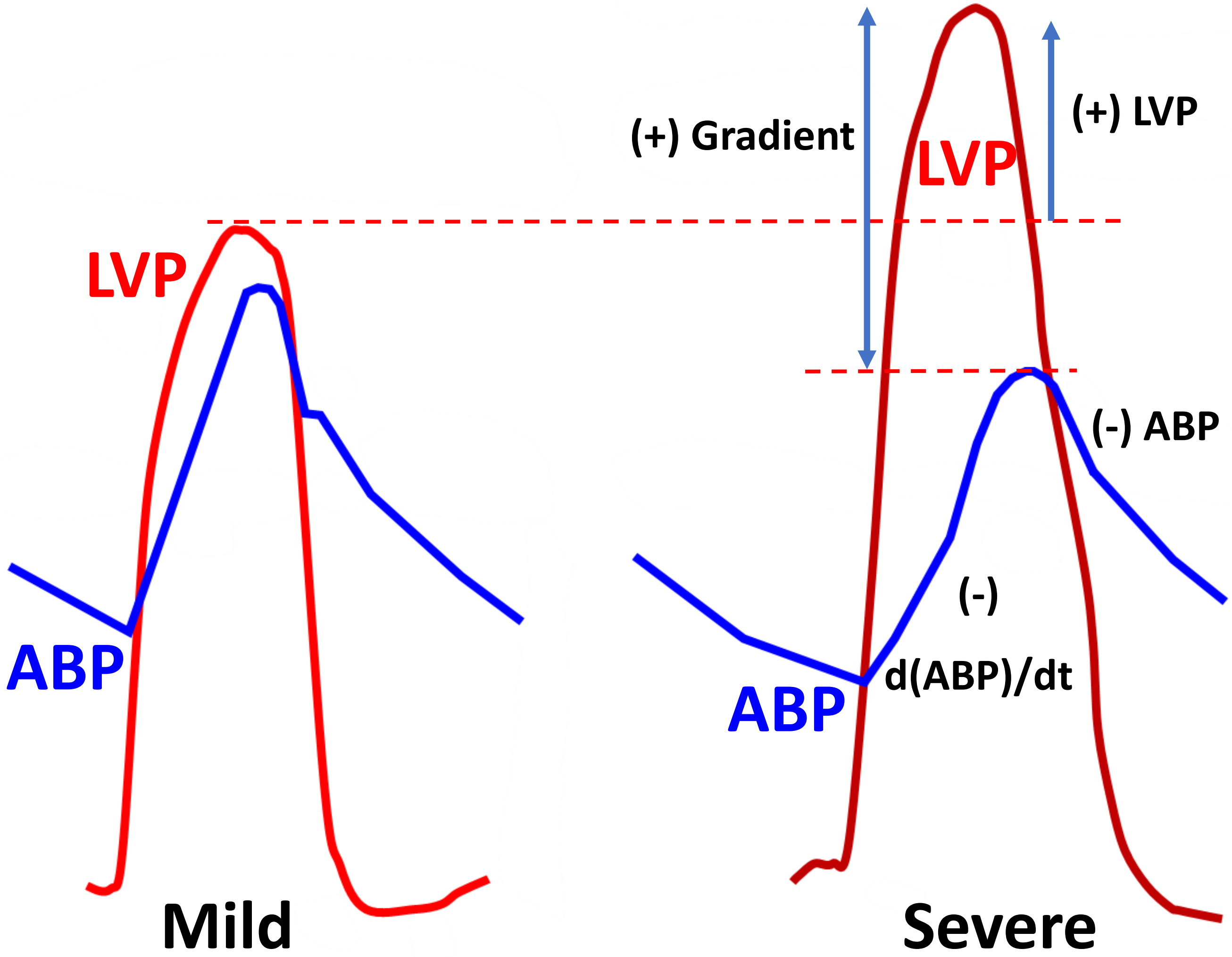
Older Age

- Calcification

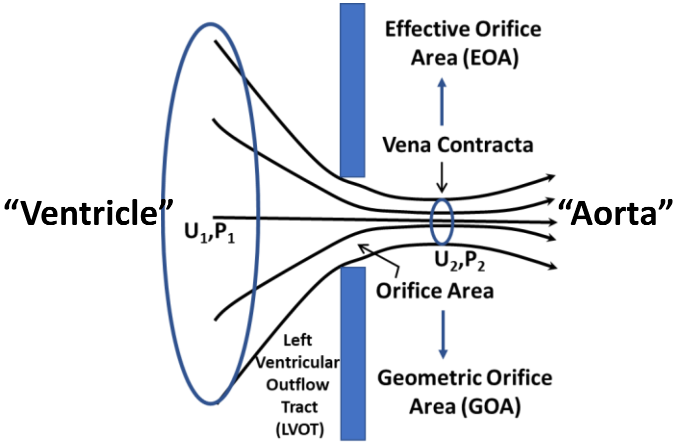
Rheumatic

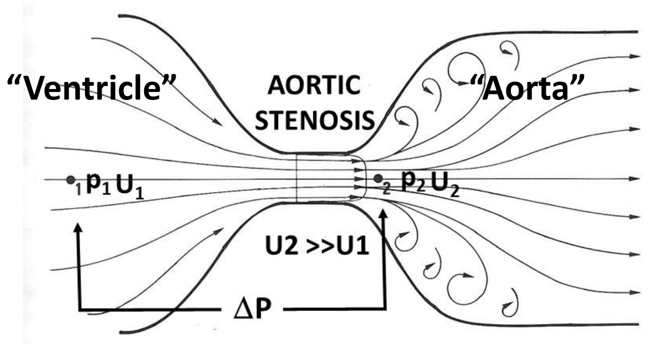
- Fibrosis
- Calcification

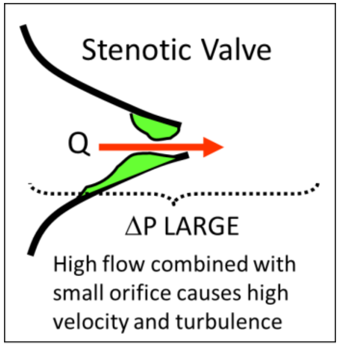
Aortic Stenosis: Mild vs. Severe



Aortic Stenosis: Pressure "Gradient" Determination







Bernoulli's Lossless Equation

$$P_1 + 0.5\rho U_1^2 = P_2 + 0.5\rho U_2^2$$

Hemodynamic
Dominance
Inertial >> Viscous

1060 Kg/m³

$\Delta P = 4(U_2^2 - U_1^2)$, $U_1^2 << U_2^2$

ΔP (mmHg) ≈ $4U_2^2$ mmHg with U in m/s

Measured by ultrasound
Yields stenosis gradient

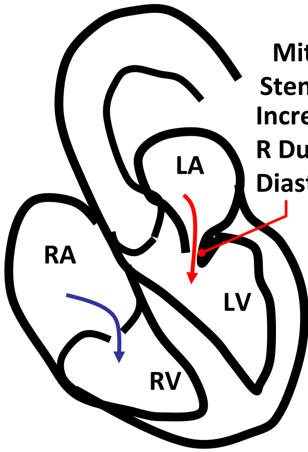
@ 3 m/s → 36 mmHg

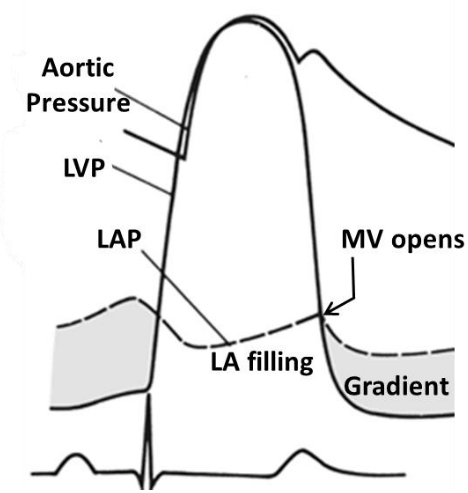
Mild	Moderate	Severe
<25 mmHg	25-40 mmHg	>40 mmHg
Aortic Stenosis Stages by Gradient		

Dr HN Mayrovitz

Mitral Stenosis

Inflow obstruction → **Diastolic velocity increase** → **Diastolic Murmur**





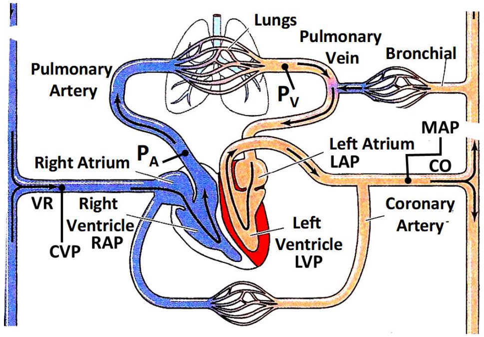
+ LAP to overcome +R

Inflow obstruction summary

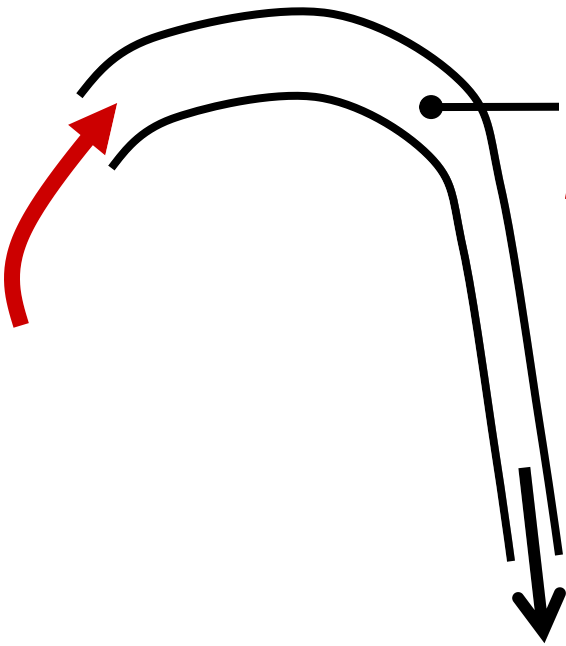
- + Valve resistance and + LAP
- + LAP predisposes to
  - → LA enlargement and volume increase
  - → Atrial Arrhythmias
  - → Pulmonary edema
- Severity measurable via the LAP – LVP gradient
- Since ventricular filling is during diastole, the stenosis causes a diastolic murmur

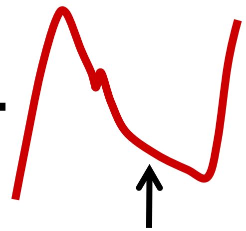
Rheumatic Carditis

- Fibrosis
- Calcification



Aortic Insufficiency – Regurgitation (AR)

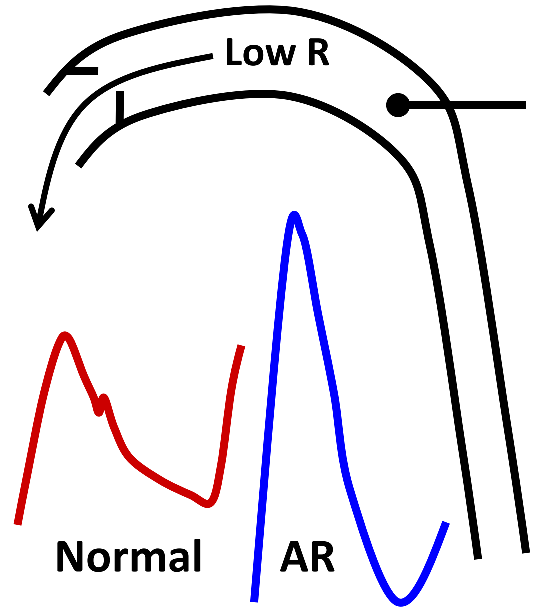




1) If aortic valve is normal and closes normally what determines:

- how fast ABP falls?
- to what level it falls?

TPR and **C** are main factors affecting ABP fall

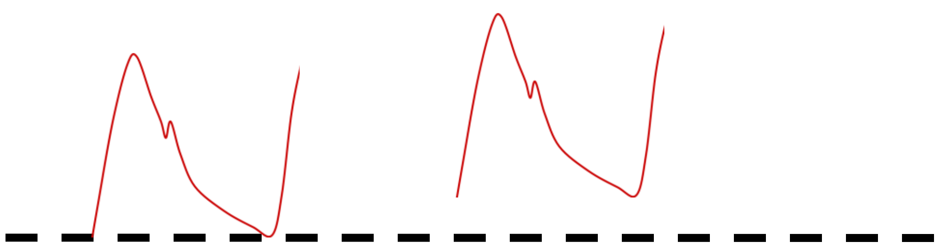


3) What happens if the valve fails to close normally?

2) If TPR increases, what would you expect to happen to diastolic pressure?

4) What accounts for the increased Systolic Pressure?

