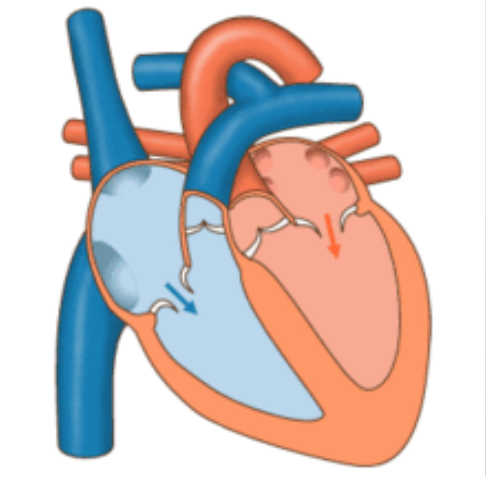
جامعة الملك سعود
King Saud University

Cardiovascular Physiology

Cardiac Cycle- 1



Dr. Abeer A. Al-Masri, PhD

A. Professor,

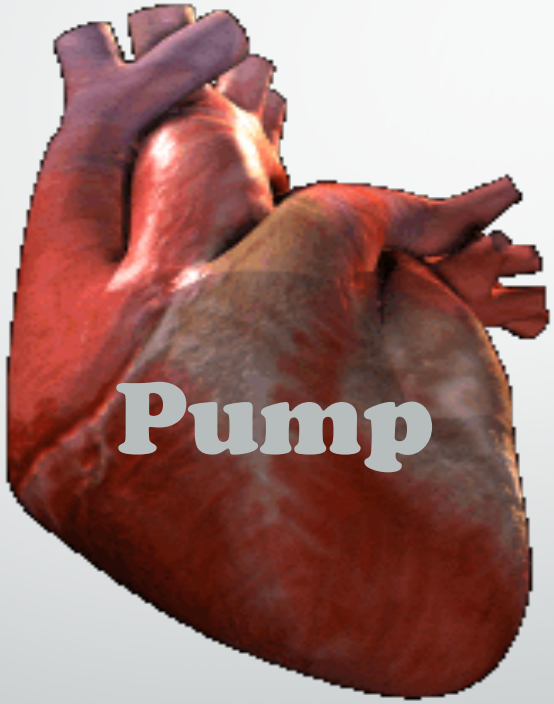
Consultant Cardiovascular Physiologist,

Faculty of Medicine, KSU.

Lecture Outcomes:

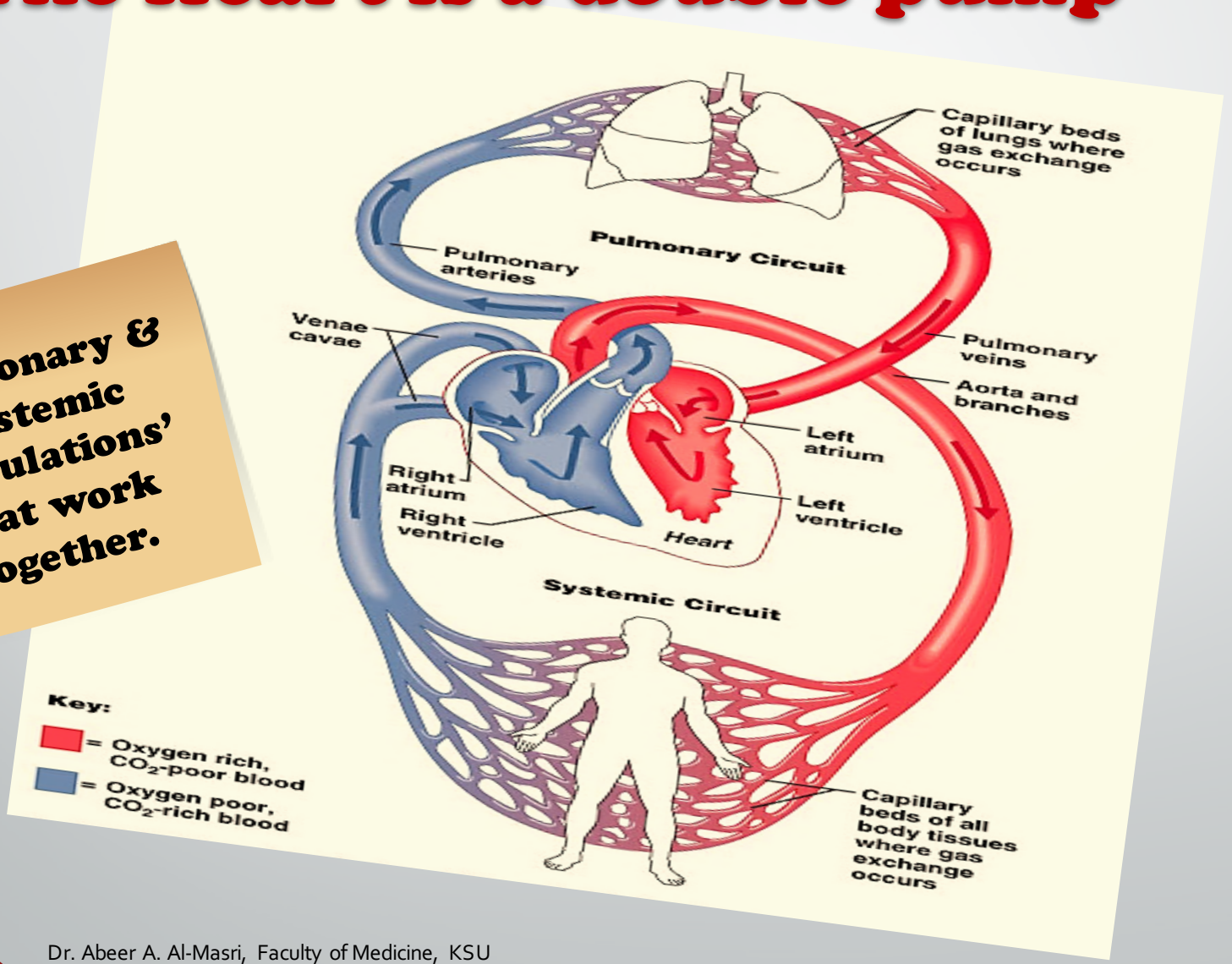
- Main function of the heart.
- Different events that occur during the cardiac cycle.
- Various mechanical phases of the cardiac cycle.
- General principles of the cardiac cycle.
- Changes in volume & pressure during the cardiac cycle.
- Heart sounds recorded during the cardiac cycle.

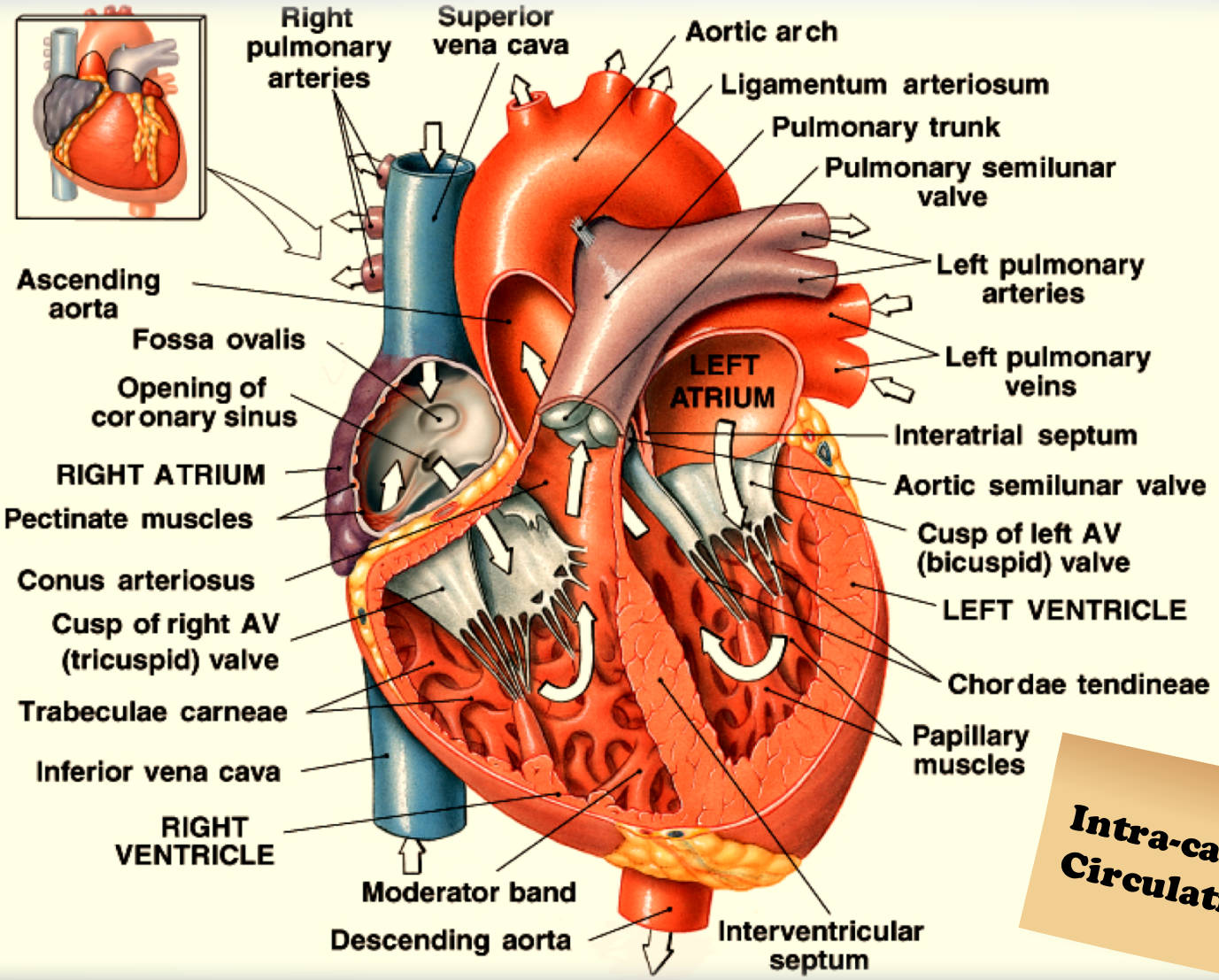
Function of the Heart ?



The Heart is a double pump

'Pulmonary & Systemic Circulations' that work together.



