Cardiovascular Physiology

Cardiac Cycle

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

- ✓ Main function of the heart.
- ✓ Function of the atria and ventricles.
- ✓ Function of the valves.
- ✓ General principles of the cardiac cycle.
- ✓ Different events that occur during the cardiac cycle.

2

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

- ✓ Volume changes that occur during the cardiac cycle.
- ✓ Pressure changes that occur during the cardiac cycle.
- ✓ General principle of the electrical changes that occur during the cardiac cycle.
- ✓ Pressure-Volume Loop.

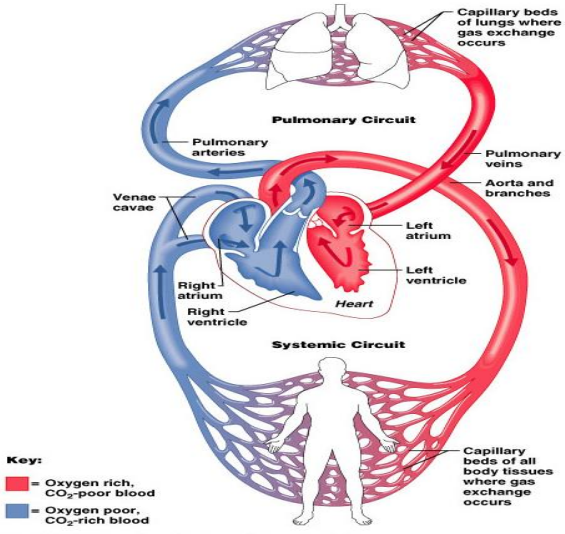
3

Function of the Heart ?

4

The Heart is a double pump

'Pulmonary & Systemic Circulations'



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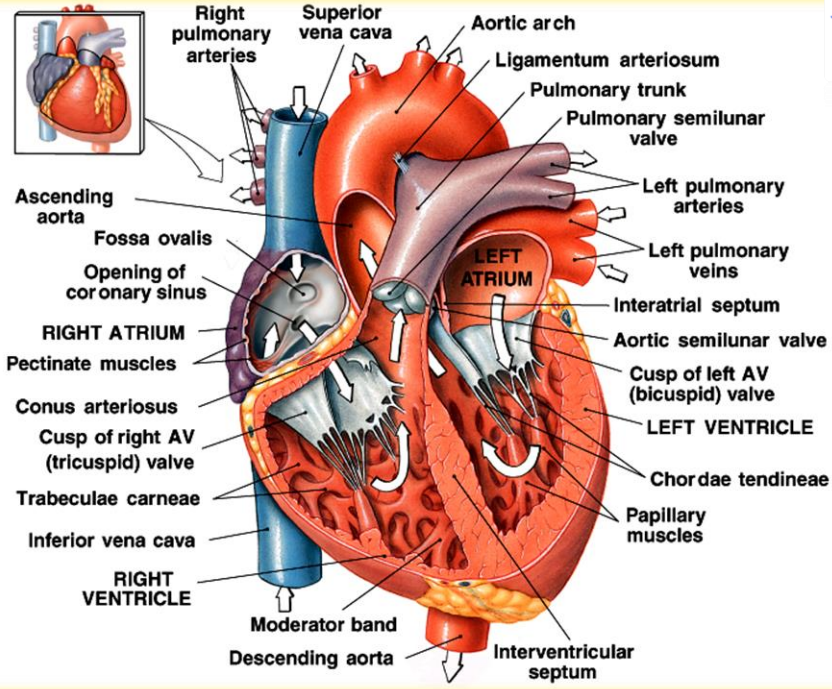

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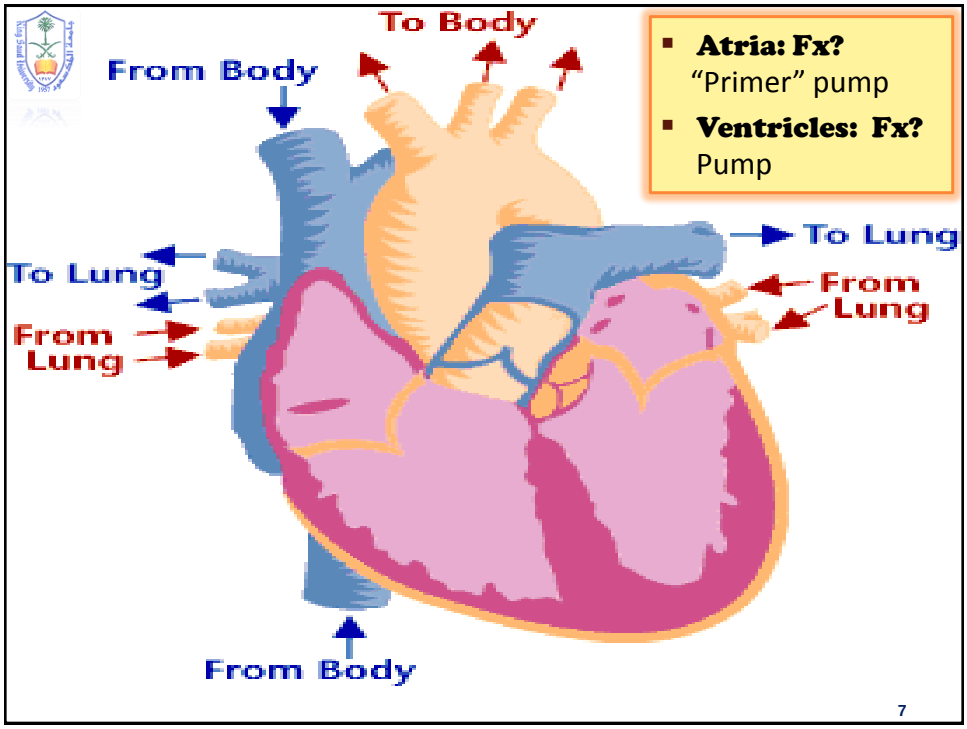
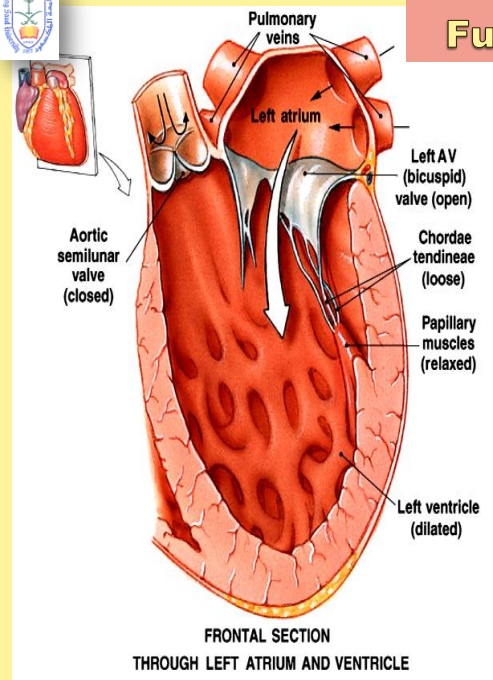


