





Cardiovascular Physiology

Cardiac Cycle- 1



Dr. Abeer A. Al-Masri
MBBS, MSc, PhD
A. Professor
Consultant Cardiovascular Physiologist
Faculty of Medicine, KSU



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

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

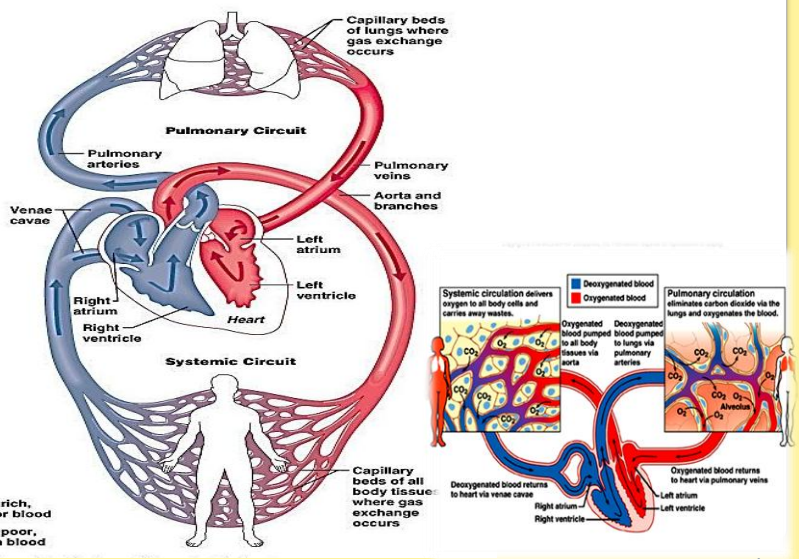
2

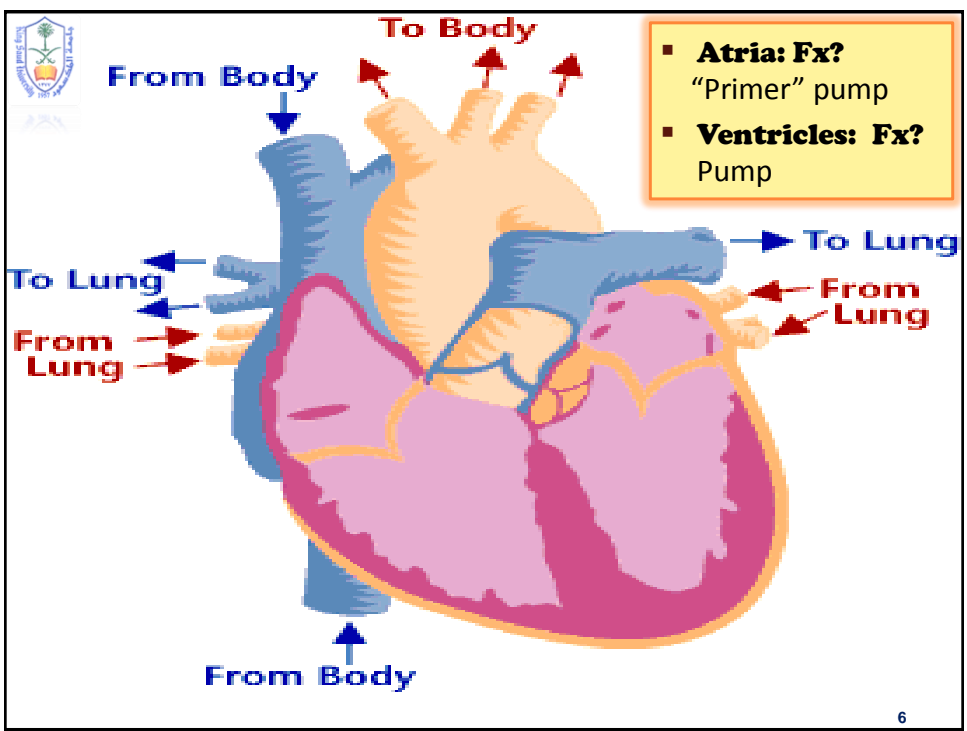
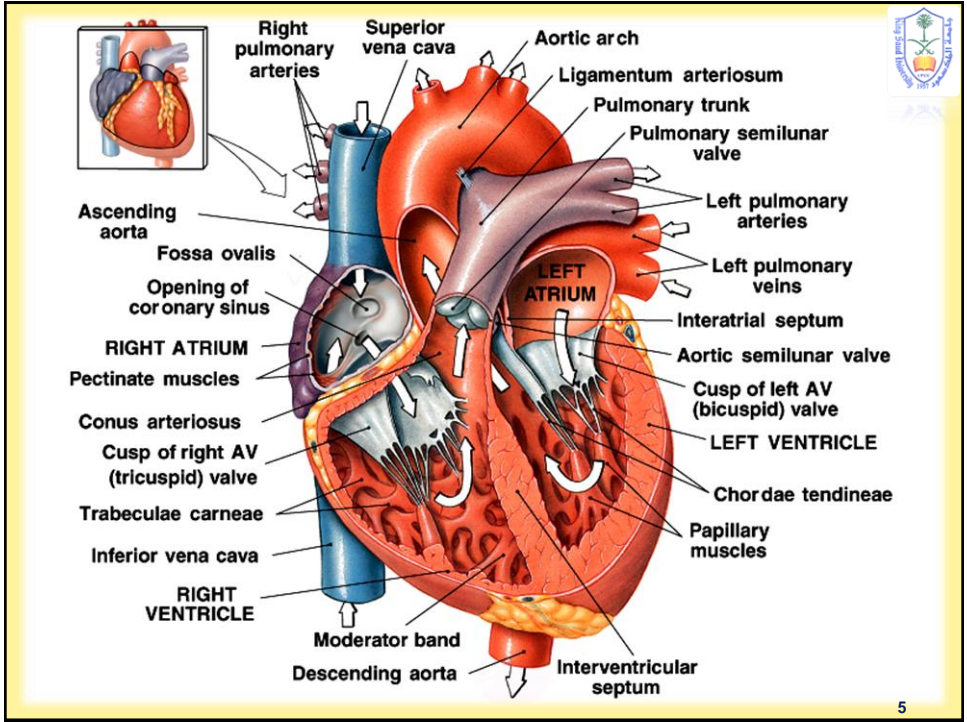