+Preload → +SV



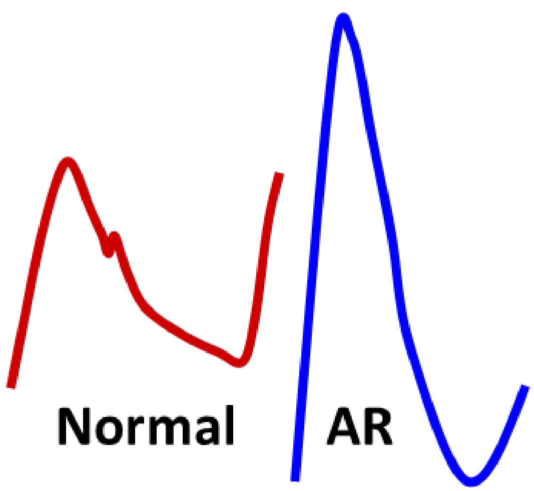
80 mmHg

Low TPR — Higher TPR

Aortic Insufficiency – Regurgitation: Summary

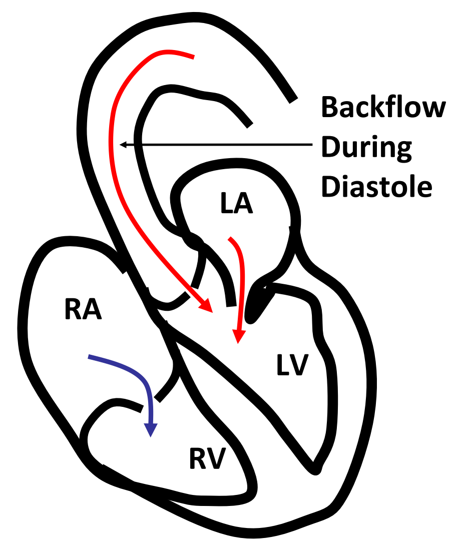
Diastolic backflow → Diastolic velocity increase → Diastolic Murmur

- + EDV → + SV → + Systolic Pressure
- Low R pathway → - Diastolic Pressure
- Combination → + Pulse Pressure



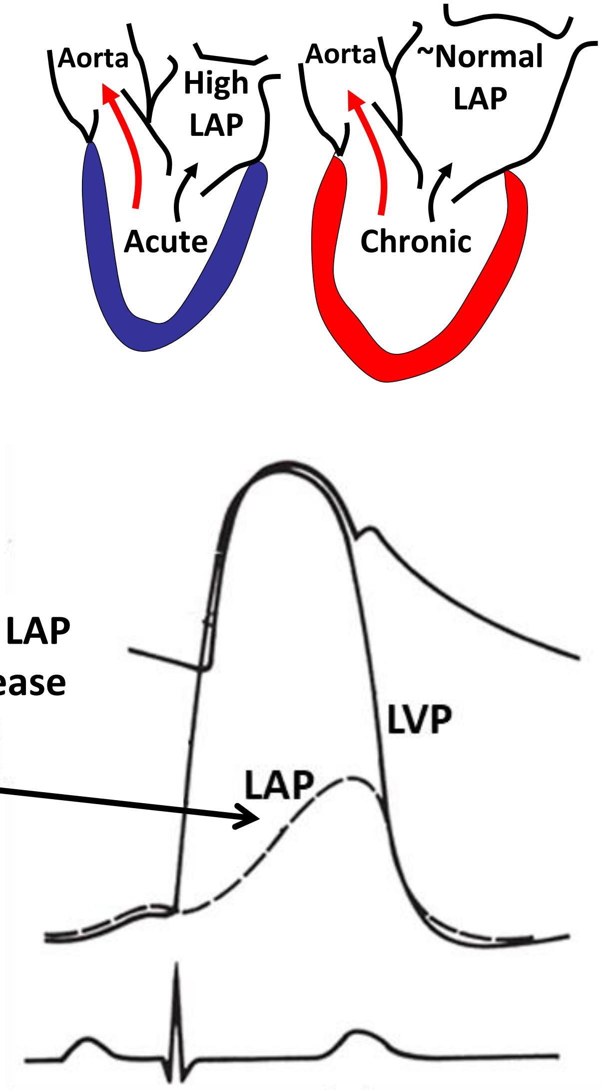
Aortic Insufficiency summary

- Aortic valve does not close fully during diastole
- Backflow from aorta to LV as long as ABP >LVP
- This low resistance pathway causes a rapid decline in ABP
- Effective SV is compromised
- Ventricle will hypertrophy (LVH) as it tries to compensate for "lost" effective SV
- Reduced valve area causes increased N_R during backflow
- Diastolic murmur!



Mitral Insufficiency - Regurgitation

Systolic backflow → Systolic Murmur



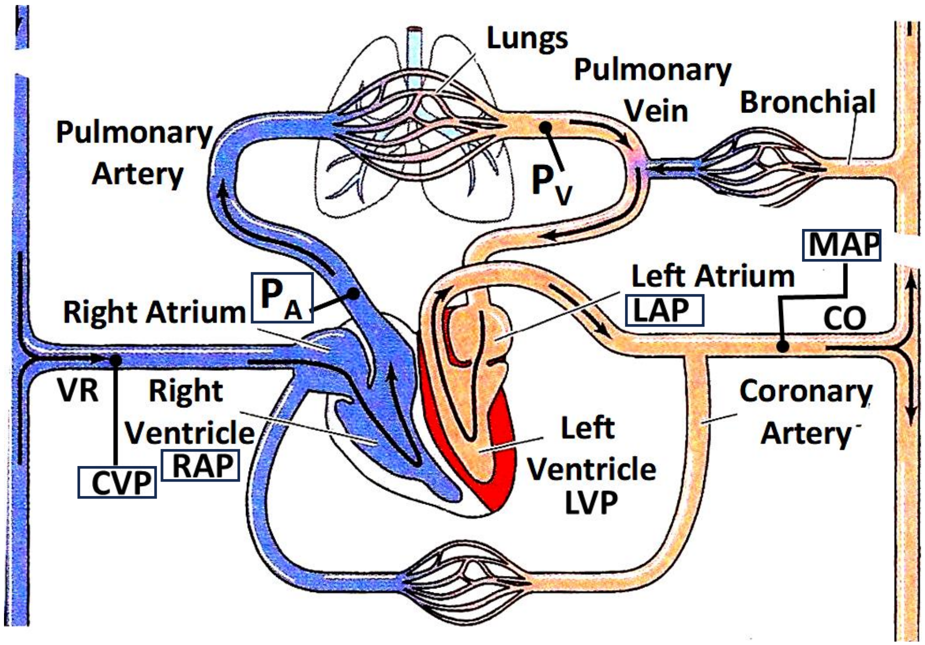
Causes LAP to increase

Mitral Insufficiency Summary

- Effect depends on if acute or slowly developing
- Acute (e.g. rupture of the chordae tendineae) causes volume to enter atrium during systole
- Result is increase in LAP since no adaption of atrial size to accommodate increased volume
- Chronic, that develops over time permits atrium to adjust to accommodate added volume with a lessor increase in LAP

Interactive Questions

Interactive Question



In the early stages of a hemodynamically significant aortic stenosis, which one of the *following* pressures increases first?

A) RAP

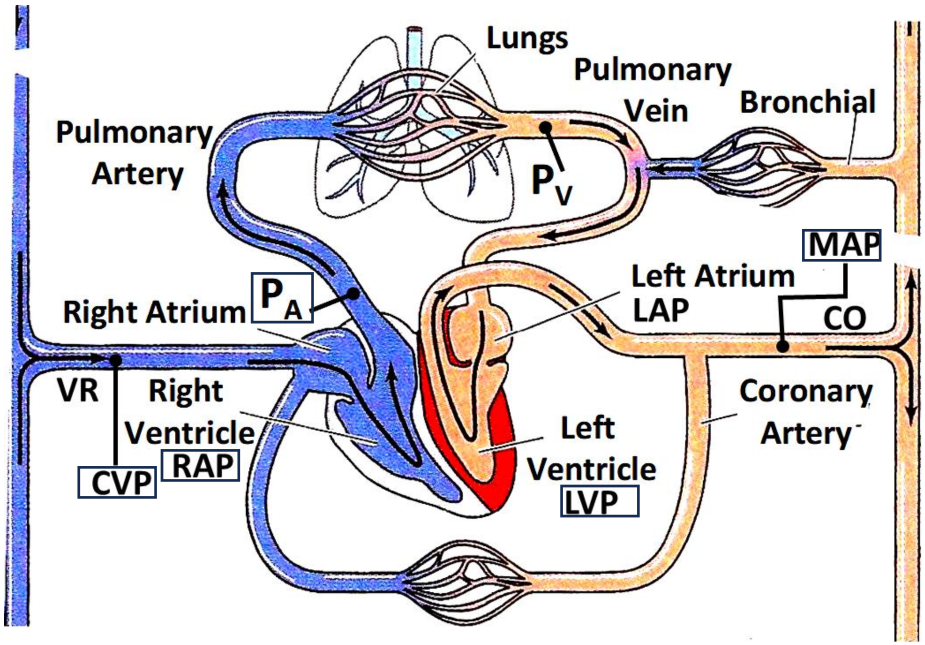
B) CVP

C) MAP

D) LAP

E) P_A

Interactive Question



Bill is a 72-year-old gentleman with a history of aortic stenosis and significant arterial hypertension. He is complaining of breathing difficulties. An elevation in which one of the following pressures most directly contributes to his symptom?

A) RAP

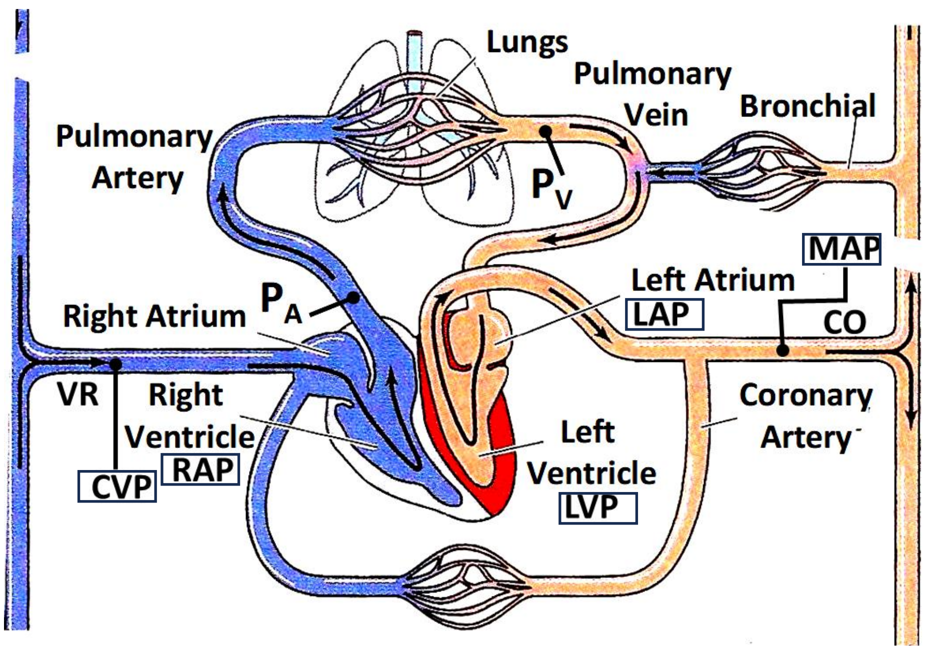
B) CVP

C) MAP

D) LVP

E) P_V

Interactive Question



Jill is a 68-year-old retired nurse who presents with significant bilateral ankle edema (swelling) and breathing difficulties on exertion. An elevation in which one of the following pressures *most directly* contributes to her ankle edema?

A) LAP

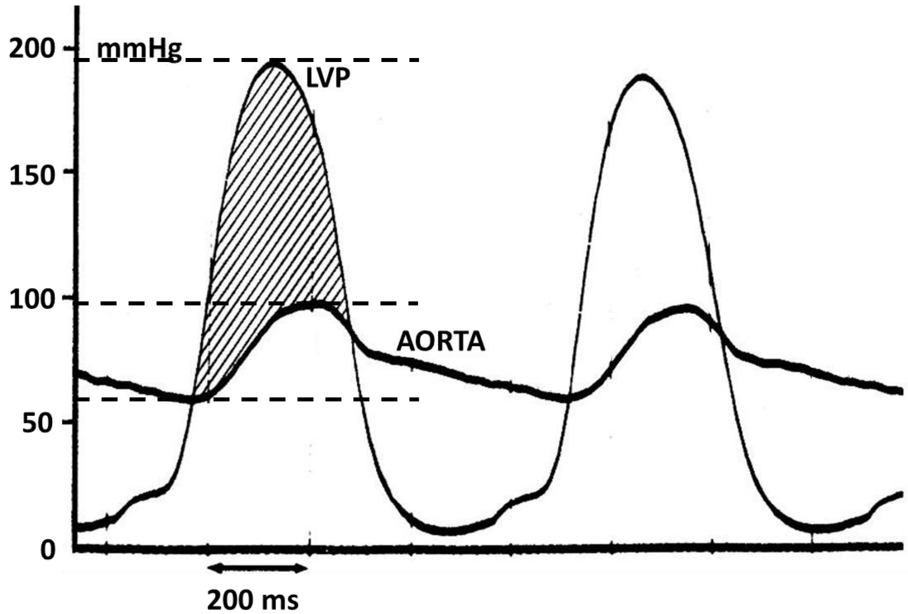
B) CVP

C) MAP

D) LVP

E) P_V

Interactive Question



The figure shows hemodynamic measurements in a 62-year-old patient with a childhood history of rheumatic fever.

