



## Cardiovascular Physiology

# Cardiac Cycle - 1


### Dr. Abeer A. Al Masri

MBBS, MSc, PhD  
Assistant Professor  
Consultant Cardiovascular Physiologist  
College of Medicine, KSU



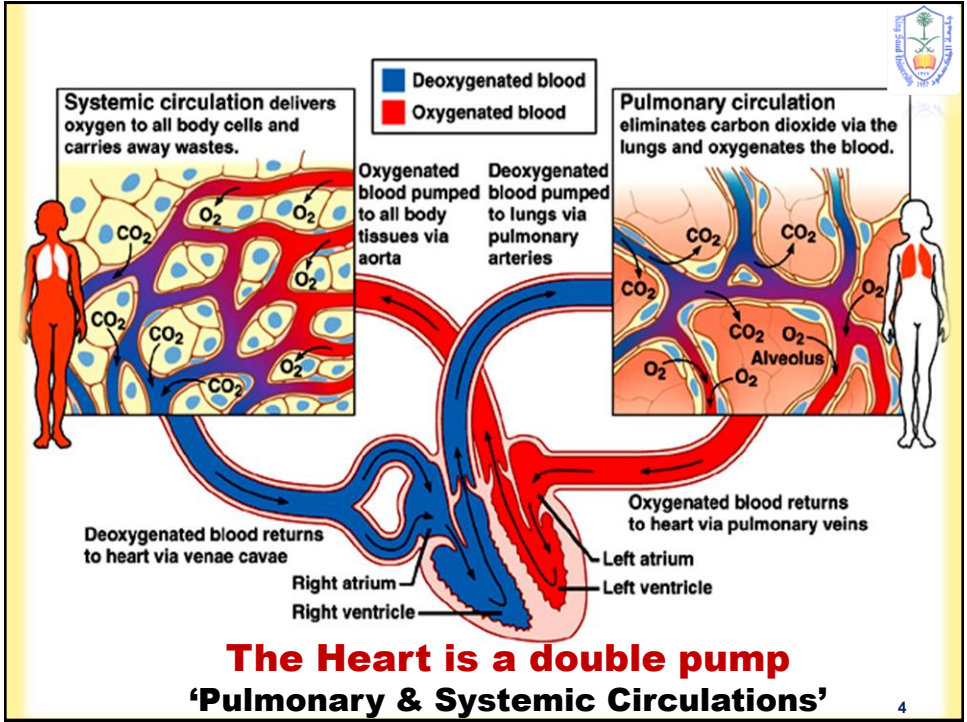
## At end of this lecture you should be able to:


- ✓ **know general principles of cardiac cycle**
- ✓ **identify events occurring during cardiac cycle: mechanical, electrical, volume & pressure changes, & heart sounds**
- ✓ **understand the various phases of mechanical cardiac cycle**




**Introduction**

3






## Cardiac Cycle ?



Describing sequence of events that take place in the heart in each beat

5



## Events in the cardiac cycle ?

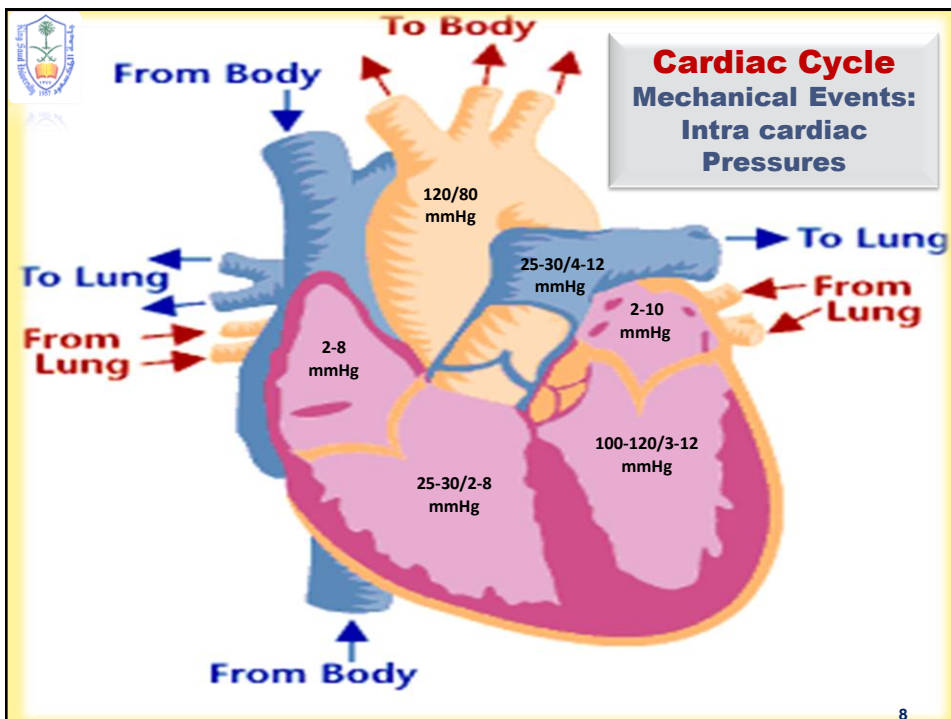
- I: Mechanical events**
- II: Volume changes**
- III: Pressure changes**
- IV: Heart sounds**
- V: Electrical events (ECG)**

