Cardiovascular Physiology

Cardiac Cycle- 2

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

- ✓ Electrical changes that occur during the cardiac cycle
- ✓ The Pressure - Volume Curve
- ✓ The Volume - Pressure Loop

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Events in the cardiac cycle

- **I:** Mechanical events
- **II:** Volume changes
- **III:** Pressure changes
- **IV:** Heart sounds
- **V:** Electrical events (ECG)

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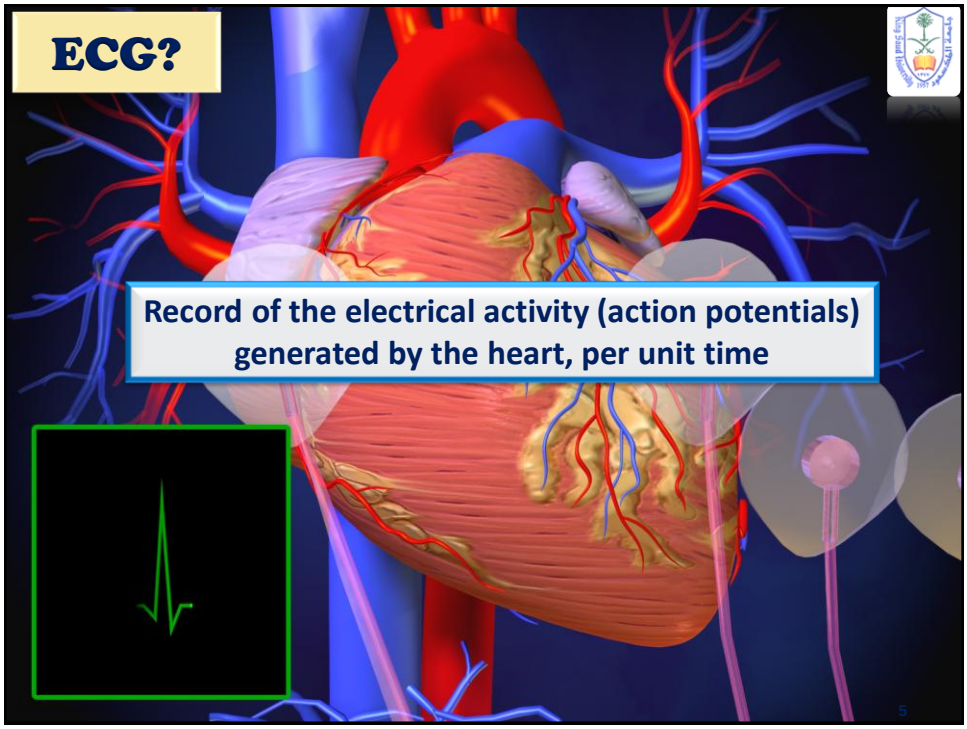
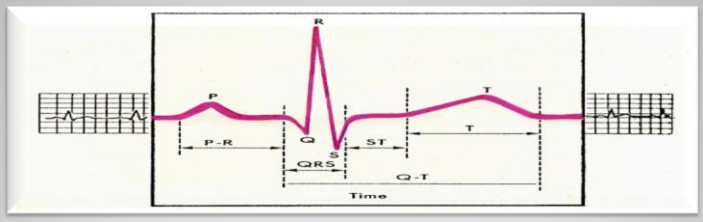
Electrical Changes (ECG) During the Cardiac Cycle



ECG waveforms:

- **One heartbeat is normally recorded as:**
  - **(3) waves:** P- wave, QRS- complex & T- wave



    - 3 positive waves … (P, R & T)
    - 2 negative waves … (Q & S)
  - **(2) intervals between waves:** PR & QT intervals
  - **(1) segment:** ST segment