Function of the Heart ?



The Heart is a double pump 'Pulmonary & Systemic Circulations'



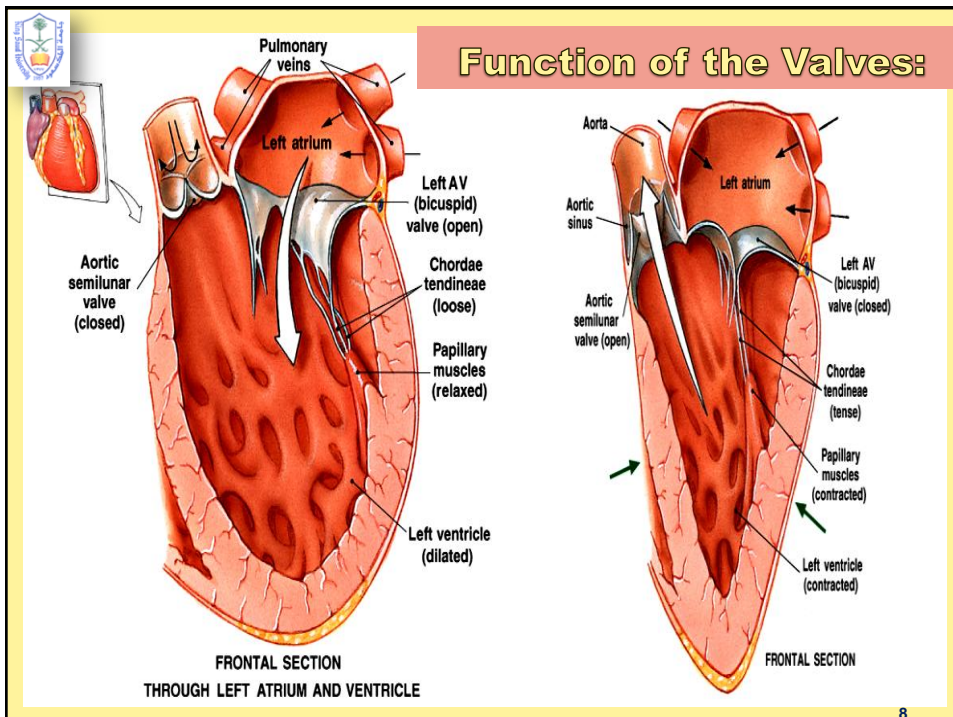


- **Atria: Fx?**
"Primer" pump
- **Ventricles: Fx?**
Pump


Valves of the Heart :

- 4 valves found at entry & exit of each ventricle
- Allow blood to flow in ONLY ONE direction
- When AV- vs open, semilunar- vs close & vice versa
- Opening & closure of vs occur as a result of pressure gradient across the vs
- AV cusps are held by chordae tendineae to muscular projections called Papillary muscles

7



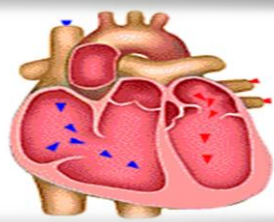
8



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 ↑


9



Events in the cardiac cycle ?