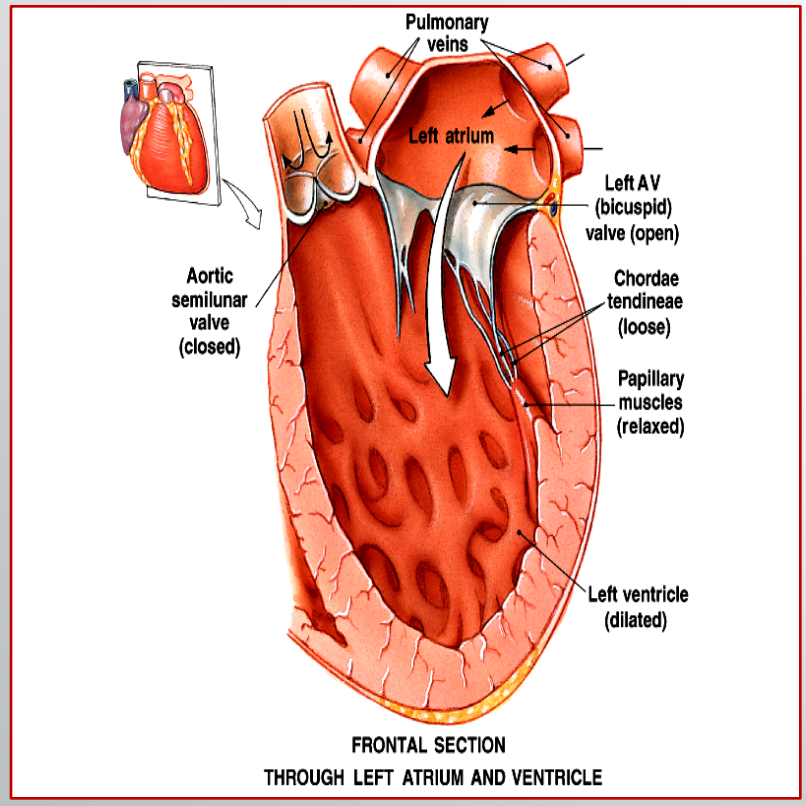


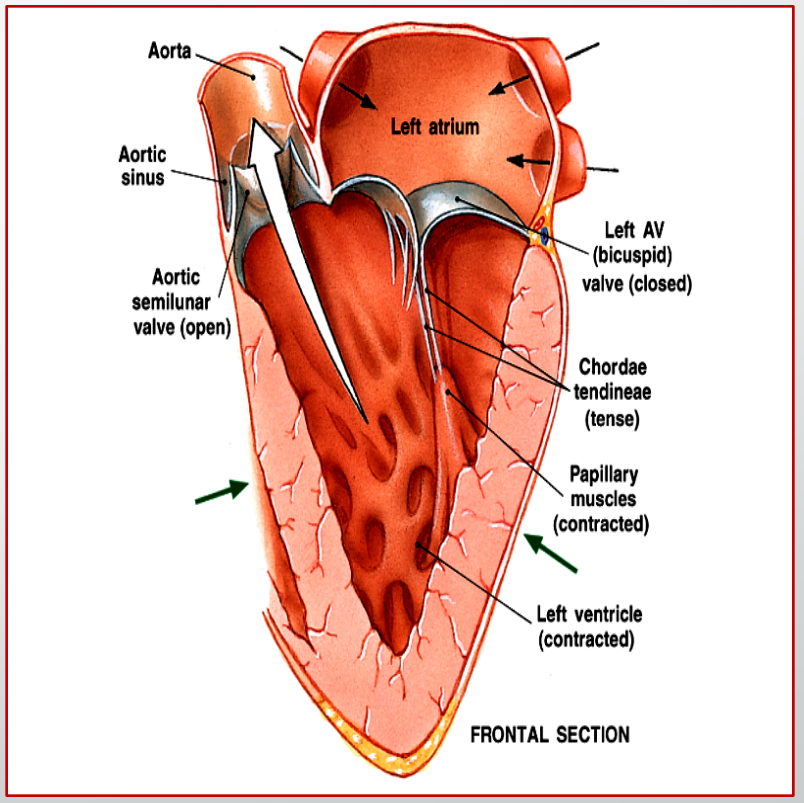
Intra-cardiac Circulations.

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 tendinea to muscular projections called Papillary muscles.

Function of the Valves





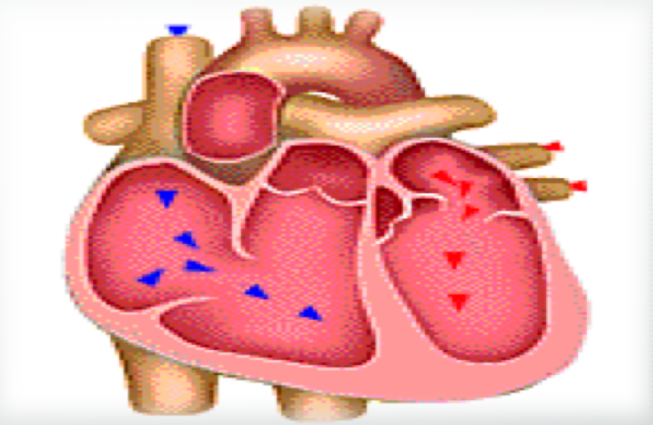
General Principles

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

Cardiac Cycle ?

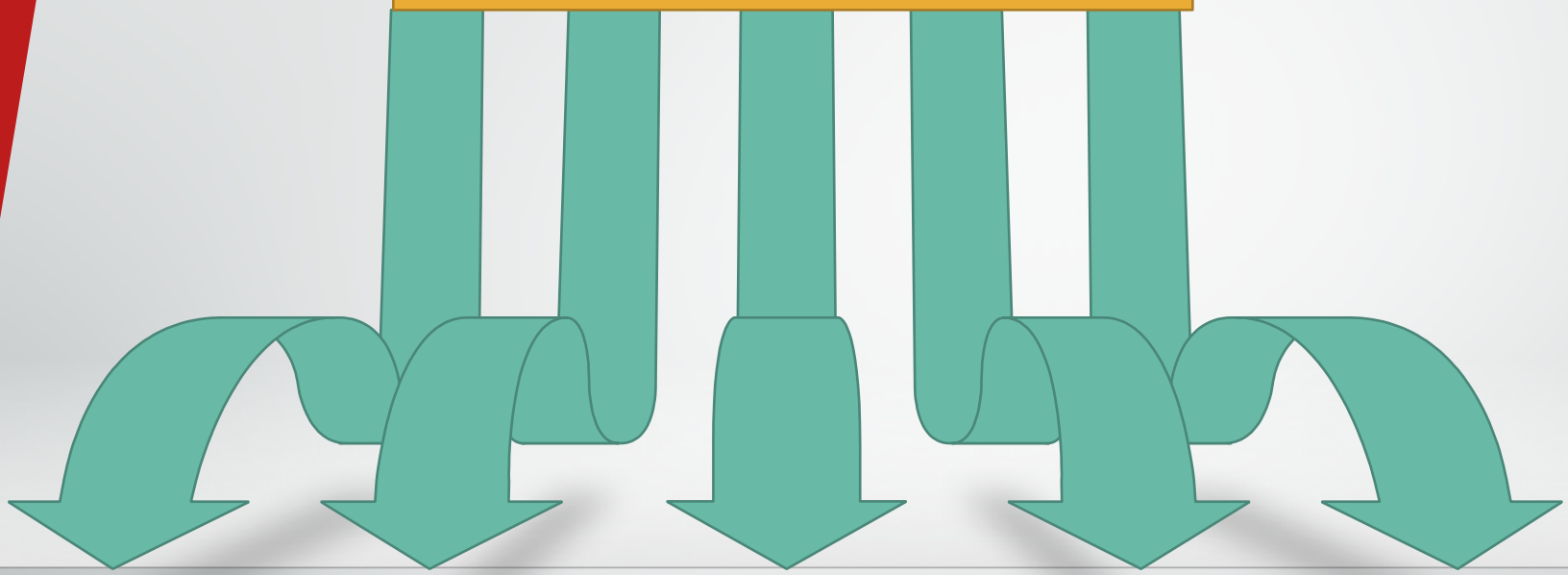
Sequence of events that take place in the heart in each beat

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



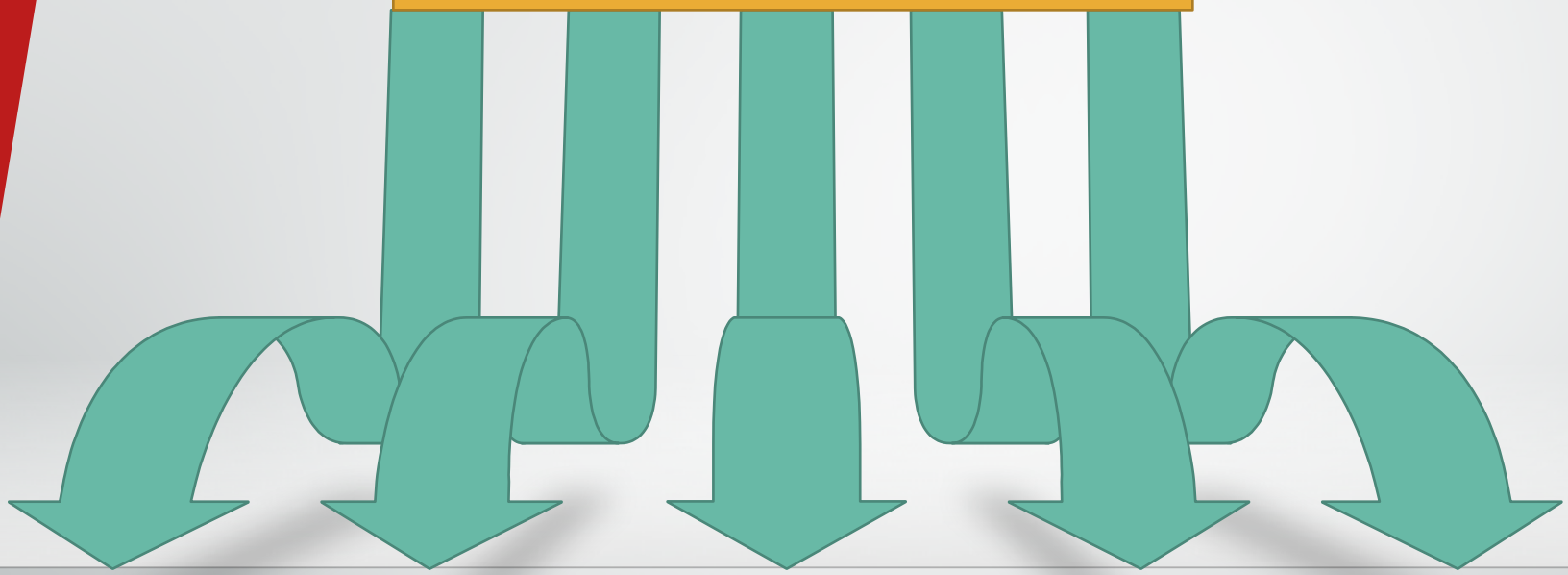
- **Cardiac cycle duration = 0.8 sec …**
  - When HR 72 bpm
    - Shortened when HR ↑

