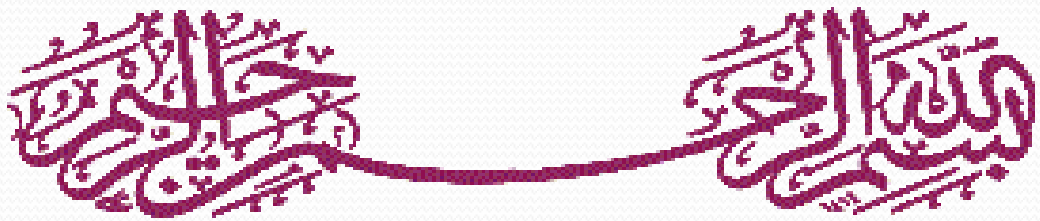


# السلام عليكم ورحمة الله وبركاته

# Cardiovascular System Block

# Cardiac Cycle- 1&2

# (Physiology)


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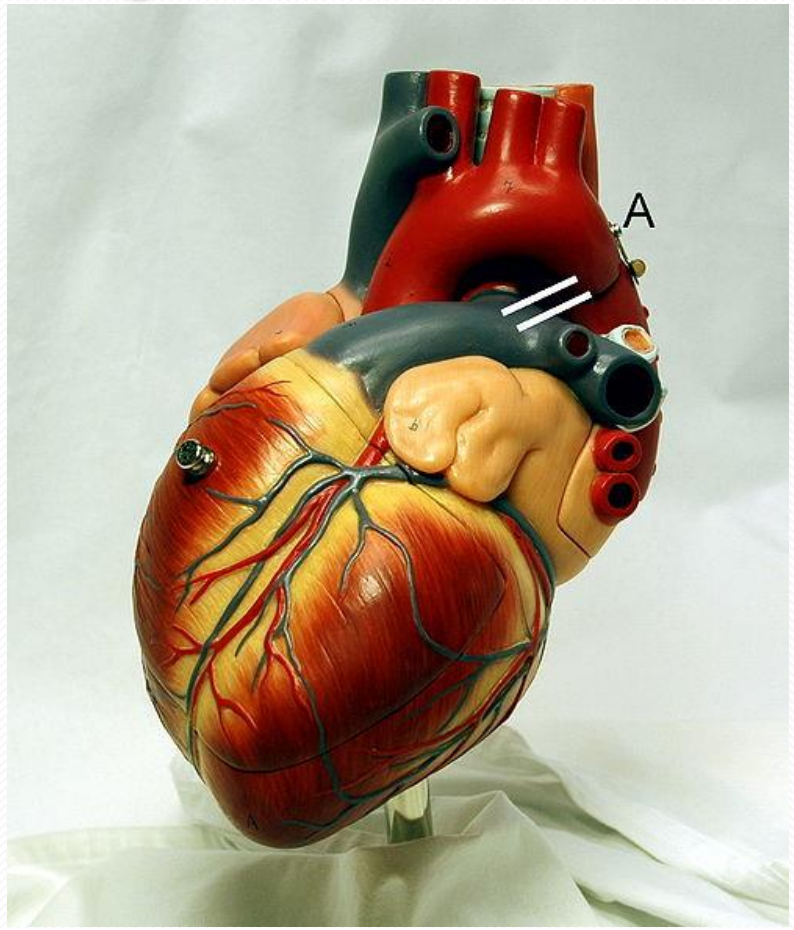


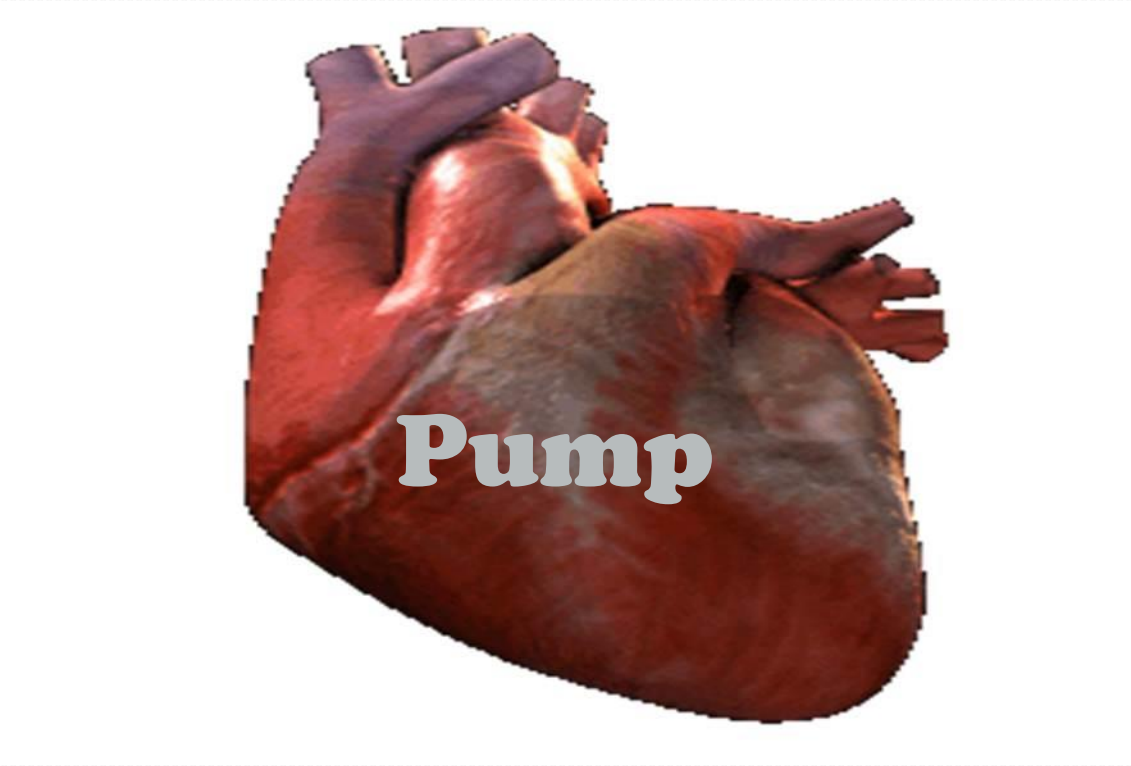
# Learning Objectives

1. Main Function of the Heart
2. Cardiac Cycle Time
3. Phases of the Cardiac Cycle
4. Ventricular Volume during Cardiac cycle

# Learning Objectives

5. Pressure Changes During Cardiac Cycle
6. Heart Sounds During Cardiac Cycle
7. Electrical Changes During Cardiac Cycle
8. Ventricular Volume-Pressure Diagram