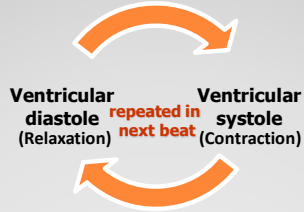
- I: Mechanical events**
- II: Volume changes**
- III: Pressure changes**
- IV: Heart sounds**
- V: Electrical events (ECG)**

10



Mechanical Events:


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



Ventricular diastole (Relaxation) repeated in next beat Ventricular systole (Contraction)

- Atrial .. systole & diastole
- Ventricular .. systole & diastole


11



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

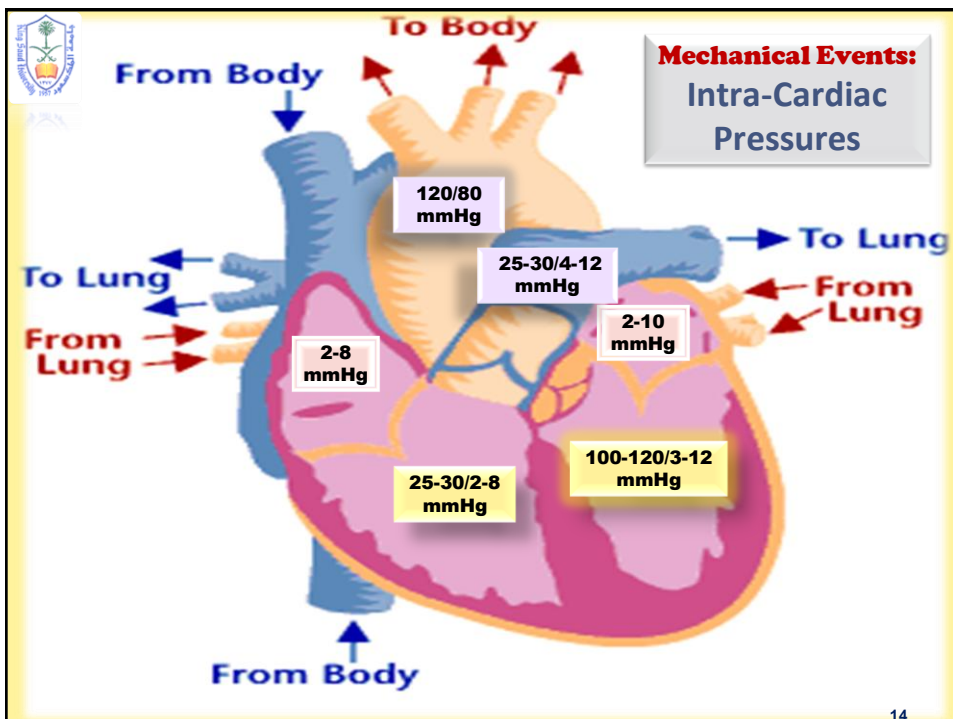
12




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

13






Definitions

- **End-diastolic volume (EDV):**
 - Volume of blood in ventricles at the end of diastole
 - $\approx 110-130$ 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
 - $\approx 40-60$ ml
- **Ejection fraction (EF):**
 - Fraction of end-diastolic volume that is ejected
 - $\approx 60-65$ %