Events in the Cardiac Cycle



1	2	3	4	5
• Mechanical events	• Volume changes	• Pressure changes	• Heart sounds	• Electrical events (ECG)

Events in the Cardiac Cycle



1	2	3	4	5
• Mechanical events	• Volume changes	• Pressure changes	• Heart sounds	• Electrical events (ECG)

Mechanical Events:

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

repeated in
(Relaxation) next beat (Contraction)

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

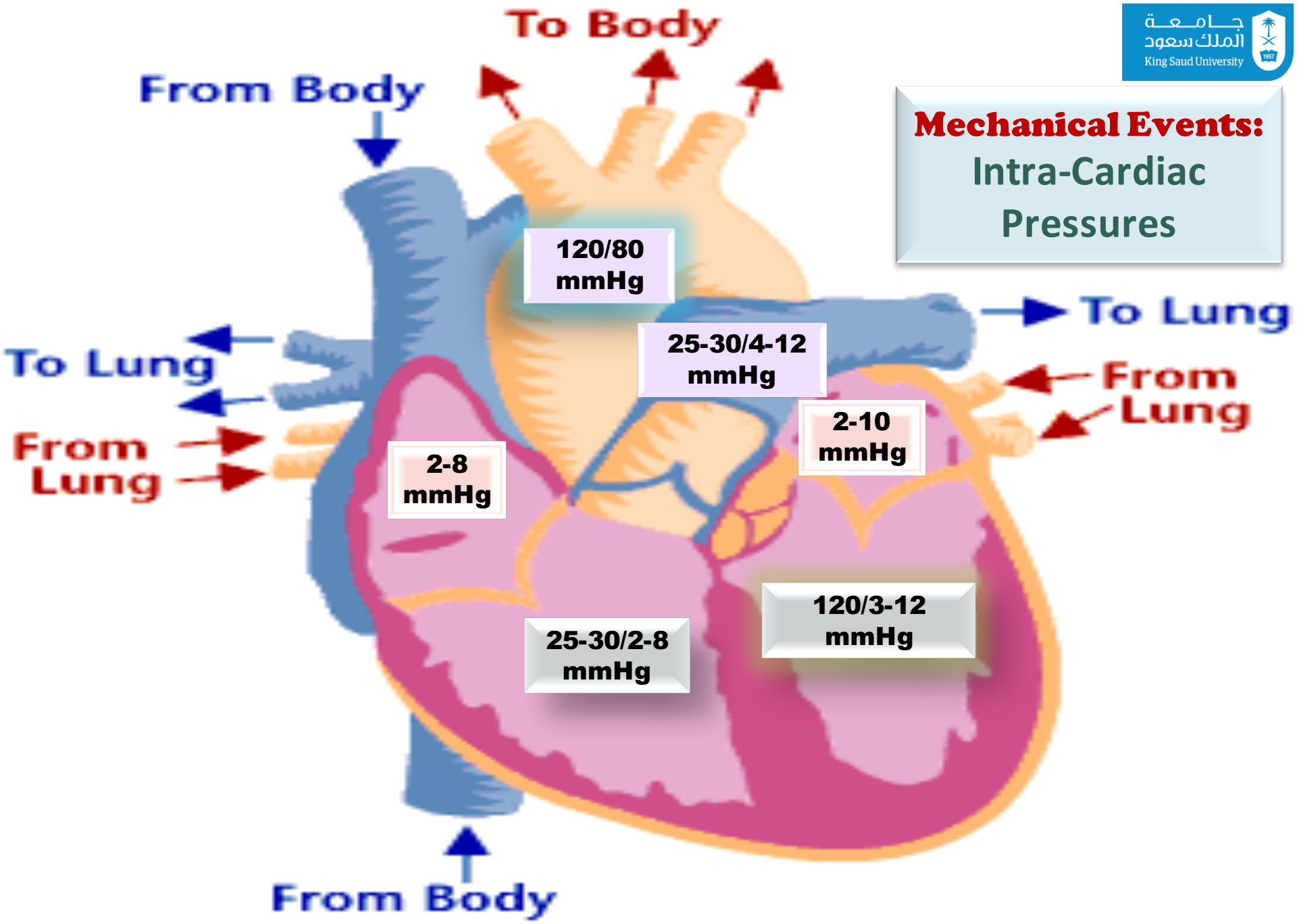
Mechanical Events' Periods

- **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

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 %.

Mechanical Events:
Intra-Cardiac Pressures



Mechanical Phases …

Consists of 7 phases.

Ventricular diastole:

Early ventricular diastole:

?? **Protodiastole**

1. Isometric relaxation phase
2. Rapid filling phase

Mid ventricular diastole:

3. Reduced filling phase

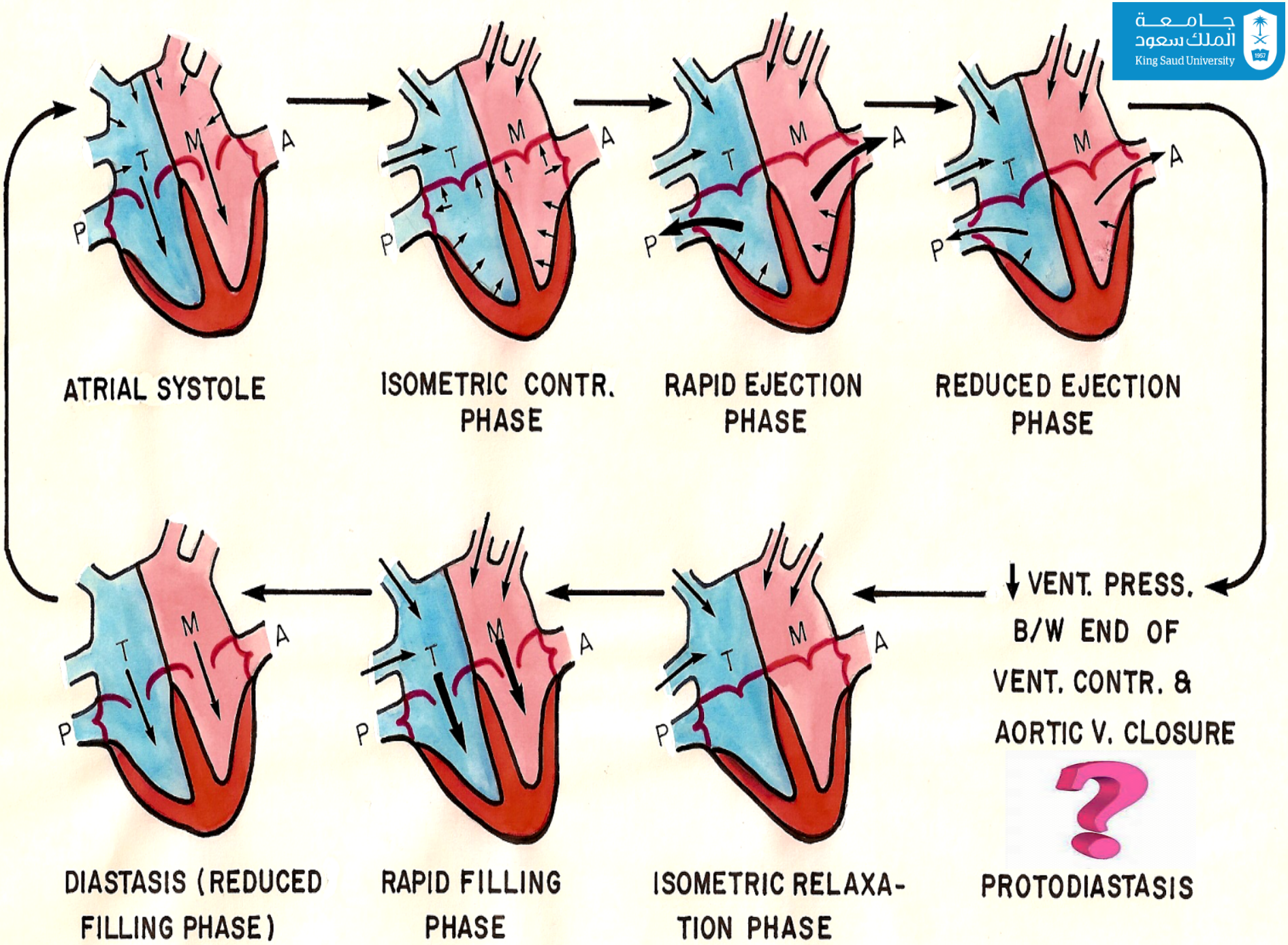
Late ventricular diastole:

4. Atrial systole

Ventricular systole:

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

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


ATRIAL SYSTOLE
ISOMETRIC CONTR. PHASE
RAPID EJECTION PHASE
REDUCED EJECTION PHASE
VENT. PRESS. B/W END OF VENT. CONTR. & AORTIC V. CLOSURE
PROTODIASTASIS
ISOMETRIC RELAXATION PHASE
RAPID FILLING PHASE
DIASTASIS (REDUCED FILLING PHASE)
A
P
T
M

Mechanical Phases of cardiac cycle:

1. Atrial Systole:

- At 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.
- **Pressure changes:** ↑ Atrial pressure.
- **4th Heart sound heard.**
- Blood arriving the heart can't enter atria, it flows back up jugular vein.

2. Isovolumetric Contraction Phase:

- At beginning of ventricular systole … (Lasts ≈ 0.04 sec.)
- Period between closure of AV- vs & opening of Semilunar- vs.
- Preceded by ventricular depolarization.
- Starts with closure of AV- vs.
- **1st Heart sound heard.**
- **Ventricle is a closed chamber.**
  - Volume in ventricle = **EDV**
  - Ventricle contracts with no changes in volume.
- Ventricular pressure ↑
- Aortic v opens at the end of this phase, when LV exceeds 80 mmHg.

3. Maximum (Rapid) Ejection Phase:

- Semilunar- vs open at beginning of this phase:
  - When LV pressure exceeds 80 mmHg.
- Almost 75% of ventricular blood is ejected, i.e. 75% of **SV**.
- Ventricular pressure reaches 120 mmHg.

4. Reduced Ejection Phase:

- End of systole.
- Almost 25% of ventricular blood is ejected, i.e. 25% of **SV**.
- Aortic- v closes at the end of this phase when LV pressure reaches 110 mmHg.