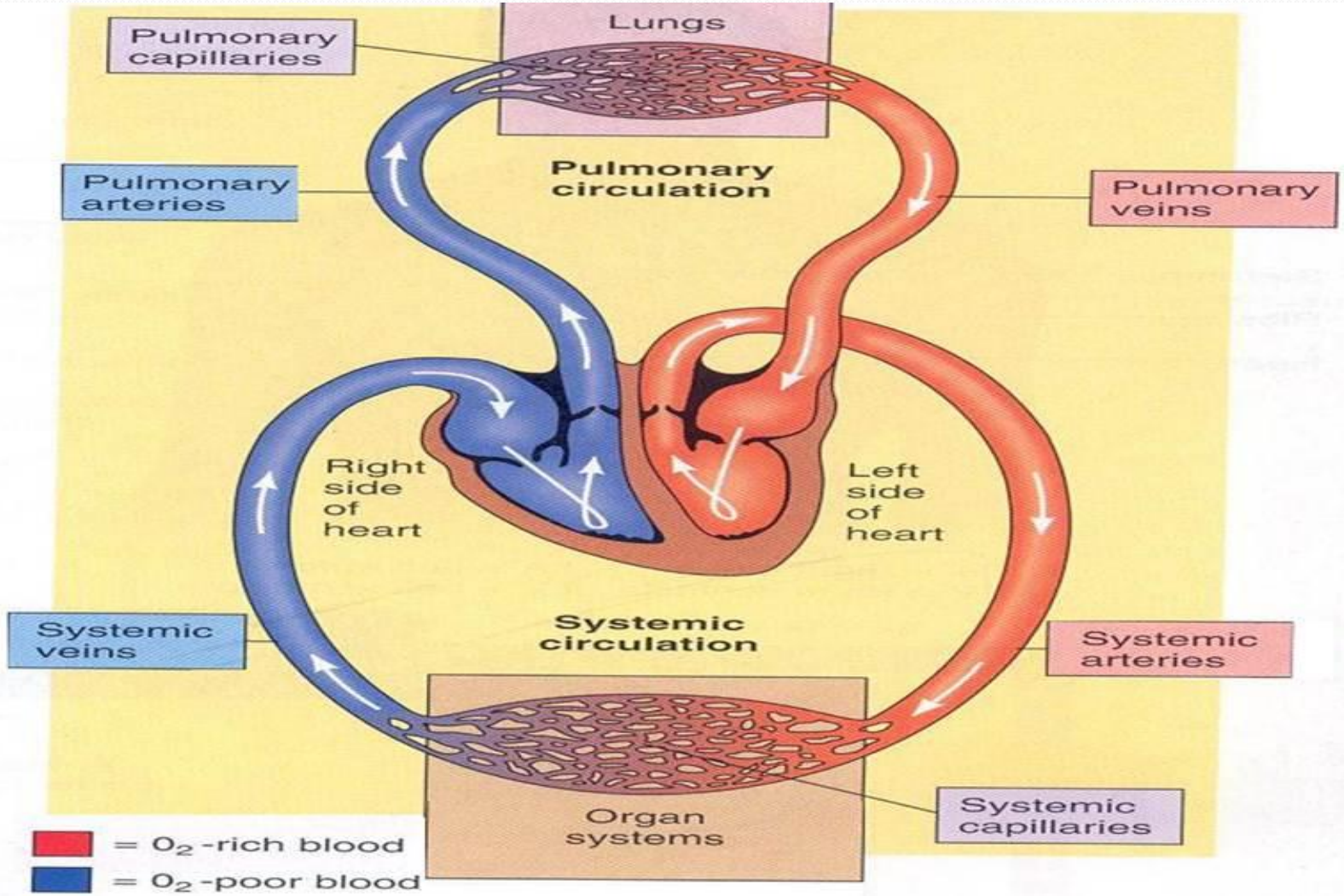
# Function of the Heart



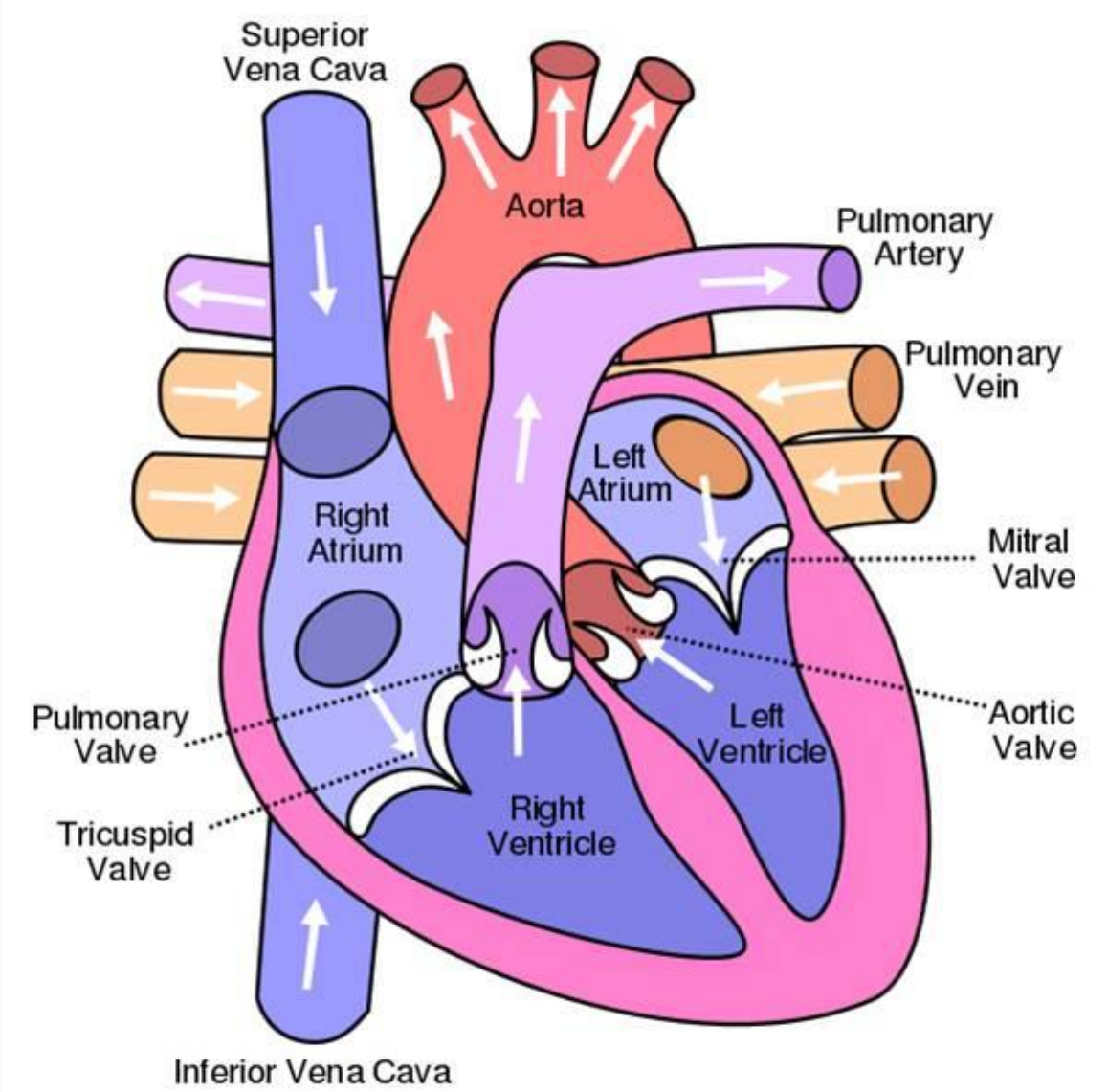
# The Heart is a double pump

Heart is a double pump (right & left) that work together.

**Systemic & Pulmonary circulation work together**



# Intracardiac Blood circulation



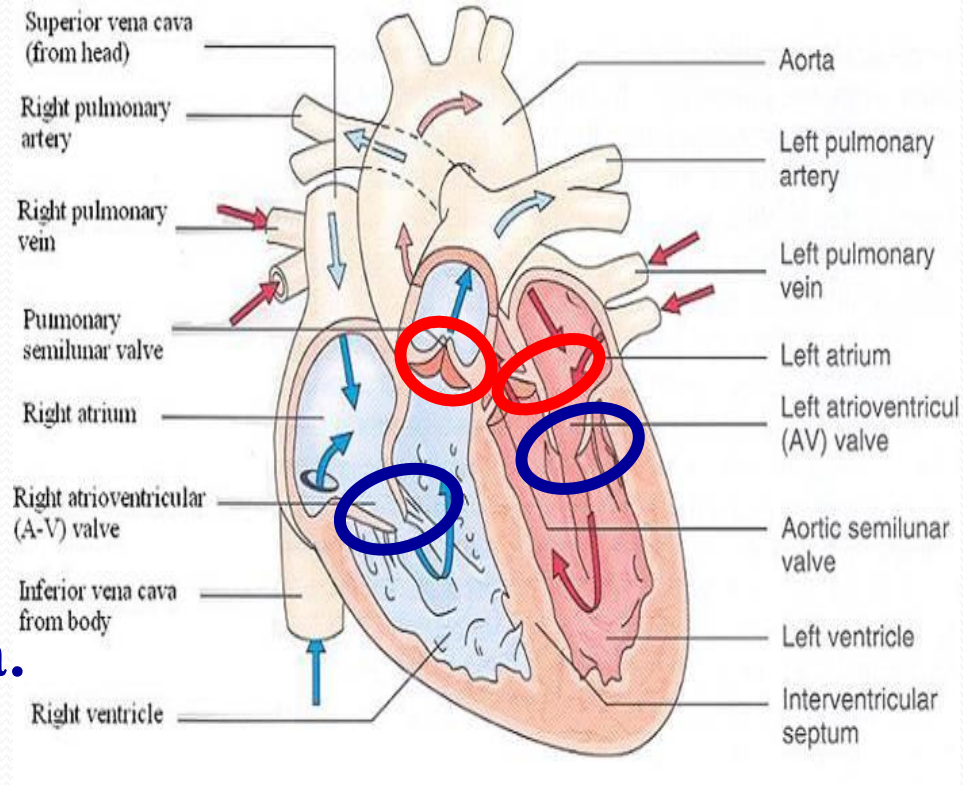
# Valves of the heart

## *Atrioventricular Valves:*

1. Tricuspid valve: between right atrium & right ventricle.
2. Mitral valve: between left atrium & left ventricle.

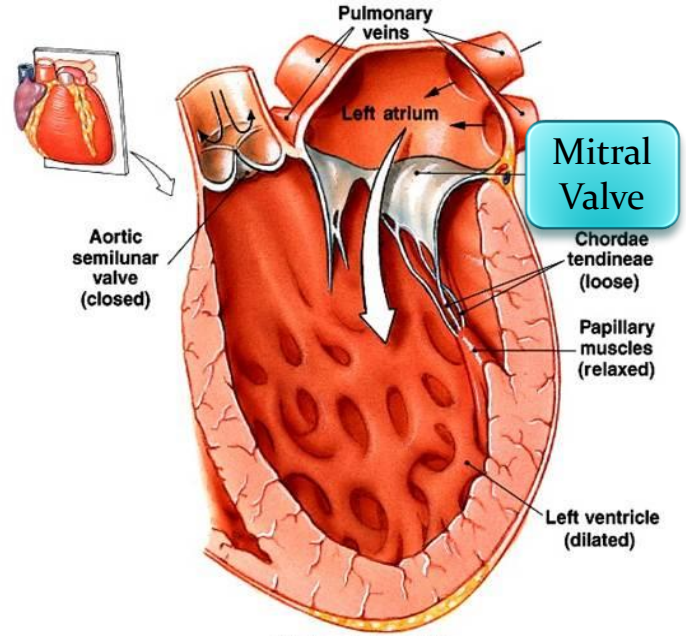
## *Semilunar Valves:*

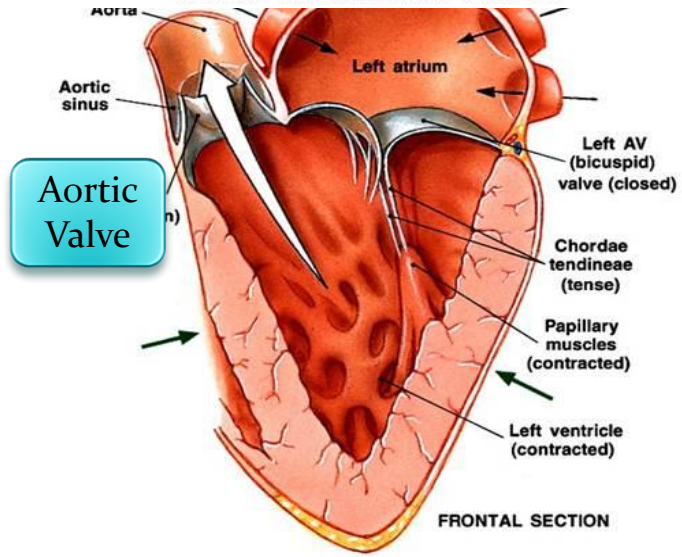
1. Pulmonary valve: between right ventricle & pulmonary artery.
2. Aortic valve: between left ventricle & aorta.

