## Cardiovascular Physiology

# Cardiac Cycle - 2

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## At end of this lecture you should be able to know:

- ✓ **Identify the systolic & diastolic period**
- ✓ **Discuss the changes of pressure & volumes in left ventricle, left atrium & the aorta during cardiac cycle**
- ✓ **Explain the meaning of isovolumetric contraction, period of ejection & isovolumetric relaxation**
- ✓ **Discuss the volume-pressure relationship in the left ventricle**

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## Cardiac Cycle

# VOLUME CHANGES

## Volume changes

| Phase | Ventricular volume |
|---|---|
| 1. Atrial systole | |
| 2. Isometric contraction phase | |
| 3. Rapid ejection phase | |
| 4. Reduced ejection phase | |
| 5. Protodiastole | |
| 6. Isometric relaxation phase | |
| 7. Rapid filling phase | |
| 8. Reduced filling phase | |

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## Cardiac Cycle

# PRESSURE CHANGES

## Pressure changes:

- Aortic pressure
- Arterial pressure waves
- Pulmonary artery pressure
- Atrial pressure
- Jugular venous pulse wave

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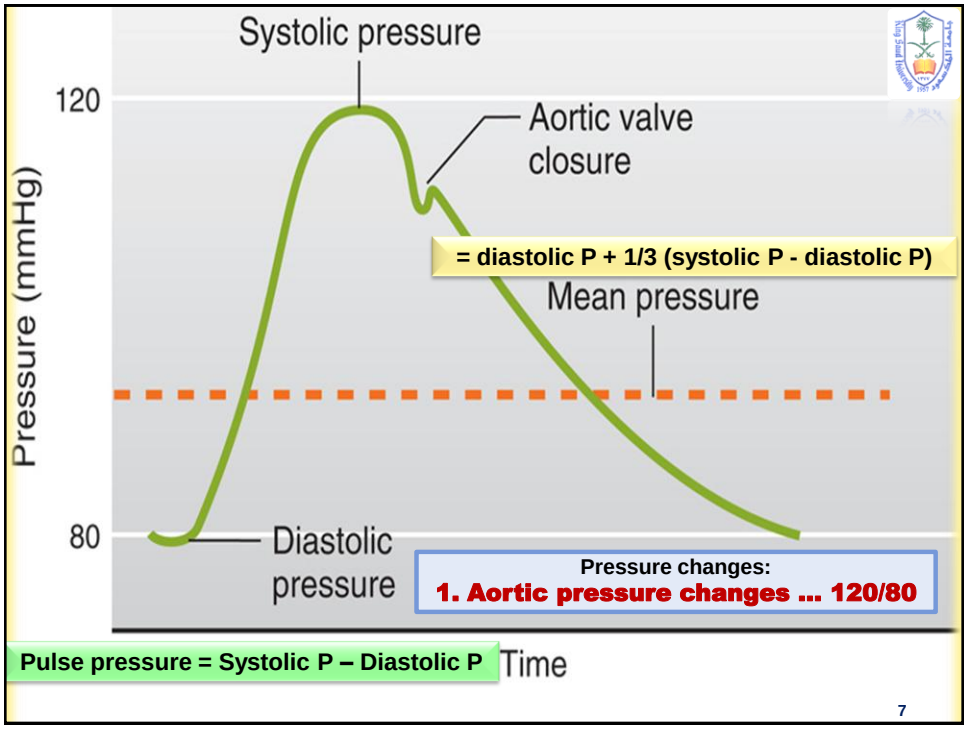
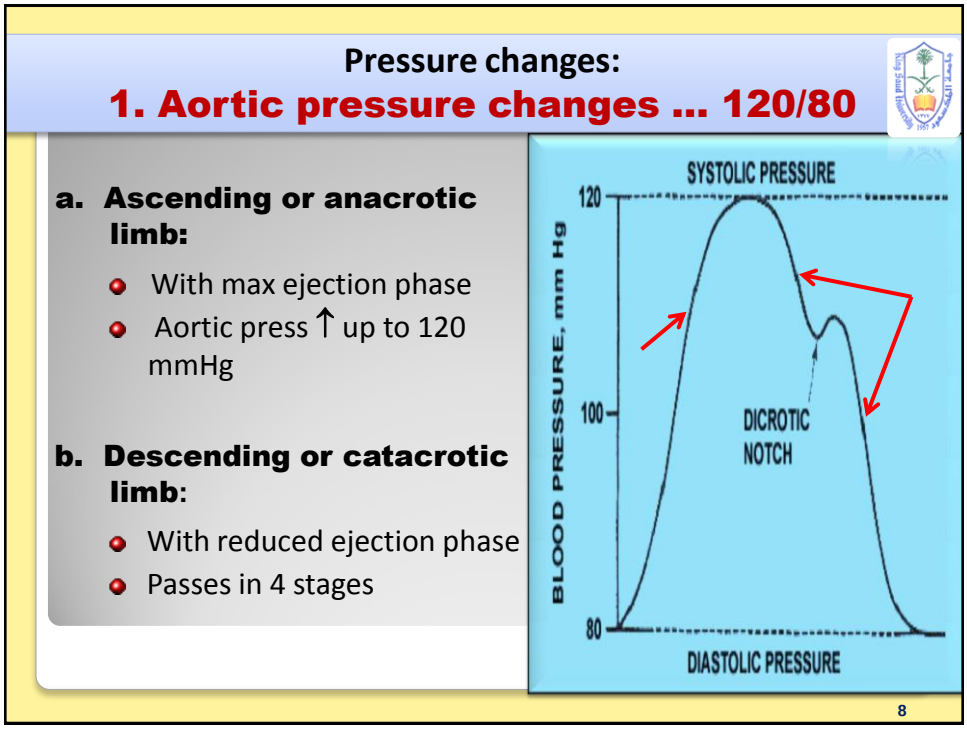