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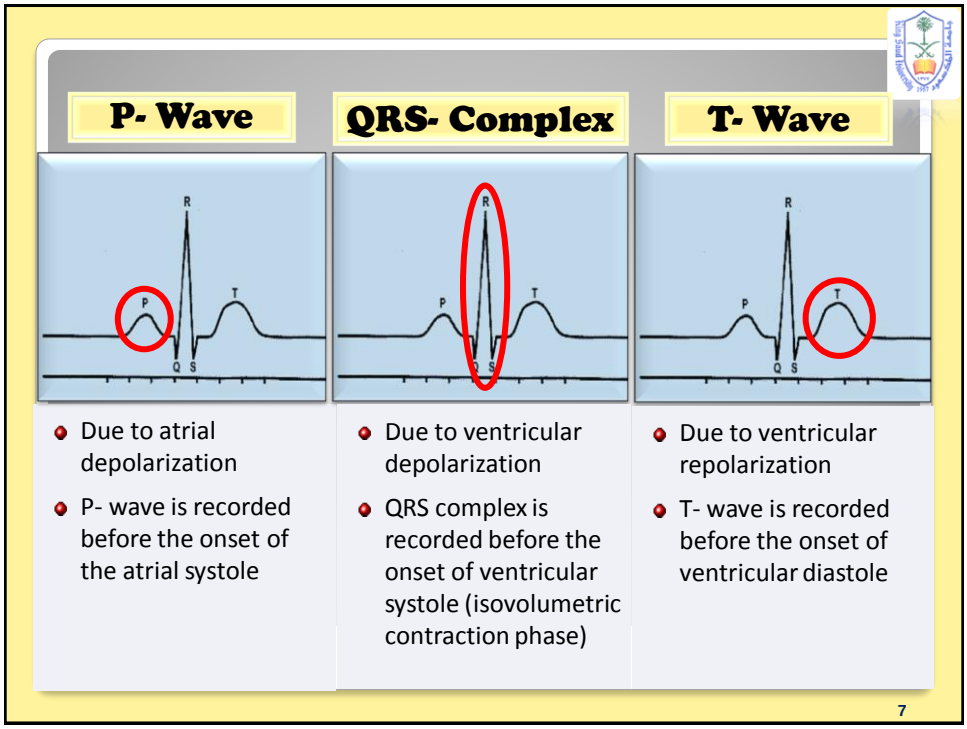
P- Wave
QRS- Complex
T- Wave
R
P
T
Q S
Due to atrial depolarization
P- wave is recorded before the onset of the atrial systole
Due to ventricular depolarization
QRS complex is recorded before the onset of ventricular systole (isovolumetric contraction phase)