15



Mechanical Events: Mechanical Phases

Consists of 7 phases

- **Early ventricular diastole:**

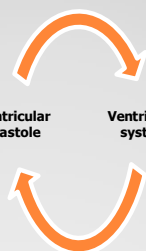
?? Protodiastole

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

Ventricular diastole

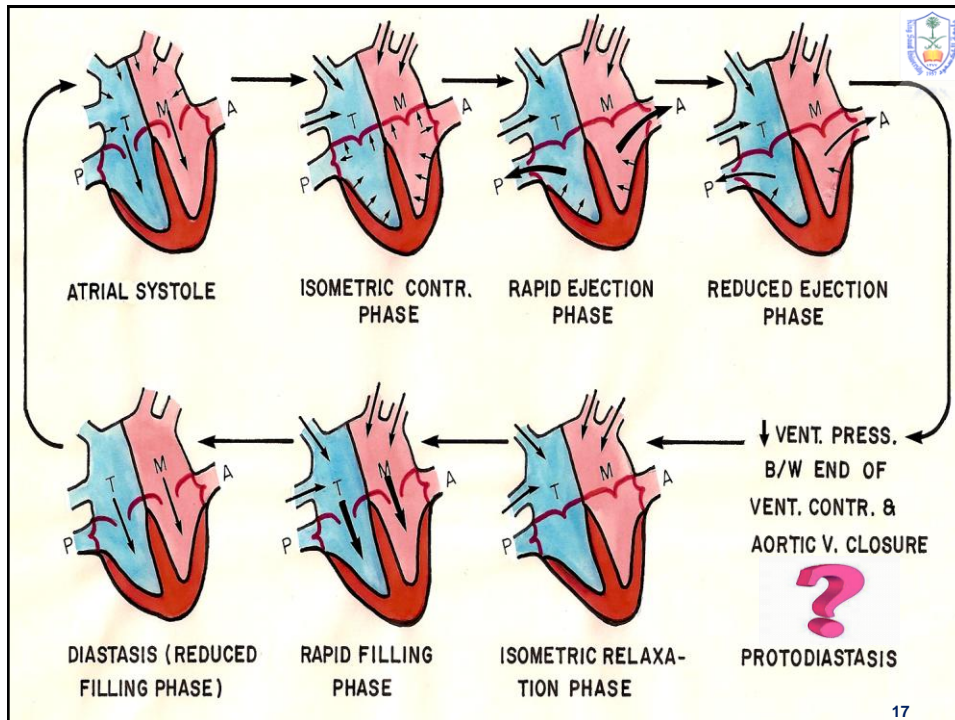
Ventricular systole

- **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

16



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 is produced**
- Blood arriving the heart can't enter atria, it flows back up jugular vein

ATRIAL SYSTOLE

18

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 closure of AV- vs:
 - Ventricular pressure > atrial pressure
- **1st Heart sound heard**
- **Ventricle is a closed chamber:**
 - Ventricle contracts w \uparrow pressure & w/out change in volume
- Volume in ventricle = **EDV**
- Ventricular pressure keeps \uparrow till reaching 80 mmHg

ISOMETRIC CONTR. PHASE

19

Mechanical Phases of cardiac cycle:

3. Maximum (Rapid) Ejection Phase:

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

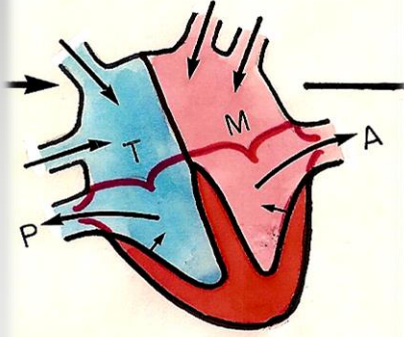
RAPID EJECTION PHASE

20

Mechanical Phases of cardiac cycle:

4. Reduced Ejection Phase:

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



REDUCED EJECTION PHASE

21

Mechanical Phases of cardiac cycle:

?? Protodiastolic Phase ...

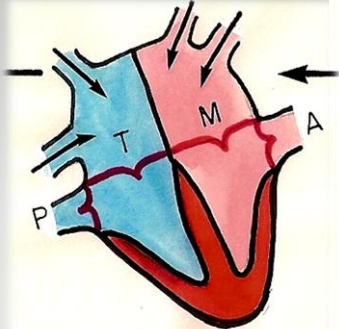
- Period b/w end of ventricular systole & aortic valve closure
- Very short ...
- Atrial diastole:
 - Atrial pressure still ↑.. due to continuous VR

22

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:**
 - Ventricle relaxes w ↓↓ pressure & w/out change in volume
- Volume of blood in ventricle = **ESV**
- AV- vs open at the end of this phase



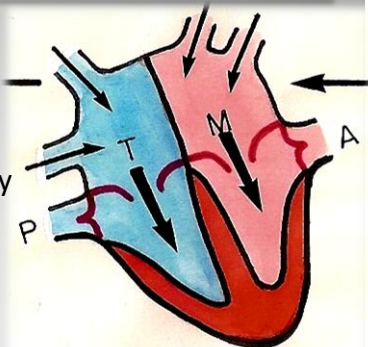
ISOMETRIC RELAXATION PHASE

23

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 is produced**



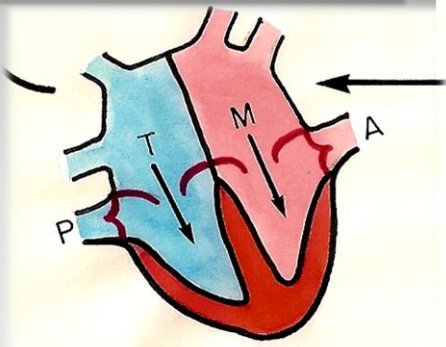
RAPID FILLING PHASE

24

Mechanical Phases of cardiac cycle:

7. Reduced Filling Phase (Diastasis):

- Remaining passive atrial blood flows slowly along pressure gradient into the ventricles
- AV- vs still open
- LV volume \uparrow > slowly
- LV pressure gradually \uparrow
- Aortic pressure still \downarrow



DIASTASIS (REDUCED FILLING PHASE)

25

Events in the cardiac cycle ... (Cont.)