Systolic pressure
120
Aortic valve closure
= diastolic P + 1/3 (systolic P - diastolic P)
Mean pressure
Pressure (mmHg)
80
Diastolic pressure
Pressure changes:
1. Aortic pressure changes … 120/80
Pulse pressure = Systolic P – Diastolic P
Time
7


Pressure changes:
1. Aortic pressure changes … 120/80
a. Ascending or anacrotic limb:
With max ejection phase
Aortic press ↑ up to 120 mmHg
b. Descending or catacrotic limb:
With reduced ejection phase
Passes in 4 stages
SYSTOLIC PRESSURE
120
100
80
BLOOD PRESSURE, mm Hg
DICROTIC NOTCH
DIASTOLIC PRESSURE
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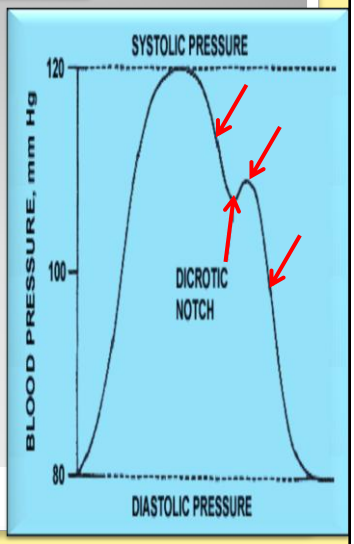
**Descending or catacrotic limb:**
**Passes through 4 stages**

1. ↓ **Aortic press:**
   - Amt of blood enters aorta < leaves
2. **Dicrotic notch (incisura):**
   = Sudden drop in aortic press
   - Due to sudden closure of aortic v
   - At end of protodiastole phase
3. **Dicrotic wave:**
   = Slight ↑ in aortic press
   - Due to elastic recoil of aorta
4. **Slow ↓ aortic press:** up to 80 mmHg
   - Due to continued flow of blood from aorta → systemic circulation

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**Clinical significant of aortic pressure changes:**

- **Aortic Stenosis**
- **Shock or dehydration**
- **Aortic Regurgitation**
- **Hypertension**
- **Pregnancy**

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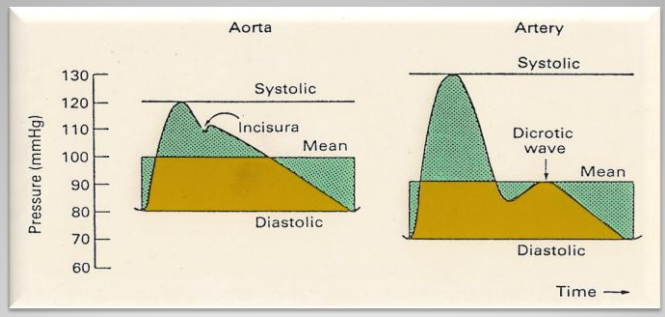
## Pressure changes:
## 2. Arterial pressure changes … 110-130/70-90