Due to ventricular repolarization
T- wave is recorded before the onset of ventricular diastole
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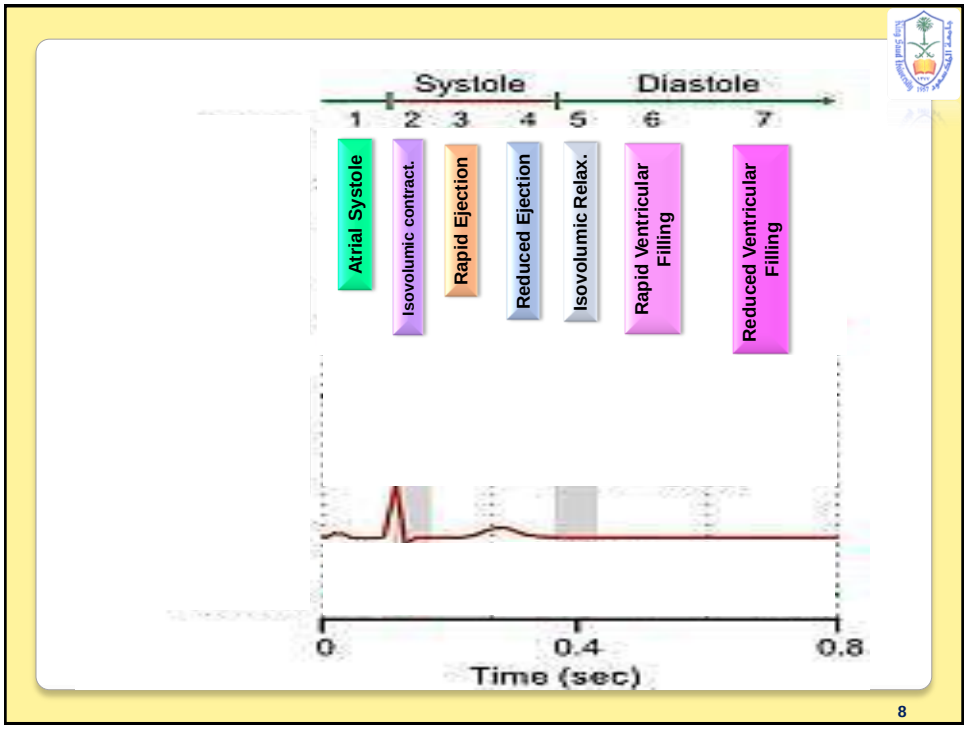
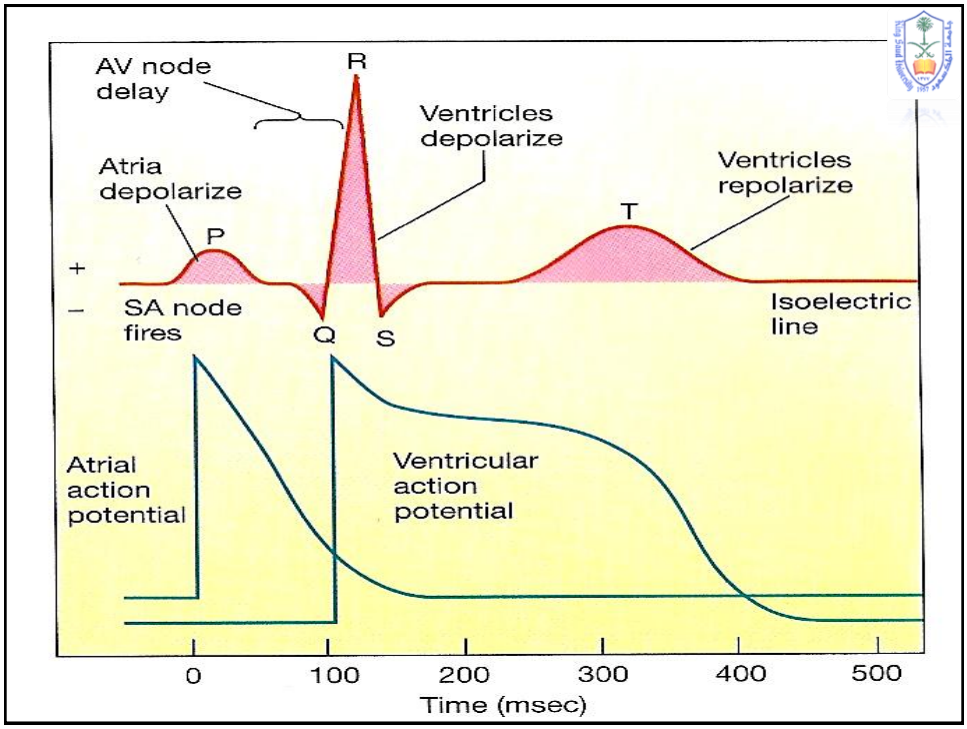
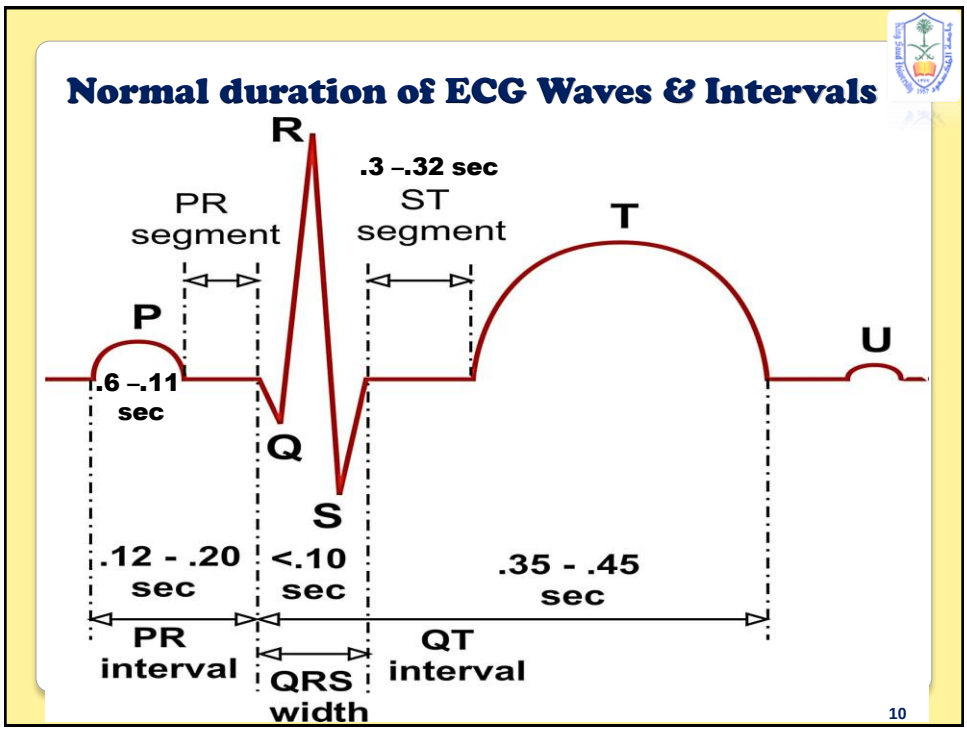