6


## General Principles

- Contraction of the heart generates pressure changes which result in the orderly movement of blood
- Blood flows from an area of high pressure to an area of low pressure
- Events on right & left sides of the heart are the same, but pressures are lower on right side

7

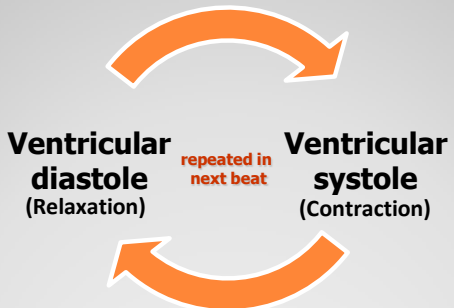


8




## Mechanical Events:

- **In each beat:**  
One complete contraction & relaxation of the heart



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


9



## Cardiac Cycle Duration

- **Cardiac cycle duration = 0.8 sec ...**
  - When HR 72 bpm
  - Shortened when HR ↑
- **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 ventricular diastole:**
  1. Coronary blood flow
  2. Ventricular filling


10



## Definitions

- **End-diastolic volume (EDV):**
  - Volume of blood in ventricle at end of diastole
  - $\approx 110-130$  ml
- **Stroke volume (SV):**
  - Amount of blood ejected from each ventricle during systole
  - $\approx 70$  ml/beat
- **End-systolic volume (ESV):**
  - Amount of blood left in each ventricle at end of systole
  - $\approx 40-60$  ml
- **Ejection fraction (EF):**
  - Fraction of end-diastolic volume that is ejected
  - $\approx 60-65$  %

11



## To Revise:

- Blood flows from an area of  pressure to an area of  pressure
- Cardiac cycle duration is  when HR = 72bpm
- Normally  period is longer than  period
- EDV  $\approx$   ml
- SV  $\approx$   ml/beat
- ESV  $\approx$   ml
- EF  $\approx$   %

12

## Mechanical Events: Phases of the cardiac cycle

Cardiac cycle consists of 8 phases

**Early ventricular diastole:**

1. Protodiastole
2. Isometric relaxation phase
3. Rapid filling phase

**Ventricular systole:**

1. Isometric contraction phase
2. Rapid ejection phase
3. Reduced ejection phase

Ventricular diastole      Ventricular systole

**Mid ventricular diastole:**

4. Reduced filling phase

**Late ventricular diastole:**

5. Atrial systole

N.B. ? Considered '7' phases if excluding 1<sup>st</sup> phase of diastole

13

ATRIAL SYSTOLE
ISOMETRIC CONTR. PHASE
RAPID EJECTION PHASE
REDUCED EJECTION PHASE

DIASTASIS (REDUCED FILLING PHASE)
RAPID FILLING PHASE
ISOMETRIC RELAXATION PHASE
PROTODIASTASIS

↓ VENT. PRESS. B/W END OF VENT. CONTR. & AORTIC V. CLOSURE

14

**Phases of cardiac cycle:**

**1. Atrial Systole:**

- At end of ventricular diastole ... lasts 0.1 sec
- Pressure changes:
  - Atrial pressure slightly ↑
  - Aortic > ventricular pressure
- Volume changes:
  - Tops off last 27-30% of ventricular filling ≈ 40 ml
- Valves:
  - AV-vs open & semilunar-vs closed