- Similar to aortic press waves but **sharper**
- Reflects a systolic peak press of 110-130 mmHg & a diastolic press of 70-90 mmHg

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## Pressure changes:
## 3. Pulmonary artery pressure changes … 25-30/4-12

- Similar to aortic press changes but with **difference in magnitude**

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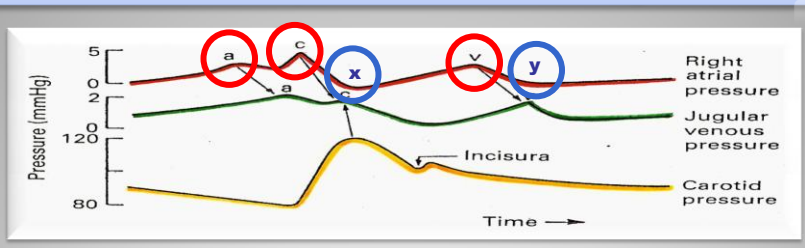
## Pressure changes:
## 4. Atrial pressure changes:




- **Results in:**
  - **3 upward deflection → a, c, & v**
    - 2 components in each wave: +ve (↑ press), -ve (↓ press)
  - **2 downward deflection → x & y**
- **The 3 wave (a, c, & v) are equal to ONE cardiac cycle = 0.8 sec**

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## Causes of atrial pressure waves:

- **'a' wave:** Atraial systole
- **'c' wave:** Ventricular sytole
  - **+ve** → bulging of TV into RA during isovolumetric contraction phase
  - **-ve** → pulling of atrial ms during ventricular contraction
- **'v' wave**: Atrial diastole or ↑ VR
  …↑ RA press due to filling of atrium w blood

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## Causes of atrial pressure waves … (Cont.)

- **'x' descent:** Downward displacement of TV during rapid ejection phase
- **'y' descent:** Rapid blood flow from RA to RV
- **'a-c' interval:**
  - Measured from the **start** of 'a' wave to **start** of 'c' wave
  - Indicates time of conduction of excitation waves through AV node & bundle
  - Corresponds to P-R interval of ECG

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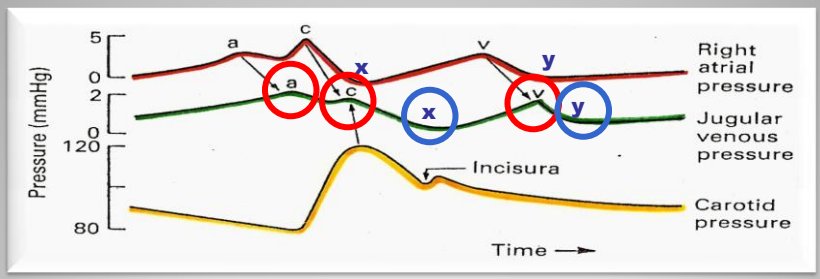
## Pressure changes:
## 5. Jugular venous pulse changes:




- **Also results in recording of transmitted:**
  - 3 upward waves: a, c, & v
  - 2 downward waves: x & y

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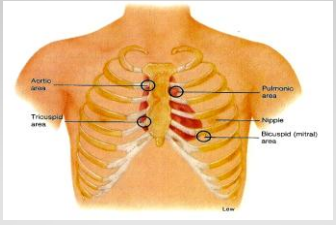
## Cardiac Cycle

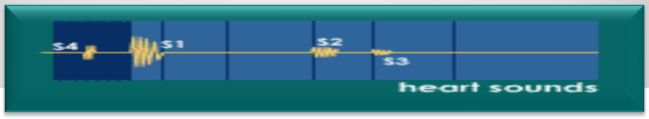
# HEART SOUNDS

## HEART SOUNDS

- **Detected over anterior chest wall by:**
  - **Stethoscope,** (auscultation)




  - **Phonocardiography,** (sound recording device)

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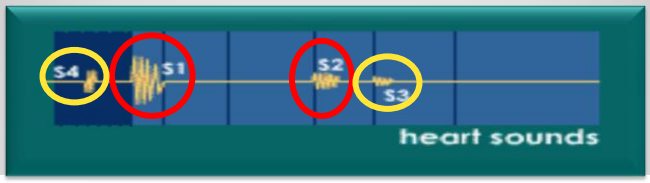
# Heart Sounds:

- '4' heart sounds:
  - 1st & 2nd ht sounds … (usually audible)
  - 3rd & 4th ht sounds … (sometimes detected)
- Important for diagnosis of valvular heart diseases (murmurs)

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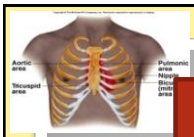

# Different Heart Sounds

| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| Cause | Sudden closure of AV-vs | Sudden closure of semilunar vs | Rush of bl during rapid vent filling → vibration of vent ms. | Vibration produced by cont of atrial ms (attributed to vent filling) |
| C-cycle | Marks beginning of vent systole (Isovolumetric cont) | Marks beginning of vent diastole (When vent press fall below arterial press) | Max vent filling phase of diastole | Atrial systole (just before 1st HS) |
| Duration | 0.15 sec (Longer) | 0.11-0.125 sec (Shorter) | 0.05 sec | 0.04 sec |
| Frequency | 25-35 Hz | 50 Hz | | |
| Character | Low pitch (LUB) (Louder) | High pitch (DUB) (Softer, sharper) Split into 2 sounds during inspiration = Physiological splitting (due to delay closure of pulm v). | Usually not audible | Usually not audible (Rarely heard) |
| Best heard | M & T | A & P | M | M |

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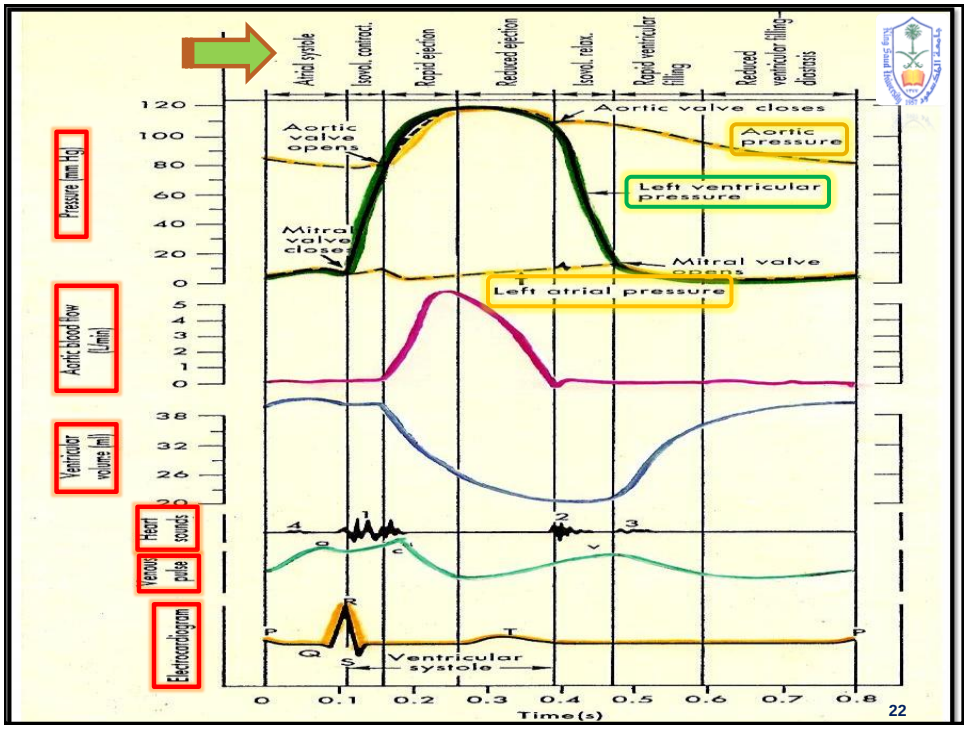
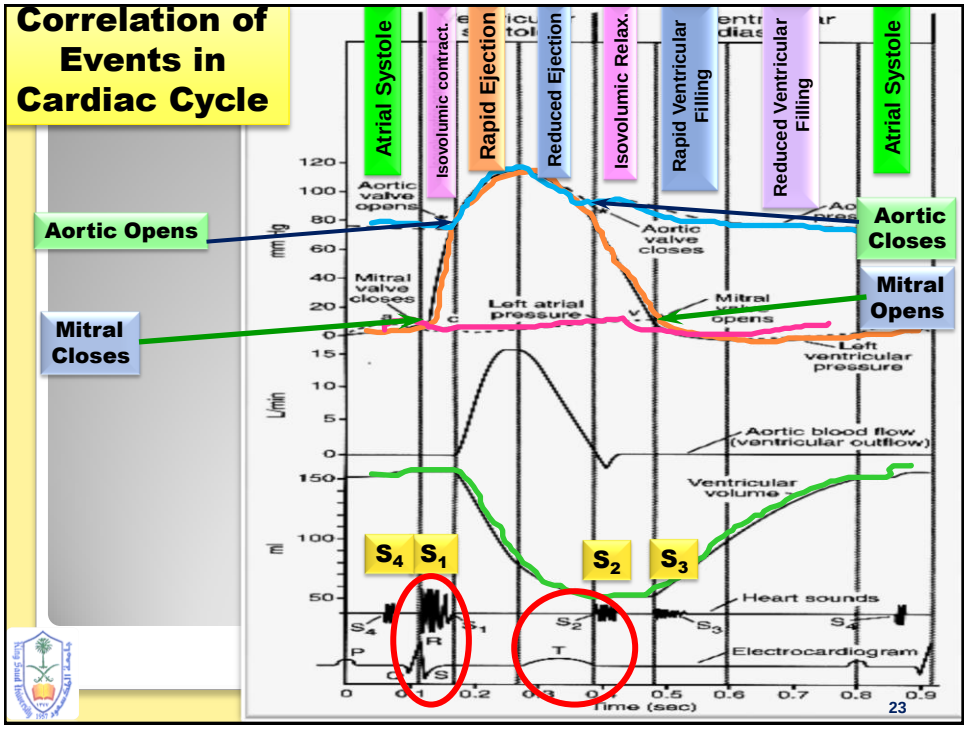
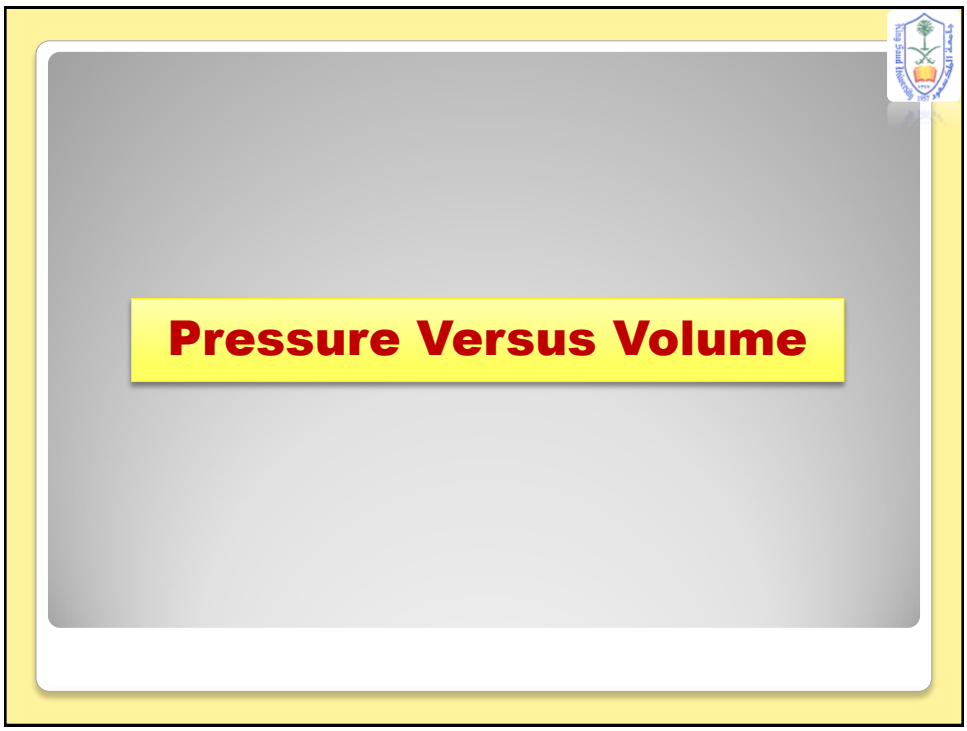
## To Revise:

# The Complete Picture

### Correlation of events in cardiac cycle




Correlation of Events in Cardiac Cycle
Atrial Systole
Isovolumic contract.
Rapid Ejection
Reduced Ejection
Isovolumic Relax.
Rapid Ventricular Filling
Reduced Ventricular Filling
Atrial Systole
Aortic Opens
Aortic Closes
Mitral Closes
Mitral Opens
Aortic valve opens
Aortic valve closes
Mitral valve closes
Mitral valve opens
Left atrial pressure
Left ventricular pressure
Aortic blood flow (ventricular outflow)
Ventricular volume
S4 S1 S2 S3
Heart sounds
Electrocardiogram
Time (sec)
23


Pressure Versus Volume

## Left Ventricular Pressure – Volume Loop

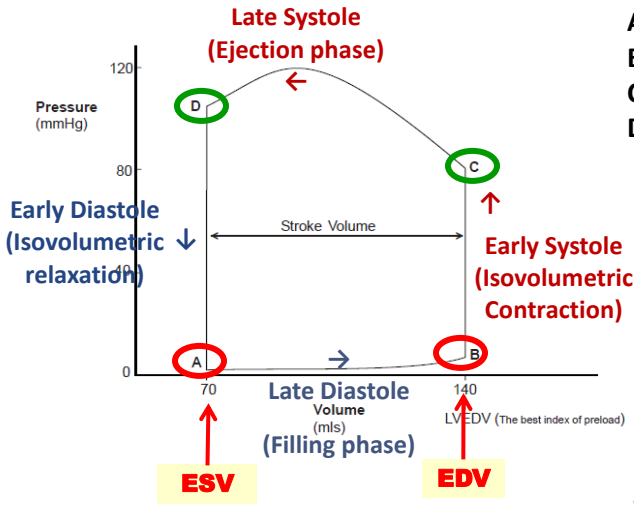
**Demonstrates changes in intraventricular volume & pressure during one cardiac cycle**

- It plots LV pressure against LV volume through one complete cardiac cycle

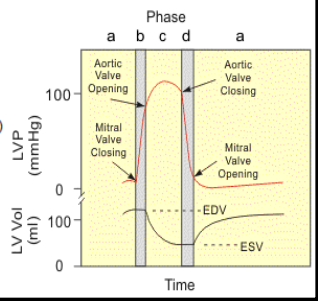
## Basic Myocardial Muscle Mechanics:

- Each part of the cardiac cycle is dominated by a relationship between volume & pressure
- Both systole & diastole can be divided into early & late phases
- **Systole:**
  - Early systole is 'Isovolumetric contraction'
  - Late systole is 'Isotonic contraction'
- **Diastole:**
  - Early diastole is 'Isovolumetric relaxation'
  - Late diastole is 'Isotonic relaxation'

# Ventricular Pressure - Volume Loop




**A – Mitral valve opens**
**B – Mitral valve closes**
**C – Aortic valve opens**
**D – Aortic valve closes**




## Basic Myocardial Muscle Mechanics … (Cont.)

**During Systole:**

- Muscle is contracting & generating pressure
- Pressure causes a change in volume
- This is measured by 'Contractility'
- Is affected by:
  - Function of the muscle
  - Initial volume (Preload)
  - Initial pressure (Afterload)

## Basic Myocardial Muscle Mechanics … (Cont.)

- **Preload:**
  - The passive load that establishes the initial muscle length of the cardiac fibers prior to contraction

  = EDV
- **Afterload:**

  Sum of all loads against which the myocardial fibers must shorten during systole
- **Contractility:**
  - Is the change in volume per time caused by a change in pressure
  - Contractility = (dV/dT) / dP