1) Which of the following cardiac valve conditions is most likely present?

A) Mitral stenosis

B) Aortic stenosis

C) Aortic regurgitation

D) Aortic insufficiency

E) Mitral regurgitation

2) His gradient is closest to which of the following values in mmHg?

A) 50

B) 75

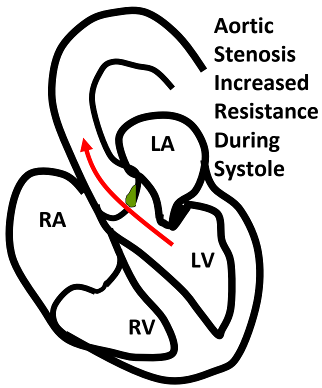
C) 100

D) 150

E) 200

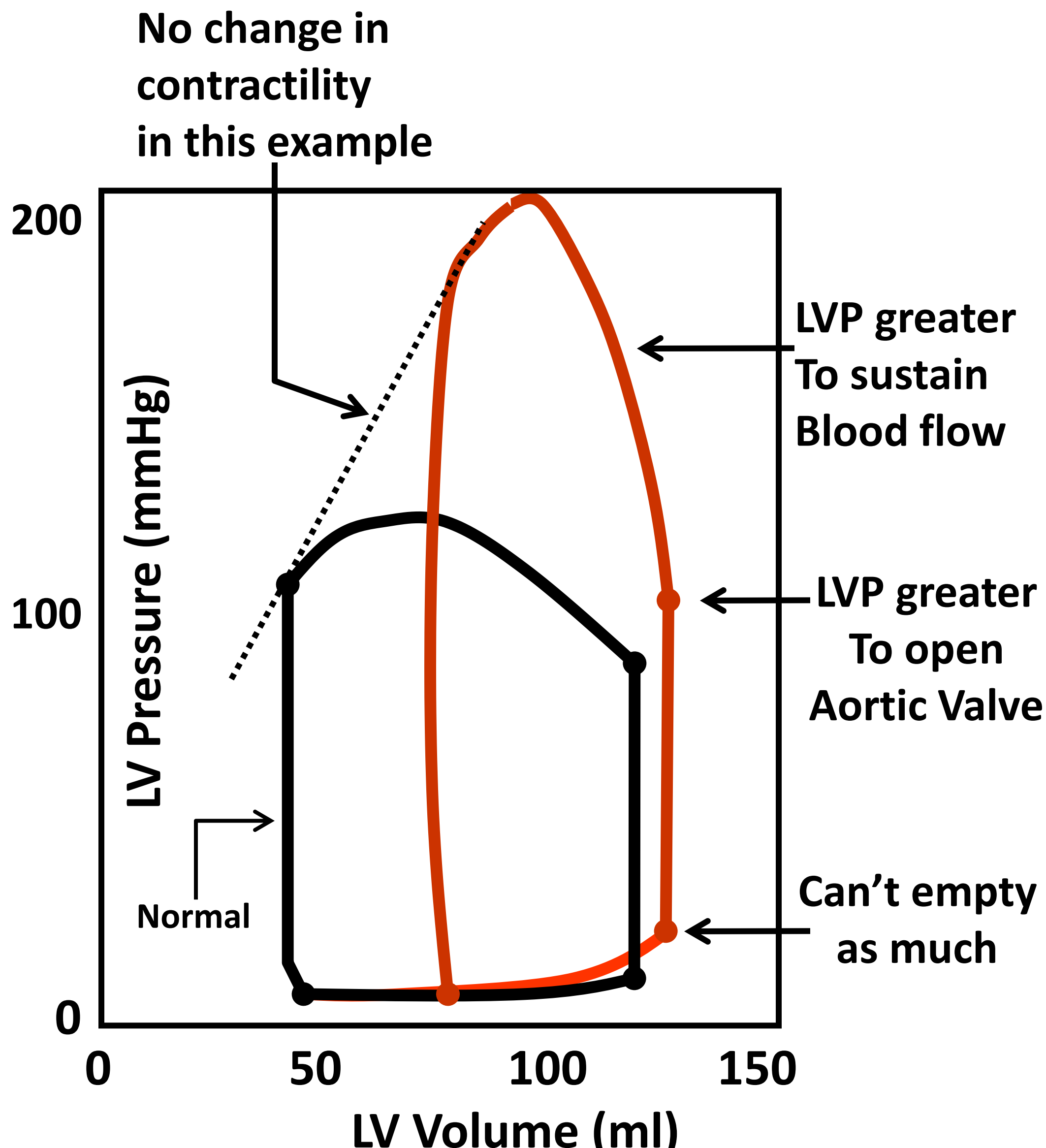
Impact of Valve Dysfunction on P-V Loops

Aortic Stenosis: P-V LOOPS

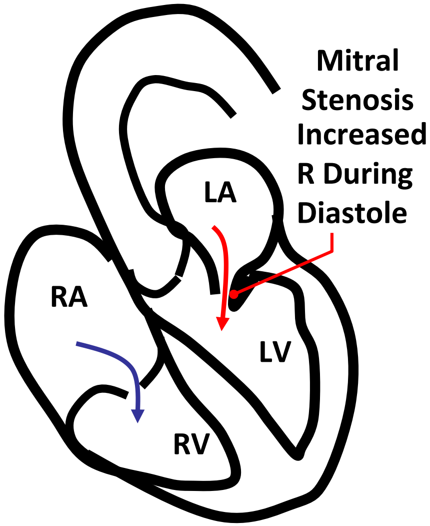


AORTIC STENOSIS

- Increased outflow R causes increase in effective afterload
- SV & EF are reduced
- LV pressures are elevated and don't represent aortic pressure as they normally would



P-V LOOPS: Mitral Stenosis (MS)



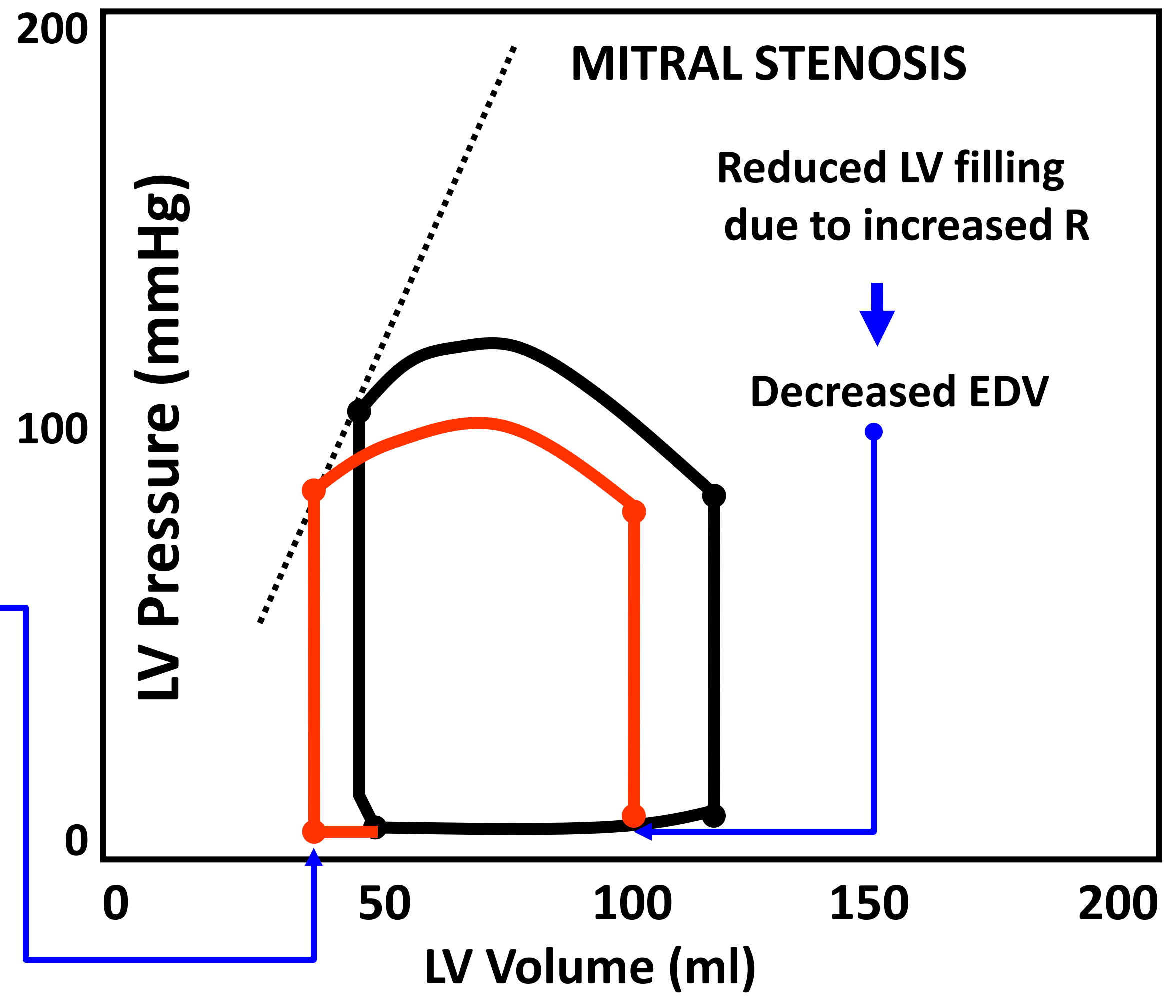
Decreased EDV

↓

Decreased ESV

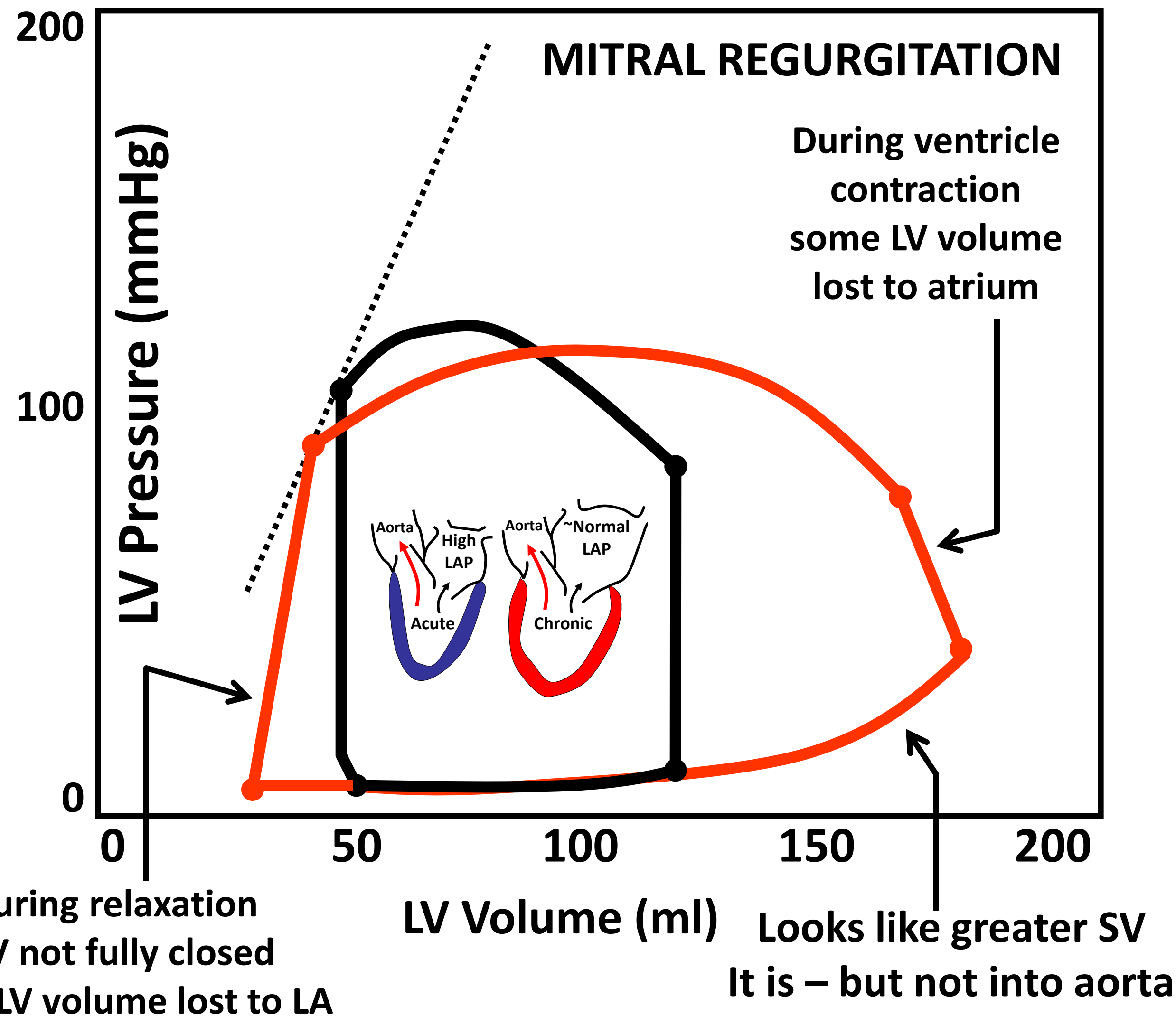
But reduced SV

and reduced EF



P-V LOOPS: Mitral Regurgitation (MR)