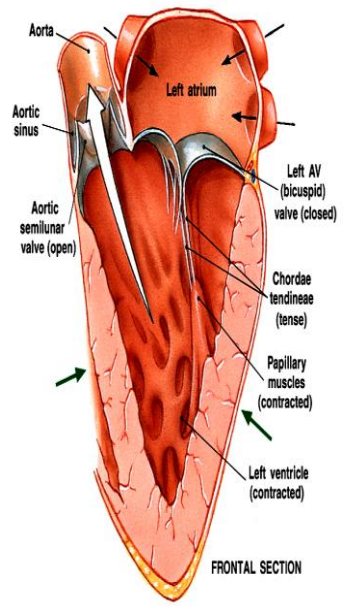
Valves of the Heart :

- Found at entry & exit of each ventricle
- Allow blood to flow in ONLY ONE direction
- When AV valve open, semilunar valve close & vice versa
- Opening & closing of valves occur as a result of pressure gradient across the vs
- AV cusps are held by chordae tendinea to muscular projections called Papillary muscles:
  - Papillary muscles limit valve movements & prevent eversion
  - Papillary muscles don't open or close the valve

8

Function of the Valves:





9

General Principles

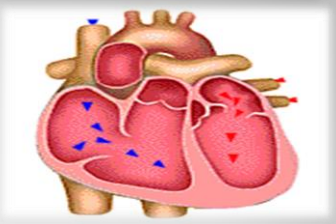
- Contraction of the heart generates pressure changes, resulting in orderly blood movement.
- Blood flows from an area of high pressure to an area of low pressure.
- Heart is a double pump (right & left sides) that work together.
- Events in the right & left sides of the heart are the same, but with lower pressures in the right side.

10

Cardiac Cycle ?

Sequence of events that take place in the heart in each beat

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



- **Cardiac cycle duration = 0.8 sec …**
  - When HR 72 bpm
    - Shortened when HR ↑

11

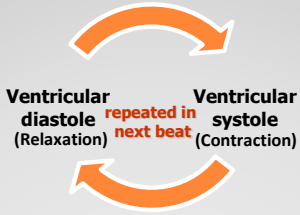
Events in the cardiac cycle ?

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

12

Mechanical Events:

- **Each heartbeat consists of 2 major periods:**
  - Systole (Contraction)
  - Diastole (Relaxation)



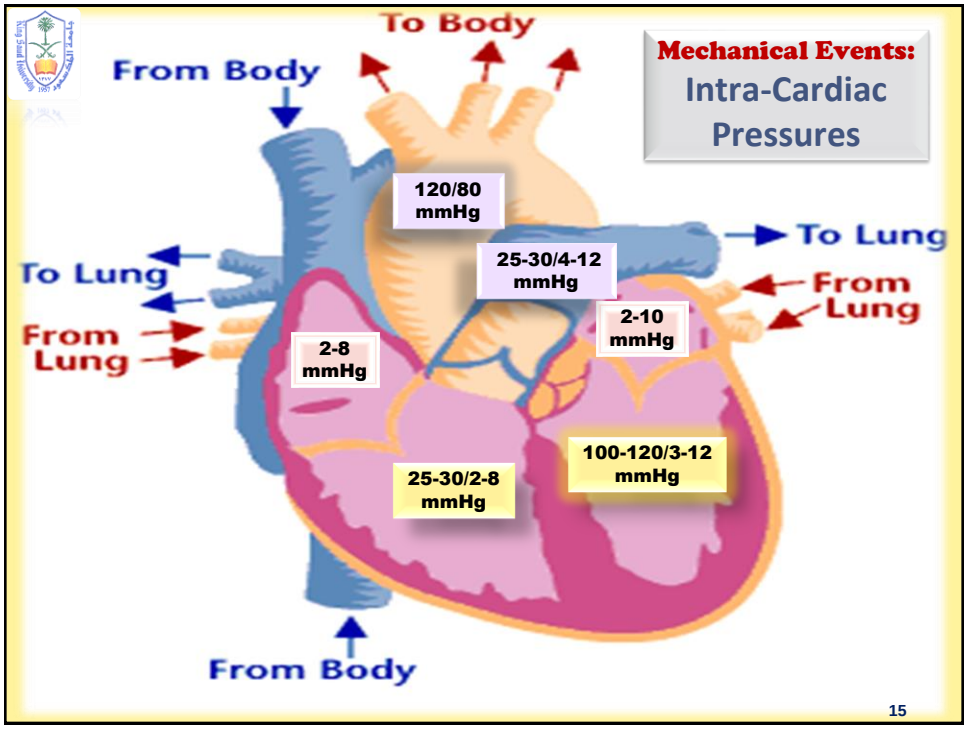
- **Atrial:** systole & diastole
- **Ventricular:** systole & diastole