5. Isovolumetric Relaxation Phase:

- Period between closure of semilunar- vs & opening of AV- vs.
- Beginning of diastole … (Lasts ≈ 0.04 sec.)
- Preceded by ventricular repolarization.
- **2nd Heart sound heard** .
- **LV is a closed chamber**, i.e. relax with no changes in volume.
- Volume of blood in ventricle = **ESV.**
- AV- vs open at the end of this phase.

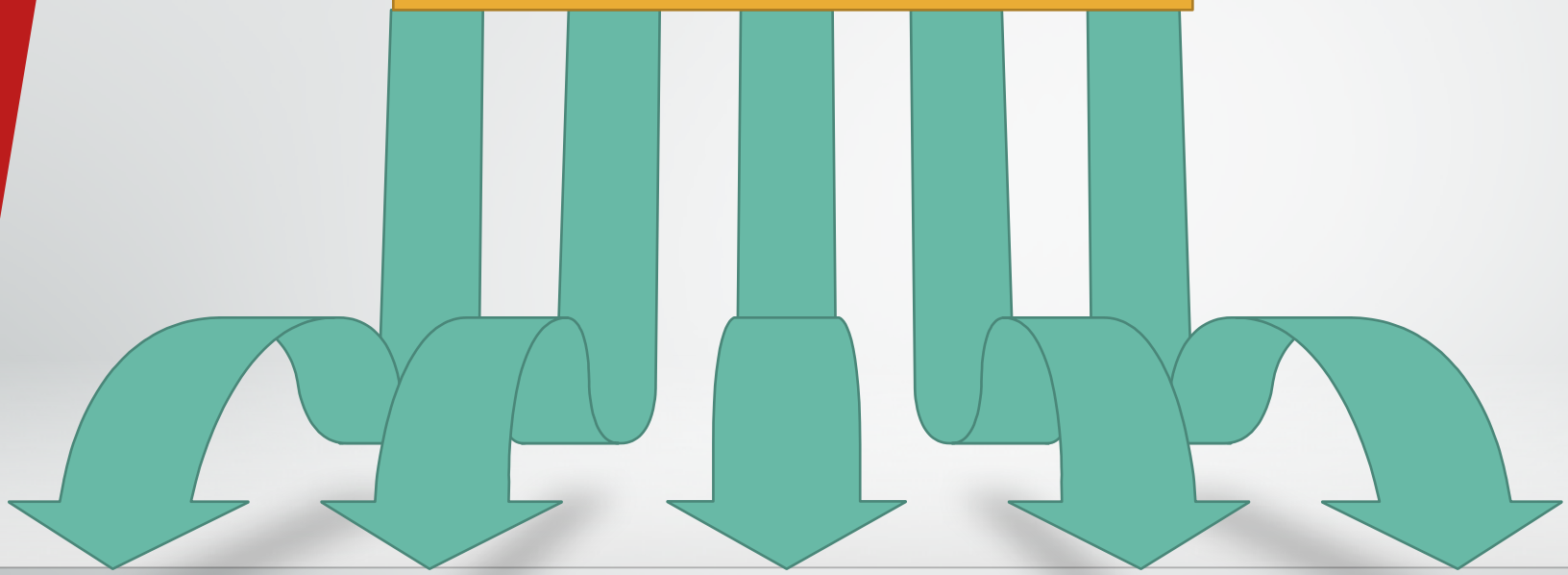
6. Rapid Filling Phase:

- Atrial pressure > ventricular pressure.
- AV- vs open.
- ≈ 60-70% of blood passes passively to the ventricles along pressure gradient.
- **3rd Heart sound heard.**

7. Reduced Filling Phase (Diastasis):

- Remaining atrial blood flows slowly into ventricles.
- AV- vs still open.

Events in the Cardiac Cycle



1	2	3	4	5
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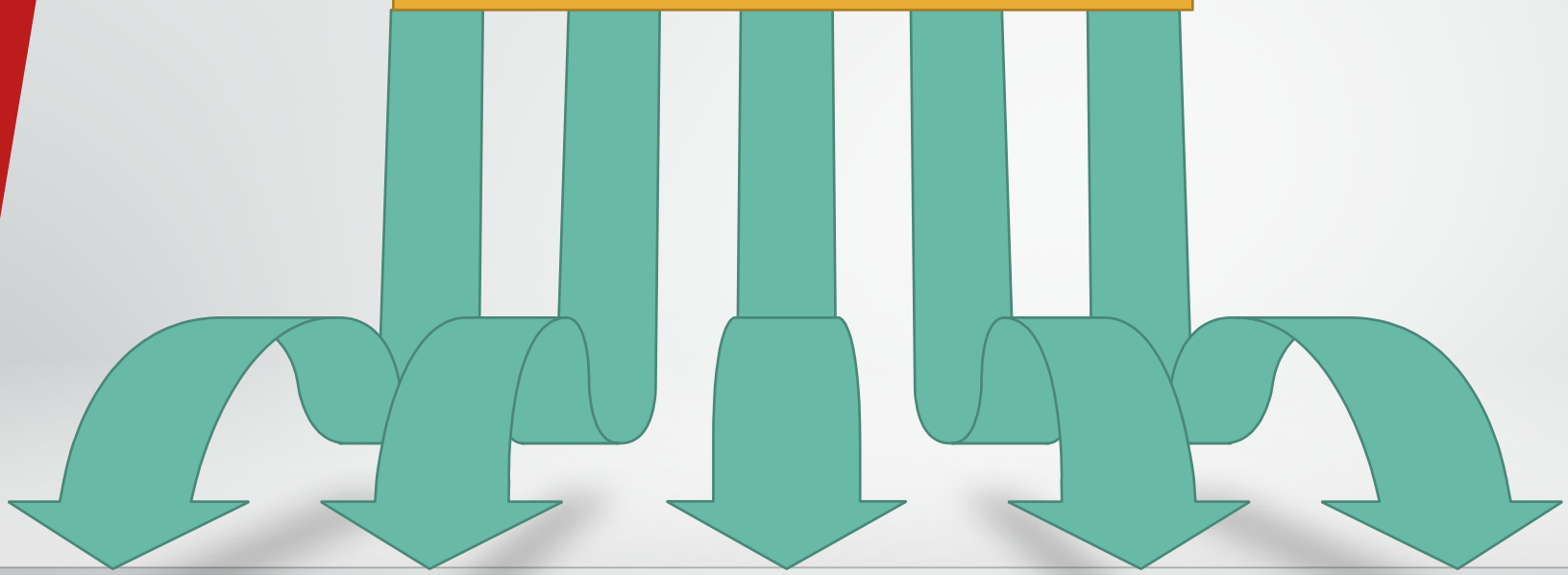
Ventricular Volume Changes During the Cardiac Cycle

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

Events in the Cardiac Cycle



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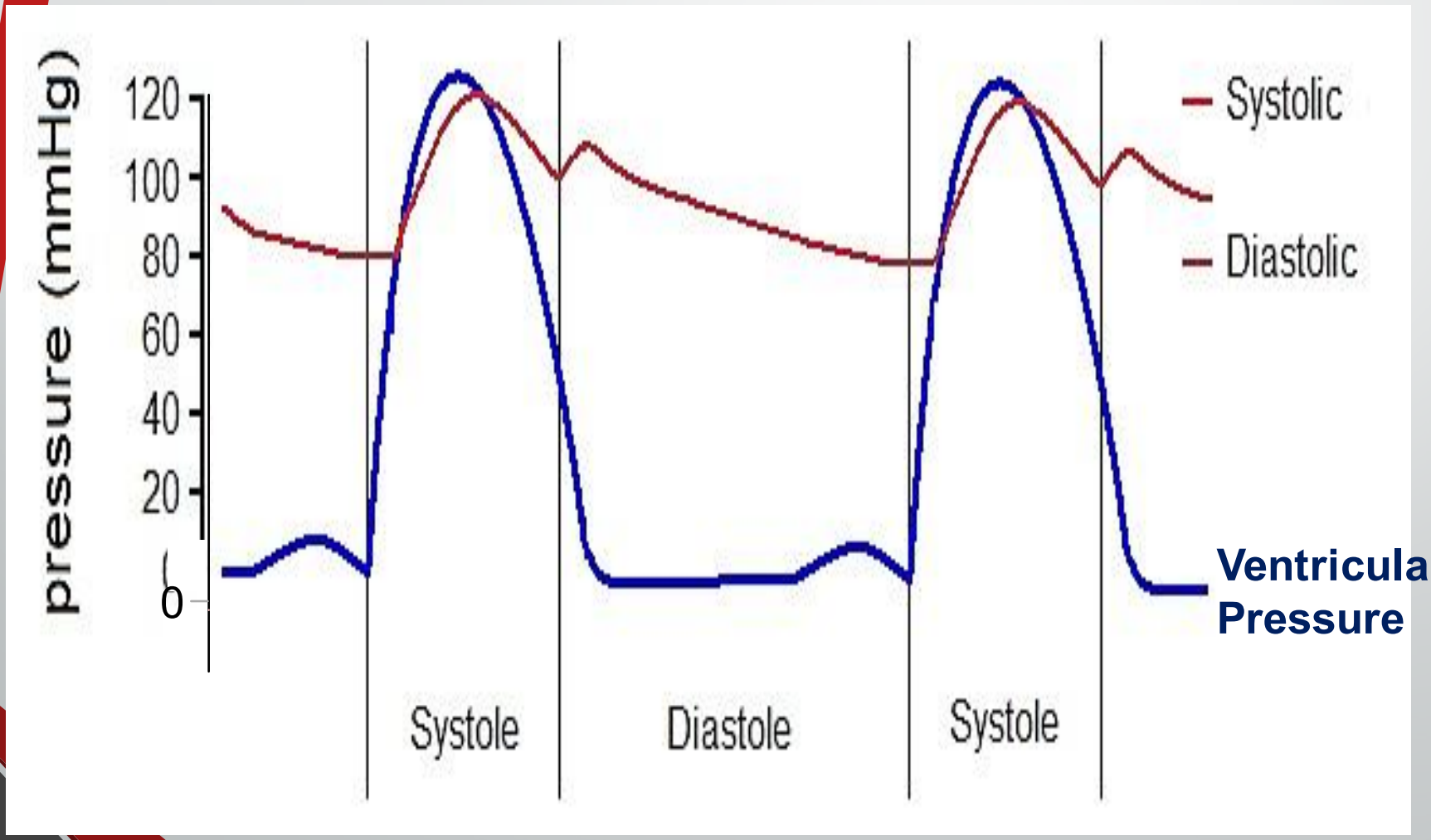
Pressure Changes During the Cardiac Cycle