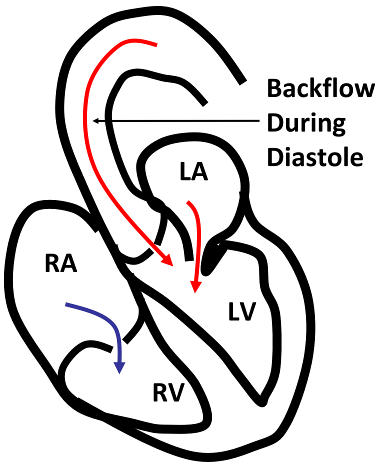
- **Systolic backflow into Left Atrium (LA)**
- **Elevated LAP transmitted to LV during filling**
- **EDV is increased**
- **Adaptation over time to compensate for lost *EFFECTIVE* SV further increases EDV**
- **No isovolumic contraction or relaxation**



P-V LOOPS: Aortic Regurgitation (AR or AI)

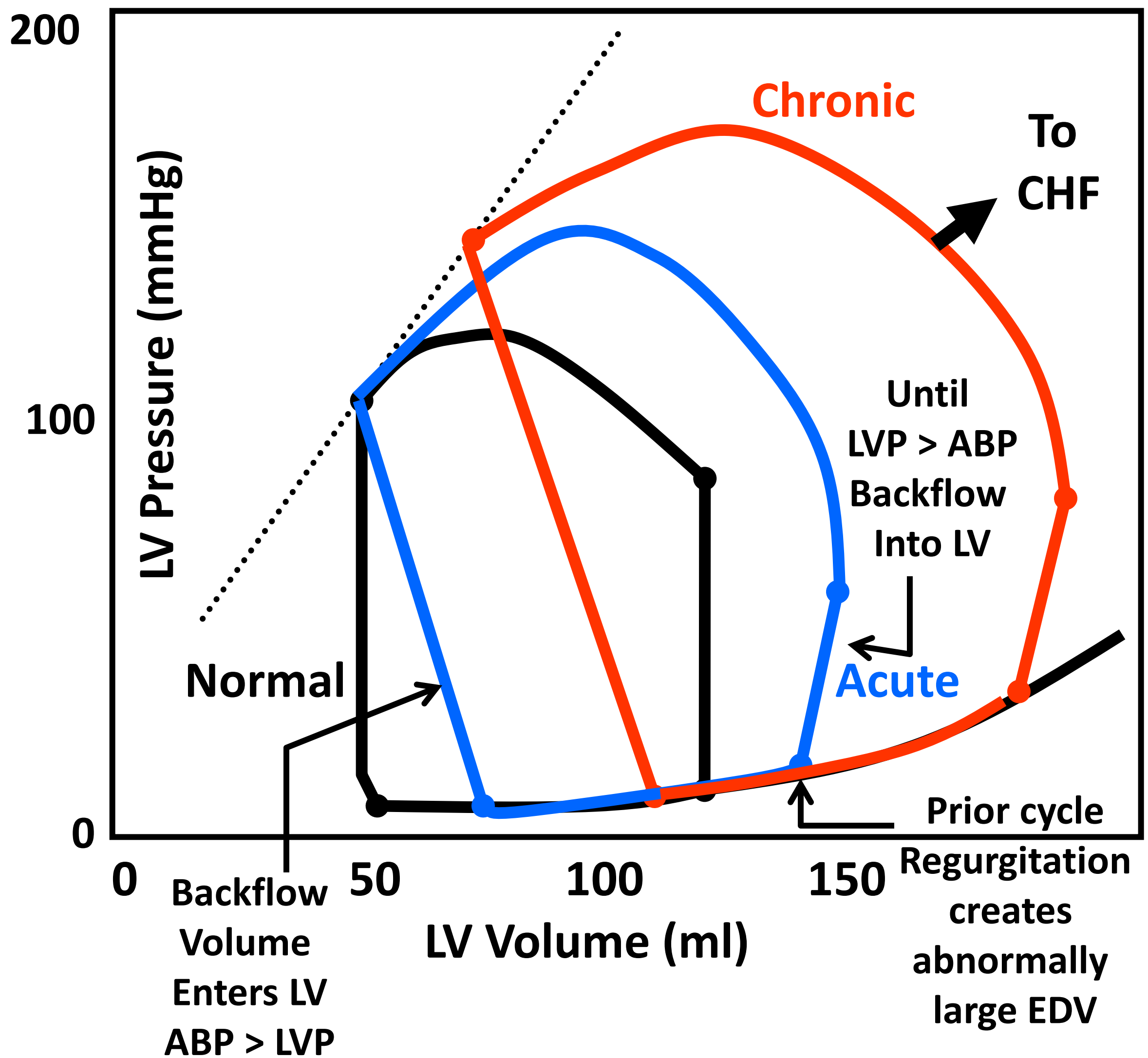
AORTIC REGURGITATION

- Regurge during ***diastole*** increases EDV and ESV



Relaxation & Contraction NOT isovolumic

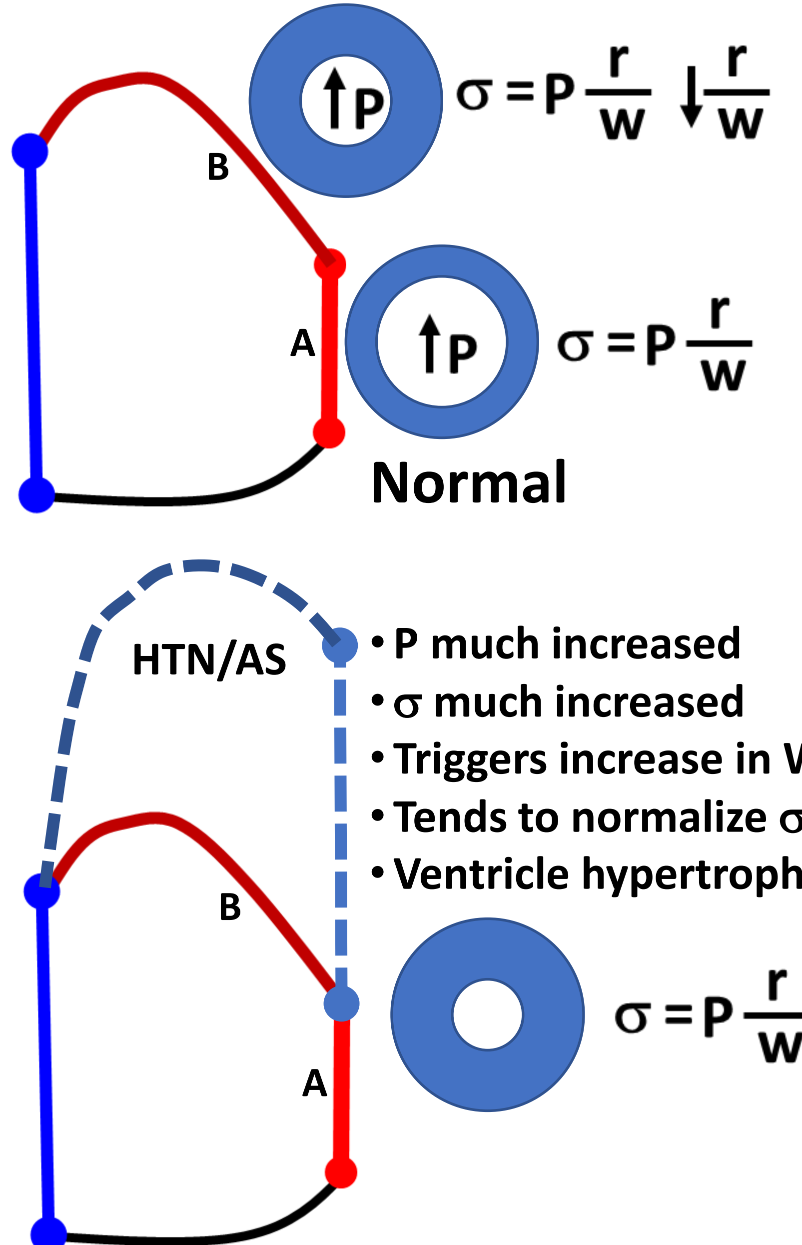
Remodeling over time adds to EDV increase (eccentric hypertrophy)



Adaptations and Remodeling

Heart Failure = Pump Failure
Develops Rapidly ('Acute') • M.I. • Infection • Post bypass surgery
Over Time ('Chronic') • Pressure / Volume Overload HTN/AS / AR/MR • Adaptive Remodeling • Functional Decline

Adaptation Impacts on Myocardial Wall Stress



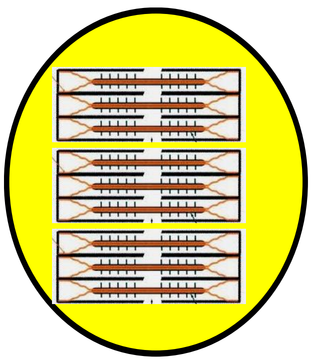
- P much increased
- σ much increased
- Triggers increase in W
- Tends to normalize σ
- Ventricle hypertrophy