## Basic Myocardial Muscle Mechanics … (Cont.)

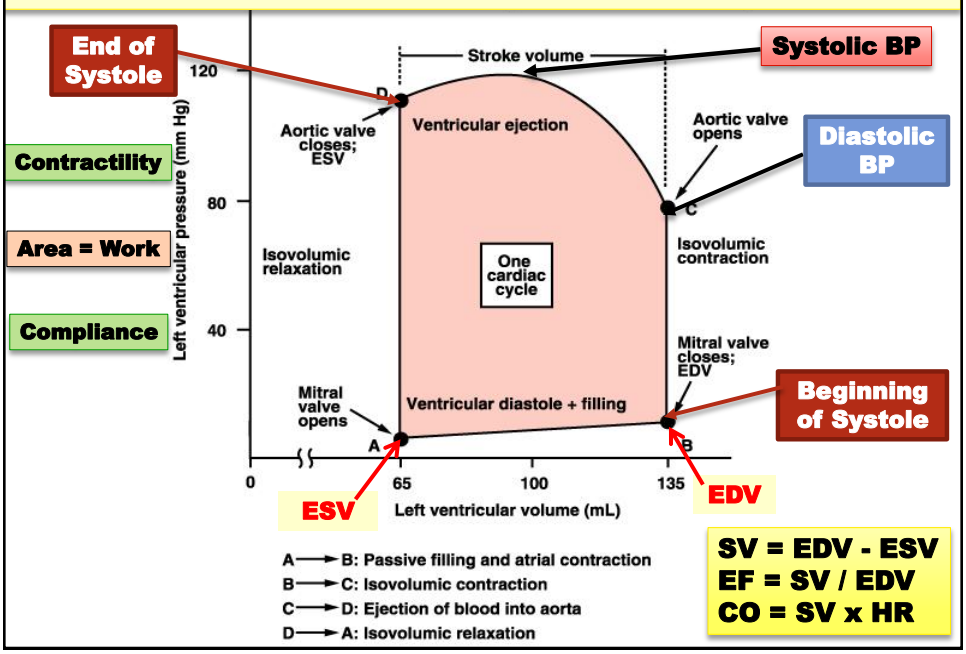
**During Diastole:**

- Muscle is relaxing & venous return to the heart
- Results in changes in absolute volume & pressure
- This relationship is measured by 'Compliance'
- Is affected by:
  - Connective tissue
  - Venous pressure
  - Venous resistance

## Basic Myocardial Muscle Mechanics … (Cont.)

- **Diastolic Compliance:**
  - Is the change in pressure caused by a change in absolute volume
  - Compliance = $\Delta P / \Delta V$
  - Point Compliance = $dP / dV$

## Ventricular Pressure - Volume Loop



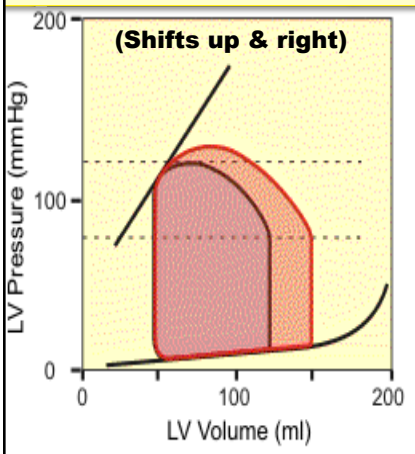
## What you should remember about pressure – volume loop?

- Closer & opening of mitral & aortic vs during each phase
- Beginning of systole (B) & end (D)
- Beginning of diastole (D) & end (B)
- Diastolic filling occurs between points A & B
- Ejection occurs between points C & D

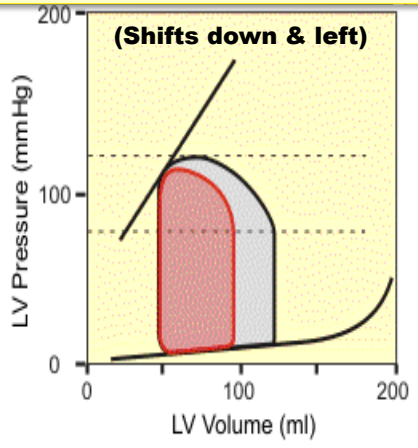
## Increasing Preload Increases SV

- **Preload:**
  The muscle length prior to contraction, dependent on EDV
- ↑ **Preload,** by ↑EDV (occurs with ↑ venous return)
  - Enhances shortening of myocardium
  - Augments force generation w contraction
  - Ventricle develops greater pressure & ejects blood more rapidly
  - N.B. ventricle ejects blood to the same ESV
- **Net effect is ↑ SV**

## Increasing Preload Increases SV




ncreased preload (increased EDV; red loop) at constant aortic diastolic pressure and notropy. SV increases and ESV remains unchanged; EF increases slightly. Dashed ines represent normal aortic systolic and diastolic pressures.