Recorded Pressure Changes

- **Ventricular pressure**
- **Aortic pressure**
  - Arterial pressure waves
  - Pulmonary artery pressure
- **Atrial pressure**
  - Jugular venous pressure

Ventricular Pressure Changes … 120/3-12 mmHg



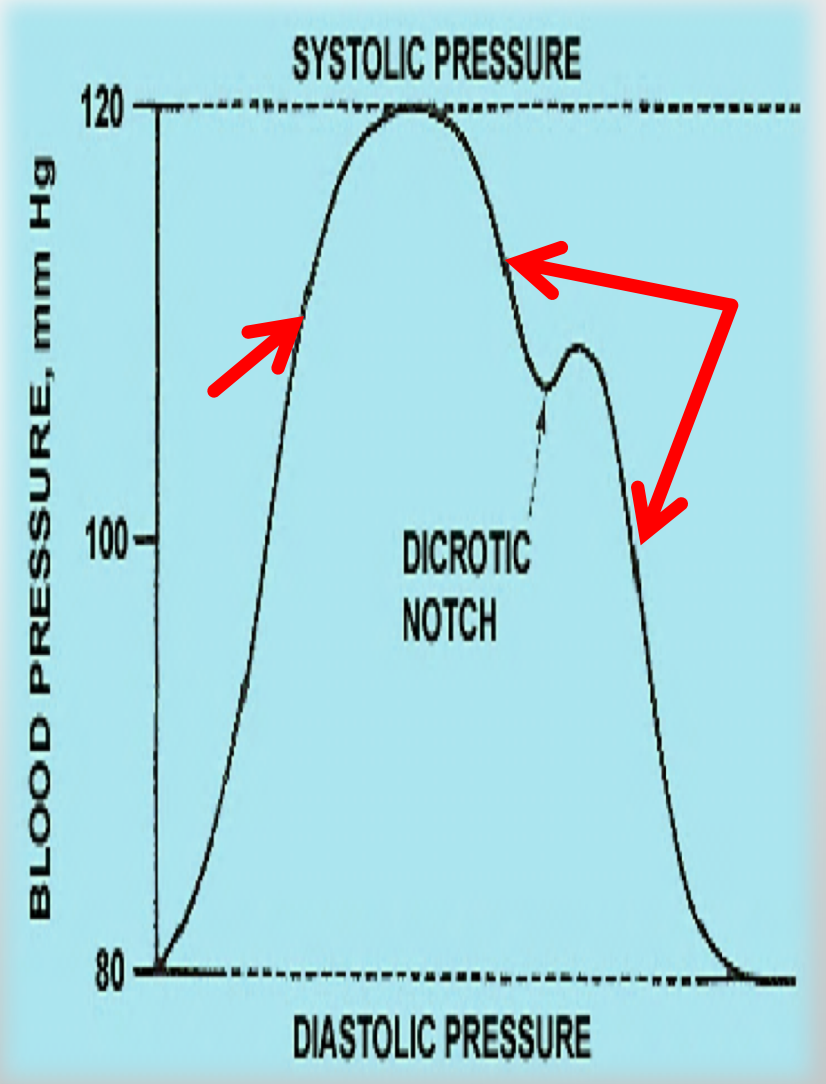
Aortic Pressure Changes … 120/80 mmHg

a. Ascending or anacrotic limb:

- With ‘rapid ejection phase.’
- Aortic press ↑ up to 120 mmHg.

b. Descending or catacrotic limb:

- Passes in 4 stages.



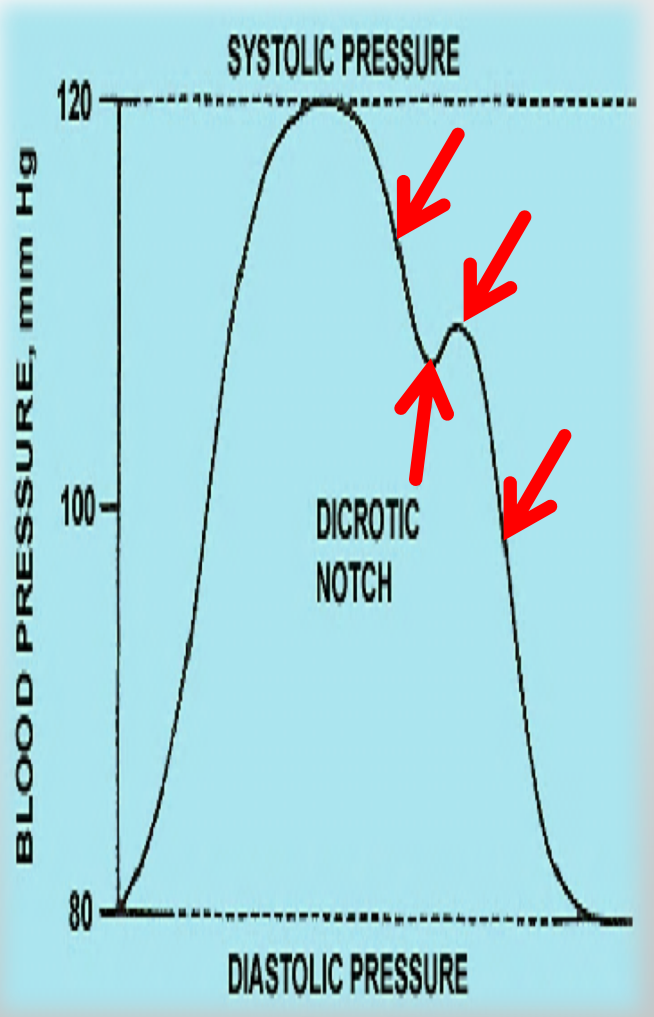
Stages of the Descending / Catacrotic Limb:

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

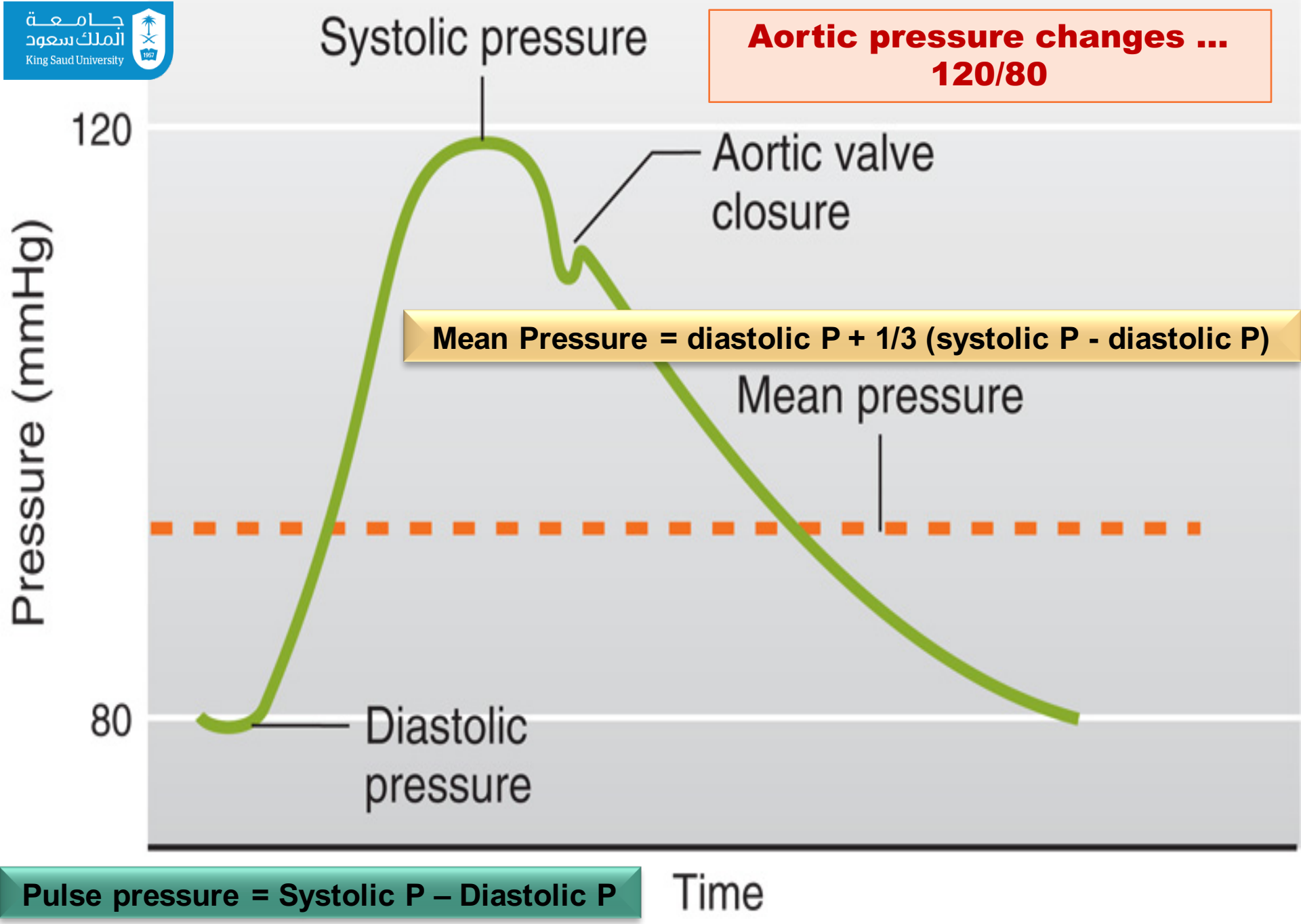
   Due to closure of aortic- v.
   - Sudden drop in aortic pressure.
   - At end of ventricular systole.
3. **Dicrotic wave:**

   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.