Adaptations and Remodeling

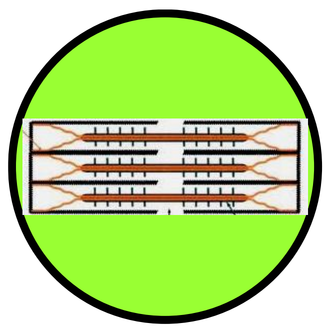
HYPERTROPHY

+ Afterload

more force needed to overcome greater load



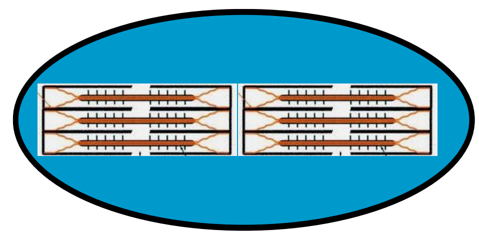
Concentric
+ Muscle Mass
AS or HTN



Normal
Mass &
Volume

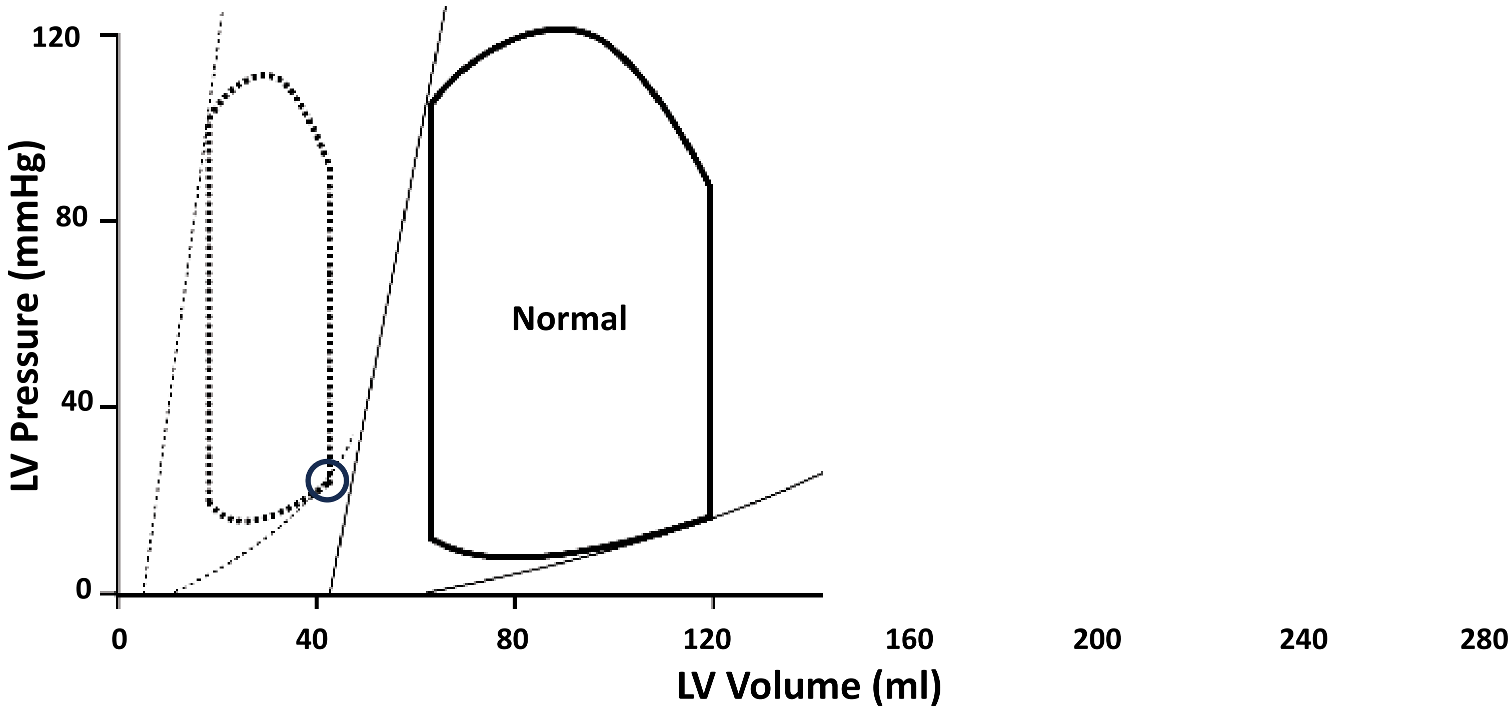
+ Preload

chamber expands to accommodate larger volume



Eccentric
+ Chamber Size
MR or AR

Remodeling Impacts on P-V Loops: Overview

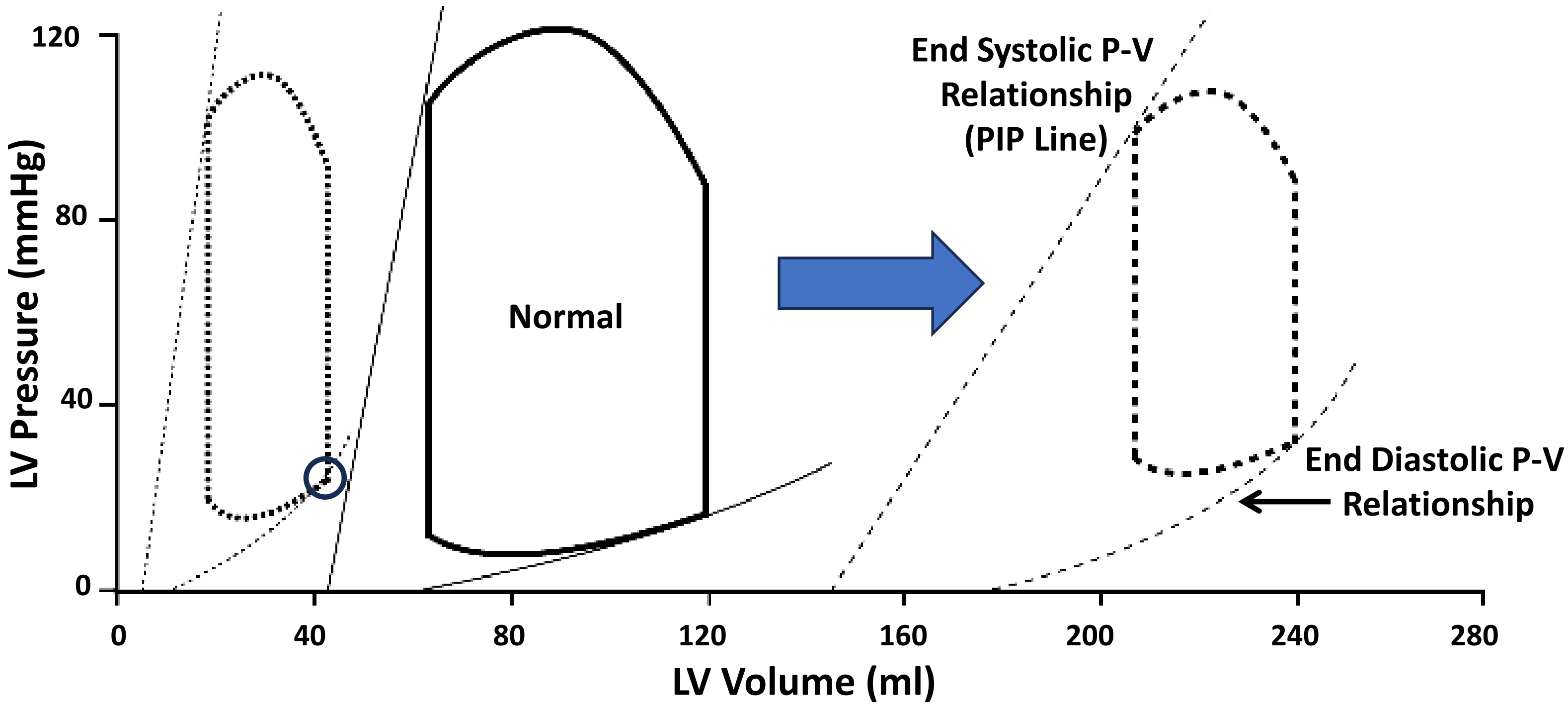


Caused by Ventricular Pressure Overload

Concentric Hypertrophy
- Diastolic Failure
- EDV Decreased
- EDP Increased
- SV Decreased

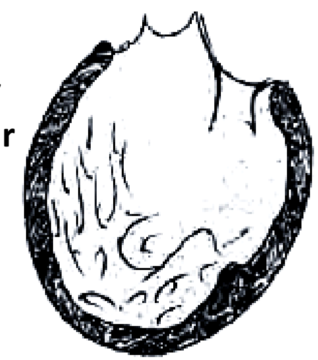
Normal

Remodeling Impacts on P-V Loops: Overview



Caused by
Ventricular
Pressure
Overload

Caused by
Ventricular
Volume
Overload



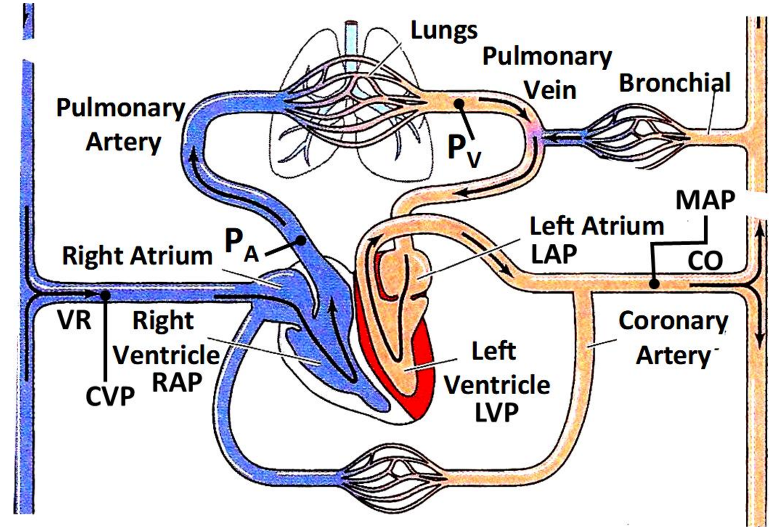
Increased wall stress
σ = P(r/W)

Concentric Hypertrophy
- Diastolic Failure
- EDV Decreased
- EDP Increased
- SV Decreased

Normal

Eccentric Hypertrophy
- Systolic Failure
- EDV Increased
- EDP Increased
- SV Decreased

Summary of Systolic Dysfunction



Systolic Dysfunction

-Myocardial Contractility ←

↓

Impaired Contraction

↓

-SV

↓

+EDV

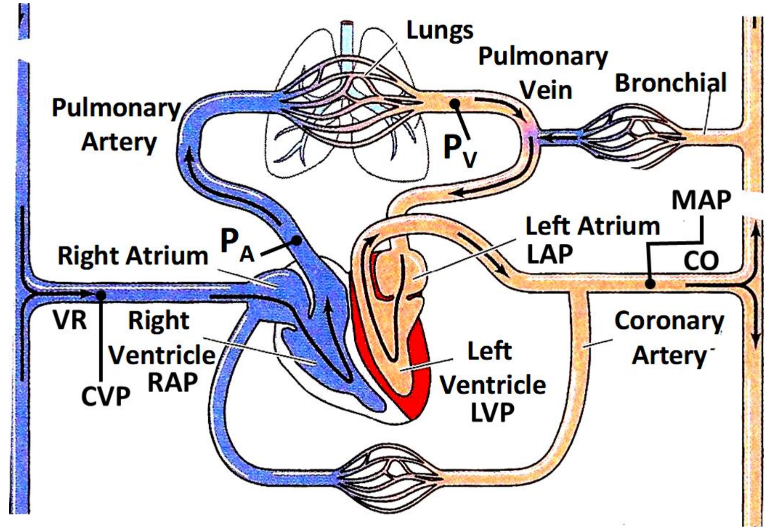
↓

+EDP →

Intrinsic dysfunction of contractile apparatus e.g. - inotropy	Loss of Viable Contracting Muscle e.g. M.I.

IF LV involved: → initially pulmonary congestion & edema
IF RV involved: → initially peripheral edema and ascites

Summary of Diastolic Dysfunction



Diastolic Dysfunction

-Ventricle Compliance

- EDV → - SV

+ EDP → Pulmonary Congestion

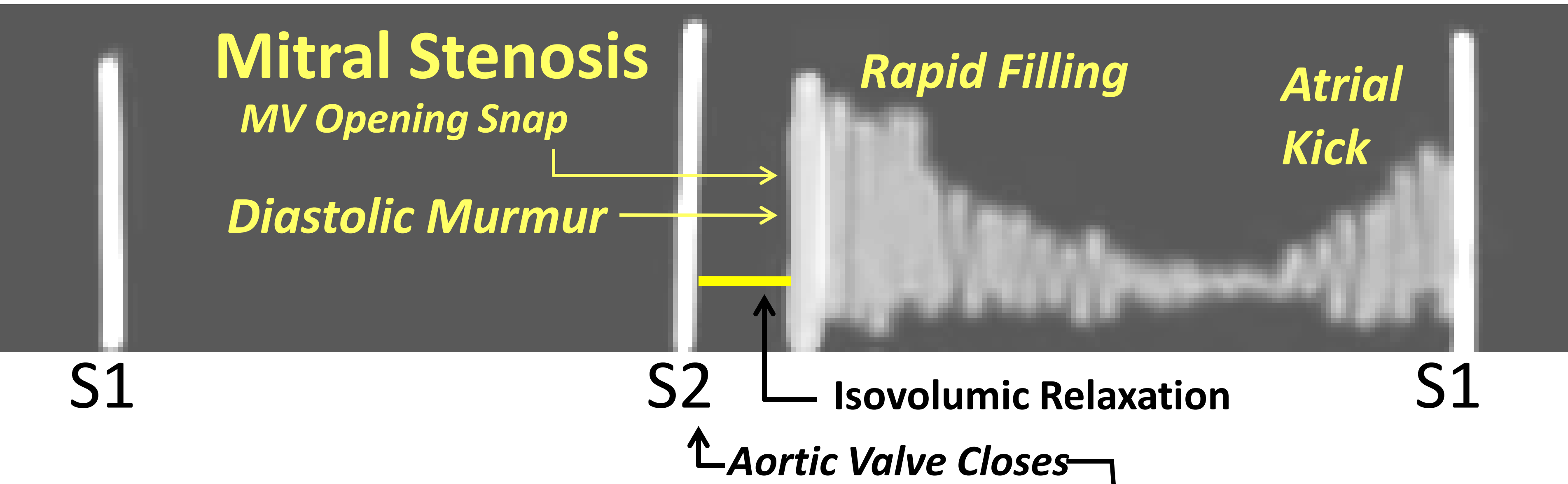
- Reduced lusitropy
- Structural Changes

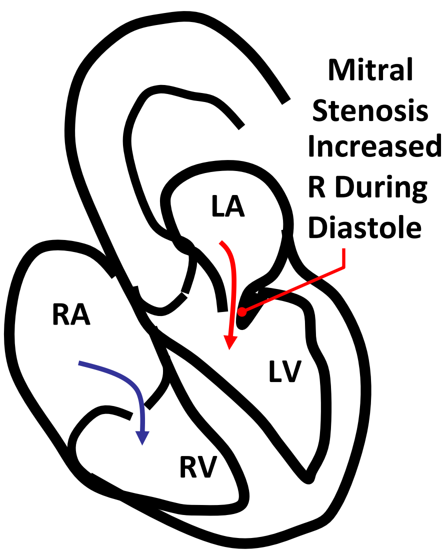
Reduced removal rate or amount of Ca^{++} from SR during diastole → Reduced lusitropy