**ATRIAL SYSTOLE**

- Blood arriving heart can't enter atrium, it flows back up jugular vein

15

**- Atrial Systole - Heart Sounds**

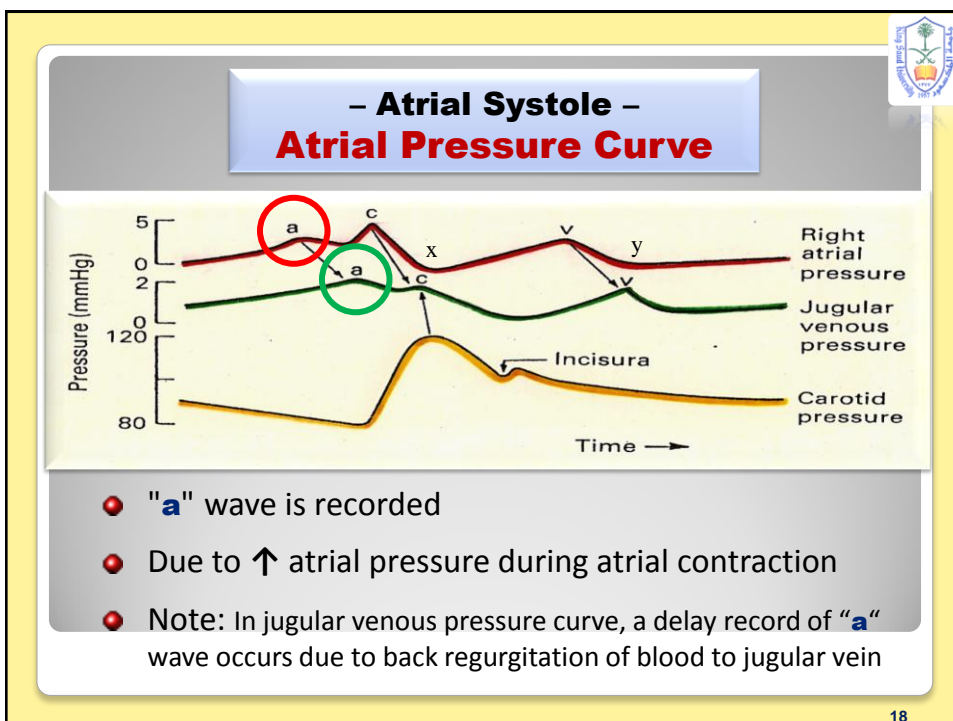
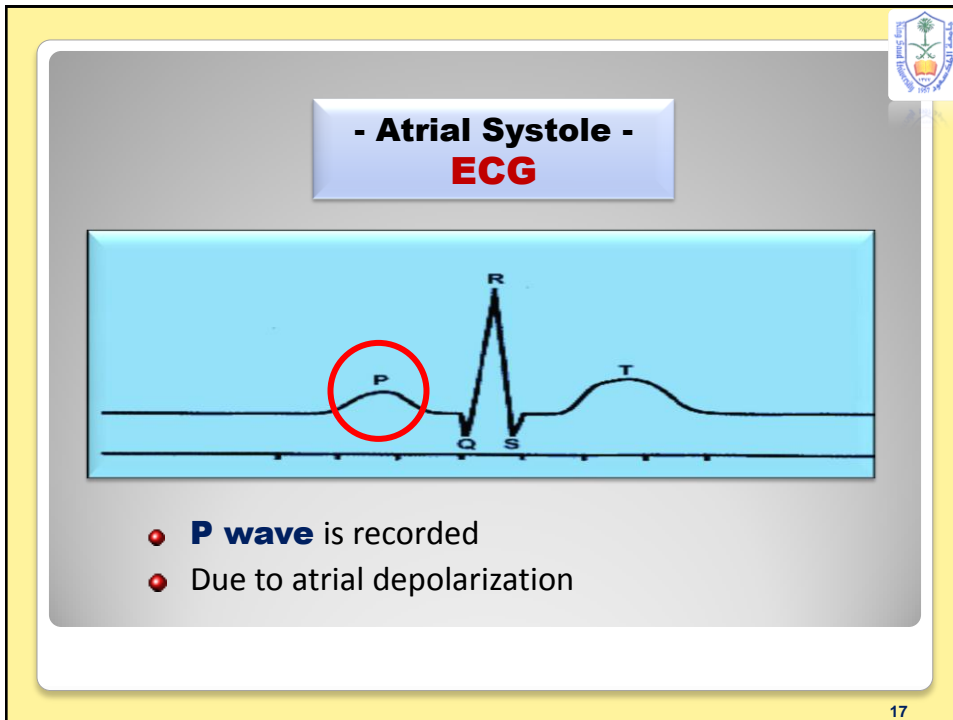
- Associated with **fourth heart sound (S4)**

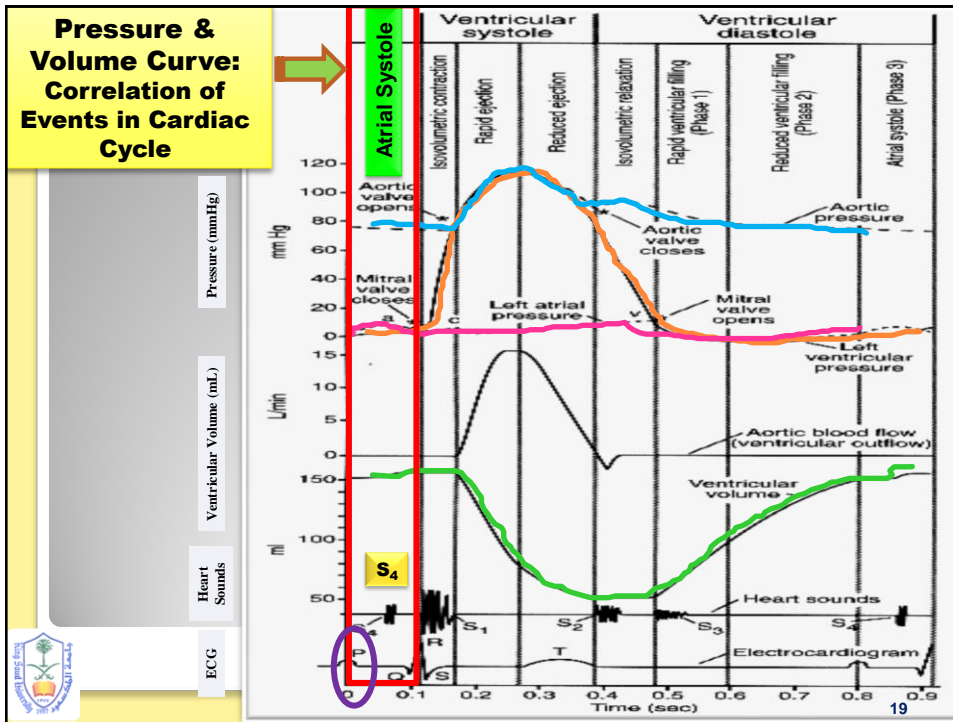
heart sounds

- S4 is recorded
- S4 is usually abnormal
- ? Normal in elderly

16







**Phases of cardiac cycle:**

**2. Isovolumetric Contraction Phase:**

- At beginning of systole ... (0.04 sec)
- Starts with closure of AV-vs:
  - Due to  $\uparrow$  ventricular pressure
  - Atria repolarize & relax
- Ventricle is a closed chamber
  - All valves are closed
- Ventricle contracts w/out change in volume
- Volume in ventricle is EDV
- Ventricular pressure  $<$  aortic pressure
- Aortic v opens at end of this phase: (when LV = 80 mmHg)