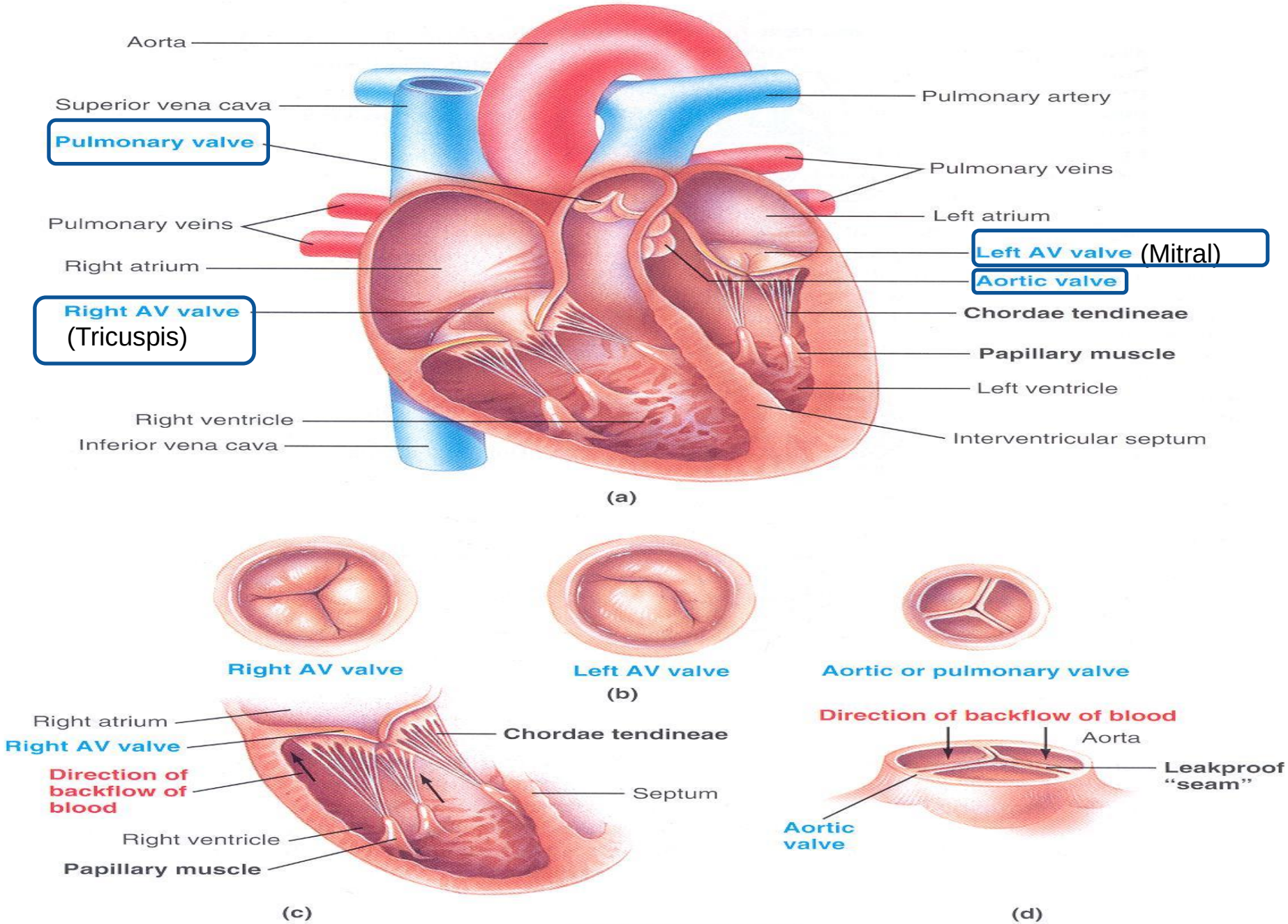


# Functions of the Valves

- Valves allow blood to flow in only <u>ONE</u> direction.
- Opening & closure of valves occur as a result of pressure gradient across the valve.
- When A-V valves open, semilunar valves close & vice versa.
- A-V cusps are held by chordae tendinea to muscular projections called “Papillary muscles”.



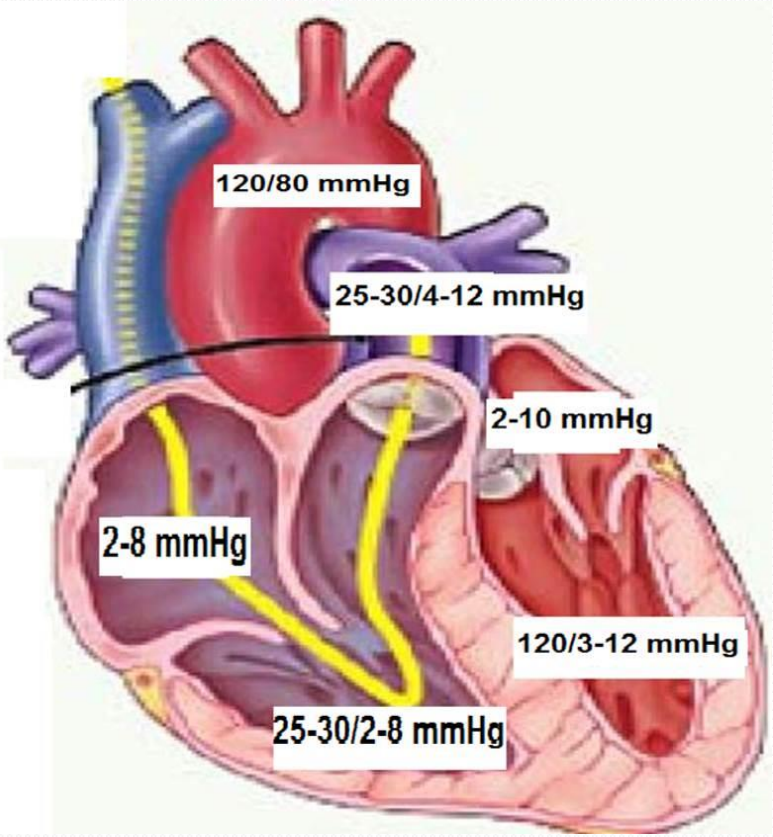






Heart valves

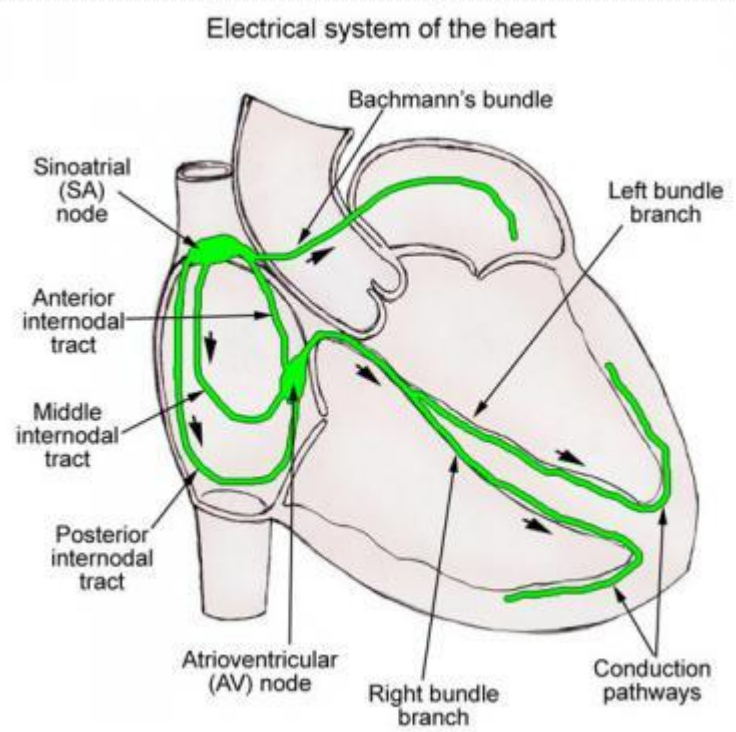
# General Principles

- Contraction of the heart generates pressure changes & results in orderly 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.
- Atrial & ventricular systole do not occur at same time, but their relaxation occurs at same time during diastole of whole heart which lasts for 0.4 sec.



# The Cardiac Cycle

- Sequence of events that take place in the heart during each beat (from the beginning of one heart beat to beginning of the next one).
- Each cycle is initiated by depolarization of S-A node, followed by contraction of the atria.
- The signal is transmitted to ventricles through A-V node & A-V bundle to cause ventricular contraction.



# Cardiac cycle Time

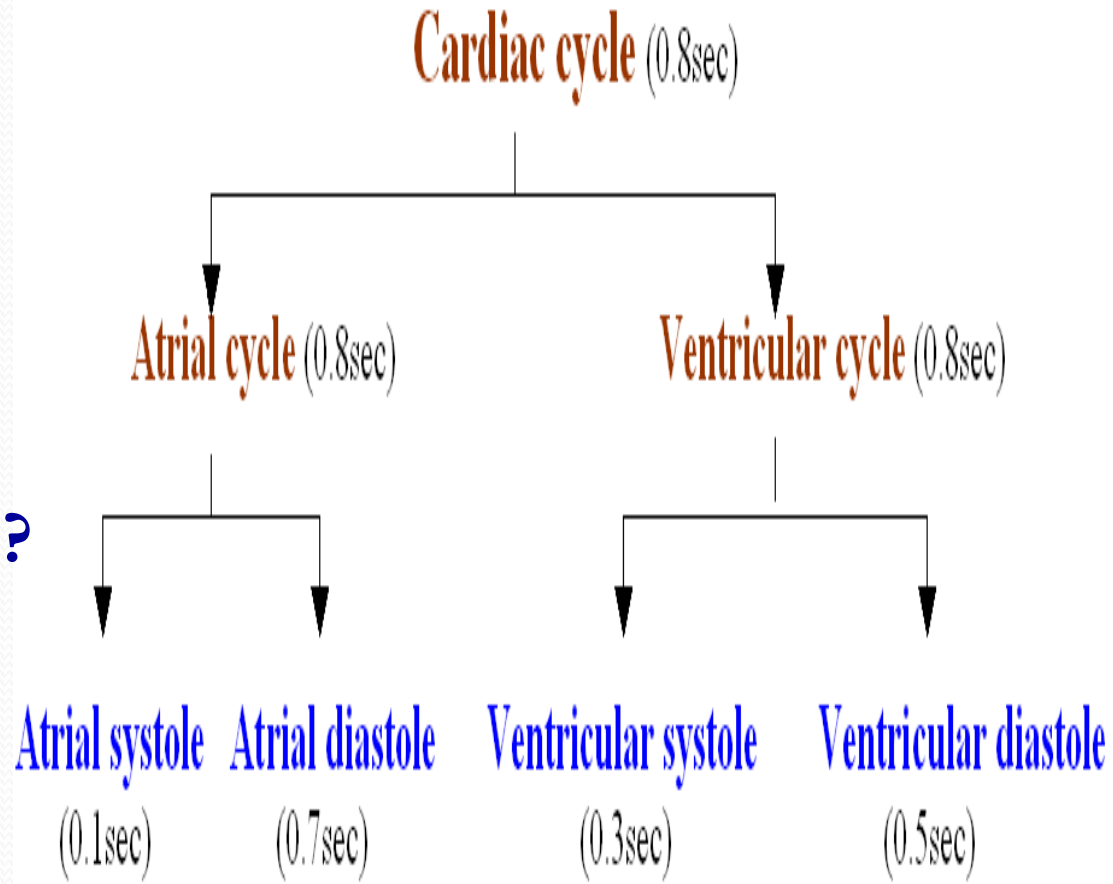
- This is time required for one complete cardiac cycle.
- When heart rate (HR) is 75 beats/min, the time will be 0.8 Sec