I: Mechanical events

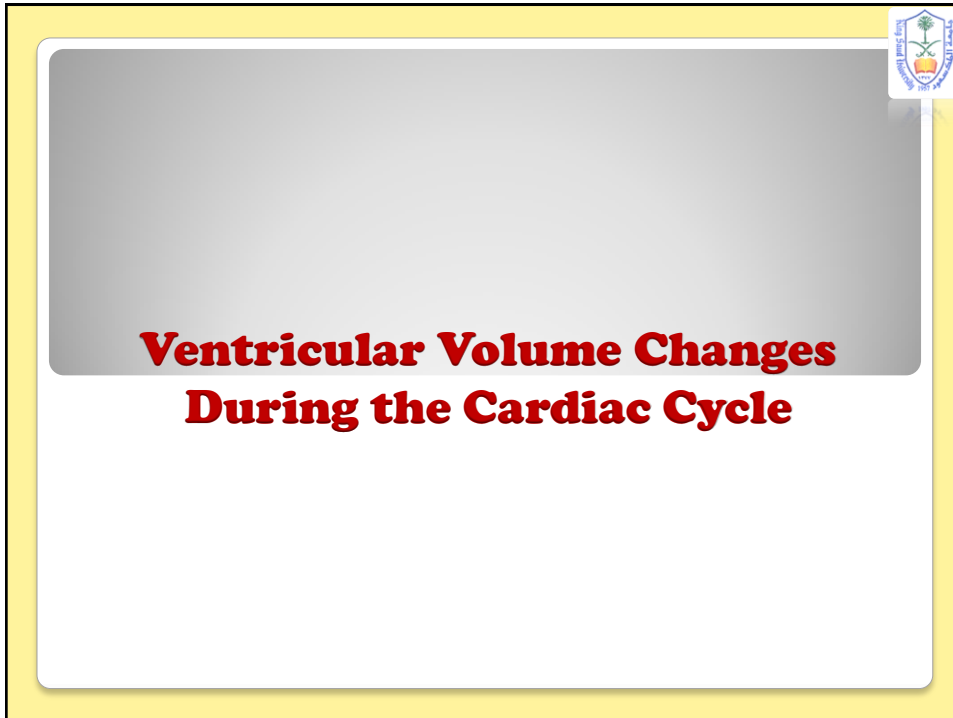
II: Volume changes

III: Pressure changes

IV: Heart sounds

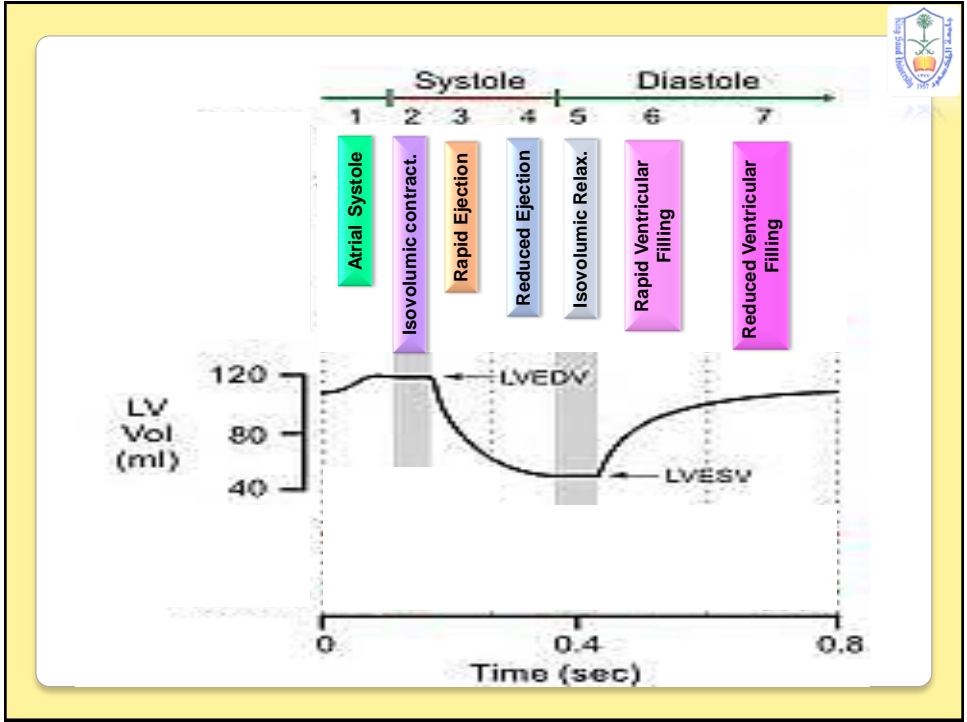
V: Electrical events (ECG)