Aortic pressure changes … 120/80

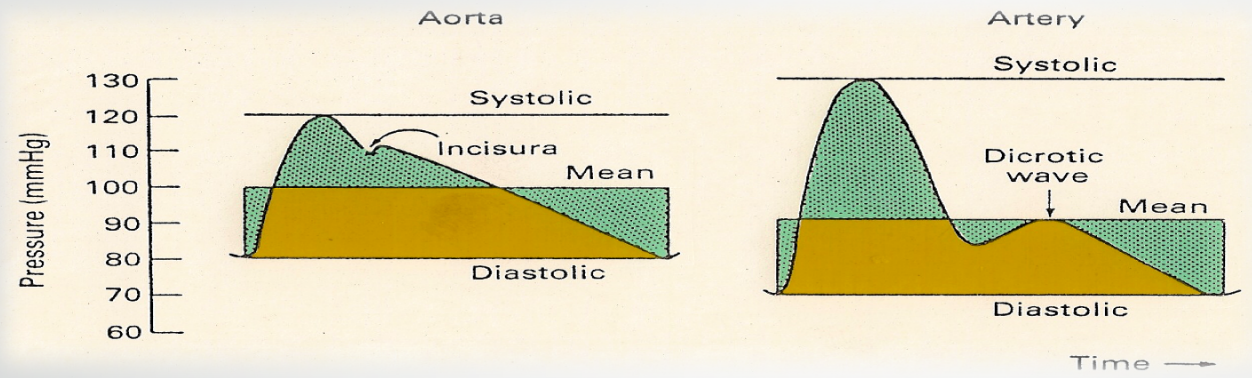


Mean Pressure = diastolic P + 1/3 (systolic P - diastolic P)

Pulse pressure = Systolic P – Diastolic P

Adapted from Guyton

Arterial Pressure Changes … 110-130/70-85 mmHg

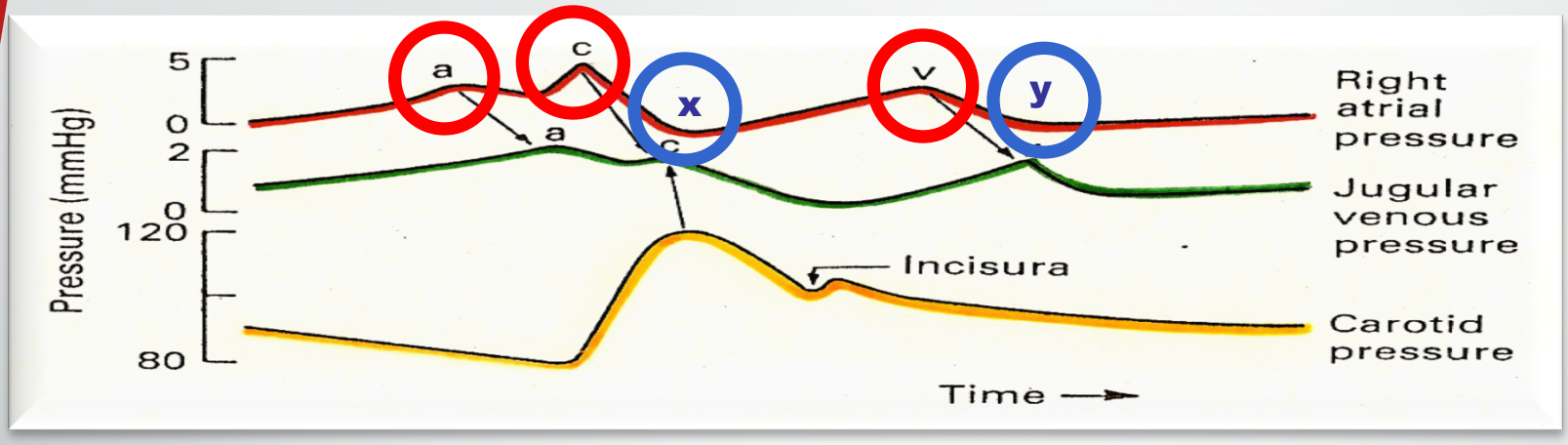


- Similar to aortic pressure waves, but **sharper.**
- Reflects a systolic peak pressure of 110-130 mmHg & a diastolic pressure of 70-85 mmHg.

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

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

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

Causes of atrial pressure waves

- **'a' wave: Atrial systole**:

  ↑ atrial pressure during atrial systole.

- **'c' wave: Ventricular systole**
  - **+ve** → due to the bulging of AV- vs into the atria during 'isovolumetric contraction phase.'
  - **-ve** → due to the pulling down of the atrial muscle & AV cusps 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.'

Causes of atrial pressure waves … (Cont.)

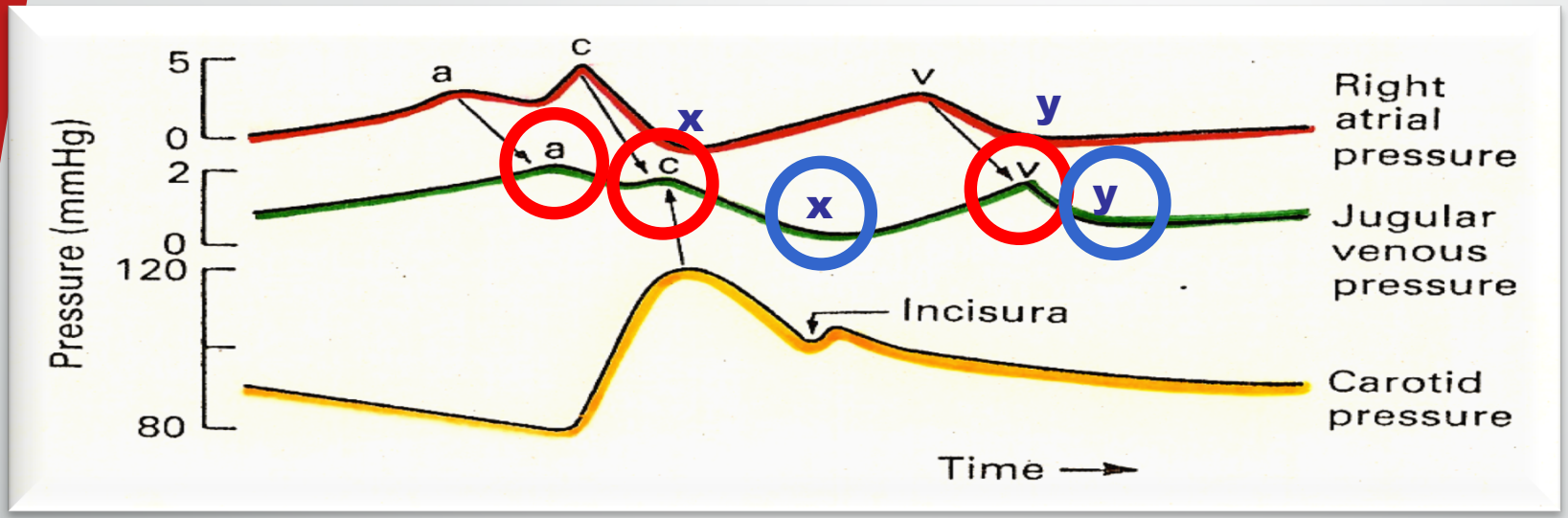
- **'x' descent:**

  Downward displacement of AV- vs during 'reduced ejection phase.'

- **'y' descent:**

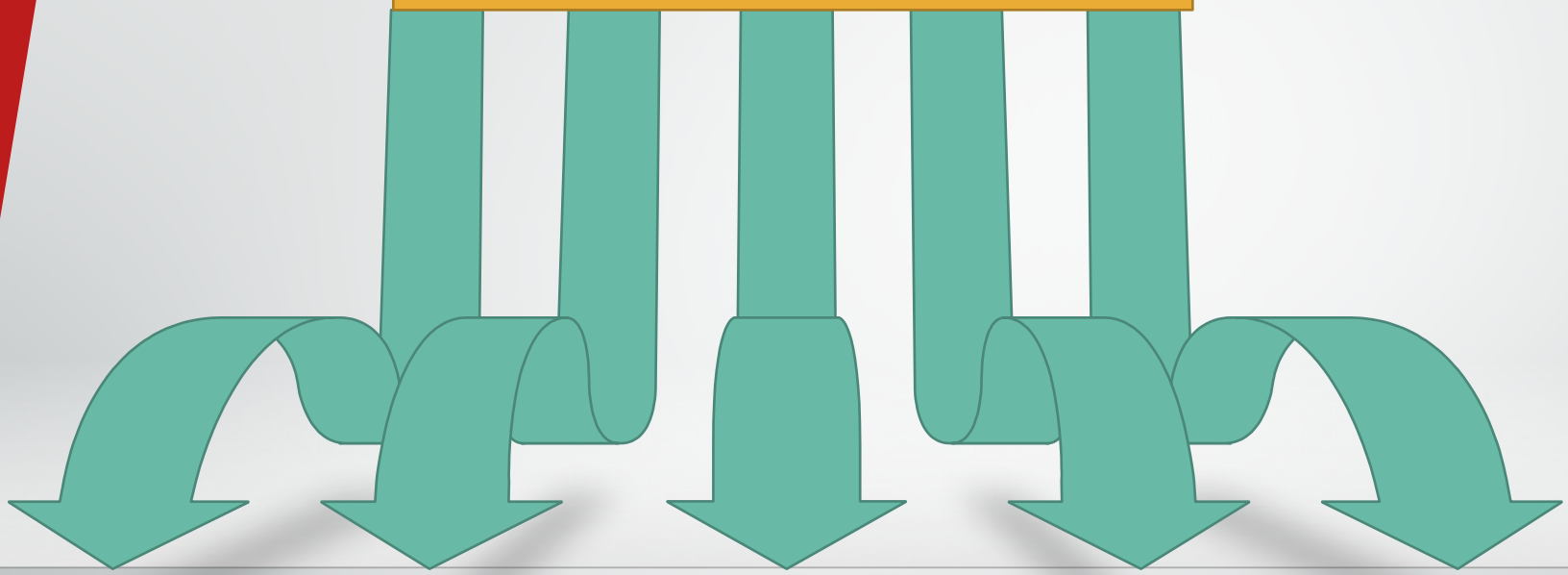
  ↓ ↓ atrial pressure during 'reduced filling phase.'