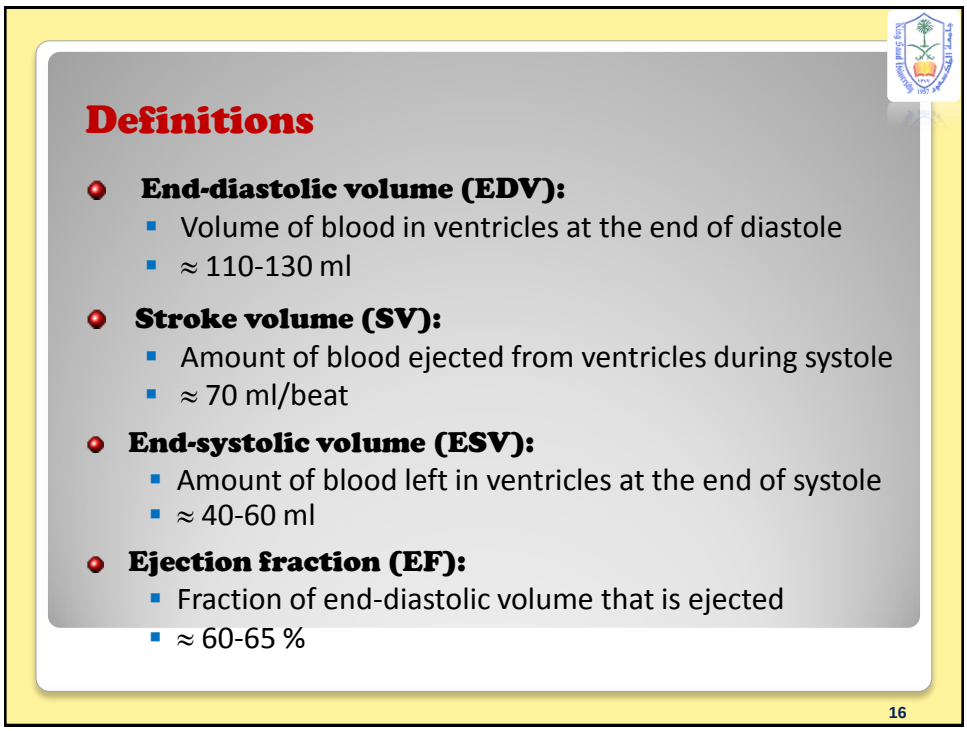
13

Mechanical Events' Periods:

- **Normally diastole is longer > systole:**
  - Ventricular systole = 0.3 sec
  - Ventricular diastole = 0.5 sec
  - Atrial systole = 0.1 sec
  - Atrial diastole = 0.7 sec
- **Importance of long ventricular diastole?**
  1. Coronary blood flow
  2. Ventricular filling

14


To Body
From Body
Mechanical Events:
Intra-Cardiac Pressures
120/80 mmHg
To Lung
25-30/4-12 mmHg
From Lung
2-10 mmHg
To Lung
From Lung
2-8 mmHg
100-120/3-12 mmHg
25-30/2-8 mmHg
From Body
15


Definitions
End-diastolic volume (EDV):
Volume of blood in ventricles at the end of diastole
≈ 110-130 ml
Stroke volume (SV):
Amount of blood ejected from ventricles during systole
≈ 70 ml/beat
End-systolic volume (ESV):
Amount of blood left in ventricles at the end of systole
≈ 40-60 ml
Ejection fraction (EF):
Fraction of end-diastolic volume that is ejected
≈ 60-65 %
16

Mechanical Events:
Mechanical Phases

Consists of 7 phases

- **Early ventricular diastole:**
  - ?? **Protodiastole**
  1. Isometric relaxation phase
  2. Rapid filling phase
- **Mid ventricular diastole:**
  3. Reduced filling phase
- **Late ventricular diastole:**
  4. Atrial systole

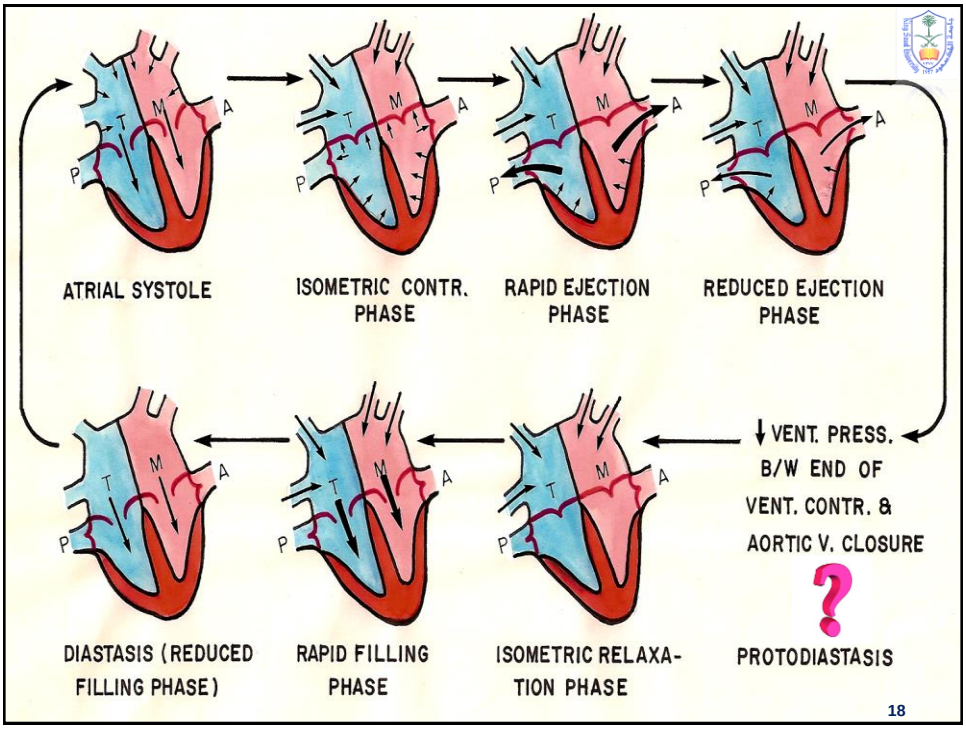
Ventricular diastole

Ventricular systole

- **Ventricular systole:**
  1. Isometric contraction phase
  2. Rapid ejection phase
  3. Reduced ejection phase

N.B. ? Considered '8' phases if including 1st phase of diastole

17

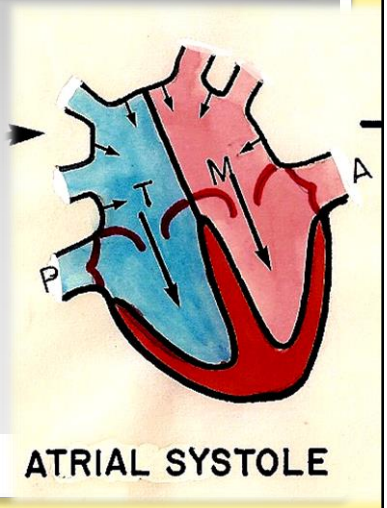


18

Mechanical Phases of cardiac cycle:

1. Atrial Systole:

- At the end of ventricular diastole … (lasts 0.1 sec)
- Preceded by atrial depolarization
- **Valves:**
  AV- vs open (semilunar- vs closed)
- **Volume changes:**
  Tops off last 27-30% of ventricular filling ≈ 40 ml
- **Pressure changes:**
  Atrial pressure ↑
- **4th Heart sound heard**
- Blood arriving the heart can't enter atria, it flows back up jugular vein