**ISOMETRIC CONTR. PHASE**

**- Isovolumetric Contraction Phase -  
Heart Sounds**

The diagram shows a horizontal timeline with four vertical grid lines. Above the timeline, four heart sounds are labeled: S4, S1, S2, and S3. S1 is circled in red. Below the timeline, the text 'heart sounds' is written.

- **First heart sound (S1, "lub")** is recorded
- Due to closure of AV-vs & the association of blood turbulence

21

**- Isovolumetric Contraction Phase -  
ECG**

The diagram shows an ECG trace with a horizontal baseline. Above the baseline, three waves are labeled: P, QRS, and T. The QRS complex is circled in red.

- **QRS complex** is recorded
- Due to ventricular depolarization

22

### - Isovolumetric Contraction Phase - Atrial Pressure Curve

The graph displays three pressure curves over time. The top curve (red) is Right atrial pressure (0-5 mmHg), the middle (green) is Jugular venous pressure (0-120 mmHg), and the bottom (orange) is Carotid pressure (80-120 mmHg). The 'c' wave in the atrial pressure curve is circled in red. Labels include 'a', 'c', 'x', 'v', 'y' for atrial pressure, 'a', 'c', 'v' for jugular venous pressure, and 'Incisura' for carotid pressure.

- Ascending limb (+ve) of "c" wave is recorded:
  - ↑ atrial pressure as a result of RV contraction
  - Pushes TV into atrium (bulging of cusps)

23

### Pressure & Volume Curve: Correlation of Events in Cardiac Cycle

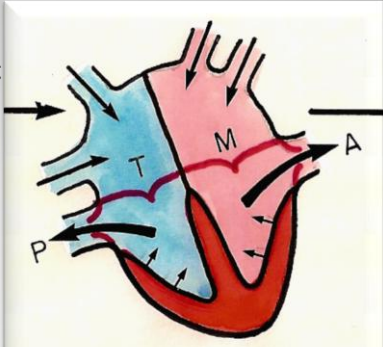
This graph correlates pressure (mmHg), ventricular volume (mL), heart sounds, and ECG with the cardiac cycle phases: Atrial systole, Isovolumic contract., Rapid ejection, Reduced ejection, Isovolumetric relaxation, Rapid ventricular filling (Phase 1), Reduced ventricular filling (Phase 2), and Atrial systole (Phase 3). Key events include Aortic valve opens, Mitral valve closes, and Aortic valve closes. Heart sounds S<sub>4</sub> and S<sub>1</sub> are marked, along with ECG waves P, Q, R, S, T.

24

**Phases of cardiac cycle:**

**3. Maximum (Rapid) Ejection Phase:**


- Contraction of ventricle causes ventricular pressure to  $\uparrow >$  aortic pressure
- Semilunar-vs open at beginning of this phase
- 75% of ventricular blood is ejected
- Volume of ejected blood = **SV**
- Ventricular volume  $\downarrow$  rapidly