Jugular venous pulse changes:



- **Similar recordings of transmitted delayed atrial waves:**
  - 3 upward waves: a, c, & v
  - 2 downward waves: x & y

Events in the Cardiac Cycle

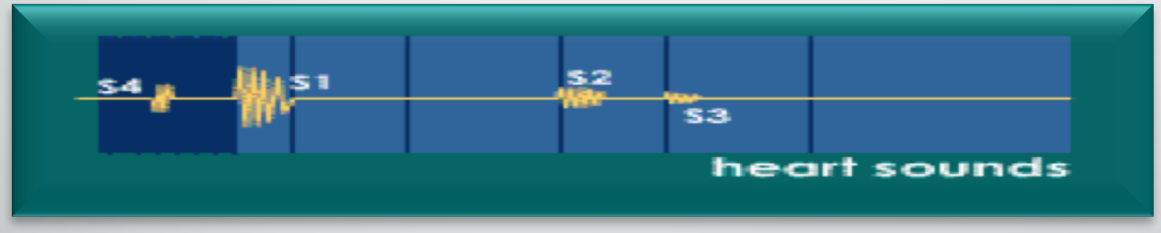


1	2	3	4	5
• Mechanical events	• Volume changes	• Pressure changes	• Heart sounds	• Electrical events (ECG)

Heart Sounds Recorded During the Cardiac Cycle

HEART SOUNDS

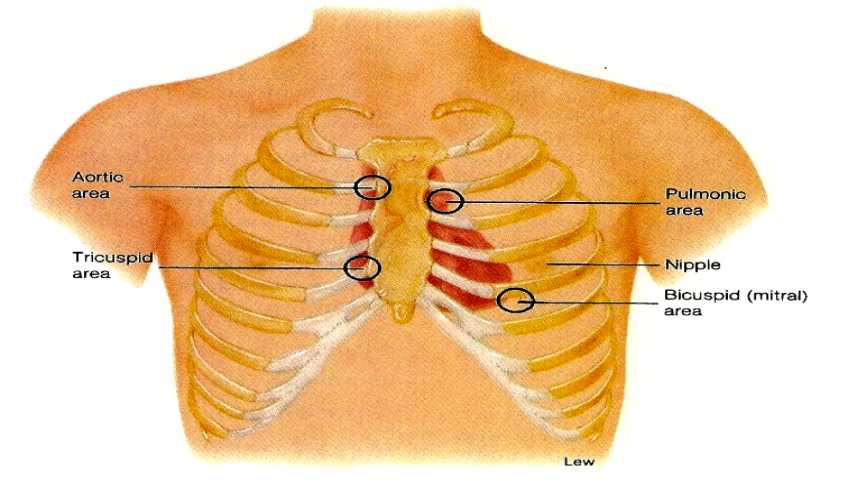
- **Detected over anterior chest wall by:**
  - Auscultation… (Stethoscope.)
  - Phonocardiography… (sound recording device.)
- **'4' heart sounds can be detected:**
  - 1st & 2nd heart sounds … (usually audible)
  - 3rd & 4th heart sounds … (of low pitch, usually not audible)



- **Important for diagnosis of valvular heart diseases (murmurs)**

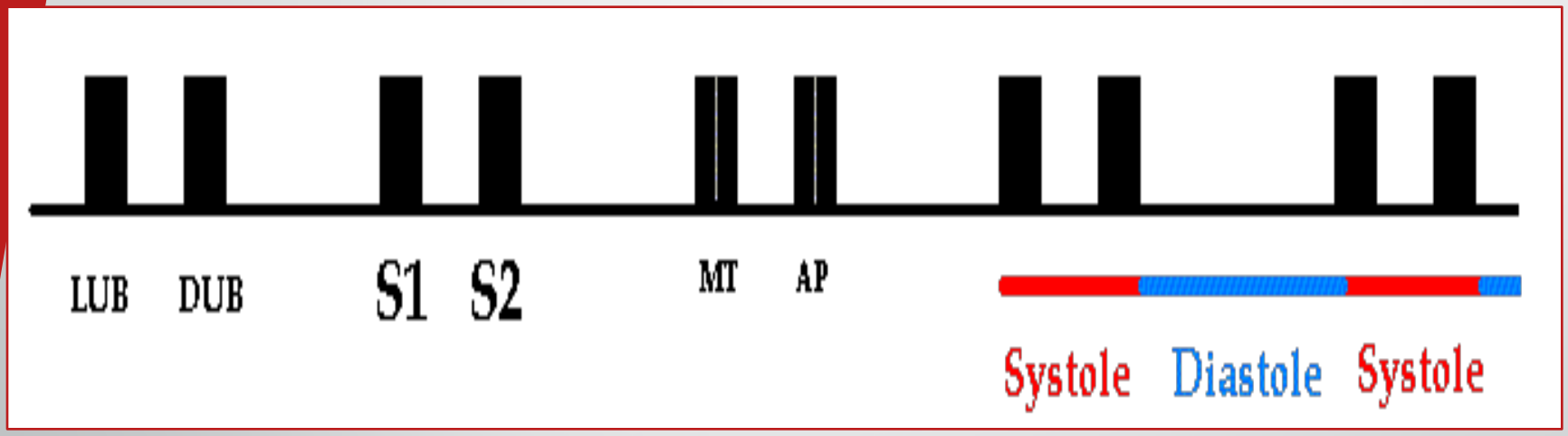
HEART SOUNDS' WINDOWS

- **Best heard at 4 certain areas:**

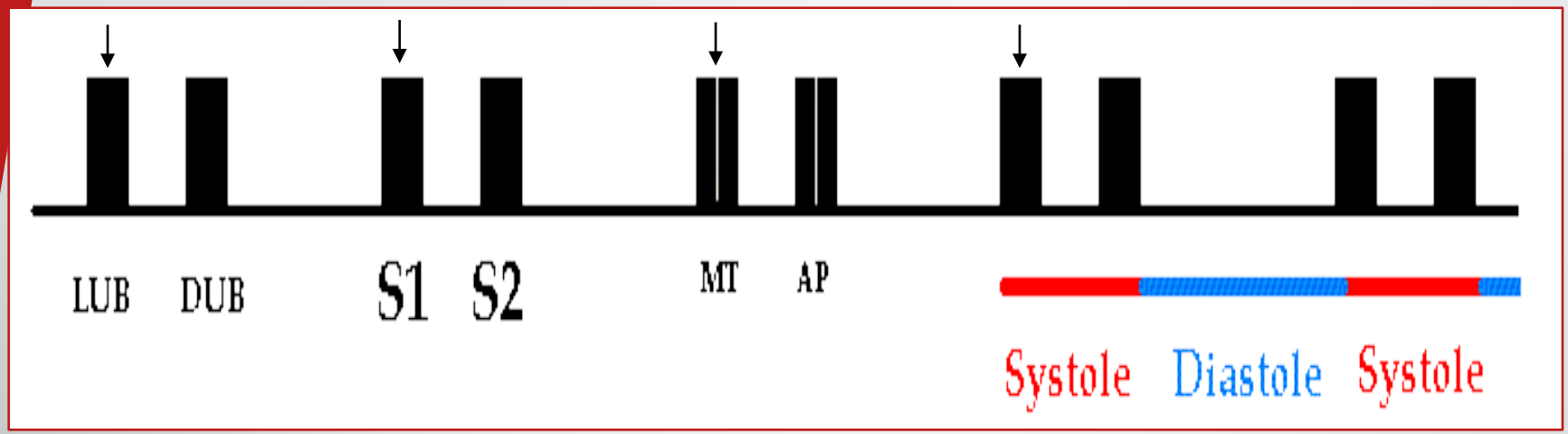


- **Pulmonary area:**
  - 2nd Lt intercostal space.
- **Aortic area:**
  - 2nd Rt costal cartilage.
- **Mitral area:**
  - 5nd Lt intercostal space crossing mid-clavicular line, or
  - 9 cm (2.5-3 in) from sternum.
- **Tricuspid area:**
  - lower part of sternum towards Rt side.

Normal Heart Sounds

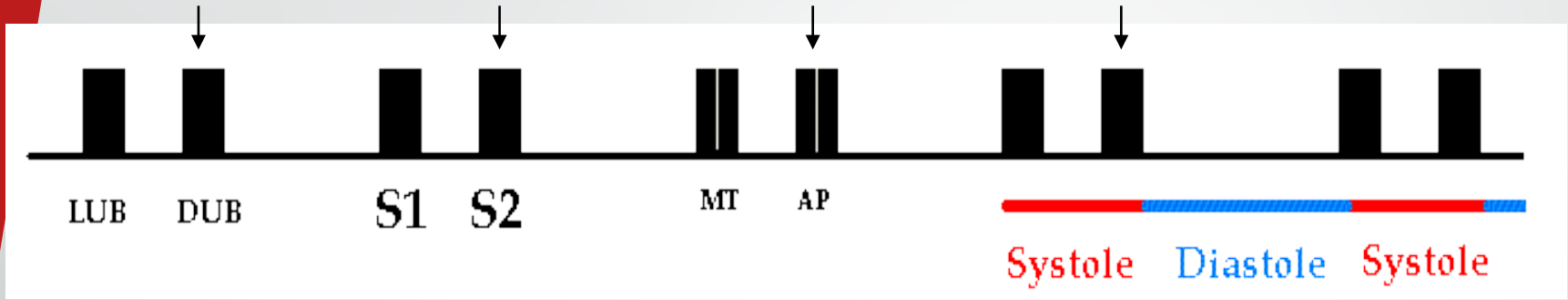


(S1)



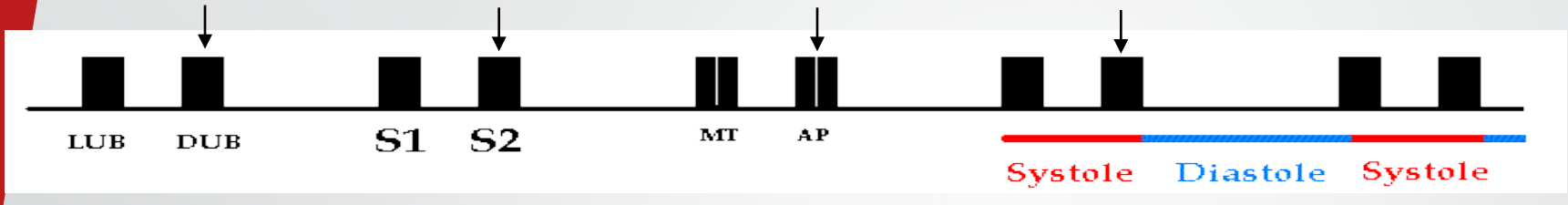
- Due to closure of the AV- vs.
- Recorded at the beginning of the the 'isovolumetric contraction phase.'
- It marks beginning of ventricular systole.
- Long in duration .. 0.15 sec.
- Of low pitch (LUB) .. Loud.
- 25-35 Hz.
- Best heard at Mitral & Tricuspid areas.

(S2)



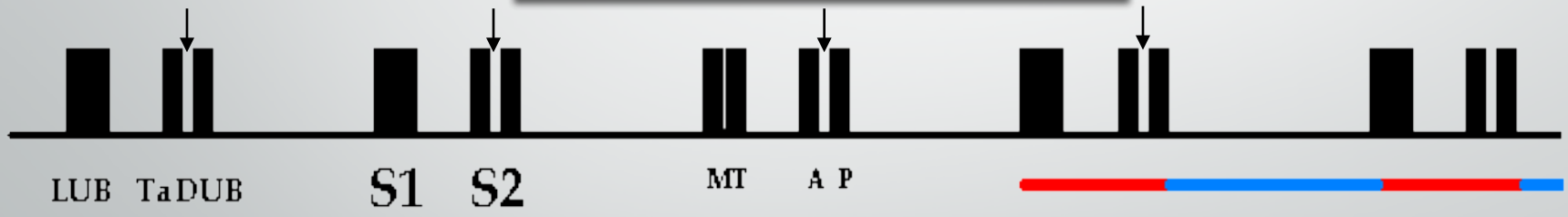
- Due to closure of semilunar- vs.
- Recorded at the beginning of the 'isovolumetric relaxation phase.'
- Marks the beginning of ventricular diastole.
- Short in duration .. 0.11-0.125 sec.
- Of high pitch (DUB) .. Soft & Sharp.
- 50 Hz.
- Best heard at Aortic & Pulmonary areas.