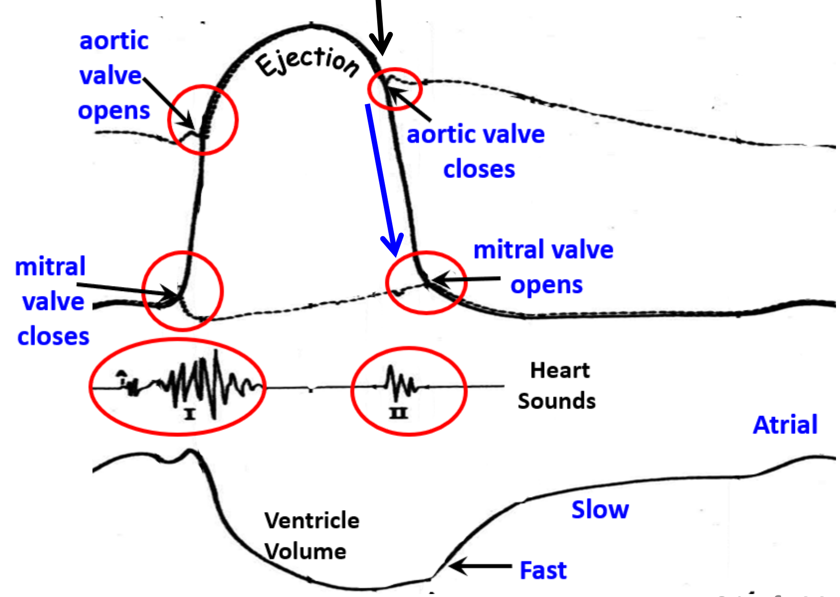
Hypertrophy
+ Muscle mass
+ Wall Thickness
+ Tissue fibrosis
→ Structural Changes

Cardiac Valve-Related Murmurs

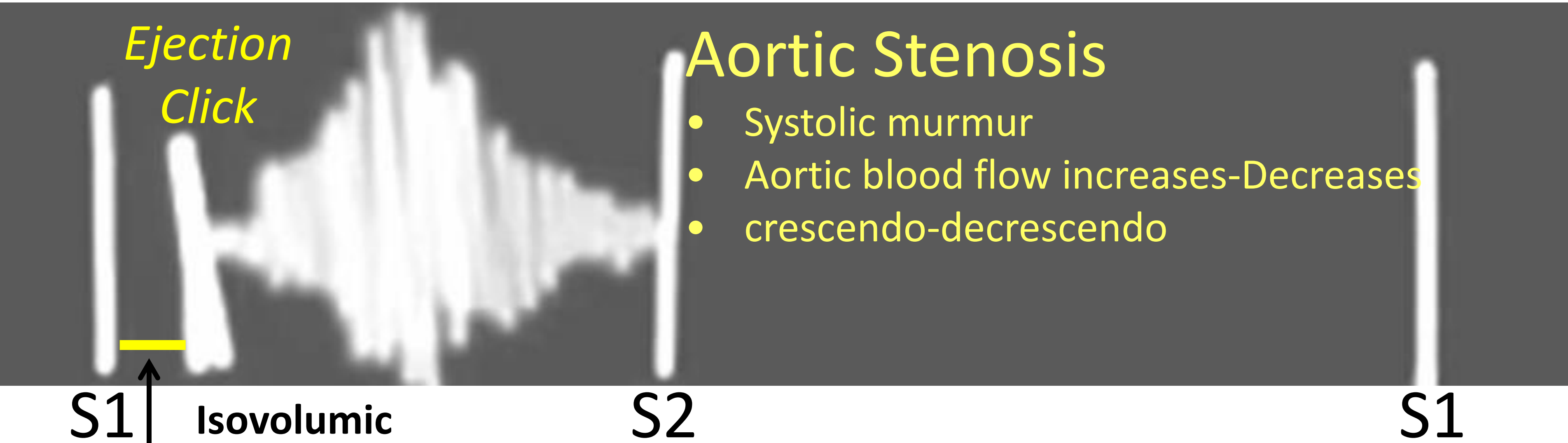
Mitral Stenosis – Diastolic Murmur





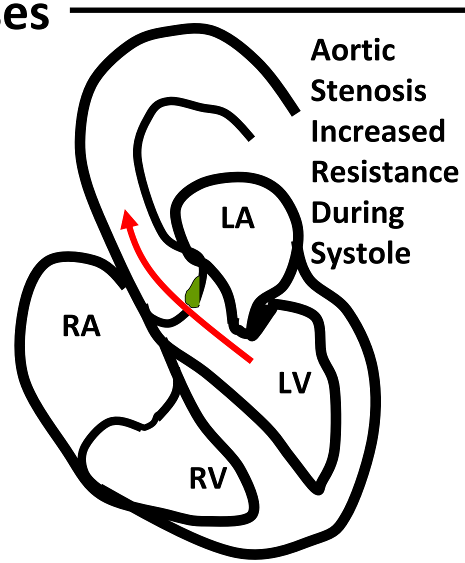


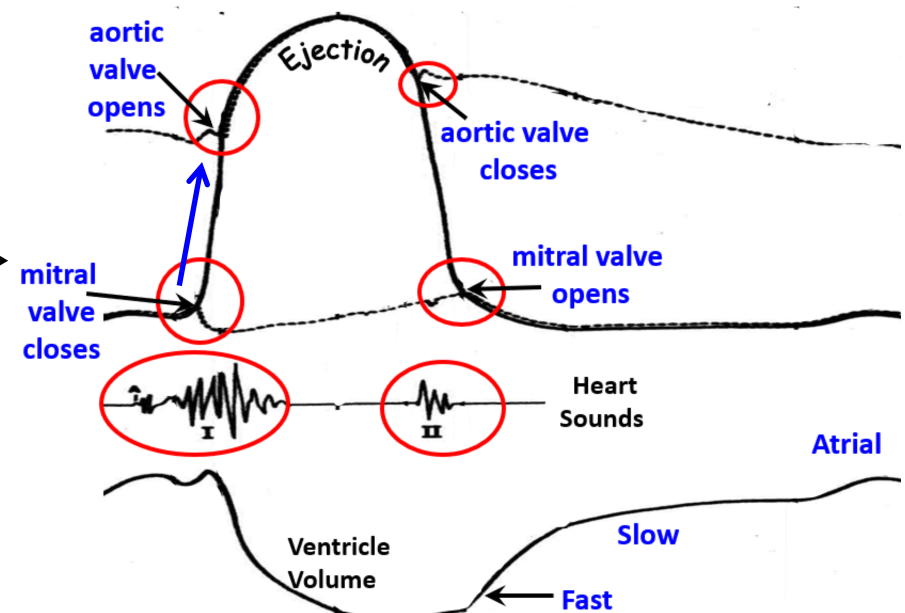
Aortic Stenosis – Systolic Murmur



Aortic Stenosis

- Systolic murmur
- Aortic blood flow increases-Decreases
- crescendo-decrescendo



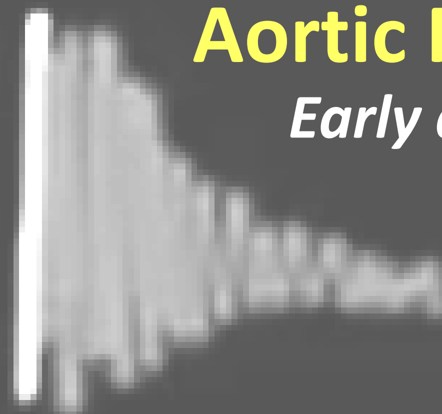


Aortic Regurgitation – Diastolic Murmur

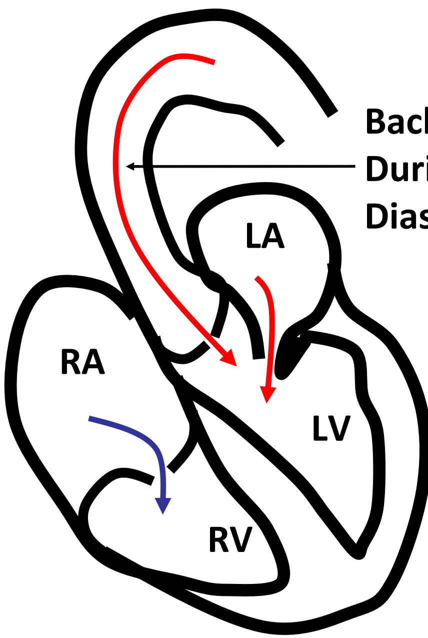
- *Back flow initially large*
- *Diminishes as ABP falls*
- *Becomes non-turbulent*
- *Murmur ends*

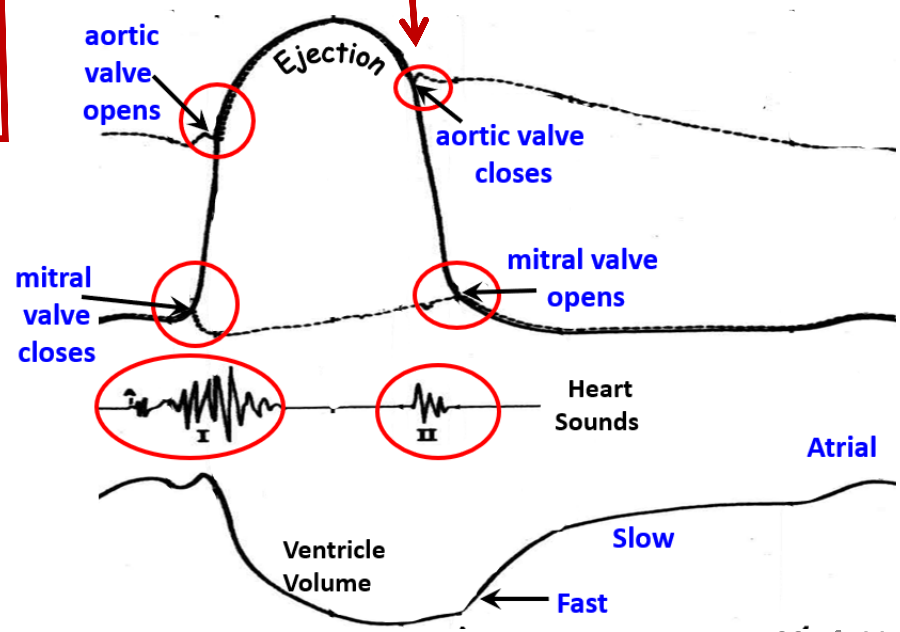
Aortic Regurgitation

Early diastolic murmur

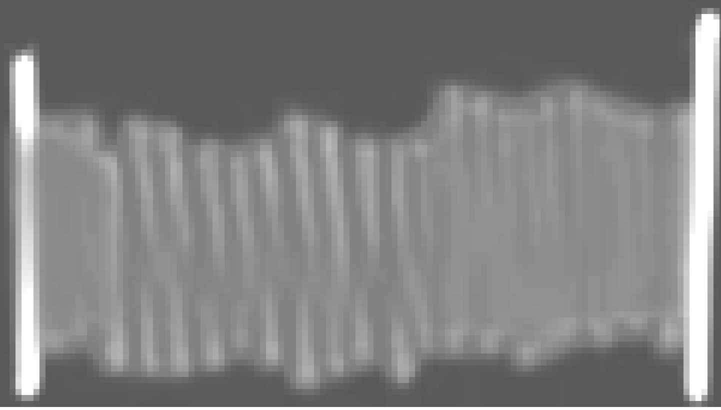


S1 S2 S1





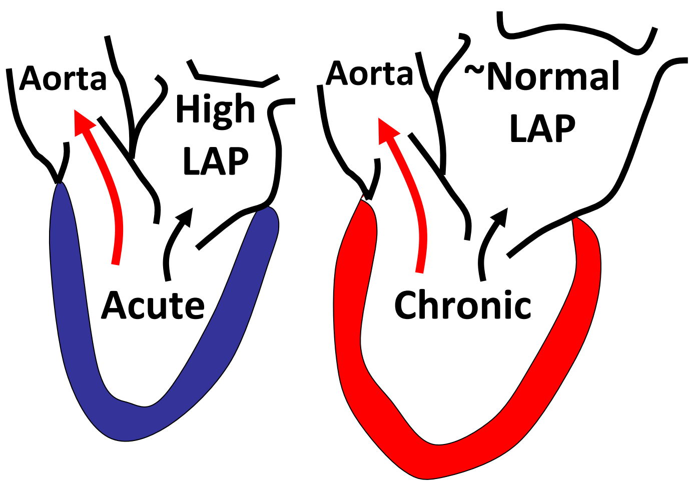
Mitral Regurgitation – Systolic Murmur

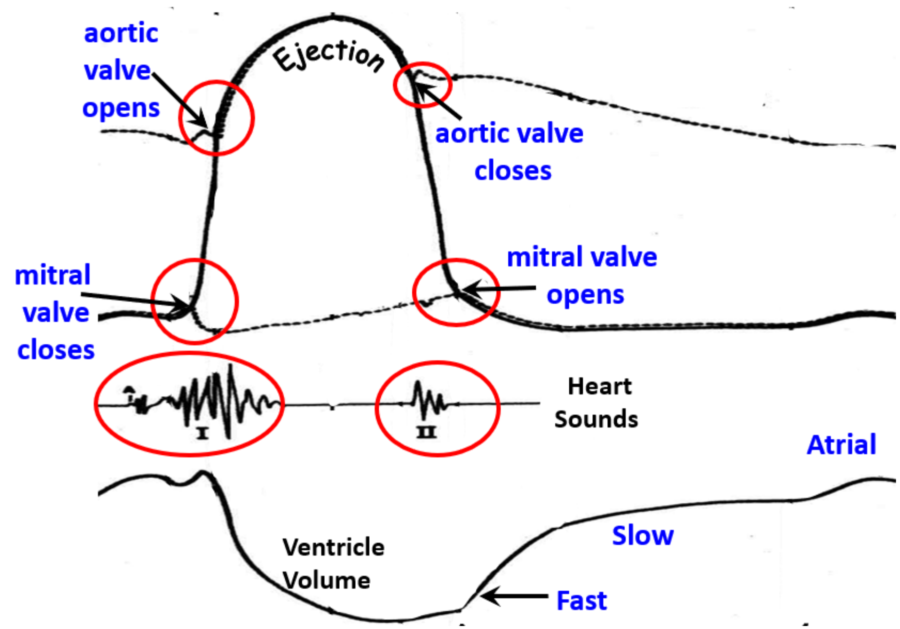


Mitral Regurgitation

Pan Systolic Murmur
(Holo Systolic)