26



Ventricular Volume Changes

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



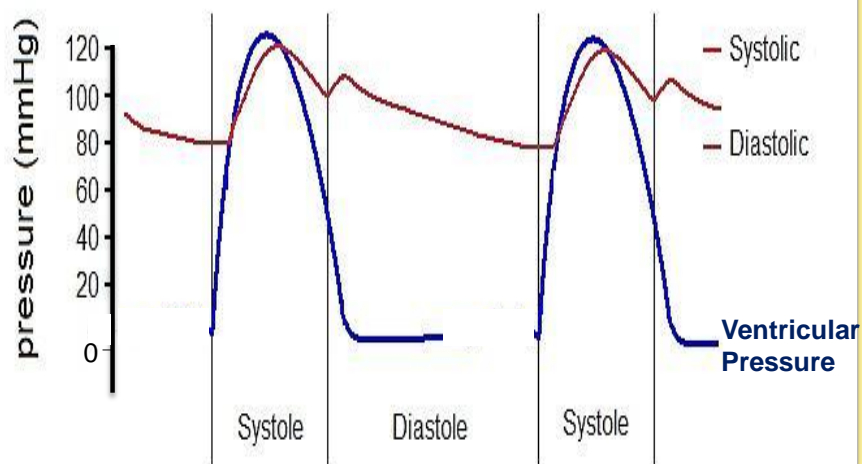
Pressure Changes During the Cardiac Cycle

Pressure Changes:


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

31

Ventricular Pressure Changes ... 120/3-12



32



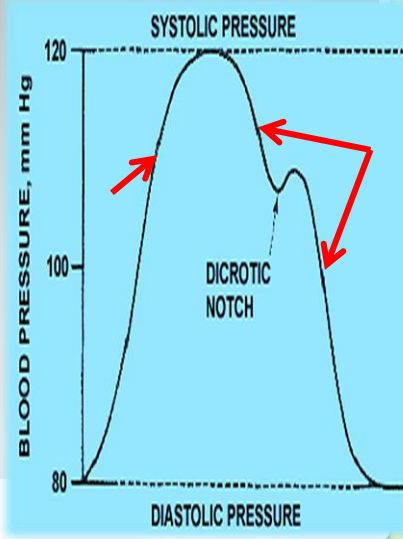
Aortic Pressure Changes ... 120/80

a. Ascending or anacrotic limb:

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

b. Descending or catacrotic limb:


- Passes in 4 stages



BLOOD PRESSURE, mm Hg

DIASTOLIC PRESSURE

33



Stages of the Descending / Catacrotic Limb:

- 1. ↓ Aortic press:**
 - With 'reduced ejection phase'
 - Amount of blood enters aorta < leaves
- 2. Dicrotic notch (incisura):**

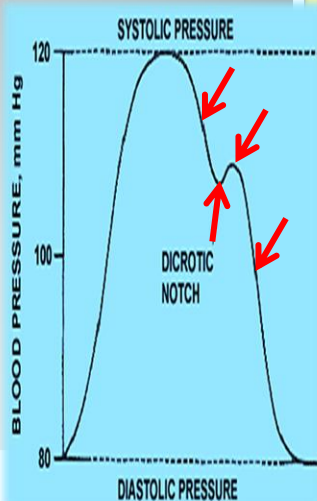
Due to closure of aortic- v

 - 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

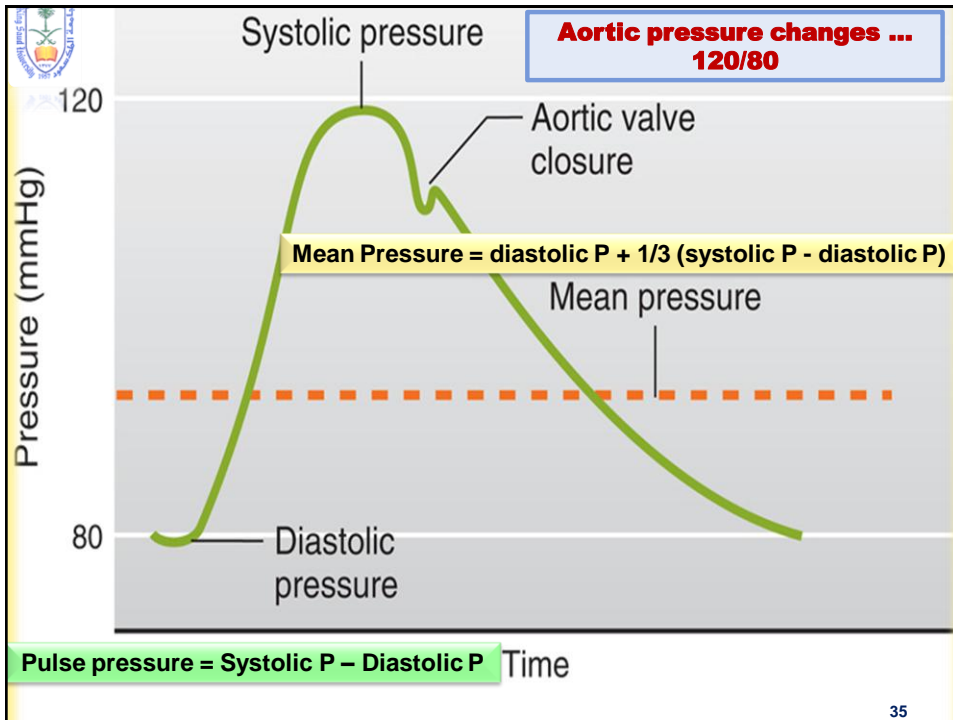
Due to continued flow of blood from aorta → systemic circulation