(S2)

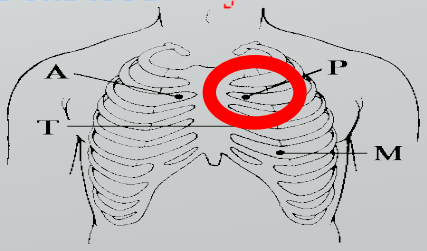


- S2 splits physiologically into 2 sounds during inspiration
  = Physiological Splitting.

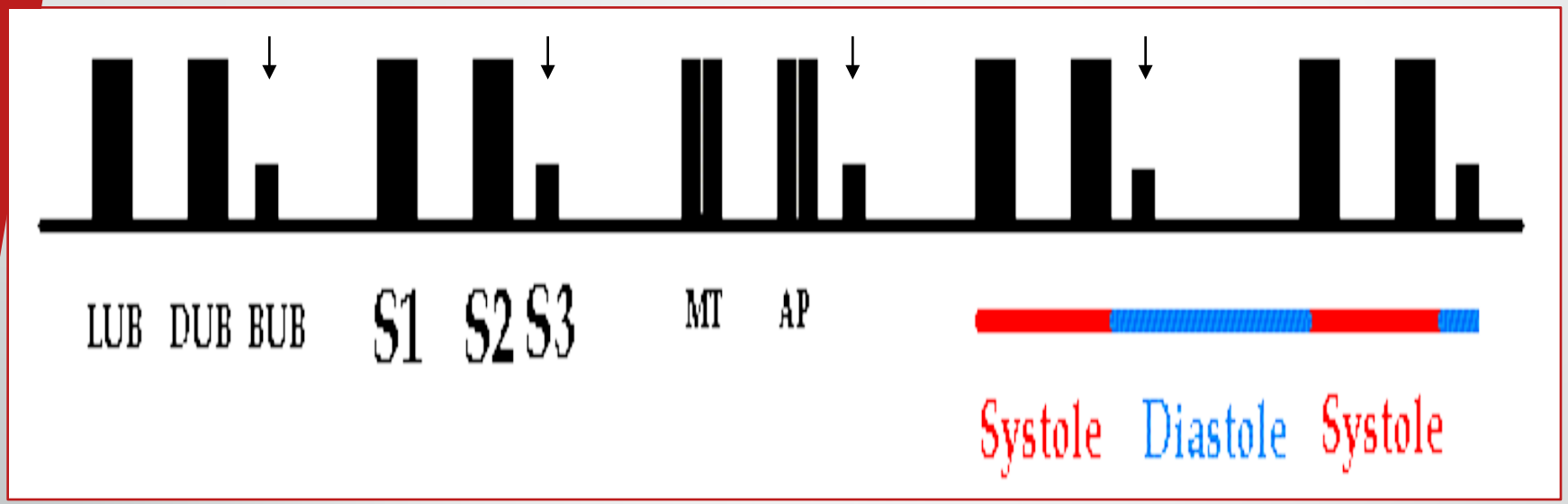
Physiological splitting during INSPIRATION



- This splitting occurs due to delay closure of pulmonary valve.

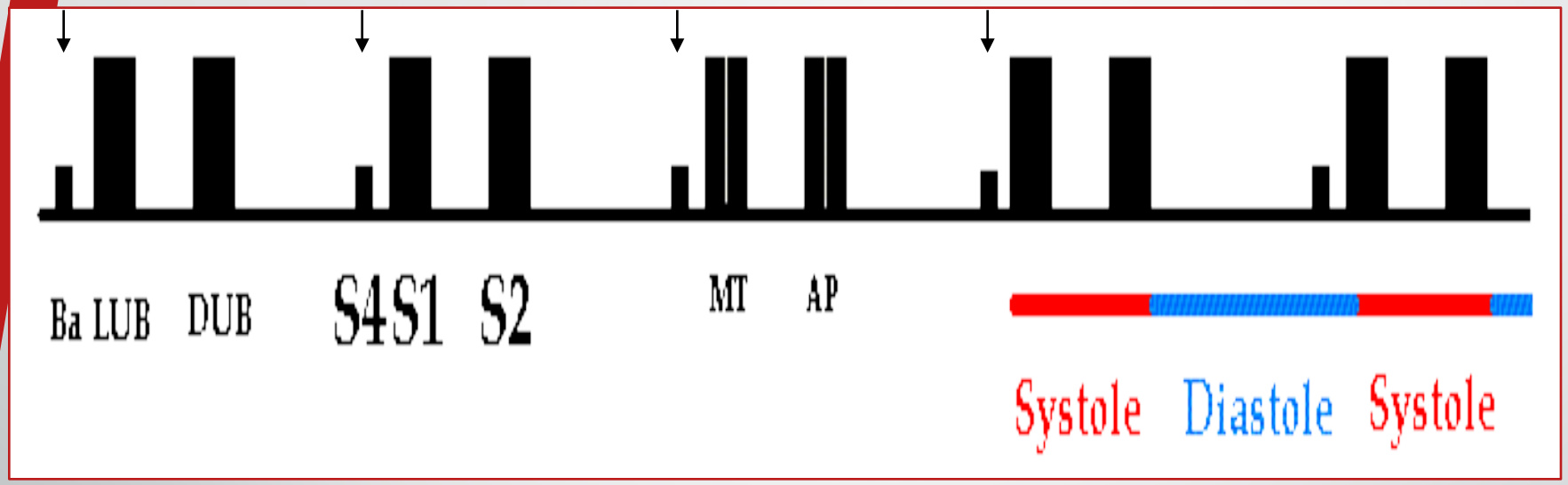


(S3)

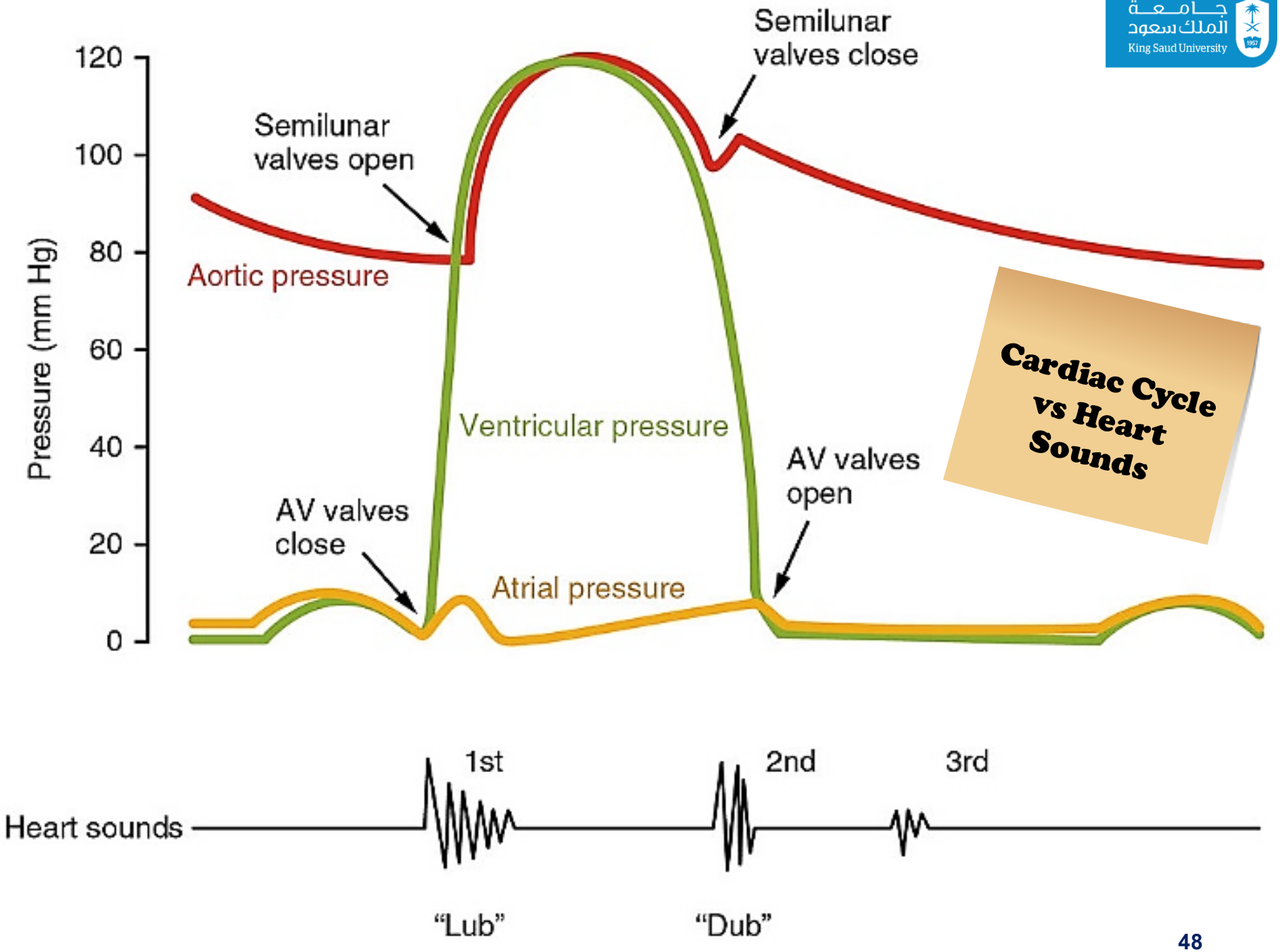


- Recorded during the 'rapid filling phase' due to rush of blood into the ventricle.
- S3 is usually not audible (very low pitch.)
- 0.05 sec.
- ? heard in children.
- Best heard at Mitral area.

(S4)



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


Semilunar valves close
Semilunar valves open
120
100
80
60
40
20
0
Pressure (mm Hg)
Aortic pressure
Ventricular pressure
AV valves close
AV valves open
Atrial pressure
Cardiac Cycle vs Heart Sounds
1st
2nd
3rd
Heart sounds
"Lub"
"Dub"


Thank You