S1 **Ventricular Systole** S2 S1

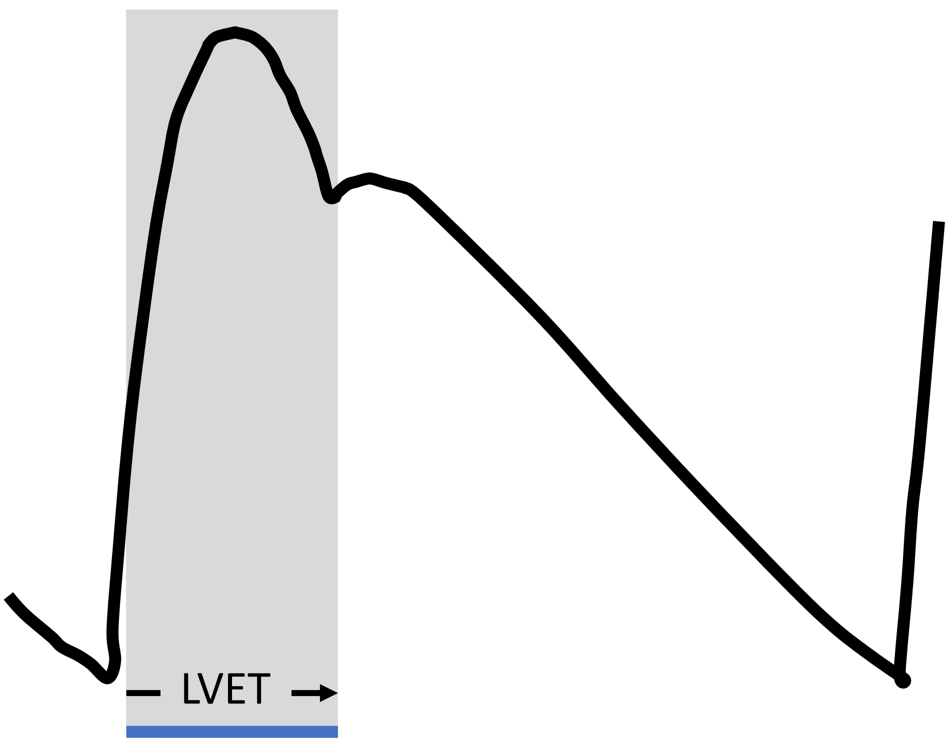




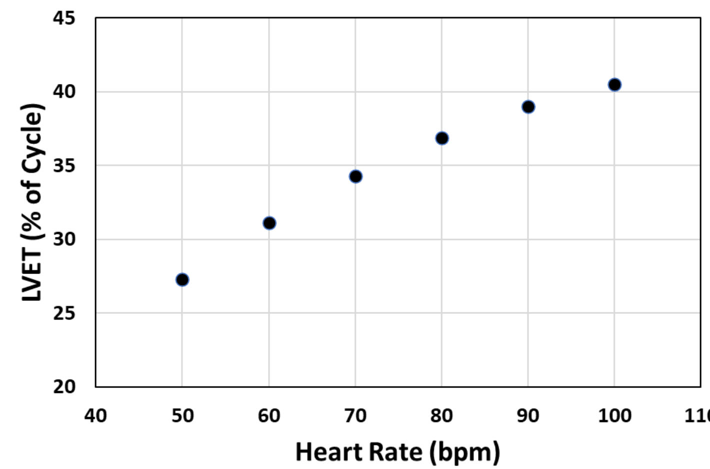
Normal Responses

- **Exercise**
- **Valsalva**

Normal Left Ventricular Ejection Time (LVET)

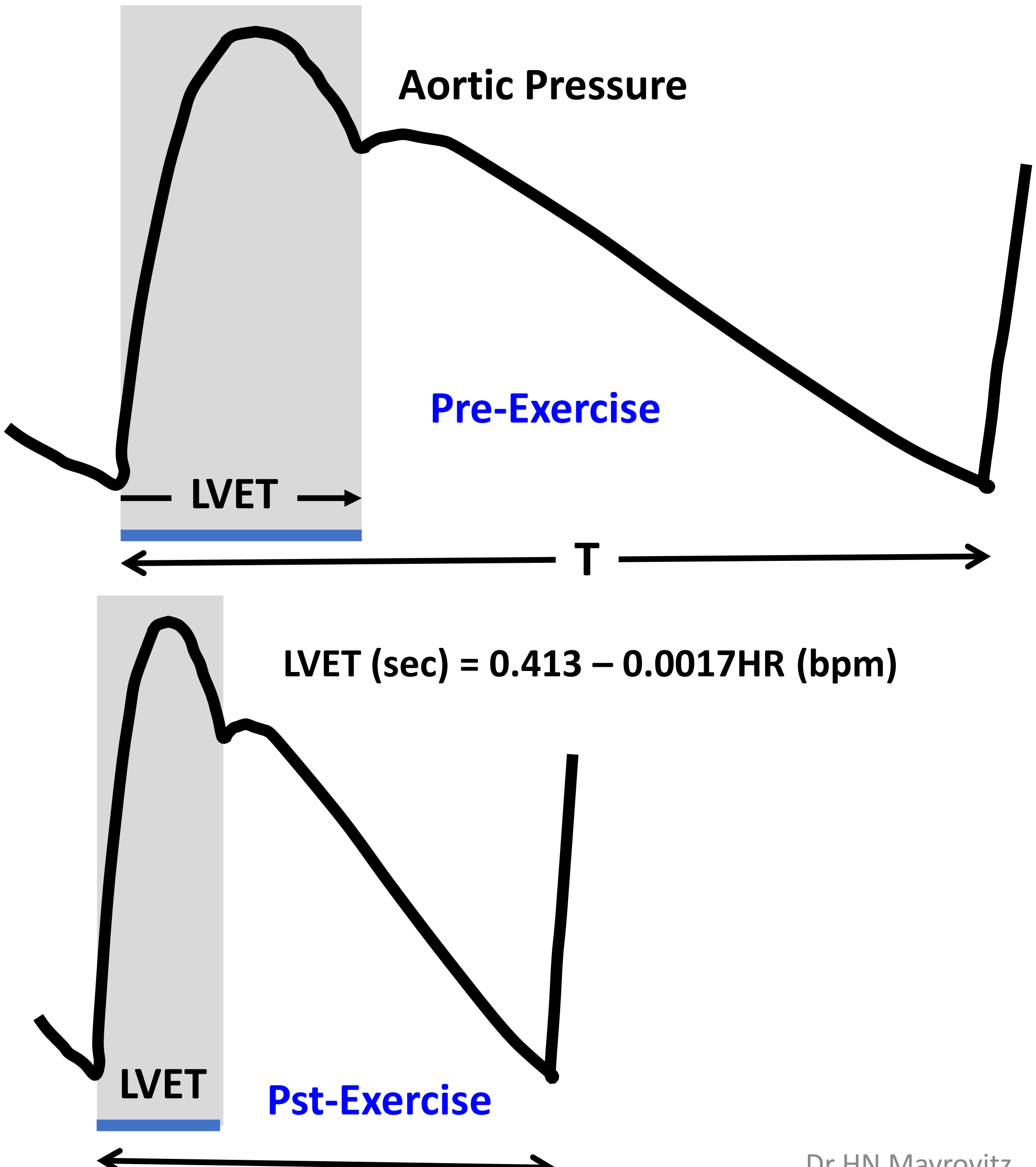


- LVET decreases with increasing HR
- LVET (sec) = 0.413 – 0.0017 x HR (bpm)
- LVET increases as a pct of cycle time



- Systolic blood flow/minute increases with increasing HR

Demonstrating LVET changes with HR



Bill is a healthy 25-year-old medical student. During his daily jogging routine his HR increases from his resting pre-exercise level of 60 to 120 bpm.

1. What is the value of time T?

T = cycle time = 60/HR = 1 sec = 1000 ms

2. What is his LVET before and after exercise?

LVET (sec) = 0.413 – 0.0017HR (bpm)

@60 → 311 ms
@120 →209 ms

3. What happens to the ratio of LVET to cycle time (T)?

311/1000 → 209/500
0.311 → 0.418
Increases! So, Flow increases

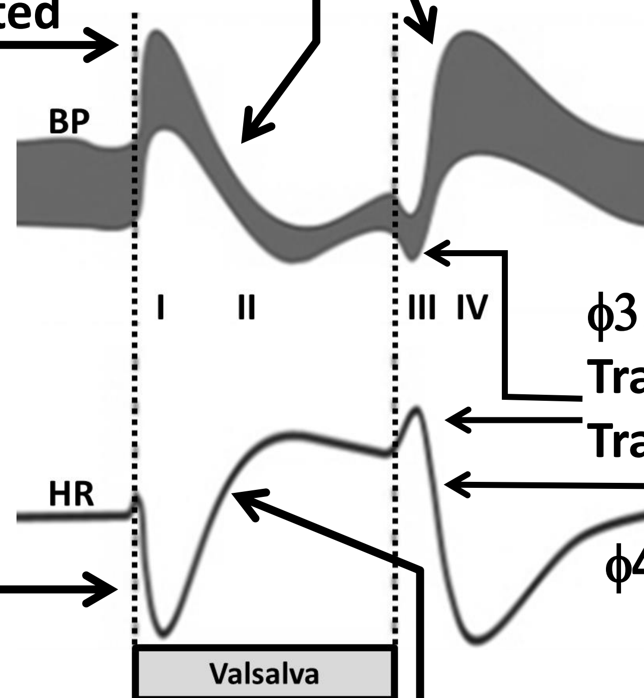
Valsalva Maneuver: Normal CV Effects

ϕ2. Maintained $+P_{TH}$ inhibits venous return to RA and compresses pulmonary vein causing reduced LA & LV filling. Reduced preload → –SV & - BP

ϕ4. Recovery
+LV filling as "trapped" lung blood freed
→ +SV→+BP

ϕ1. Initial P_{TH} increase partly transmitted to aorta causes transient +BP

Forced expiration against a closed glottis



ϕ3. Release
Transient -BP
Transient +HR

ϕ1. Baroreceptor initiated -HR

ϕ4. Recovery
→ -HR (reflex)

Valsalva may snuff out some Supraventricular Arrhythmias!