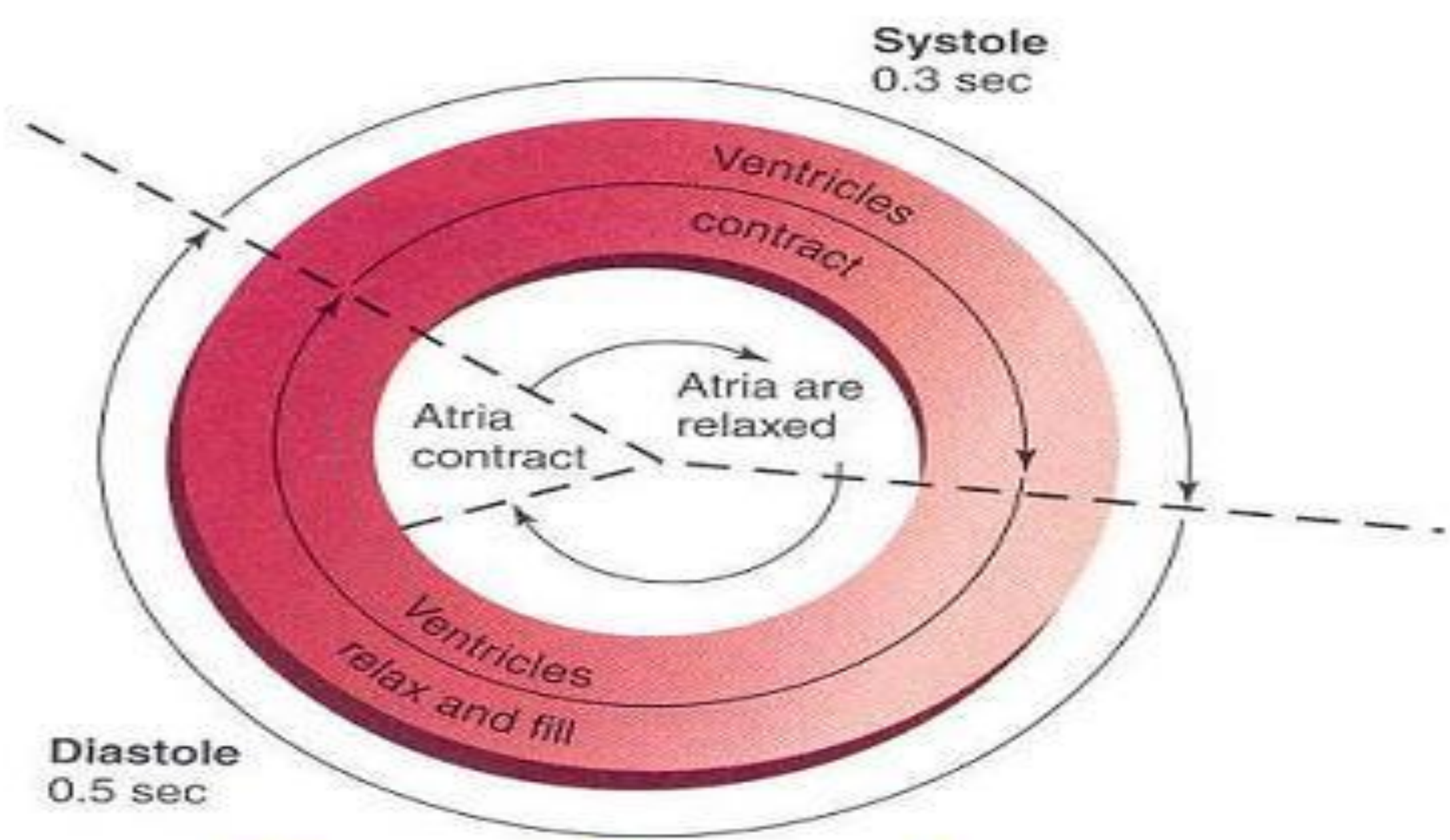
Cardiac cycle time= 60/HR = 60/75= 0.8 Sec.

- The time is inversely proportional to HR.
- Cardiac cycle starts by systole of both atria (0.1 sec), then systole of both ventricles (0.3 sec), then diastole of whole heart (0.4 sec).

# Cardiac Cycle Duration

- Cardiac cycle duration = 0.8 sec (when HR 75 beats/min).
  - Ventricular systole = 0.3 sec
  - Ventricular diastole = 0.5 sec
  - Atrial systole = 0.1 sec
  - Atrial diastole = 0.7 sec
- Normally, diastole is longer > systole
- Importance of long ventricular diastole?
  - Coronary blood flow
  - Ventricular filling



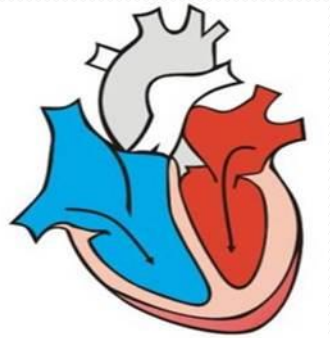



# The cardiac cycle

# Definitions

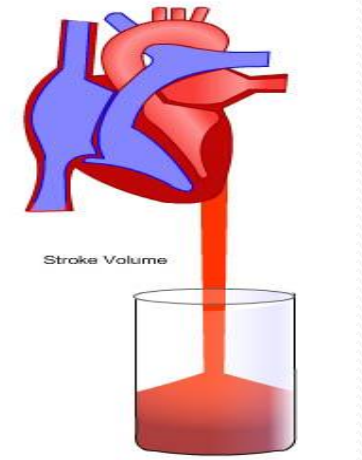
- **End-diastolic volume (EDV):**

  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.**

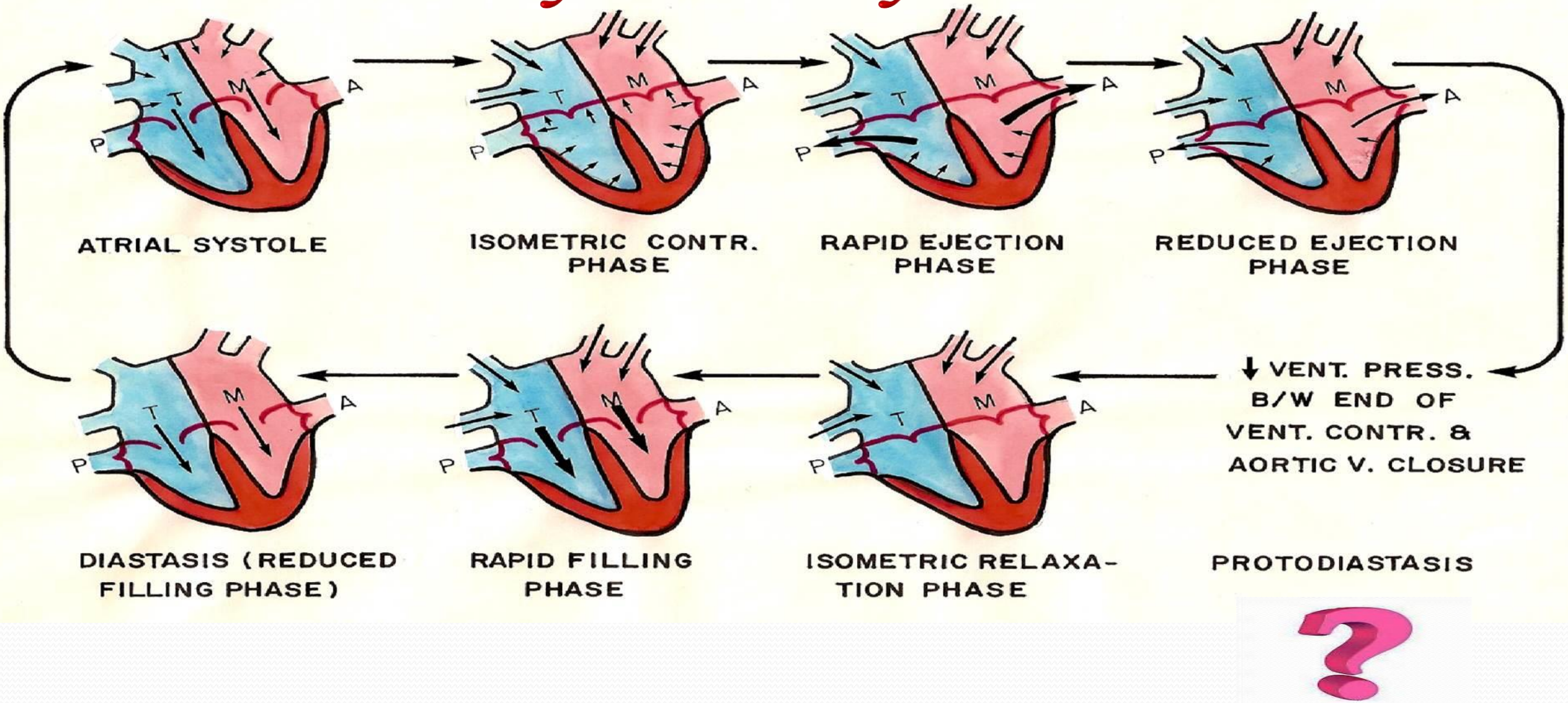
- **Ejection fraction (EF):**

  Fraction of end-diastolic volume that is ejected = **60-65 %.**

# *Phases of cardiac cycle*

- Atrial systole (0.1 sec.)
- Ventricular systole (0.3 sec.)
  - Isovolumic (isovolumetric) contraction phase (0.05 sec.)
  - Maximum ejection phase (0.15 sec.)
  - Reduced ejection phase (0.1 sec)
- Ventricular diastole (0.4)
  - Protodiastolic phase (0.04 sec.).....????
  - Isovolumic (isovolumetric) relaxation phase (0.06 sec.)
  - Rapid filling phase (0.1 sec.)
  - Reduced filling phase (0.2 sec.)