**RAPID EJECTION PHASE**

25

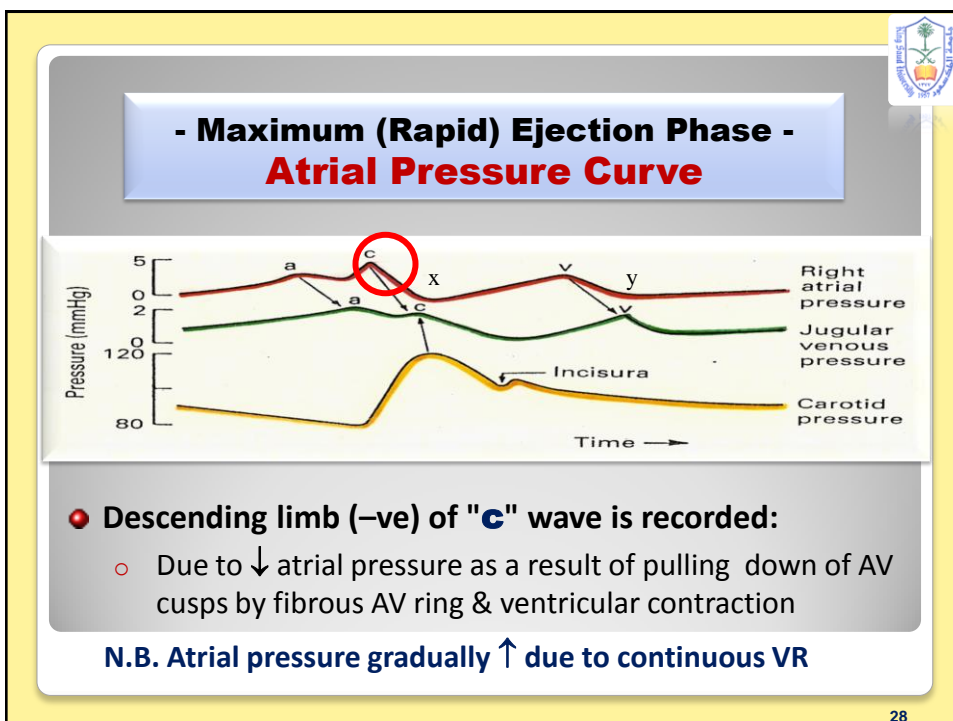
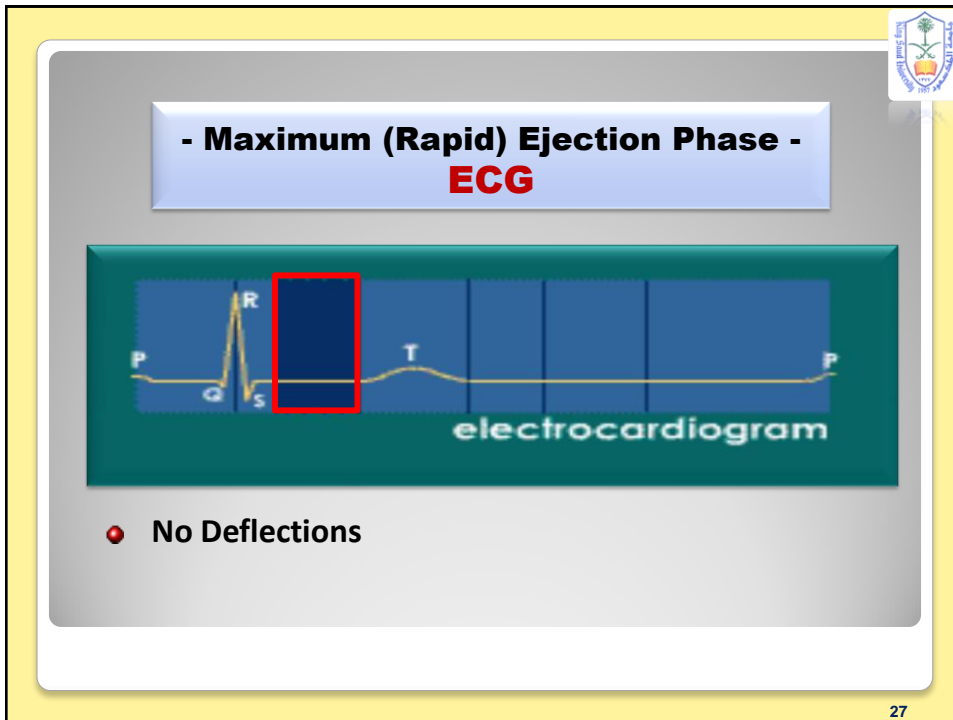
**- Maximum (Rapid) Ejection Phase - Heart Sounds**

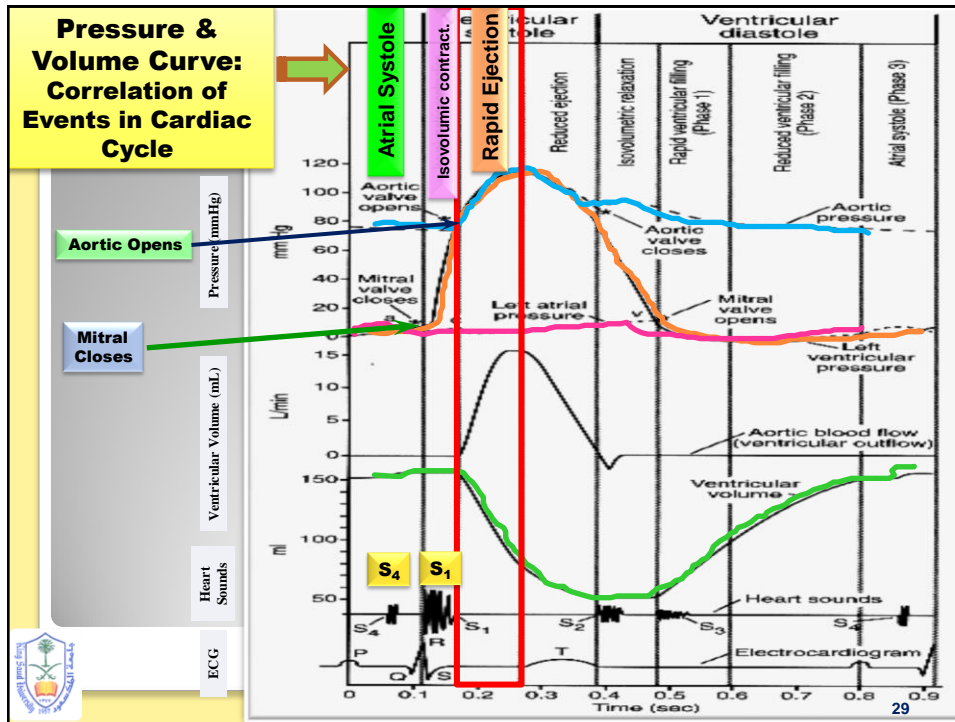


**heart sounds**

- **None**

26





**Phases of cardiac cycle:**


**4. Reduced Ejection Phase:**

- At end of systole
- 25% of ventricular blood is ejected
- Ventricular volume ↓ more slowly
- Ventricular pressure starts to ↓ < aortic pressure