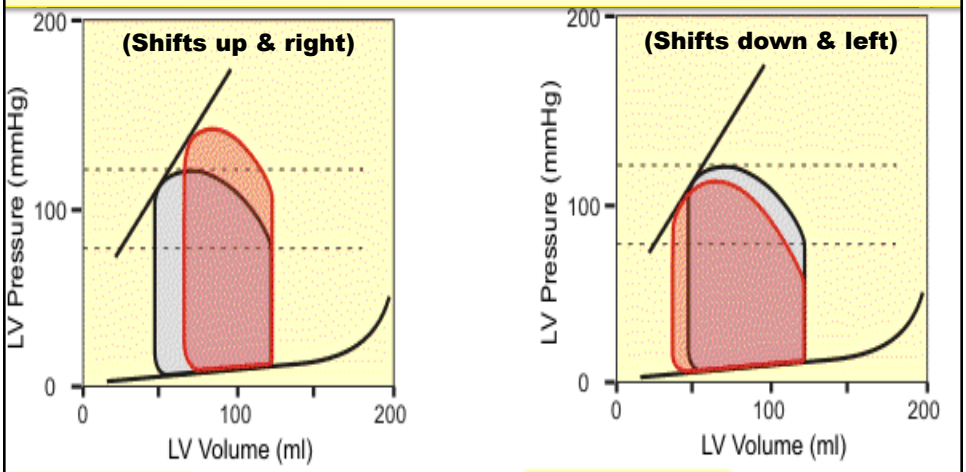



Decreased preload (decreased EDV; red loop) at constant aortic diastolic pressure and inotropy. SV decreases and ESV remains unchanged; EF decreases slightly. Dashed lines represent normal aortic systolic and diastolic pressures.

## Increasing Afterload Decreases SV

- **Afterload:**
  The tension against which the ventricle must contract
- **↑ Afterload,** by ↑aortic diastolic pressure
  - Reduces the velocity of muscle fibre shortening
  - Reduces the velocity by which blood is ejected
- **Net effect is to ↑ ESV & to ↓ SV**

## Increasing Afterload Decreases SV



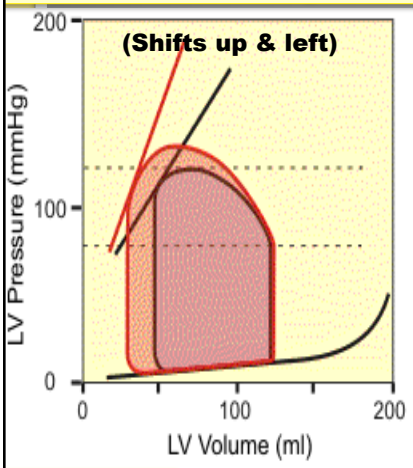

ncreased afterload increased aortic pressure; red loop) at constant preload (EDV) & inotropy. SV decreases and ESV increases; EF decreases. Dashed lines represent normal aortic systolic and diastolic pressures.

Decreased afterload (decreased aortic pressure; red loop) at constant preload (EDV) & inotropy. SV increases and ESV decreases; EF increases. Dashed lines represent normal aortic systolic and diastolic pressures.

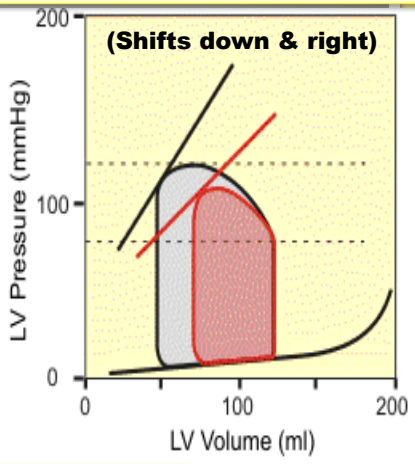
## Increasing Contractility Increases SV

- **Contractility:**
  The force of contraction for a given fibre length
- **↑ Inotropy,**
  - Increases the velocity of muscle fibre shortening
  - Increases the velocity of ventricular pressure development & ejection
- **Net effect is to ↓ ESV & to ↑ SV**

## Increasing Contractility Increases SV




ncreased inotropy (red loop) at constant preload (EDV) & aortic diastolic pressure. SV ncreases and ESV decreases; EF increases. Dashed lines represent normal aortic systolic and diastolic pressures.




Decreased inotropy (red loop) at constant preload (EDV) & aortic diastolic pressure. SV decreases and ESV increases; EF decreases. Dashed lines represent normal aortic systolic and diastolic pressures.