# Phases of Cardiac Cycle: 7 Phases

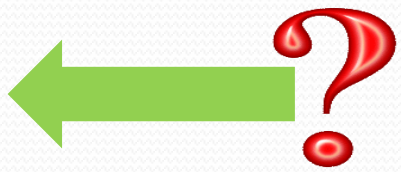





**N.B. ? Considered ‘8’ phases if including 1st phase of diastole**

# *Events in the cardiac Cycle*

1. Mechanical events



2. Ventricular Volume Changes
3. Pressure Changes
4. Heart Sounds
5. Electrical Events (ECG)

# 1- Atrial Systole:

- It is a phase of atrial contraction, lasts for ≈ 0.1 sec.
- It is preceded by atrial depolarization.
- Valves: A-V valves open (semilunar valves closed). blood goes from atria to ventricles.
- Ventricular volume: ↑ due to blood passage into ventricle. It reaches the end diastolic volume (EDV) 130 ml.
- Ventricular pressure: First slightly ↑ due to entry of blood from atria. Then ↓ due to dilatation of ventricles. In both cases, it is less than atrial P.
- Atrial pressure: First ↑ due to systole of atria. Then ↓ due to blood passage into ventricles.
- $4^{th}$ Heart sound heard.

# 2- Isovolumetric Contraction Phase:

- It occurs at beginning of ventricular systole. It lasts for ≈ 0.04 sec.
- Starts with closure of A-V valves.
- 1st Heart sound heard.
- Semilunar valves: Still closed.
- Ventricle is a closed chamber. It contracts with no changes in volume (isometrically, no shortening)
- Volume in ventricle = EDV
- Ventricular pressure ↑ suddenly
- Aortic valve opens at the end of this phase, when LV exceeds 80mmHg.
- Atrial pressure: ↑ due to doming of cusps of closed A-V valves into atria.

# 3- Maximum (Rapid) Ejection Phase:

- The ventricles contract isotonically (with shortening) pushing most of ventricular blood (75% of stroke volume) into aorta & pulmonary artery.
- Duration: 0.15 sec.
- Semilunar valves open at beginning of this phase when LV pressure exceeds 80 mmHg.
- AV valves: Still closed.
- Ventricular pressure reaches 120 mmHg in left V .
- Ventricular volume: ↓ sharply due to shortening of ventricular wall and ejection of blood.
- Atrial pressure: First ↓ because when ventricles contract, they pull fibrous AV ring with AV valves downward thus ↓ atrial P.

# 4- Reduced Ejection Phase:

- The ventricles contract with less shortening than the previous phase and less blood is ejected (end of systole).
- Almost 25% of ventricular blood is ejected, i.e. 25% of stroke volume.
- Duration: 0.1 sec.
- AV valves: Still closed.
- Semilunar valves: Still opened.
- Atrial pressure: Still ↑ gradually due to accumulation of venous blood.
- Ventricular volume: Continue ↓ gradually till it reaches the end systolic volume (60 ml).
- Ventricular pressure: ↓ gradually, as volume of blood leaving ventricles > the decrease in ventricular volume.

# 5- Isovolumetric Relaxation Phase:

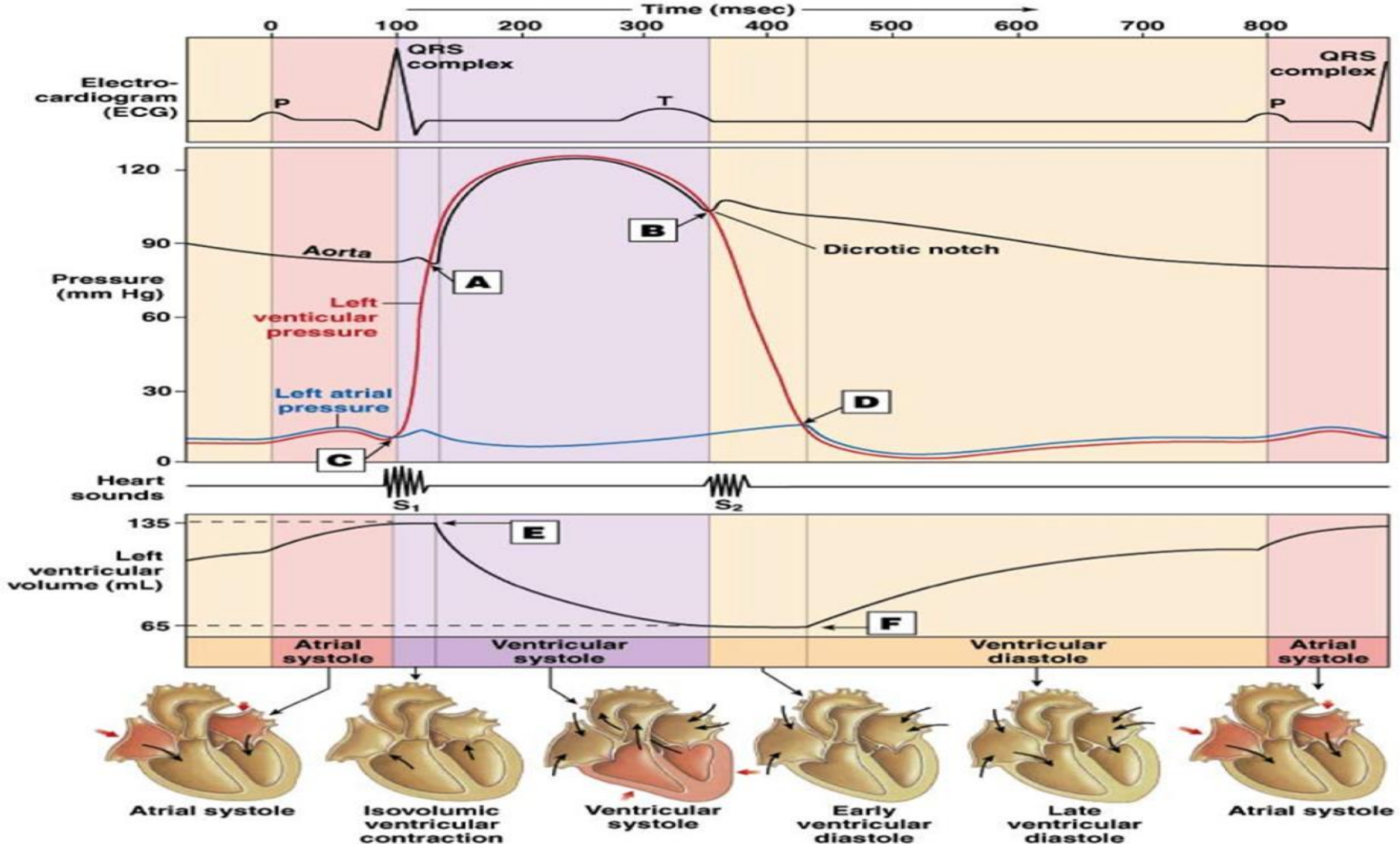
- At the beginning of diastole, the ventricles relax without changing their volume. It lasts for ≈ 0.04 sec.
- Ventricular volume is constant at the ESV (60 ml).
- Semilunar valves: close at the beginning of the phase.
- 2nd Heart sound is heard.
- A-V valves: Still closed.
- Ventricular pressure: ↓ rapidly, because the valves are closed & the relaxation is isometric.
- Atrial pressure: Still ↑ gradually due to accumulation of venous blood.

# 6- Rapid Filling Phase:

- Atrial pressure > ventricular pressure. A-V valves open.
- ≈ 60-70% of blood passes passively to the ventricles along pressure gradient.
- Duration ≈ 0.1 sec.
- 3rd Heart sound heard due to rush of blood into ventricles and vibration in ventricular wall.
- Semilunar valves: Still closed.
- Atrial pressure: First sudden ↓ due to rush of blood from atria to ventricles. Then gradually ↑ due to entry of venous blood.
- Ventricular volume: ↑ because it is being filled with blood.
- Ventricular pressure: Slightly ↑ but < atrial pressure

# 7- Reduced Filling Phase (Diastasis):

- Remaining atrial blood flows slowly into ventricles by pressure gradient.
- Duration ≈ 0.2 sec.
- A-V valves still open.
- Semilunar valves: Still closed.
- Atrial pressure: Still ↑ gradually due to continuous venous return.
- Ventricular volume: Still ↑ due to entry of blood into ventricles.
- Ventricular pressure: Slightly ↑ gradually because the increase in volume is less than the entering blood.