**REDUCED EJECTION PHASE**



**- Reduced Ejection Phase -  
Heart Sounds**




heart sounds

- None

31

**- Reduced Ejection Phase -  
ECG**



electrocardiogram

- **T wave** is recorded
- Due to ventricular repolarization

32



### - Reduced Ejection Phase - Atrial Pressure Curve


The graph displays three pressure curves over time. The y-axis represents pressure in mmHg, with scales for 0-5 (Right atrial), 0-2 (Jugular venous), and 80-120 (Carotid). The x-axis is Time. The Right atrial pressure curve (top) shows a small dip labeled 'X' during the reduced ejection phase. The Jugular venous pressure curve (middle) shows a similar dip. The Carotid pressure curve (bottom) shows a prominent incisura during the reduced ejection phase.

- **"X"** Descend is recorded:
  - Due to more ↓ atrial pressure as a result of pulling down of AV cusps by fibrous AV ring & ventricular contraction

N.B. Later, atrial pressure gradually ↑ due to continuous VR

### Pressure & Volume Curve: Correlation of Events in Cardiac Cycle

This graph correlates pressure and volume curves with the cardiac cycle. The y-axis shows pressure (mmHg) and volume (mL). The x-axis shows time in seconds. Key events are marked: Aortic valve opens, Mitral valve closes, Aortic valve closes, and Mitral valve opens. The cardiac cycle is divided into Atrial Systole, Isovolumic contraction, Rapid Ejection, Reduced Ejection, Isovolumic relaxation, Rapid ventricular filling (Phase 1), Reduced ventricular filling (Phase 2), and Atrial systole (Phase 3). Heart sounds (S<sub>4</sub>, S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, S<sub>4</sub>) and ECG traces (P, Q, R, S, T) are also shown.




**To Revise:**

Regarding 'Atrial Systole':

- Atrial systole occurs at the end of ventricular
- Tops off last % of ventricular filling
- On Atrial Pressure Curve,  wave is recorded
- In ECG,  wave is recorded
- Associated with  heart sound

35



**To Revise:**

Regarding phases of ventricular contraction:

- During 'isovolumetric contraction' phase, all valves are
- 'c' wave in atrial pressure curve occurs during:  &  phases
- QRS is reported during  phase
- heart sound marks the beginning of systole
- Maximum Lt ventricular systolic pressure =  mmHg
- In ECG, 'T- wave' occurs during  phase

36

Phases of cardiac cycle:

### 5. Protodiastolic Phase:

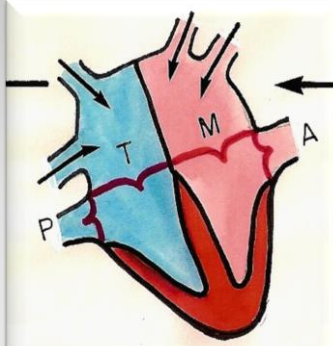
- Period b/w end of ventricular systole & aortic-v closure
- Very short ... (lasts 0.04 sec)
- Aortic v closes at this phase, as a result of:
  - ↓ ventricular pressure < aortic pressure
  - aortic back pressure (when LV pressure 110 mmHg)
- Atrial pressure still ↑, due to continuous VR

37

Phases of cardiac cycle:

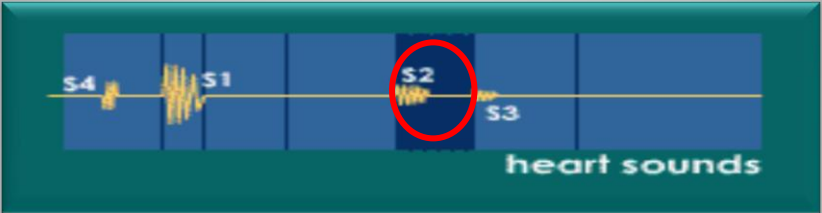
### 6. Isovolumetric Relaxation Phase:

- Quiescent period
- At beginning of diastole ... (0.04 sec)
- Period b/w closure of semilunar-vs & opening of AV-vs
- 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 end of this phase



38

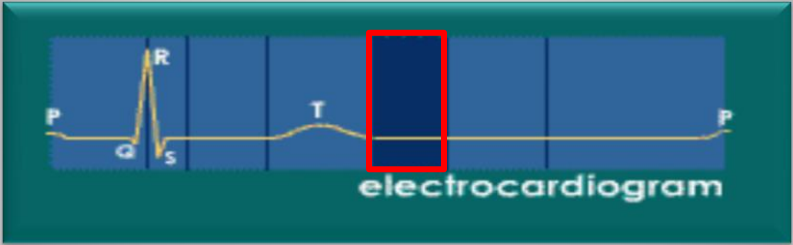
**- Isometric Relaxation Phase -  
Heart Sounds**