Systole
Diastole
1 2 3 4 5 6 7
Atrial Systole
Isovolumic contract.
Rapid Ejection
Reduced Ejection
Isovolumic Relax.
Rapid Ventricular Filling
Reduced Ventricular Filling
0
0.4
0.8
Time (sec)
8


AV node delay
R
Ventricles depolarize
Atria depolarize
Ventricles repolarize
P
T
+
–
SA node fires
Q
S
Isoelectric line
Atrial action potential
Ventricular action potential
0
100
200
300
400
500
Time (msec)


Normal duration of ECG Waves & Intervals
R
.3 –.32 sec
PR segment
ST segment
T
P
U
.6 –.11 sec
Q
S
.12 - .20 sec
<.10 sec
.35 - .45 sec
PR interval
QRS width
QT interval
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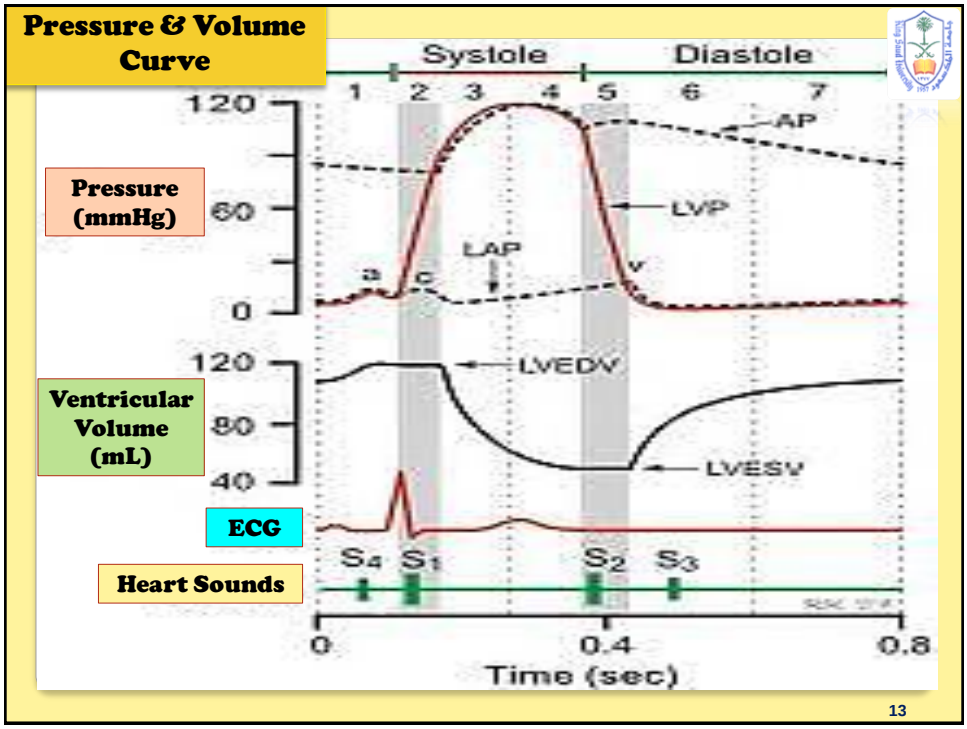
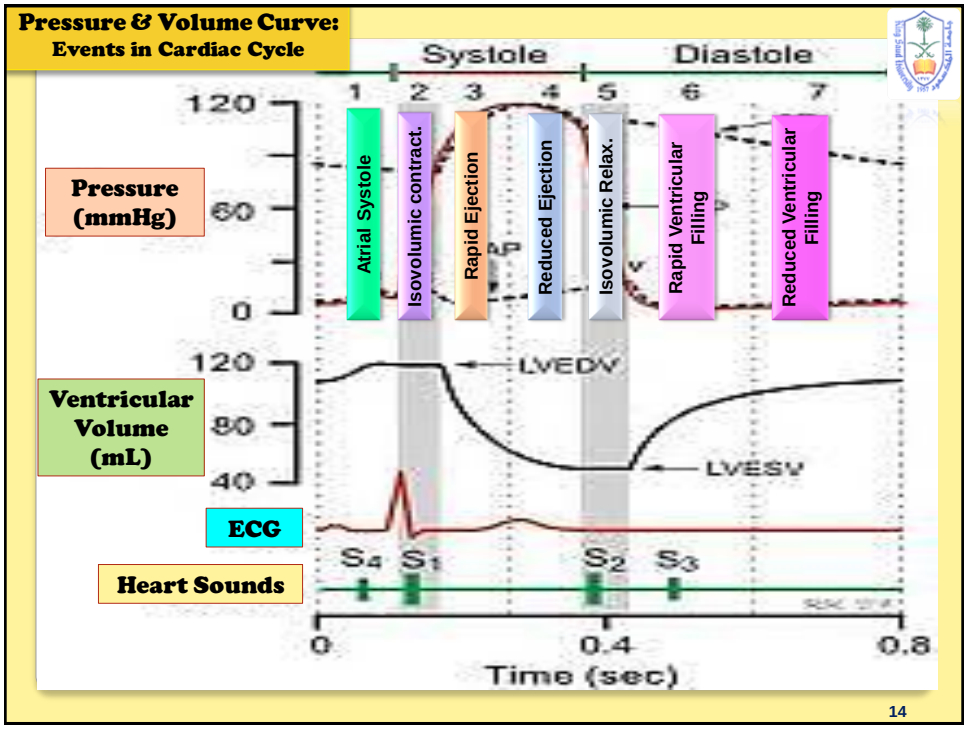
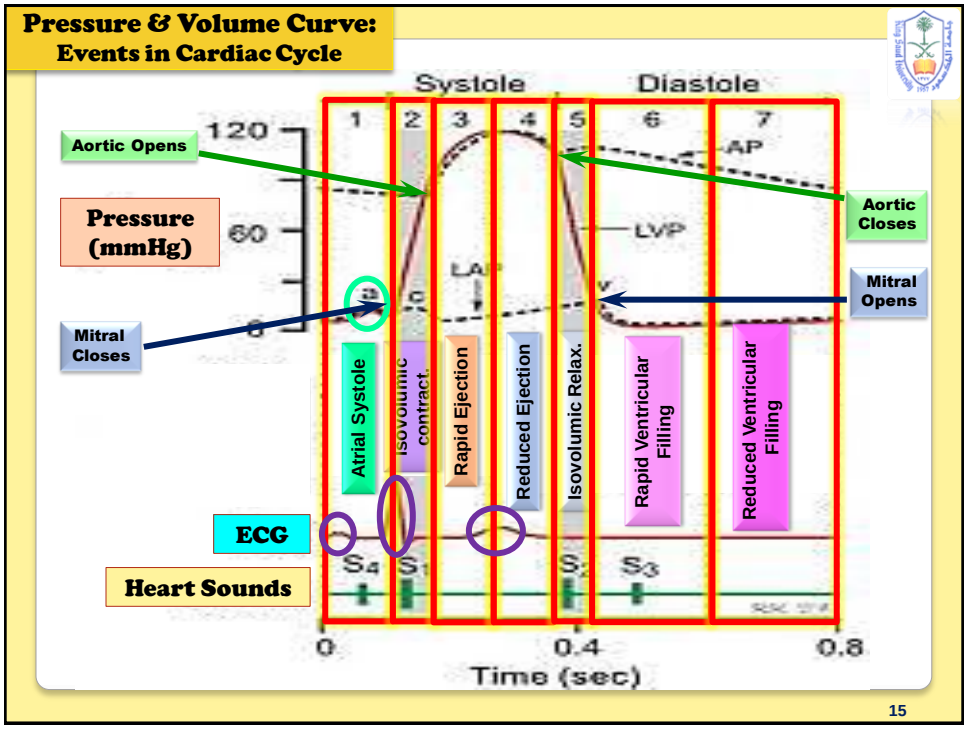
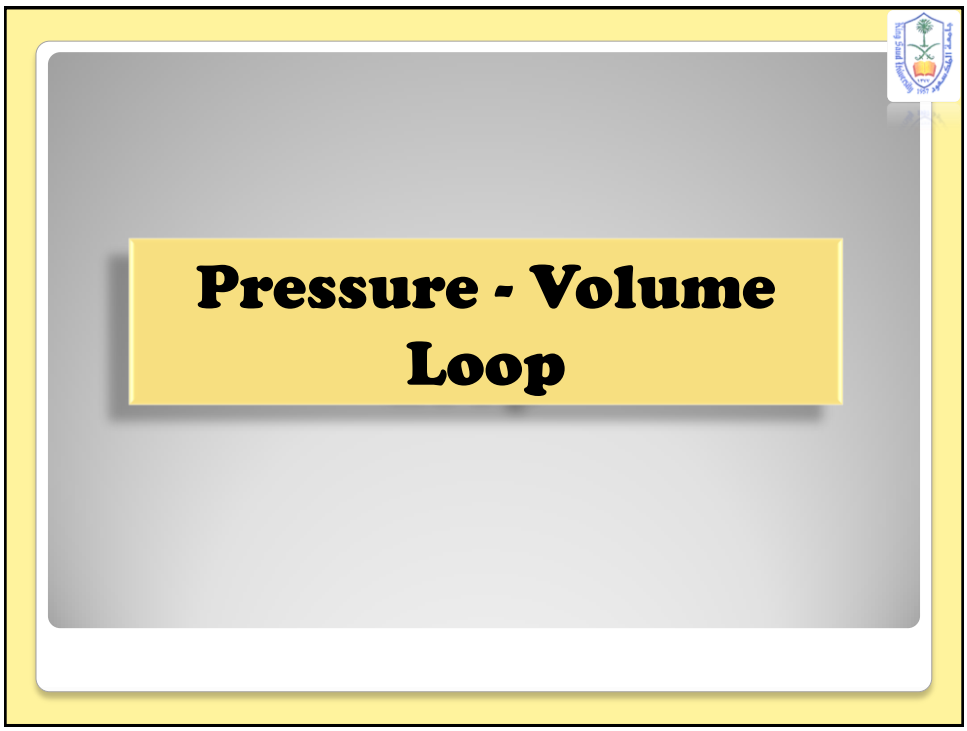
Pressure Versus Volume