Time (msec)
0
100
200
300
400
500
600
700
800
Electro-cardiogram (ECG)
QRS complex
P
T
QRS complex
P
120
90
Pressure (mm Hg)
60
30
0
Aorta
Left venticular pressure
Left atrial pressure
A
B
C
D
Dicrotic notch
Heart sounds
S1
S2
135
Left ventricular volume (mL)
65
E
F
Atrial systole
Ventricular systole
Ventricular diastole
Atrial systole
Atrial systole
Isovolumic ventricular contraction
Ventricular systole
Early ventricular diastole
Late ventricular diastole
Atrial systole

# *Events in the cardiac Cycle*

1. Mechanical events
2. Ventricular volume changes
3. Pressure Changes
4. Heart Sounds
5. Electrical Events (ECG)

# Ventricular Volume Changes

| Phases | Ventricular Volume |
|---|---|
| 1- Atrial systole | ↑ |
| 2- Isometric contraction | Constant |
| 3- Rapid Ejection | ↓ rapidly |
| 4- Reduced Ejection | ↓ slowly |
| ? Protodiastolic | Constant |
| 5- Isometric Relaxation | Constant |
| 6- Rapid Filling | ↑ rapidly |
| 7- Reduced Filling | ↑ slowly |

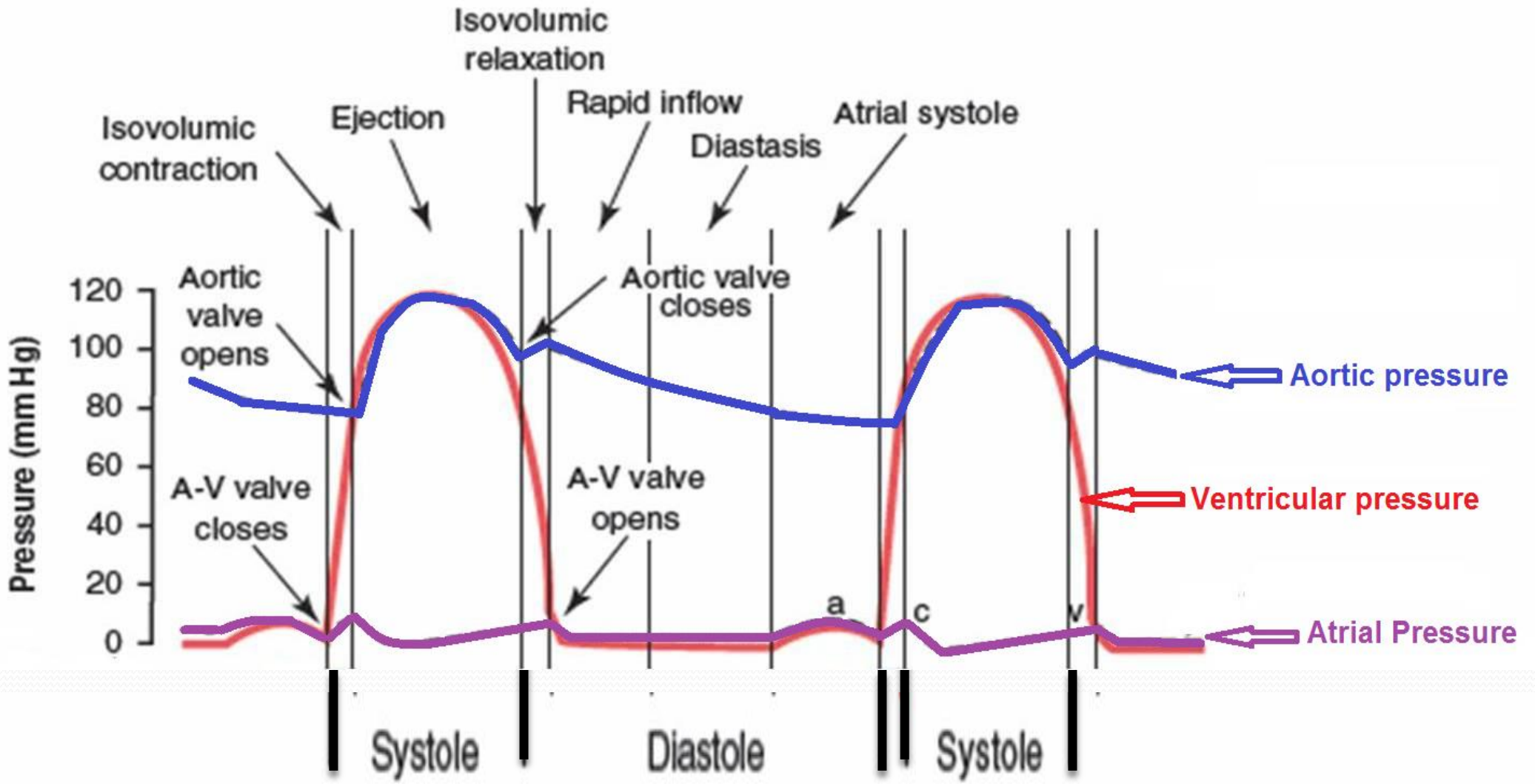
# *Events in the cardiac Cycle*

1. Mechanical events
2. Ventricular Volume Changes
3. Pressure Changes
4. Heart Sounds
5. **Electrical Events (ECG)**

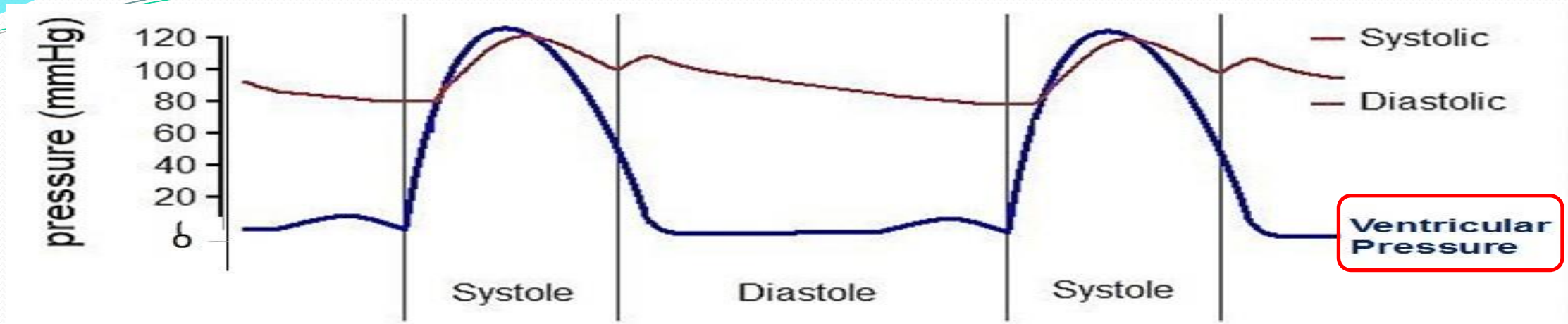
# Recorded Pressure Changes During Cardiac Cycle

- Ventricular pressure
- Aortic pressure
  - Arterial pressure waves
- Atrial pressure
  - Jugular venous pressure

# Left Ventricular Pressure Changes … 120/3-12 mmHg



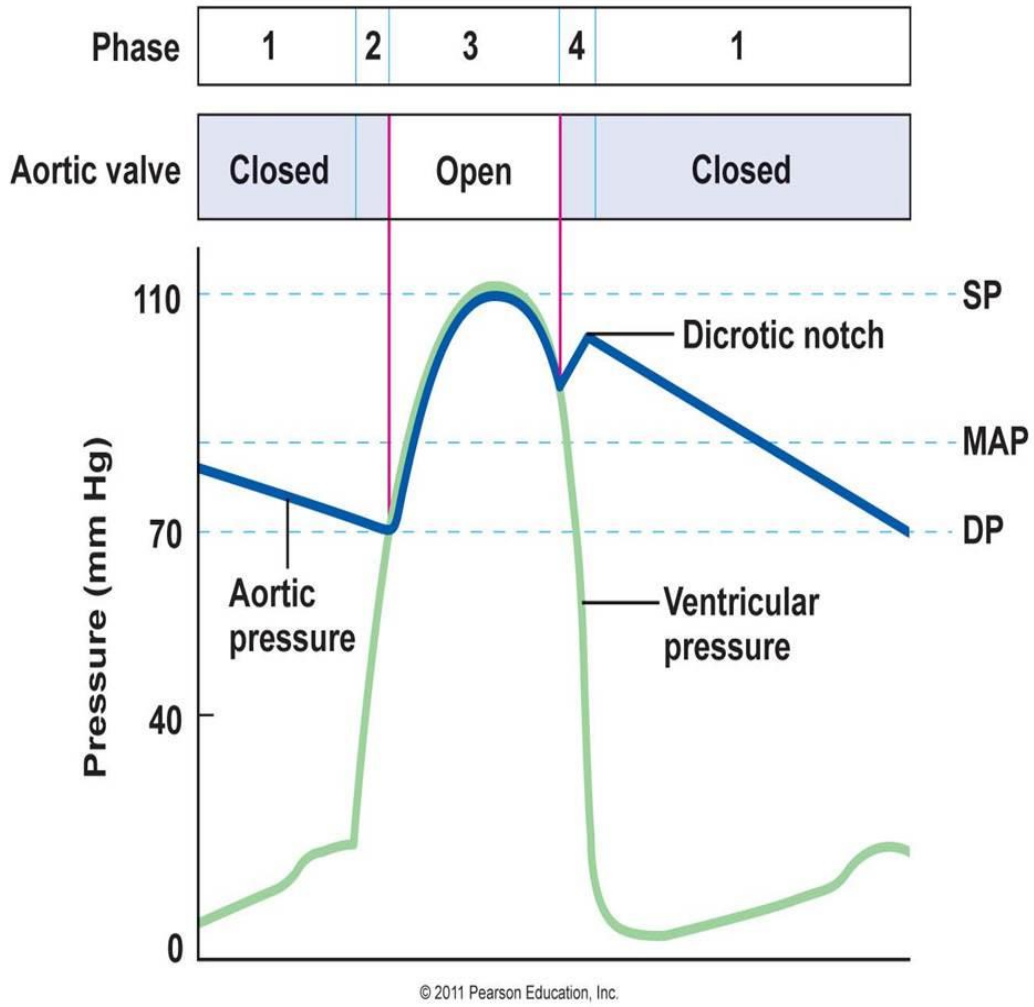
# Left Ventricular Pressure Changes During Cardiac Cycle




| Phases | Ventricular Pressure | Cause |
|---|---|---|
| 1- Atrial systole | First slightly ↑<br>Then ↓ | Entry of blood from atria<br>Dilatation of ventricles |
| 2- Isovolumetric contraction | ↑ suddenly (80 mmHg ) | All the valves are closed & the contraction is isovolumetric |
| 3- Rapid Ejection | ↑ sharply (120 mmHg ) | Shortening of ventricular wall and ejection of blood |
| 4- Reduced Ejection | ↓ gradually | Volume of blood leaving ventricles > the decrease in ventricular volume. |
| 5- Isovolumetric Relaxation | ↓ rapidly | All the valves are closed & the relaxation is isovolumetric |
| 6- Rapid Filling | Slightly ↑ but < atrial pressure | Entry of blood from atria |
| 7- Reduced Filling | Slightly ↑ gradually | Entry of blood from atria |

# Aortic Pressure Changes … 120/80 mmHa

- ***Ascending or anacrotic limb:***
  - With 'rapid ejection phase'.
  - Aortic press↑ up to 120 mmHg.
- ***Descending or catacrotic limb:***
  - Passes in 4 stages.