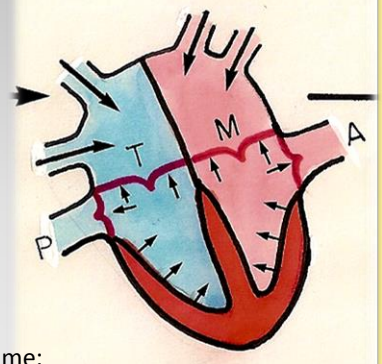
ATRIAL SYSTOLE

19

Mechanical Phases of cardiac cycle:

2. Isovolumetric Contraction Phase:

- At the beginning of systole … (0.04 sec)
- Quiescent period (b/w closure of AV- vs & opening of Semilunar- vs)
- Preceded by ventricular depolarization
- Starts with <u>closure</u> of AV- vs:
  - Ventricular pressure > atrial pressure
  - Atrial diastole
- **1st Heart sound heard**
- **Ventricle is a closed chamber:**
- Ventricle contracts w/out change in volume:
  - Volume in ventricle is the '**EDV**'
- Ventricular pressure < aortic pressure
  - Aortic v <u>opens</u> at the end of this phase: (when LV = 80 mmHg)



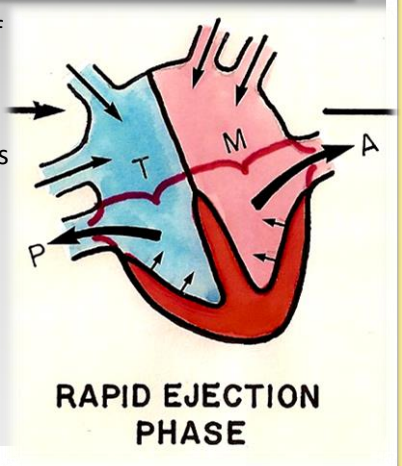
ISOMETRIC CONTR. PHASE

20

Mechanical Phases of cardiac cycle:

3. Maximum (Rapid) Ejection Phase:

- Semilunar- vs open at beginning of this phase:
  - when LV = 80 mmHg
- Contraction of the ventricle causes ventricular pressure > aortic pressure
- Almost 75% of ventricular blood is ejected:
  - Volume of ejected blood = **SV**
  - Ventricular volume ↓ rapidly
- Atrial diastole



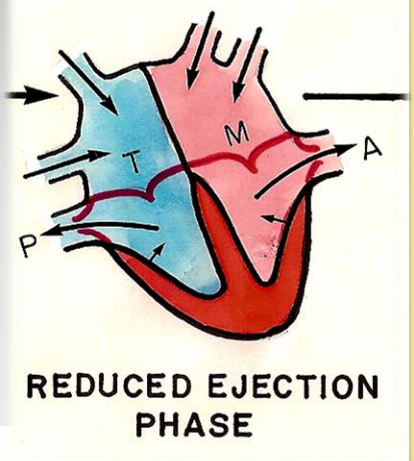
RAPID EJECTION PHASE

21

Mechanical Phases of cardiac cycle:

4. Reduced Ejection Phase:

- At the end of systole
- Almost 25% of ventricular blood is ejected:
  - Ventricular volume ↓ more slowly
- Aortic- v closes at the end of this phase, as a result of:
  - ↓ Ventricular pressure < aortic pressure
  - when LV pressure 110 mmHg (Aortic back pressure)
- Atrial diastole



REDUCED EJECTION PHASE

22

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Mechanical Phases of cardiac cycle:

?? Protodiastolic Phase …

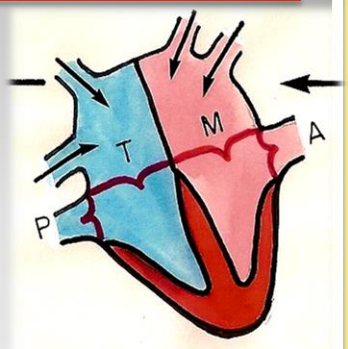
- Period b/w end of ventricular systole & aortic valve closure
- Very short …
- Atrial diastole:
  - Atrial pressure still ↑, due to continuous VR

23

Mechanical Phases of cardiac cycle:

5. Isovolumetric Relaxation Phase:

- Quiescent period (b/w closure of semilunar- vs & opening of AV- vs)
- At beginning of diastole … (0.04 sec)
- Preceded by ventricular repolarization
- **2nd Heart sound heard**
- **LV is a closed chamber**, i.e. relax w/out change in volume:
  - Volume of blood in ventricle = **ESV**
  - LV relaxes with ↓↓ pressure
- AV- vs open at the end of this phase



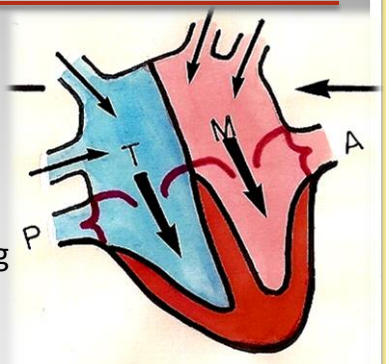
ISOMETRIC RELAXA-TION PHASE

24

Mechanical Phases of cardiac cycle:

6. Rapid Filling Phase:

- Atrial pressure > ventricular pressure
- AV- vs open
- ≈ 60-70% of blood passes passively to the ventricles along pressure gradient:
  - Ventricular volume ↑ rapidly
  - Ventricular pressure starts to ↑ & atrial pressure starts to ↓
- **3rd Heart sound heard**



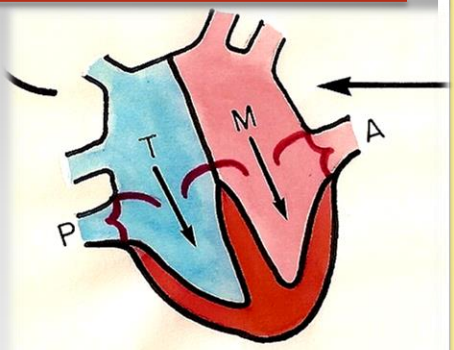
RAPID FILLING PHASE

25

Mechanical Phases of cardiac cycle:

7. Reduced Filling Phase (Diastasis):

- Remaining atrial blood flows slowly into ventricles
- AV- vs still open
- LV volume ↑ > slowly
- LV pressure gradually ↑
- Aortic pressure still ↓



DIASTASIS (REDUCED FILLING PHASE)

26

Events in the cardiac cycle ?