Pressure – Volume Curve
"The Complete Picture"


Pressure & Volume Curve
Systole
Diastole
1 2 3 4 5 6 7
120
60
0
Pressure (mmHg)
AP
LVP
LAP
a
c
v
120
80
40
Ventricular Volume (mL)
LVEDV
LVESV
ECG
Heart Sounds
S4 S1 S2 S3
0
0.4
0.8
Time (sec)
13


Pressure & Volume Curve: Events in Cardiac Cycle
Systole
Diastole
1 2 3 4 5 6 7
120
60
0
Pressure (mmHg)
Atrial Systole
Isovolumic contract.
Rapid Ejection
Reduced Ejection
Isovolumic Relax.
Rapid Ventricular Filling
Reduced Ventricular Filling
AP
v
120
80
40
Ventricular Volume (mL)
LVEDV
LVESV
ECG
Heart Sounds
S4 S1 S2 S3
0
0.4
0.8
Time (sec)
14


Pressure & Volume Curve:
Events in Cardiac Cycle
Systole
Diastole
1
2
3
4
5
6
7
120
60
0
AP
LVP
LA
Aortic Opens
Aortic Closes
Mitral Opens
Mitral Closes
Pressure (mmHg)
Atrial Systole
Isovolumic contract.
Rapid Ejection
Reduced Ejection
Isovolumic Relax.
Rapid Ventricular Filling
Reduced Ventricular Filling
ECG
Heart Sounds
S4
S1
S2
S3
0
0.4
0.8
Time (sec)
15


Pressure - Volume Loop

Left Ventricular Pressure – Volume Loop

Correlation of intra-ventricular changes in volume & pressure that occur during one cardiac cycle

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Basic Myocardial Muscle Mechanics:

- Both ventricular systole & diastole can be divided into early & late phases
- **Systole:**
  - Early systole = 'Isovolumetric Contraction'
  - Late systole = 'Isotonic Contraction'
    = 'Ejection Phase'
- **Diastole:**
  - Early diastole = 'Isovolumetric Relaxation'
  - Late diastole = 'Isotonic Relaxation'
    = 'Filling Phase'

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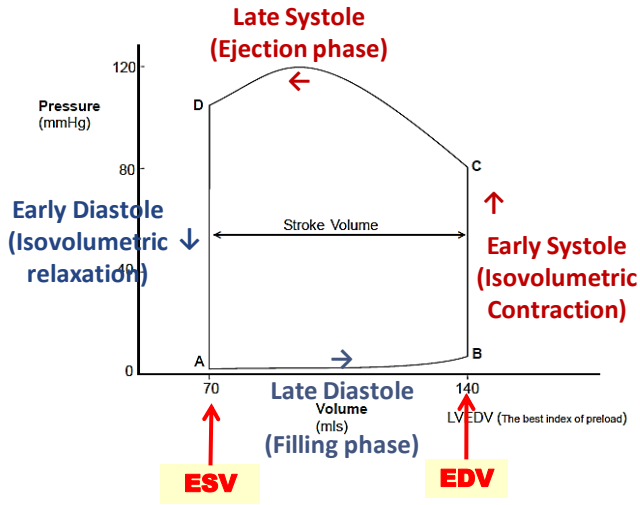
Ventricular Pressure - Volume Loop



- **Plots LV pressure against LV volume through one complete cardiac cycle**
- **Systole:** divided into,
  - Early systole
  - Late systole
- **Diastole:** divided into,
  - Early diastole
  - Late diastole

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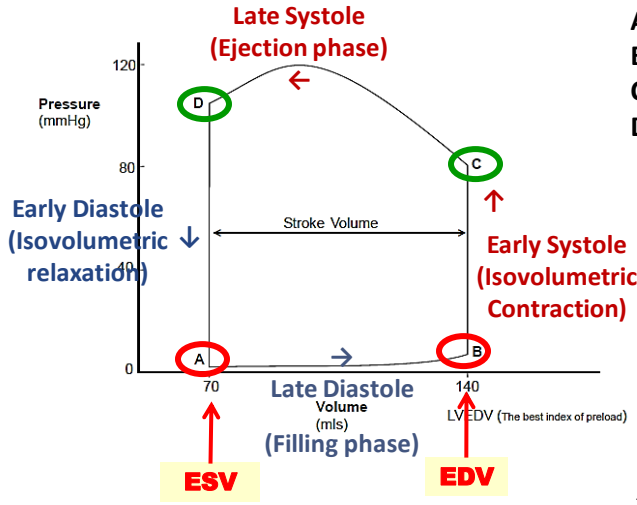
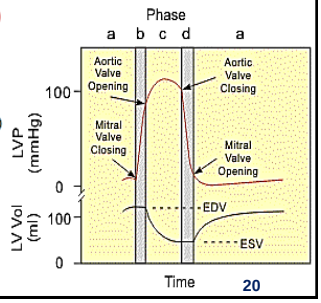
Ventricular Pressure - Volume Loop