- **Second heart sound (S2, "dup")** is recorded, when semilunar (aortic & pulmonary) vs close
  - S2 physiologically splits, as aortic v closes slightly earlier than pulmonary v

39

**- Isometric Relaxation Phase -  
ECG**



- **No Deflections**

40

### - Isovolumetric Relaxation Phase - Atrial Pressure Curve

The graph displays three pressure curves over time. The y-axis represents pressure in mmHg, with scales for Right atrial pressure (0-5), Jugular venous pressure (0-120), and Carotid pressure (80-120). The x-axis represents time. The right atrial pressure curve shows waves labeled 'a', 'c', 'x', 'v', and 'y'. The 'v' wave is circled in red. The jugular venous pressure curve shows a similar pattern with waves 'a', 'c', and 'v'. The carotid pressure curve shows a sharp systolic peak followed by a dicrotic notch (incisura) and a diastolic decay.

- "v" wave is recorded
  - Due to continuous venous return (VR) to the atria
- Ventricular pressure continues ↓

41

### Pressure & Volume Curve: Correlation of Events in Cardiac Cycle

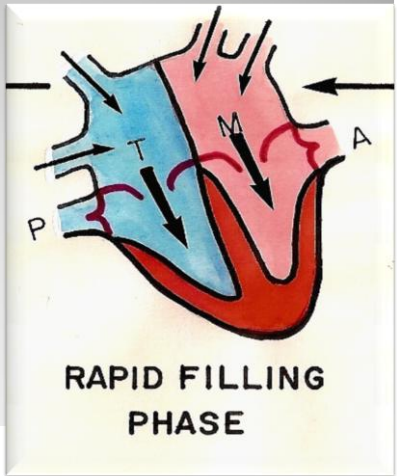
This graph correlates pressure and volume curves with the cardiac cycle. The y-axis shows pressure (mmHg) and volume (mL). The x-axis shows time in seconds. Key events are marked: Aortic valve opens, Mitral valve closes, Aortic valve closes, and Mitral valve opens. The cardiac cycle is divided into Atrial Systole, Isovolumetric contract., Rapid Ejection, Reduced Ejection, Isovolumetric Relax., Rapid ventricular filling (Phase 1), Reduced ventricular filling (Phase 2), and Atrial systole (Phase 3). Heart sounds (S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, S<sub>4</sub>) and ECG (P, Q, R, S, T) are also shown.

42

**Phases of cardiac cycle:**

**7. Rapid Filling Phase:**

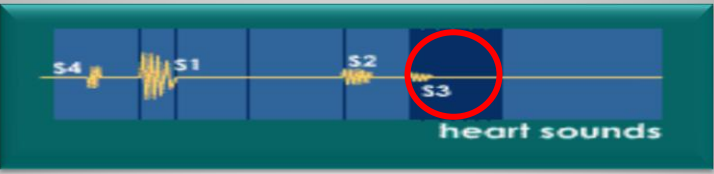
- Atrial > ventricular pressure
- AV-vs open
- $\approx$  60-70% of blood passes passively to ventricles along pressure gradient
- Ventricular volume  $\uparrow$  rapidly



**RAPID FILLING PHASE**


43

**- Rapid Filling Phase - Heart Sounds**

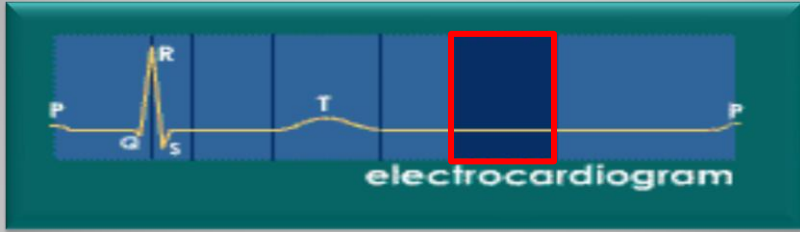


- **Third heart sound (S3)** is recorded
- Due to rapid passive ventricular filling
- S3 is usually abnormal
- ? Normal in children

44




**- Rapid Filling Phase -  
ECG**



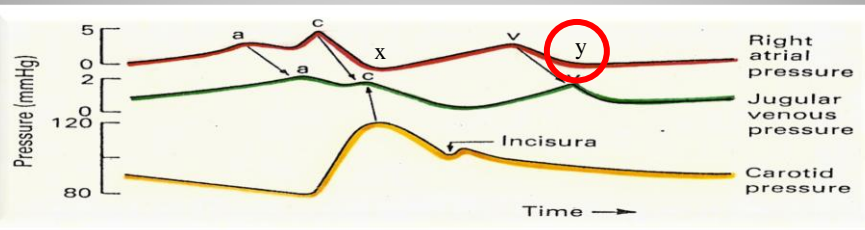
electrocardiogram

- No Deflections

45



**- Rapid Filling Phase -  
Atrial Pressure Curve**



Pressure (mmHg)