BLOOD PRESSURE, mm Hg

DIASTOLIC PRESSURE

34



Clinical significant of aortic pressure changes:

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

36

Arterial Pressure Changes ... 110-130/70-85

- Similar to aortic pressure waves but **sharper**
- Reflects a systolic peak pressure of 110-130 mmHg & a diastolic pressure of 70-85 mmHg

Pulmonary Artery Pressure Changes ... 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:** Atrial systole:
 - ↑ atrial pressure during atrial contraction
- **'c' wave:** Ventricular systole
 - **+ve** → bulging of AV- vs 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:**
 - **+ve** → ↑ Atrial pressure **due to** ↑ **venous return (VR)** during atrial diastole
 - **-ve** → ↓↓ atrial pressure during 'rapid filling phase'

39



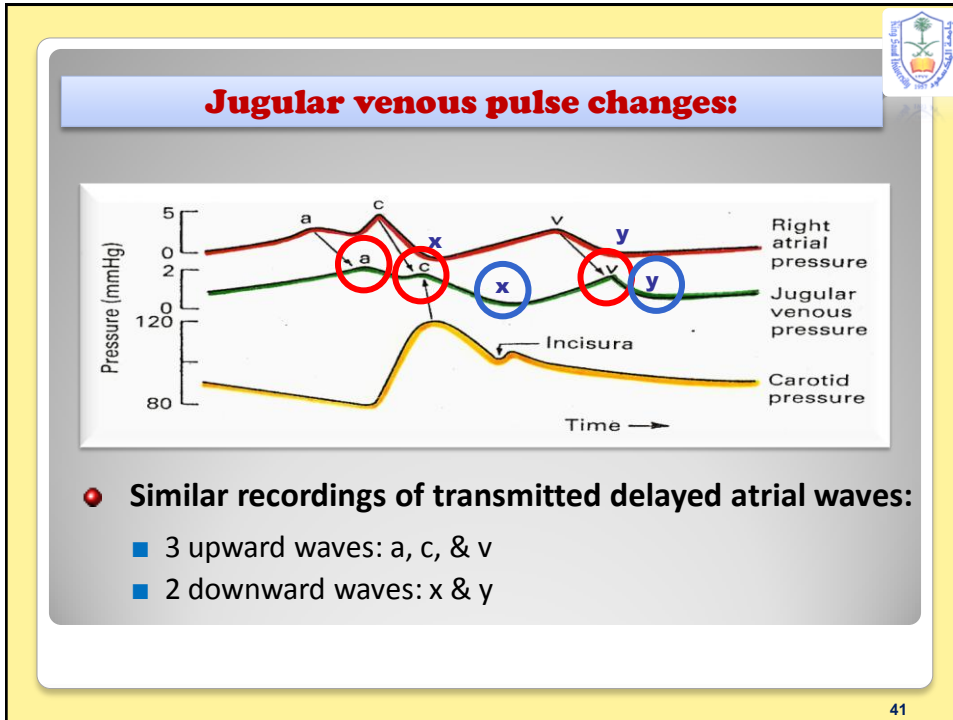
Causes of atrial pressure waves ... (Cont.)

- **'x' descent:**


Downward displacement of AV- vs during 'reduced ejection phase'
- **'y' descent:**

↓↓ atrial pressure during 'reduced filling phase'


40

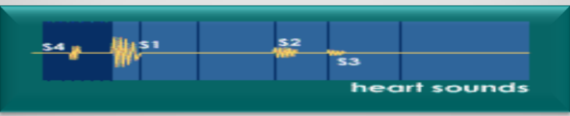


Heart Sounds Recorded During the Cardiac Cycle




HEART SOUNDS

- Detected over anterior chest wall by:
 - Auscultation: ... (Stethoscope) 
 - Phonocardiography: (sound recording device)



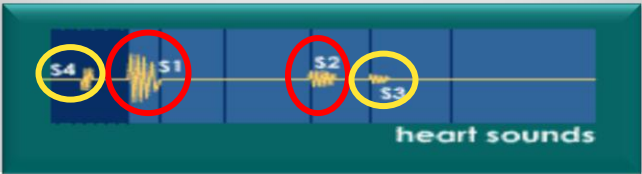
The diagram shows a horizontal timeline labeled 'heart sounds' with four distinct sound waveforms labeled S4, S1, S2, and S3 from left to right.

43



Heart Sounds:

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



The diagram shows the same heart sound timeline as slide 43. In this version, the S1 and S2 waveforms are circled in red, and the S4 and S3 waveforms are circled in yellow.