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



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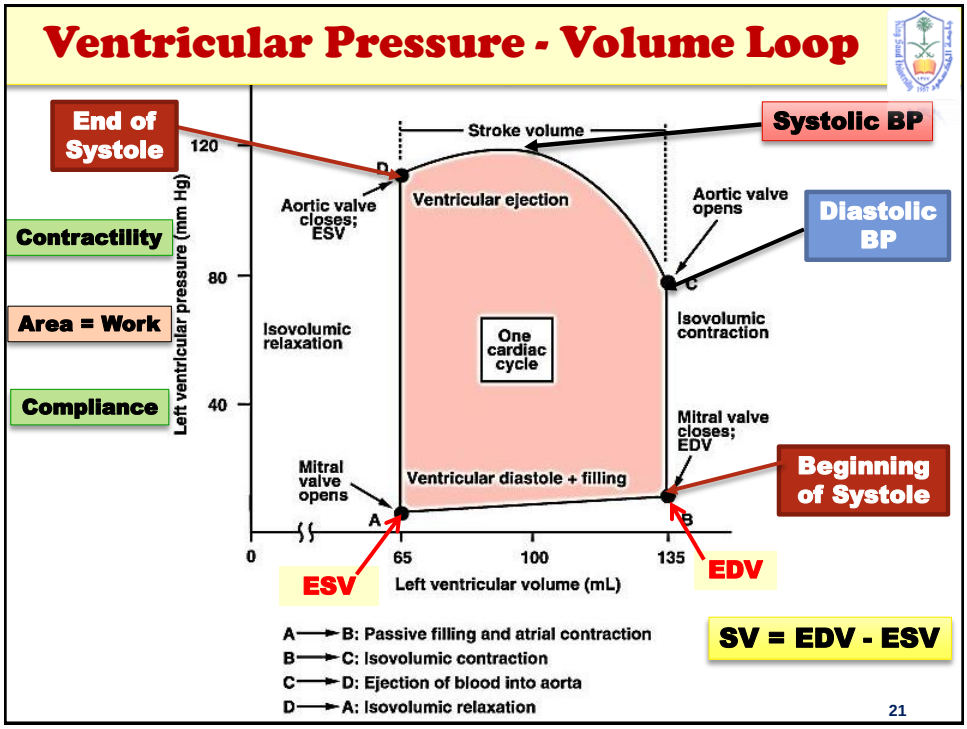
Ventricular Pressure - Volume Loop
End of Systole
Contractility
Area = Work
Compliance
Systolic BP
Diastolic BP
Stroke volume
Aortic valve closes; ESV
Ventricular ejection
Aortic valve opens
Isovolumic relaxation
One cardiac cycle
Isovolumic contraction
Mitral valve closes; EDV
Mitral valve opens
Ventricular diastole + filling
Beginning of Systole
ESV
EDV
Left ventricular pressure (mm Hg)
120
80
40
0
65
100
135
Left ventricular volume (mL)
A → B: Passive filling and atrial contraction
B → C: Isovolumic contraction
C → D: Ejection of blood into aorta
D → A: Isovolumic relaxation
SV = EDV - ESV
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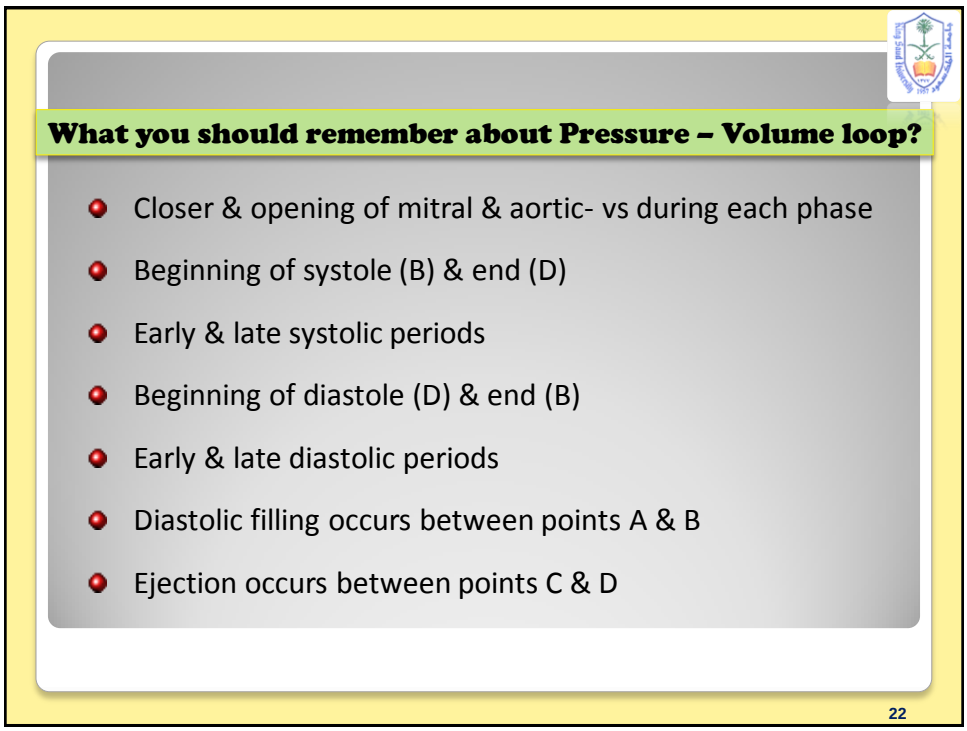
What you should remember about Pressure – Volume loop?
Closer & opening of mitral & aortic- vs during each phase
Beginning of systole (B) & end (D)
Early & late systolic periods
Beginning of diastole (D) & end (B)
Early & late diastolic periods
Diastolic filling occurs between points A & B
Ejection occurs between points C & D
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During Ventricular Systole:

- Muscle contracts & generates pressure which causes changes in volume
- Measured by '**Contractility**'
- Affected by:
  - Function of the muscle
  - Initial volume (Preload)
  - Initial pressure (Afterload)

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During Ventricular Diastole:

- Muscle is relaxing & venous blood returns to the heart resulting in changes in absolute volume & pressure
- Measured by '**Compliance**': $C = \Delta V / \Delta P$
- Affected by:
  - Connective tissue
  - Venous pressure
  - Venous resistance

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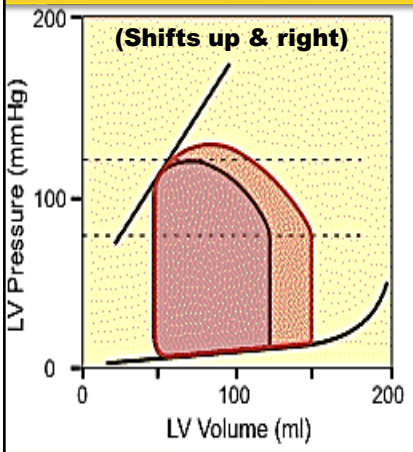
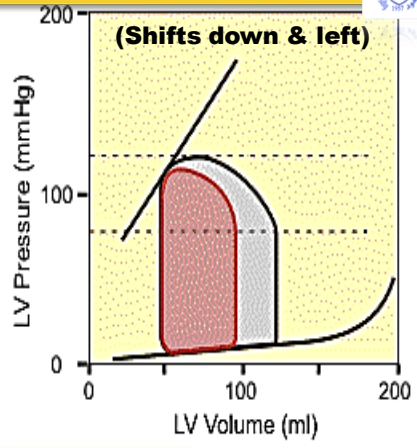
Increasing Ventricular Preload Increases SV





Increased preload (increased EDV; red loop) at constant aortic diastolic pressure and inotropy. SV increases and ESV remains unchanged; EF increases slightly. Dashed lines 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.

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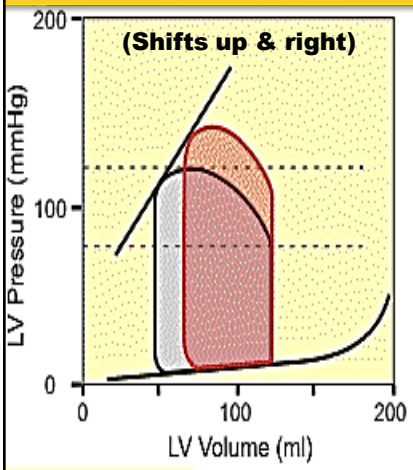
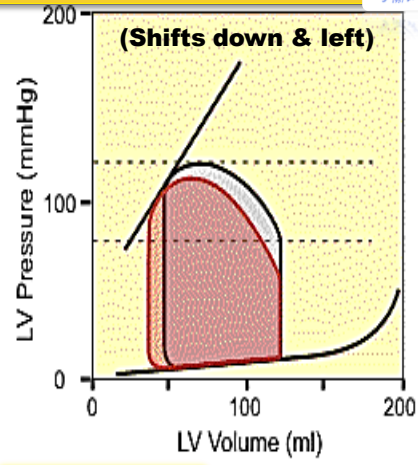
Increasing Ventricular Afterload Decreases SV





Increased 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.

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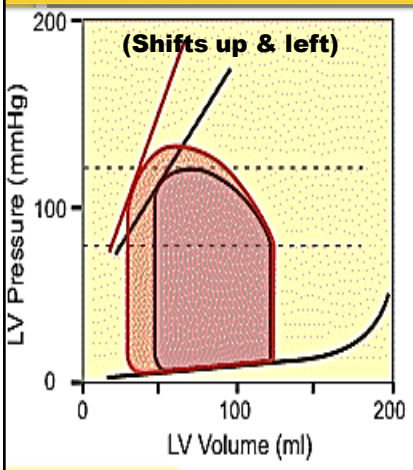
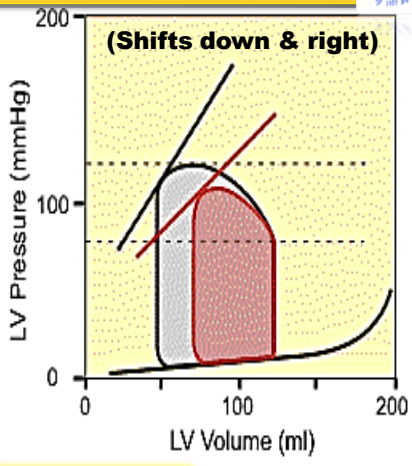
Increasing Ventricular Contractility Increases SV



Increased inotropy (red loop) at constant preload (EDV) & aortic diastolic pressure. SV increases 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.

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