Time →

Right atrial pressure

Jugular venous pressure

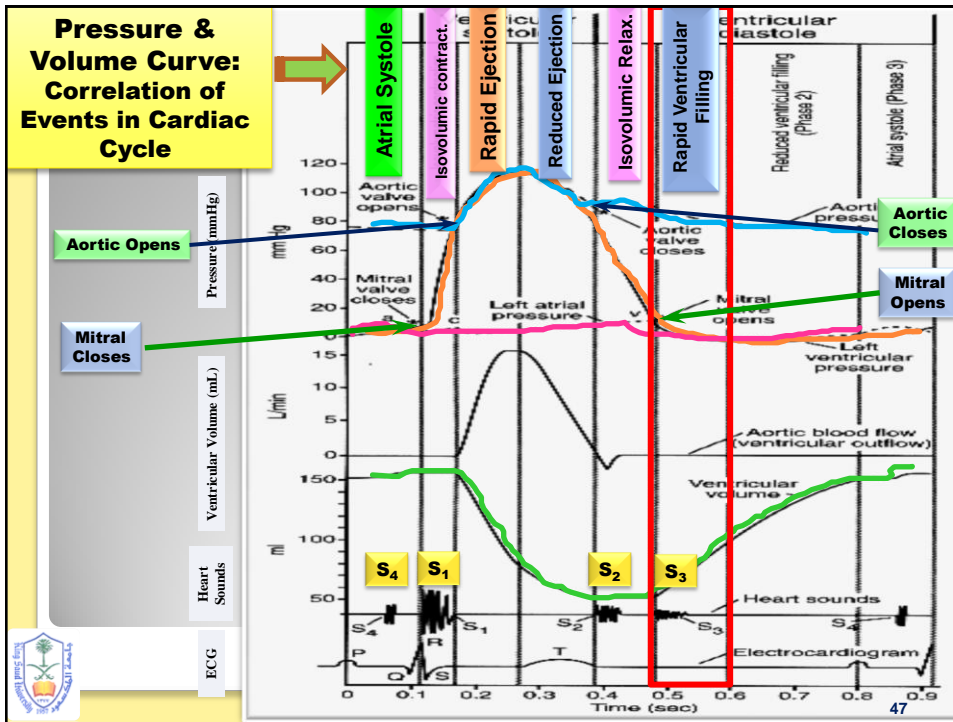
Carotid pressure

Incisura

- **"y"** Descend is recorded:
  - Due to more ↓ atrial pressure as a result of emptying blood

46





**Phases of cardiac cycle:**

**8. Reduced Filling Phase (Diastasis):**

- Remaining atrial blood flows slowly into ventricles
- AV-vs still open
- LV volume  $\uparrow$  > slowly

**DIASTASIS (REDUCED FILLING PHASE)**

48



**- Reduced Filling Phase -  
Heart Sounds**

heart sounds

- None

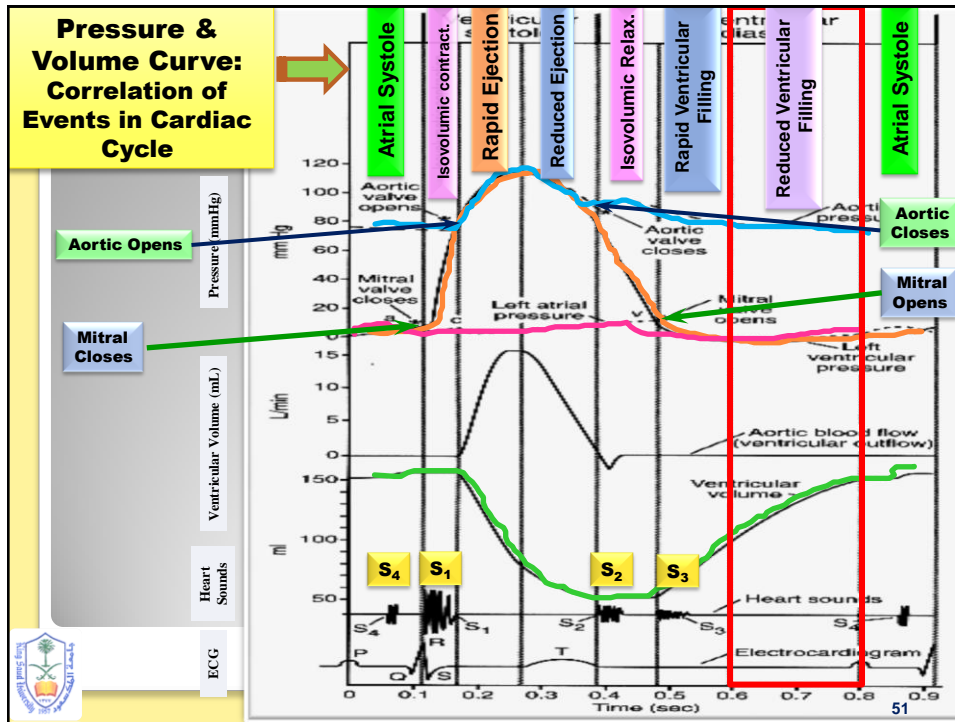
49

**- Reduced Filling Phase -  
ECG**

electrocardiogram

- No Deflections

50



## To Revise:

Regarding phases of ventricular relaxation:

- 'v' wave in atrial pressure curve occurs during:  phase
- heart sound marks the beginning of diastole
- % of blood passes passively during 'rapid filling' phase
- heart sound is recorded during 'rapid filling' phase