I: Mechanical events

II: Volume changes

III: Pressure changes

IV: Heart sounds

V: Electrical events (ECG)

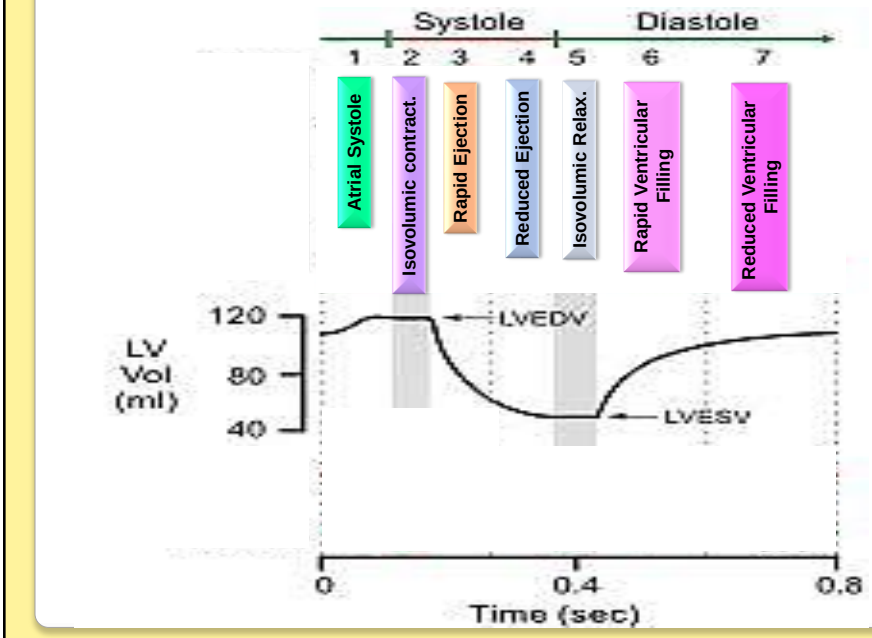
27

Ventricular Volume Changes During the Cardiac Cycle

Volume changes

Phase	Ventricular volume
1. Atrial systole	↑
2. Isometric contraction phase	Constant
3. Rapid ejection phase	↓ rapidly
4. Reduced ejection phase	↓ slowly
5. ? Protodiastole	Constant
6. Isometric relaxation phase	Constant
7. Rapid filling phase	↑ rapidly
8. Reduced filling phase	↑ slowly

29



30

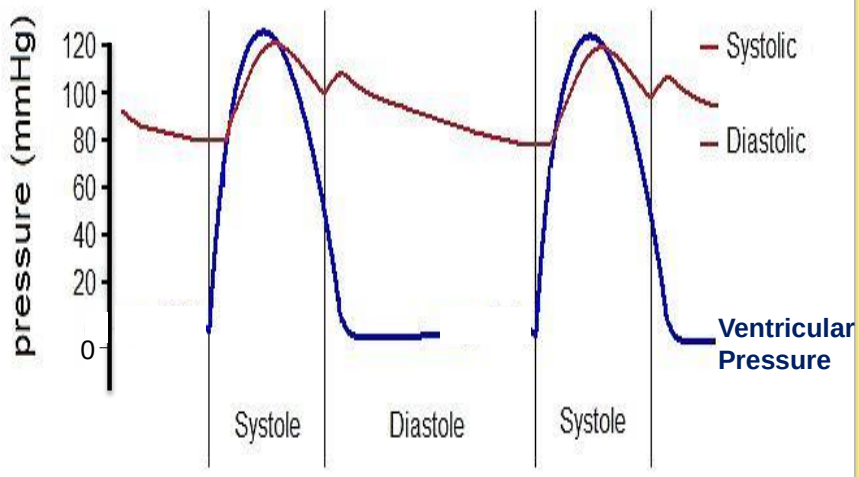
Pressure Changes During the Cardiac Cycle

Pressure Changes:

- **Ventricular Pressure Changes.**
- **Arterial Pressure Changes:**
  - Aortic pressure
  - Arterial pressure waves
  - Pulmonary artery pressure
- **Venous Pressure Changes:**
  - Atrial pressure
  - Jugular venous pulse wave

32

Pressure Changes in the Ventricle … 120/3-12



33

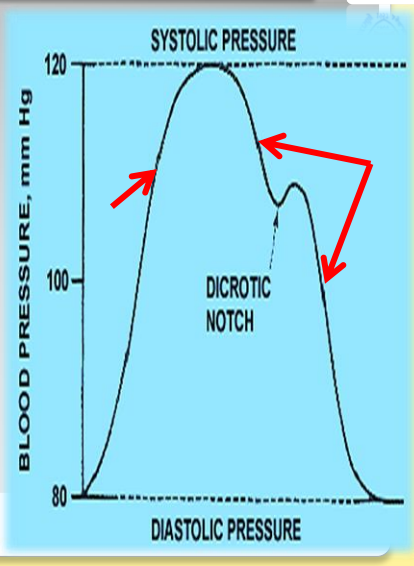
Pressure Changes in the Aorta … 120/80

a. Ascending or anacrotic limb:

- With 'rapid ejection phase'
- Aortic press ↑ up to 120 mmHg

b. Descending or catacrotic limb:

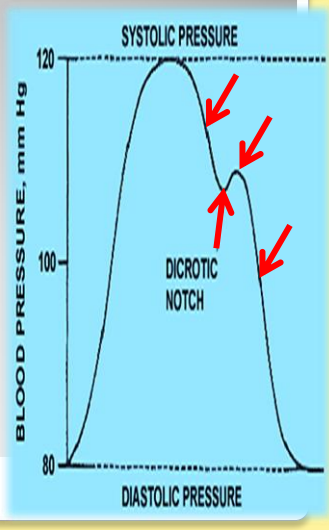
- Passes in 4 stages



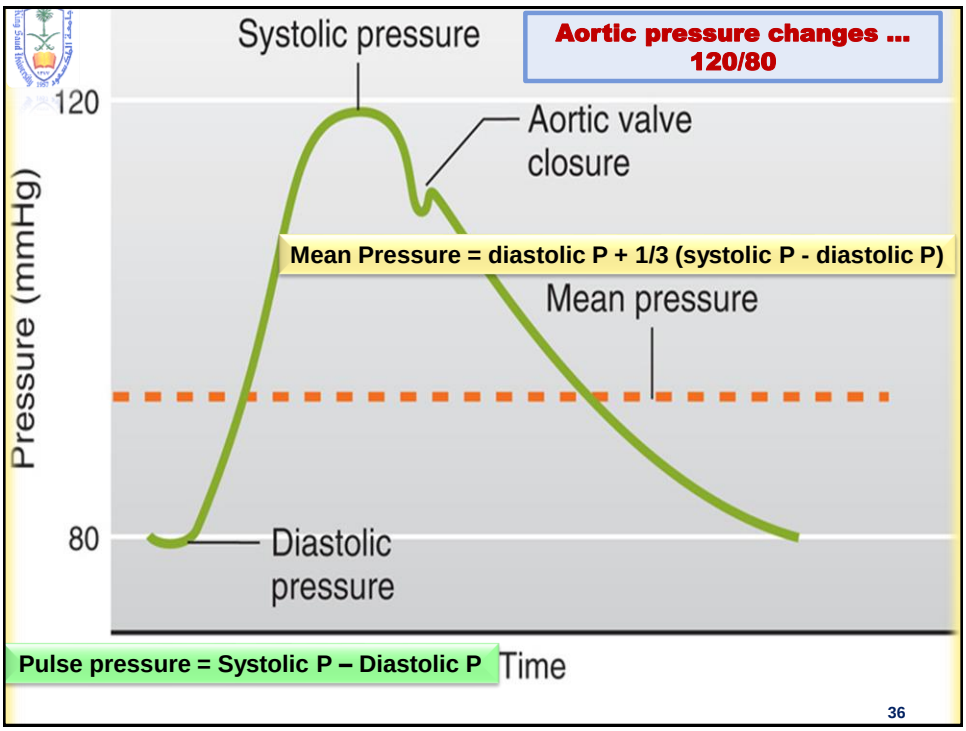
34

Stages of the Descending / Catacrotic Limb:

1. **↓ Aortic press:**
   - With 'reduced ejection phase'
   - Amount of blood enters aorta < leaves
2. **Dicrotic notch (incisura):**
   Due to closure of aortic- v
   - Sudden drop in aortic pressure
   - At end of ventricular systole
3. **Dicrotic wave:**
   Due to elastic recoil of the aorta
   - Slight ↑ in aortic pressure
4. **Slow ↓ aortic press:** up to 80 mmHg
   Due to continued flow of blood from aorta → systemic circulation

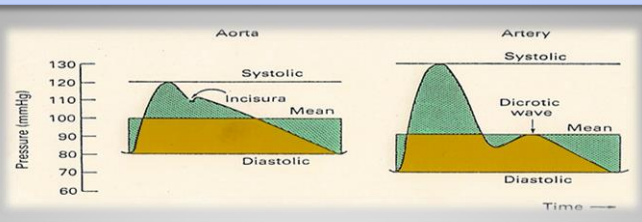


35



36

Pressure Changes in Peripheral Arteries … 110-130/70-90



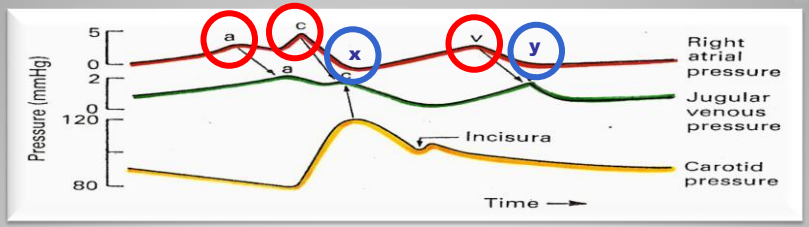
- Similar to aortic pressure waves but **sharper**
- Reflects a systolic peak pressure of 110-130 mmHg & a diastolic pressure of 70-90 mmHg

Pressure Changes in Pulmonary Artery … 25-30/4-12

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

37

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

38

Causes of atrial pressure waves

- **'a' wave: Atraial systole**: ↑ atrial pressure during atrial contraction
- **'c' wave: Ventricular systole**
  - **+ve** → bulging of AV valve into the atria during 'isovolumetric contraction phase'
  - **-ve** → pulling of the atrial muscle & AV cusps down during 'rapid ejection phase', resulting in ↓ atrial pressure
- **'v' wave: Atrial diastole or ↑ venous return (VR)**
  - **+ve** → atrial pressure ↑ gradually due to continuous VR
  - **-ve** → ↓ atrial pressure during 'rapid filling phase'

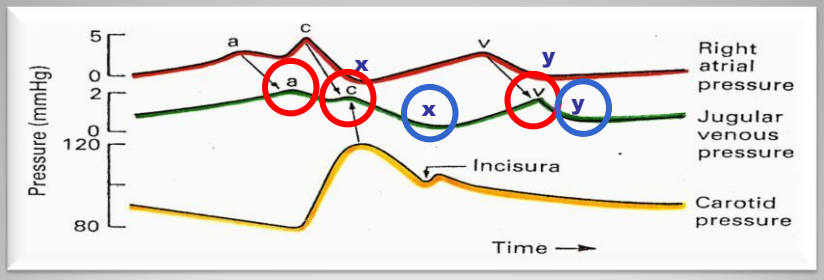
39

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

- **'x' descent:**
  Downward displacement of AV- vs during 'reduced ejection phase'
- **'y' descent:**
  ↓ atrial pressure during 'reduced filling phase'

40

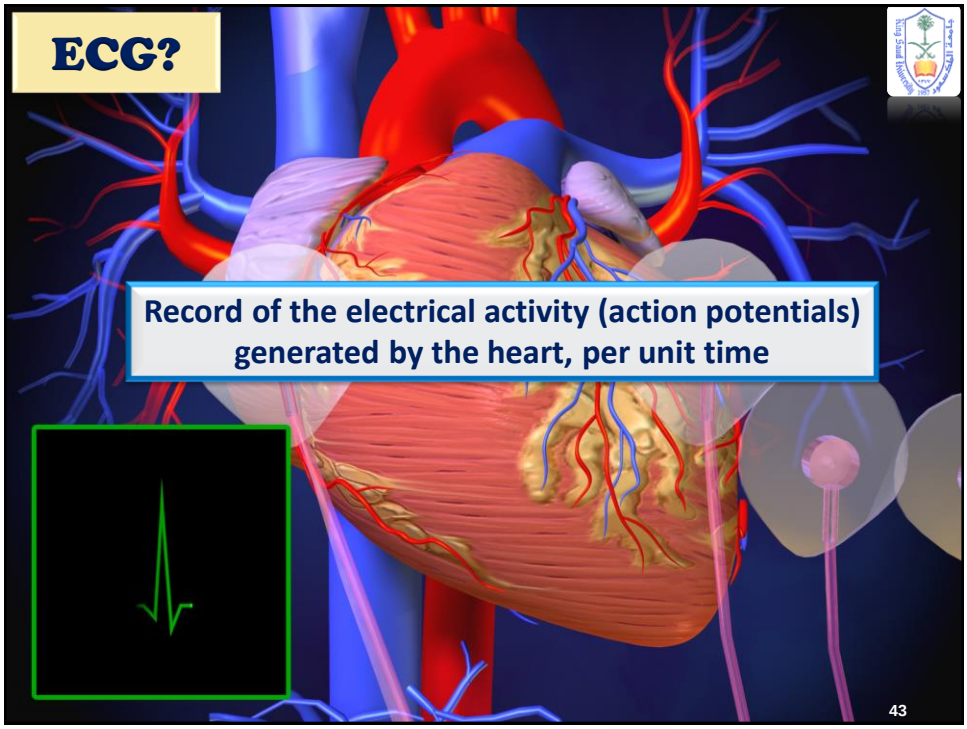
Jugular venous pulse changes:

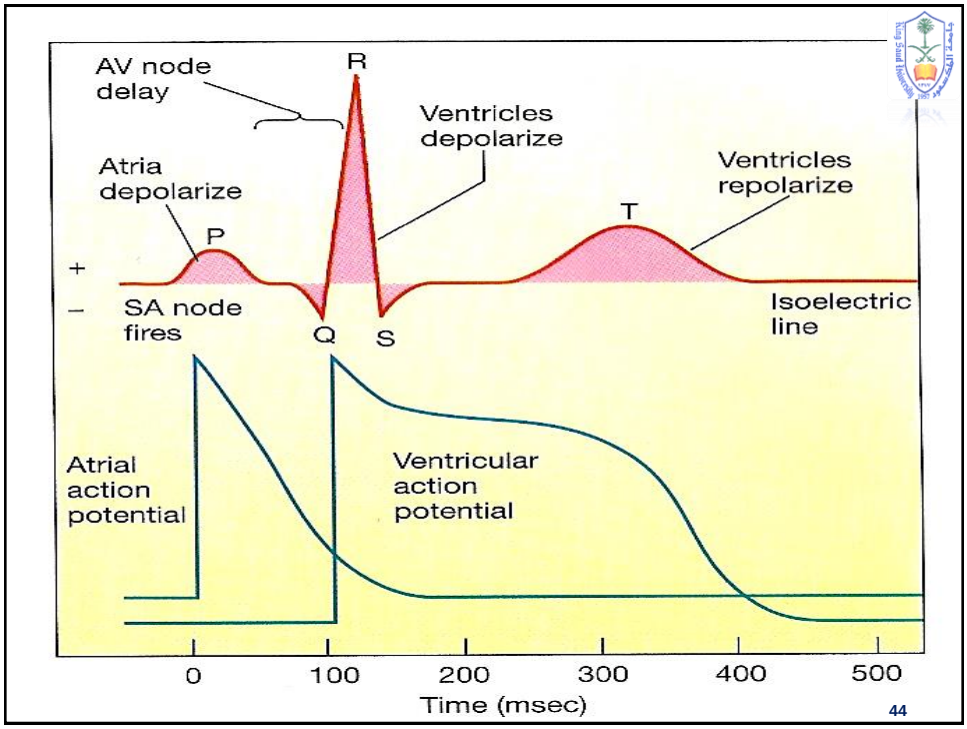


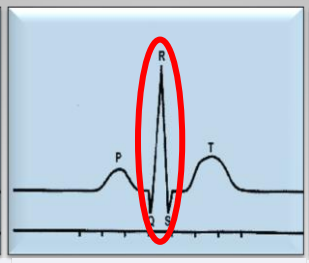
- **Also results in recording of transmitted atrial waves:**
  - 3 upward waves: a, c, & v
  - 2 downward waves: x & y

41

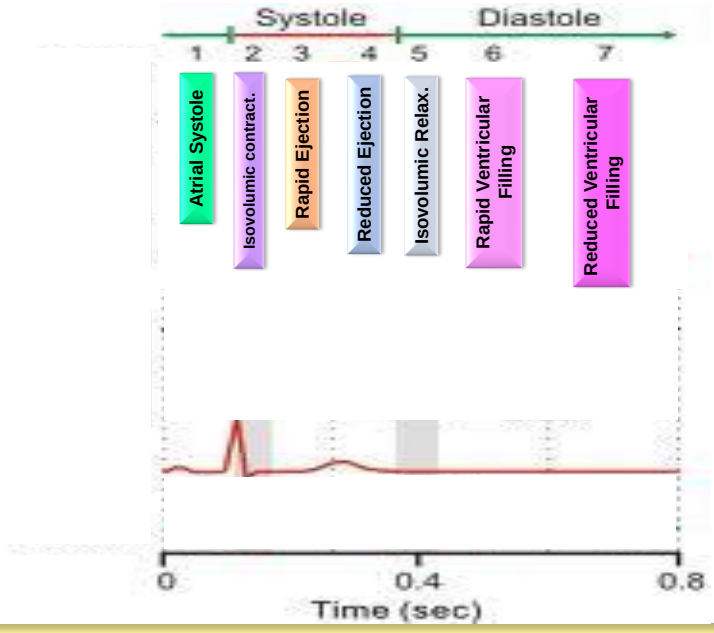
Electrical Changes (ECG) During the Cardiac Cycle


ECG?
Record of the electrical activity (action potentials) generated by the heart, per unit time
43