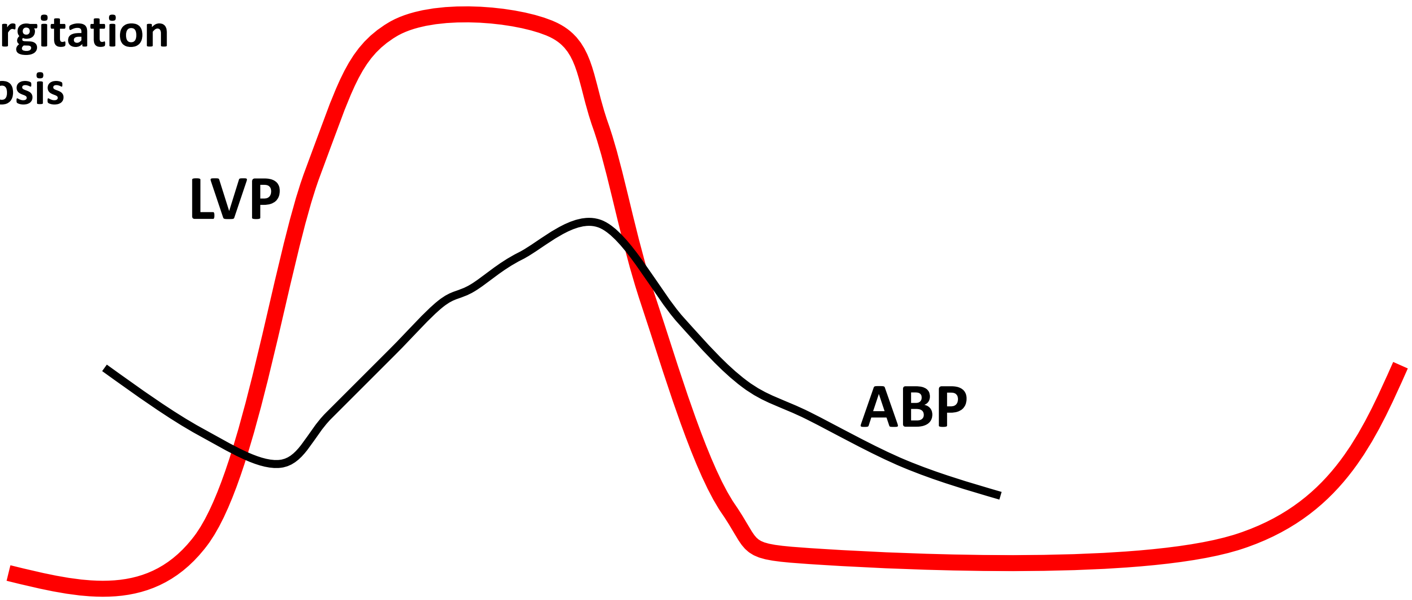
ϕ2. Increase in HR initiated via baroreceptors sensing fall in BP

Interactive Questions

Interactive Question

What is Cardiac Valve Condition?

A. Normal
B. Mitral Stenosis
C. Mitral Regurgitation
D. Aortic Regurgitation
E. Aortic Stenosis



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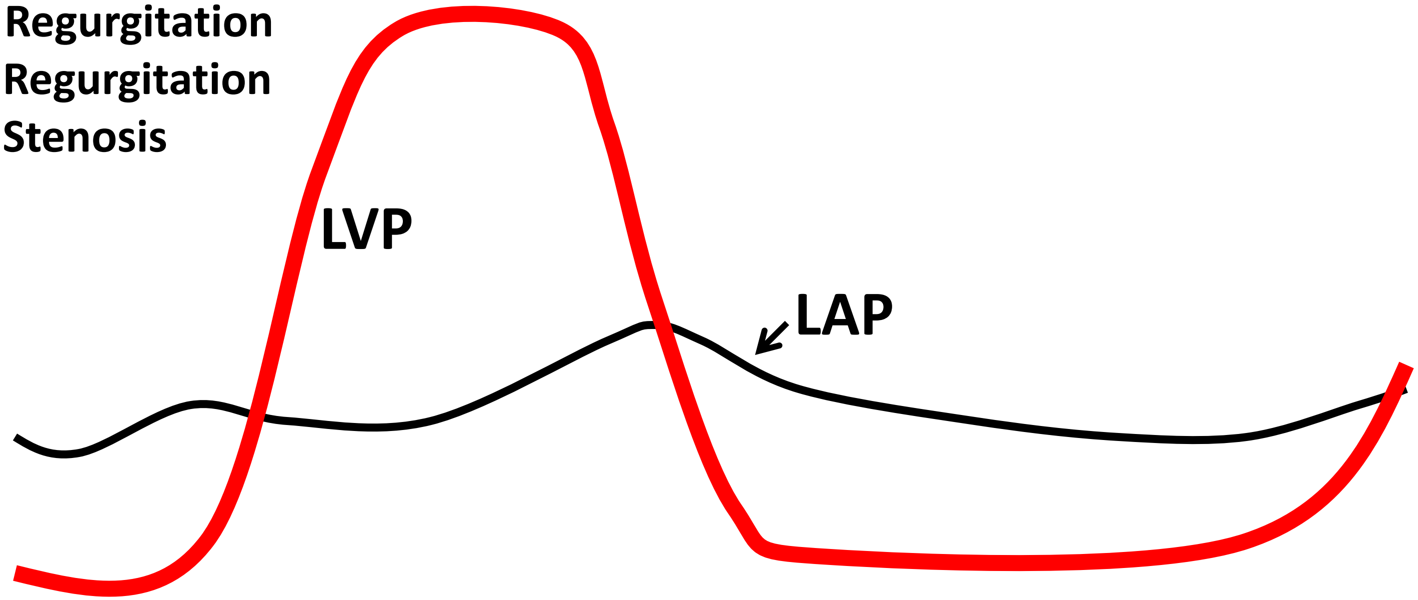

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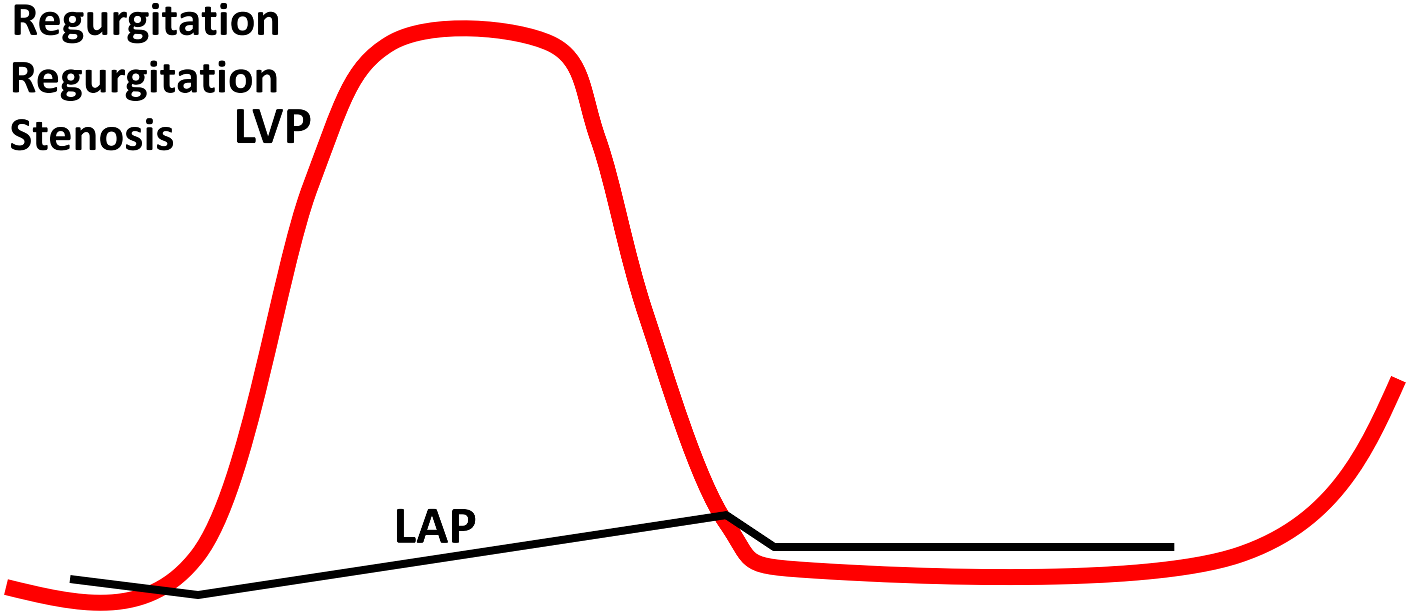

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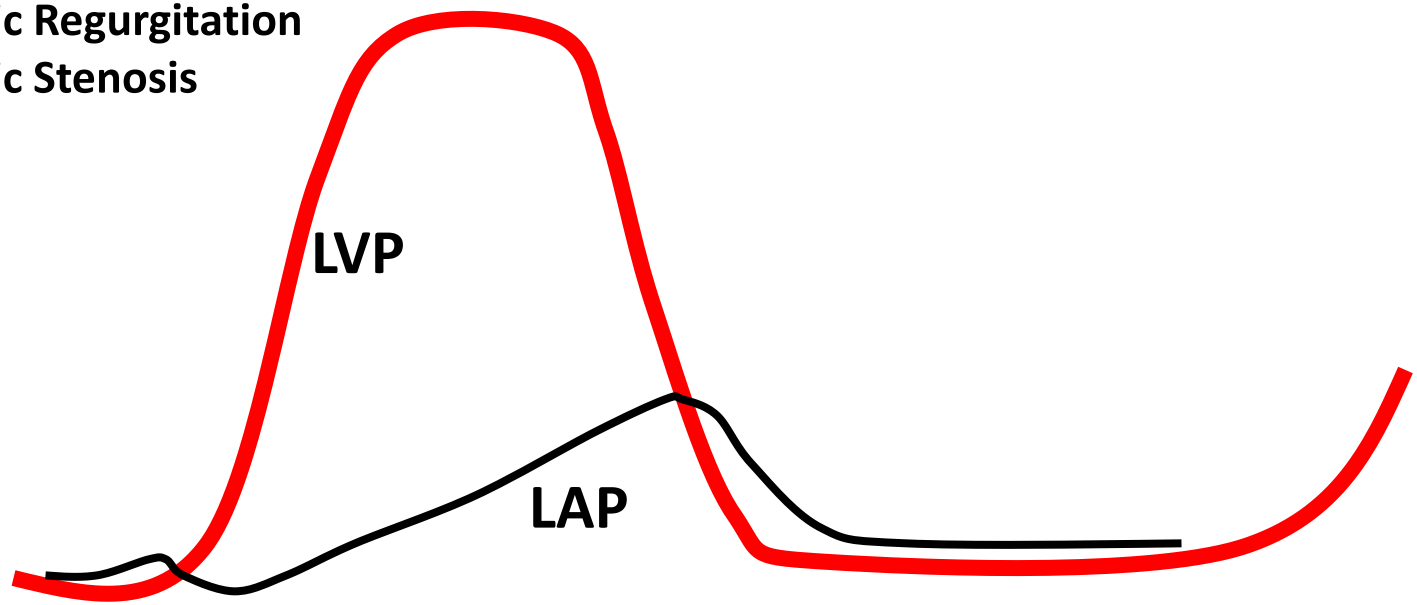

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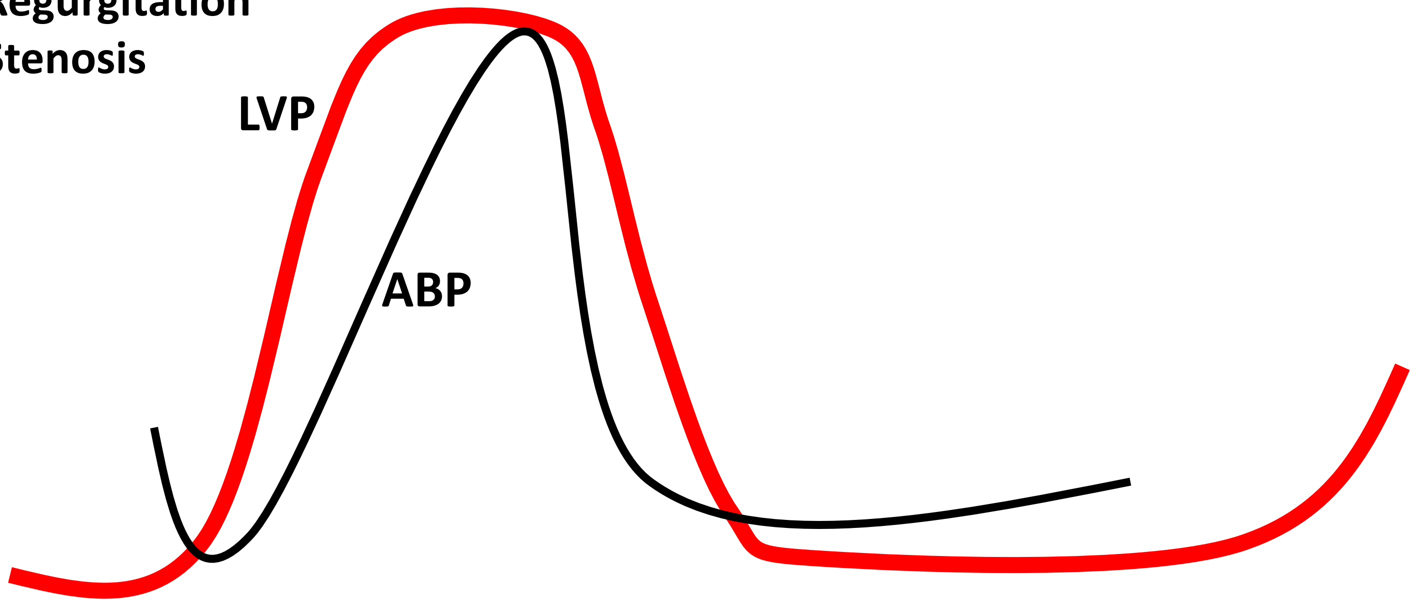

End CV Physiology Lecture 11