# *Stages of the Descending / Catacrotic Limb:*

1. **↓ Aortic pressure:**
   With 'reduced ejection phase.'
   Amount of blood enters aorta **<** amount leaves.

2. **Dicrotic notch (incisura):**

   Sudden drop in aortic pressure.

   Due to closure of aortic valve.

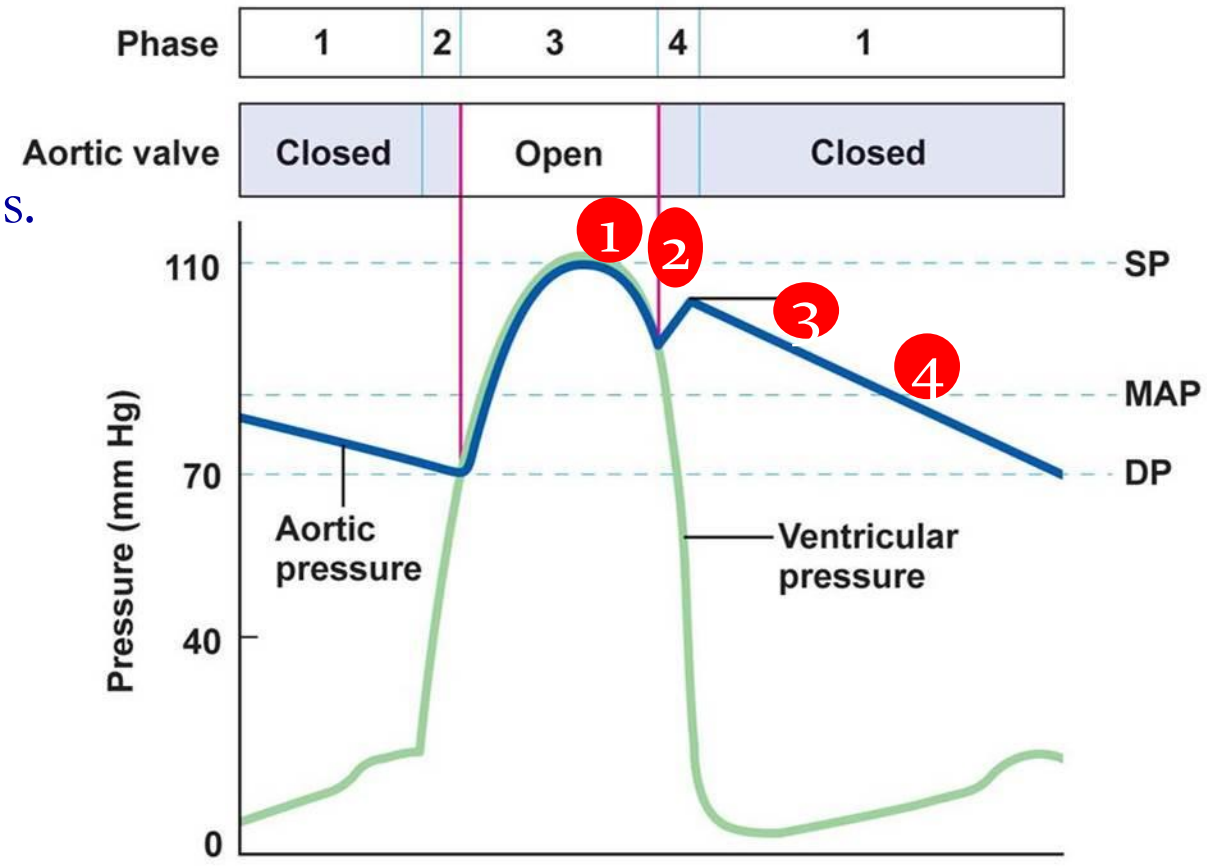
3. **Dicrotic wave:**

   Slight ↑ in aortic pressure.

   Due to elastic recoil of the aorta.

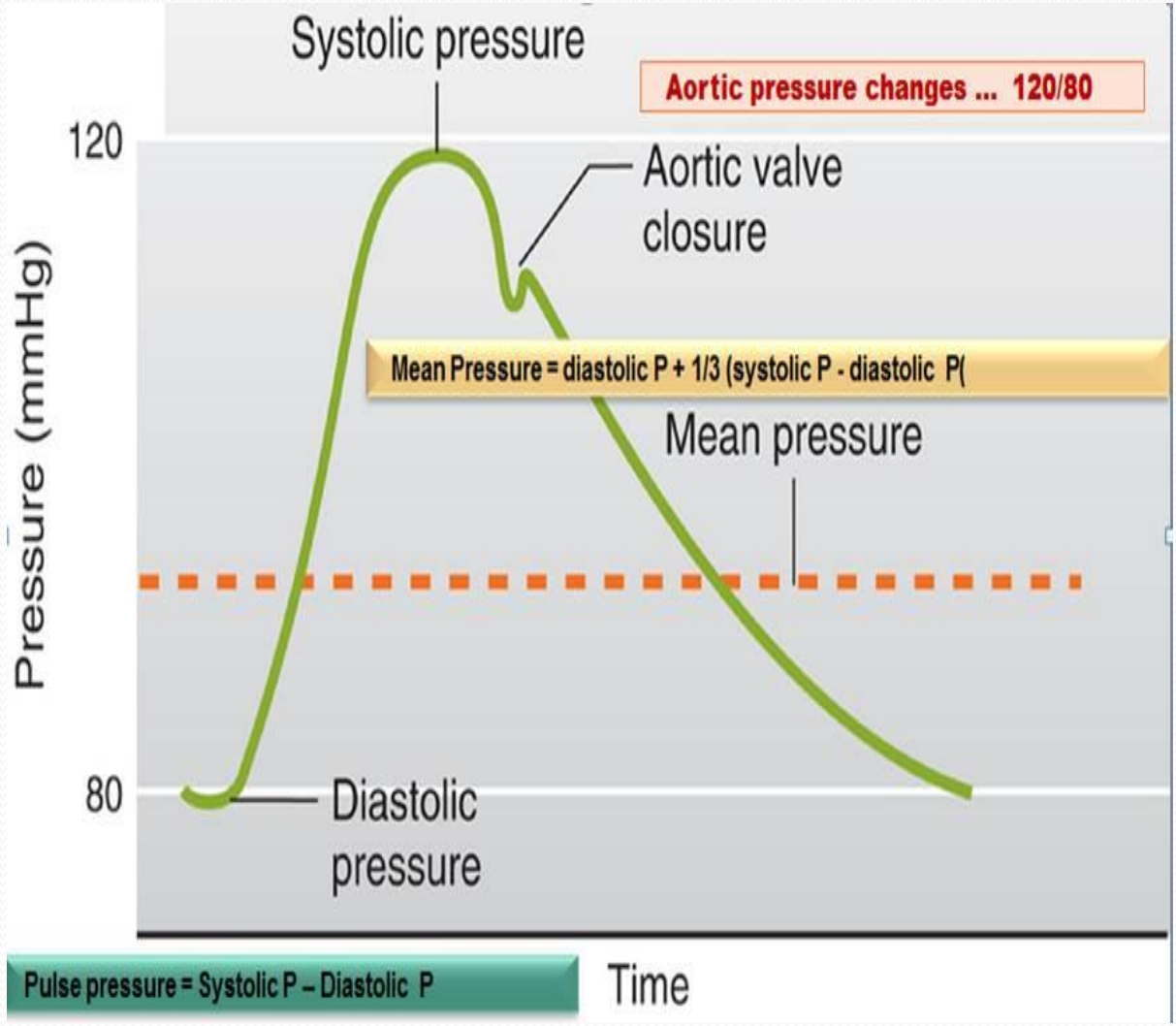
4. **Slow ↓ aortic press:** down to 80 mmHg.

   Due to continued flow of blood from aorta into systemic circulation.



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

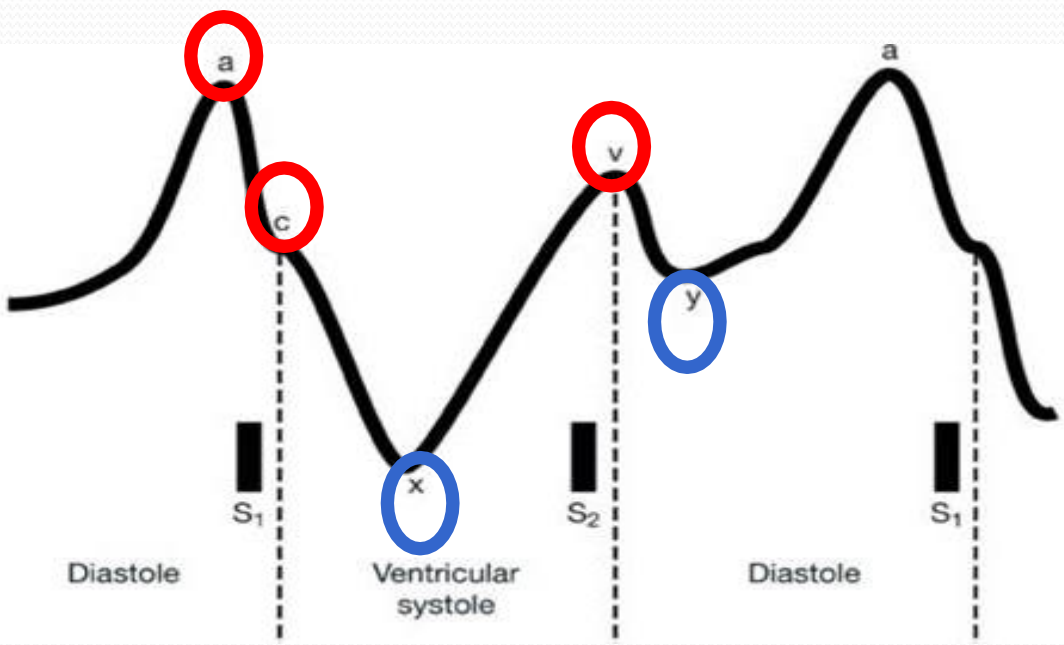
- Similar to aortic pressure waves, but sharper.
- Reflects a systolic peak pressure of 110-130 mmHg & a diastolic pressure of 70-85 mmHg.
- N.B Pulmonary artery pressure changes (25-30/4-12) mmHg are similar to aortic pressure changes, but with difference in magnitude.