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)
44

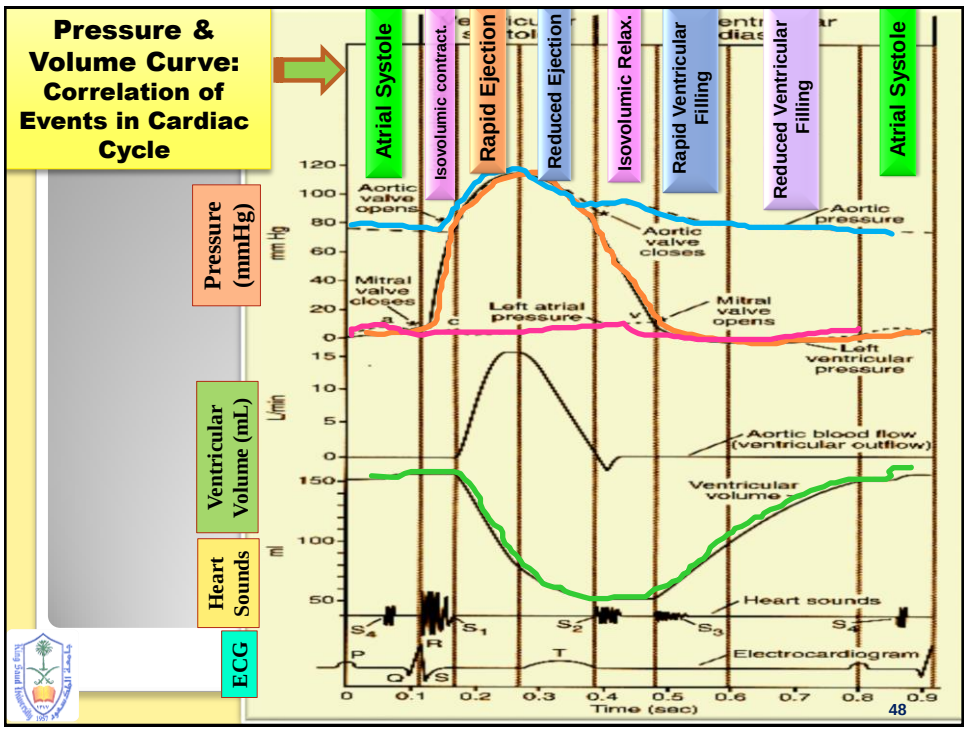
P- Wave	QRS- Complex	T- Wave
		
• Due to atrial depolarization • P- wave is recorded before the onset of the atrial systole	• Due to ventricular depolarization • QRS complex is recorded before the onset of ventricular systole (isovolumetric contraction phase)	• Due to ventricular repolarization • T-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

45



46

Pressure – Volume Curve
"The Complete Picture"



Cardiovascular Physiology

Pressure-Volume Loop

Left Ventricular Pressure – Volume Loop

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

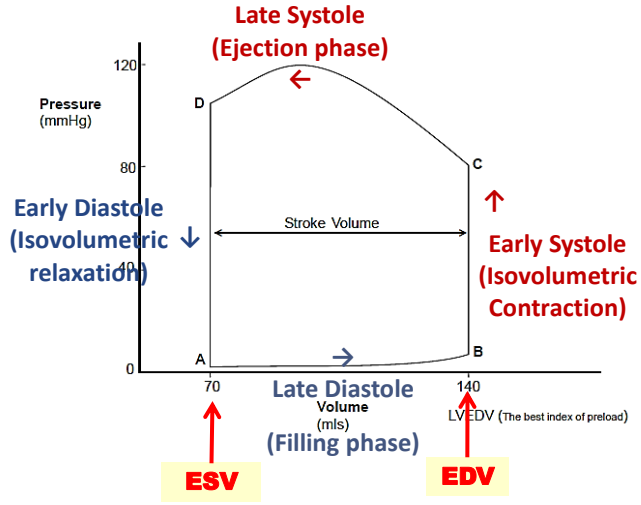
50

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'

51

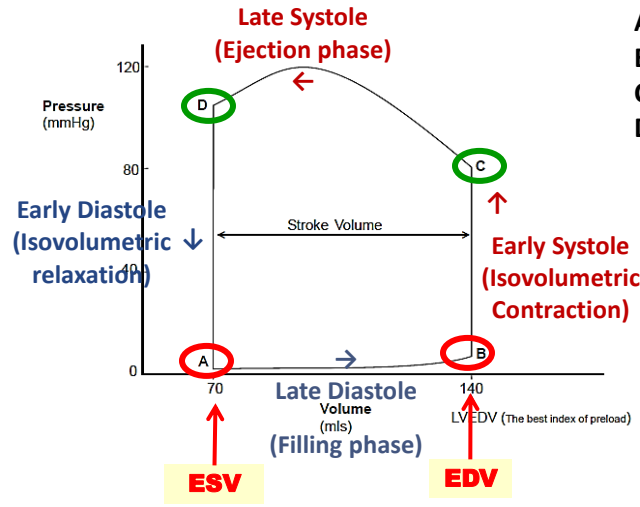
Ventricular Pressure - Volume Loop



- **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

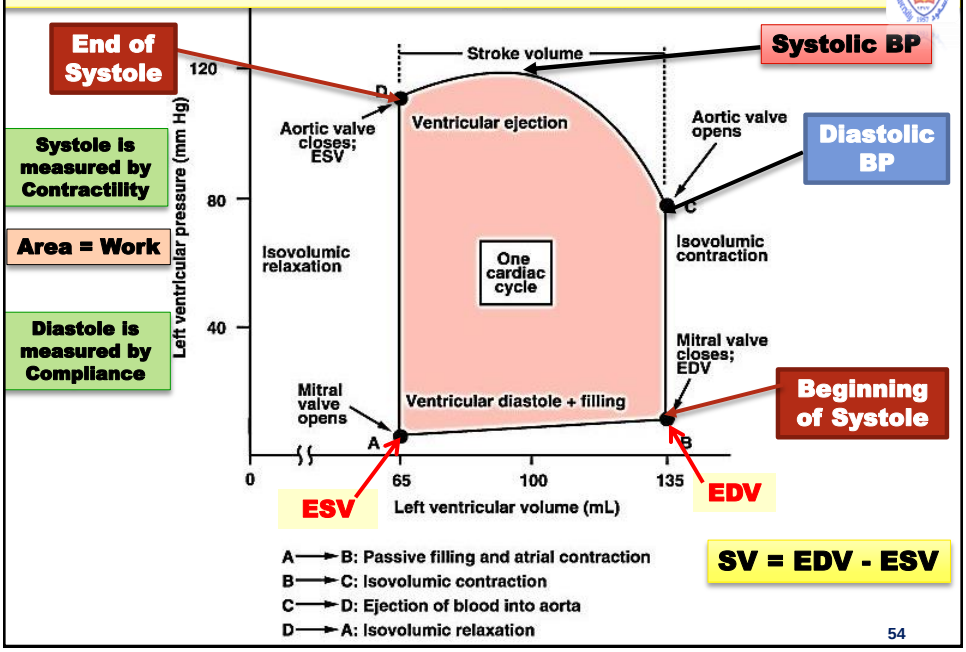
52

Ventricular Pressure - Volume Loop



53

Ventricular Pressure - Volume Loop



54

Ventricular Systole:

- It is measured by 'Contractility'
- Affected by:
  - Function of the muscle
  - Initial volume (Preload)
  - Initial pressure (Afterload)

55

Ventricular Diastole:

- It is measured by 'Compliance': $C = \Delta V / \Delta P$
- Affected by:
  - Connective tissue
  - Venous pressure
  - Venous resistance

56

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
  - Ejection occurs between points C & D
- Beginning of diastole (D) & end (B)
  - Early & late diastolic periods
  - Diastolic filling occurs between points A & B
- Systolic and diastolic blood pressure levels

57