44

HEART SOUNDS' WINDOWS

Best heard at 4 certain areas:

■ **Pulmonary area:**

- 2nd Lt intercostal space

■ **Aortic area:**

- 2nd Rt costal cartilage

■ **Mitral area:**

- 5th Lt intercostal space crossing mid-clavicular line, or
- 9 cm (2.5-3 in) from sternum

■ **Tricuspid area:**

- lower part of sternum towards Rt side


45

Normal Heart Sounds

LUB DUB S1 S2 MI AP

Systole Diastole Systole

46




(S1)

LUB DUB S1 S2 MT AP Systole Diastole Systole

- Due to closure of the AV- vs
- Recorded at the beginning of the the 'isovolumetric contraction phase'
- It marks beginning of ventricular systole
- Long in duration .. 0.15 sec
- Of low pitch (LUB) .. Loud
- 25-35 Hz
- Best heard at Mitral & Tricuspid areas

47



(S2)

LUB DUB S1 S2 MT AP Systole Diastole Systole

- Due to closure of semilunar- vs
- Recorded at the beginning of the 'isovolumetric relaxation phase'
- Marks the beginning of ventricular diastole
- Short in duration .. 0.11-0.125 sec
- Of high pitch (DUB) .. Soft & Sharp
- 50 Hz
- Best heard at Aortic & Pulmonary areas

48

(S2)

LUB DUB S1 S2 MT AP

Systole Diastole Systole

- S2 splits physiologically into 2 sounds during inspiration = Physiological Splitting

Physiological splitting during INSPIRATION

LUB TaDUB S1 S2 MT AP

Systole Diastole Systole

- This splitting occurs due to delay closure of pulmonary valve

49


(S3)

LUB DUB BUB S1 S2 S3 MT AP

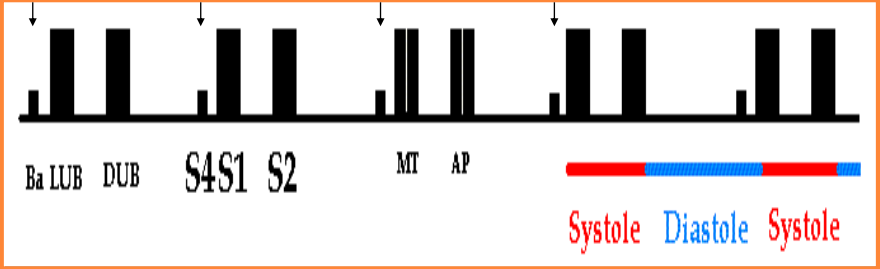
Systole Diastole Systole

- Recorded during the 'rapid filling phase' due to rush of blood into the ventricle
- S3 is usually not audible (very low pitch)
- 0.05 sec
- ? heard in children
- Best heard at Mitral area

50




(S4)

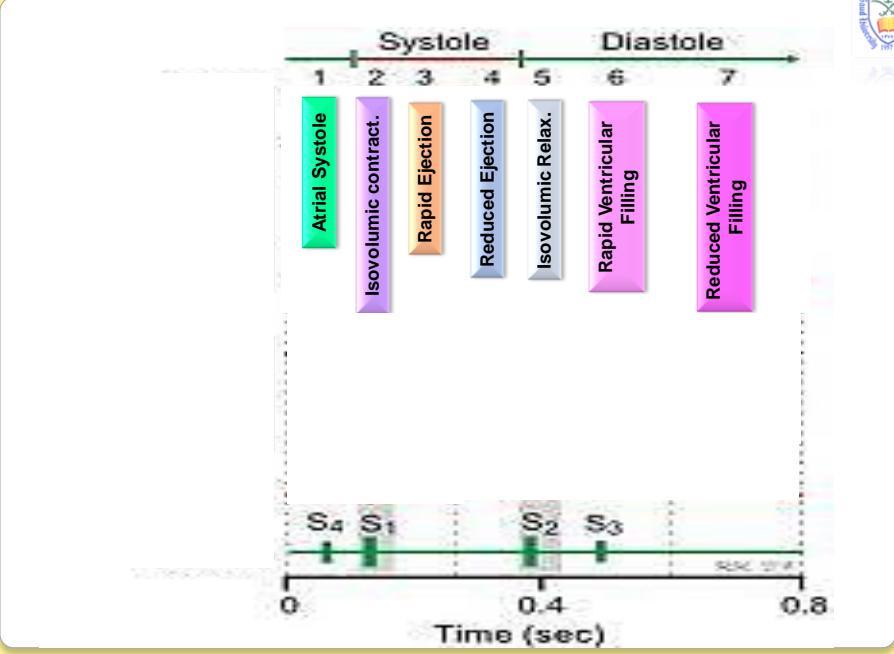


- Recorded during 'atrial systole'
- S4 is usually not audible (very low pitch)
- 0.04 sec
- ? heard in elderly
- Best heard at Mitral area

51



Systole Diastole



Time (sec)