# Atrial Pressure Changes:

**Results in:**

- 3 upward deflection → a, c, & v
- 2 components in each wave: +ve (↑ atrial pressure, -ve (↓ atrial pressure)
- 2 downward deflection → x & y



# *Causes of atrial pressure waves*

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

  +ve due to atrial systole

  -ve due to blood passage into ventricles.

- ***'c' wave: Ventricular systole***

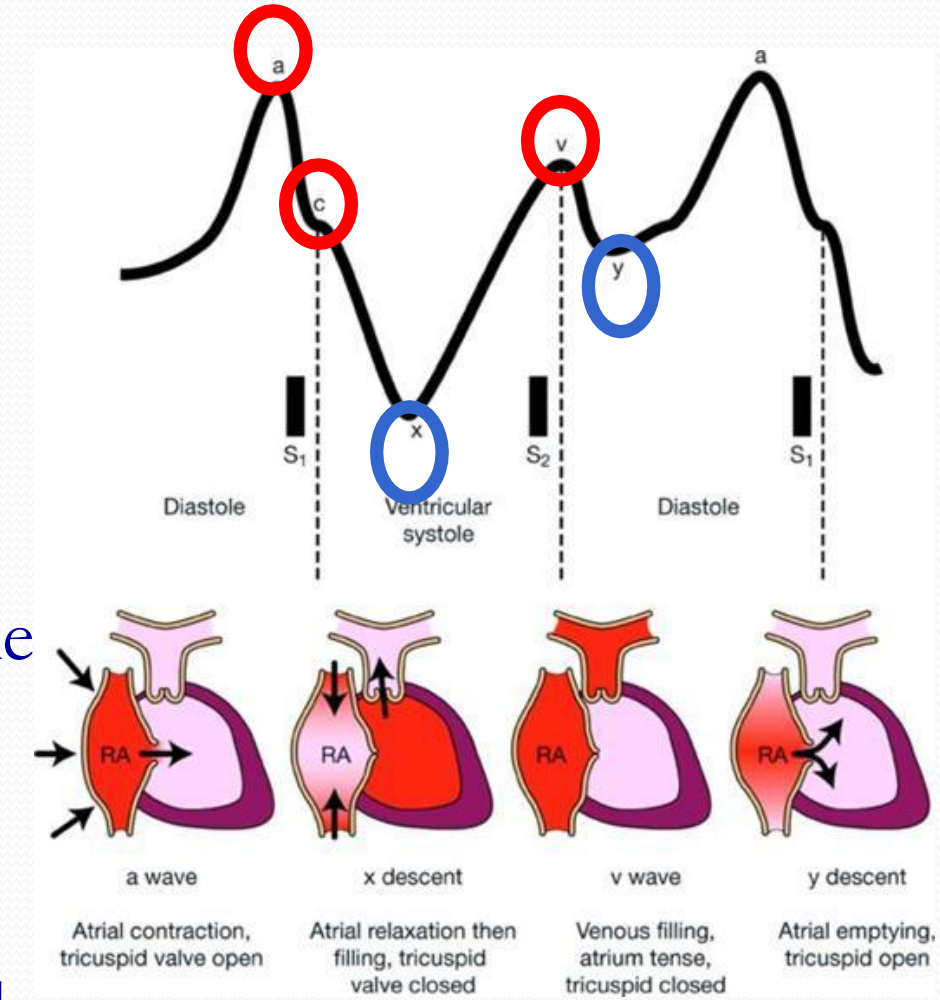
  +ve due to the bulging of A-V valves into the atria during 'isovolumetric contraction phase.'

  -ve due to the pulling down of the atrial muscle & A-V cusps during 'rapid ejection phase', resulting in ↓ atrial pressure.

- ***'v' wave:***

  +ve due to ↑ venous return during atrial diastole.

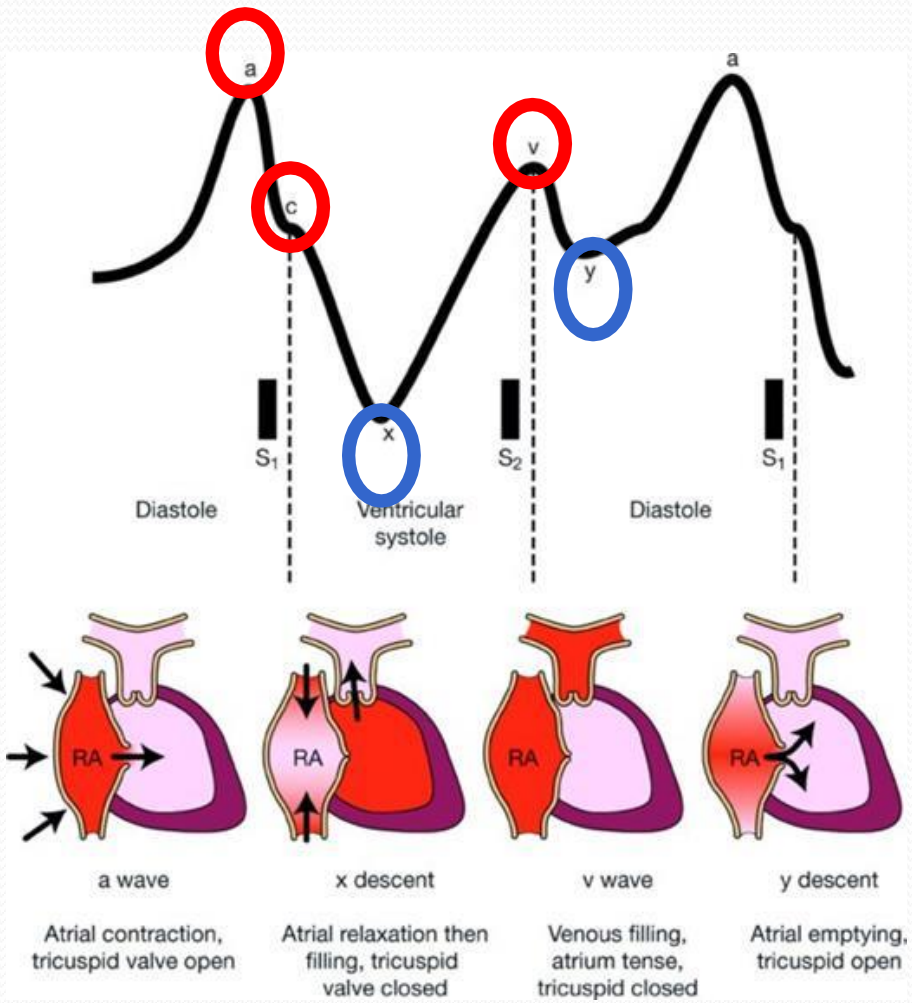
  -ve due to entry of blood into ventricles during 'rapid filling phase.'



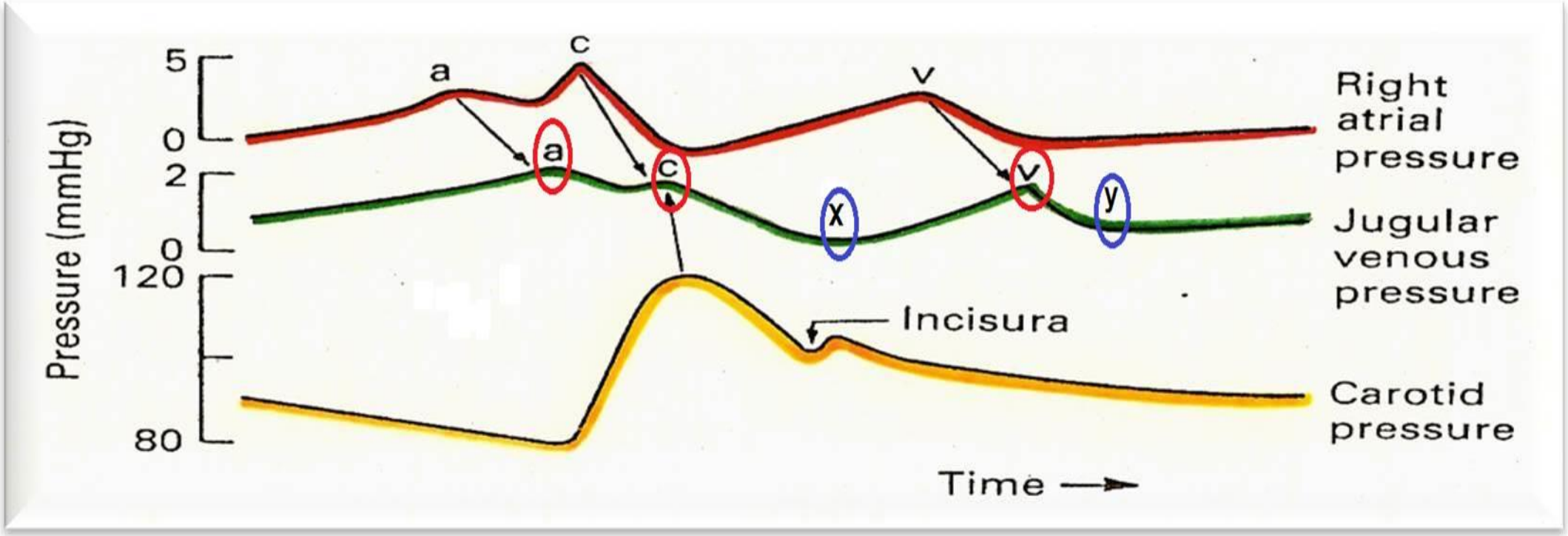
# *Causes of atrial pressure waves…..Cont.*

- ***'x' descent:***
  **Downward displacement of A-V valves during 'reduced ejection phase.'**

- ***'y' descent:***
  **↓↓ atrial pressure due to entry of blood into ventricles 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***

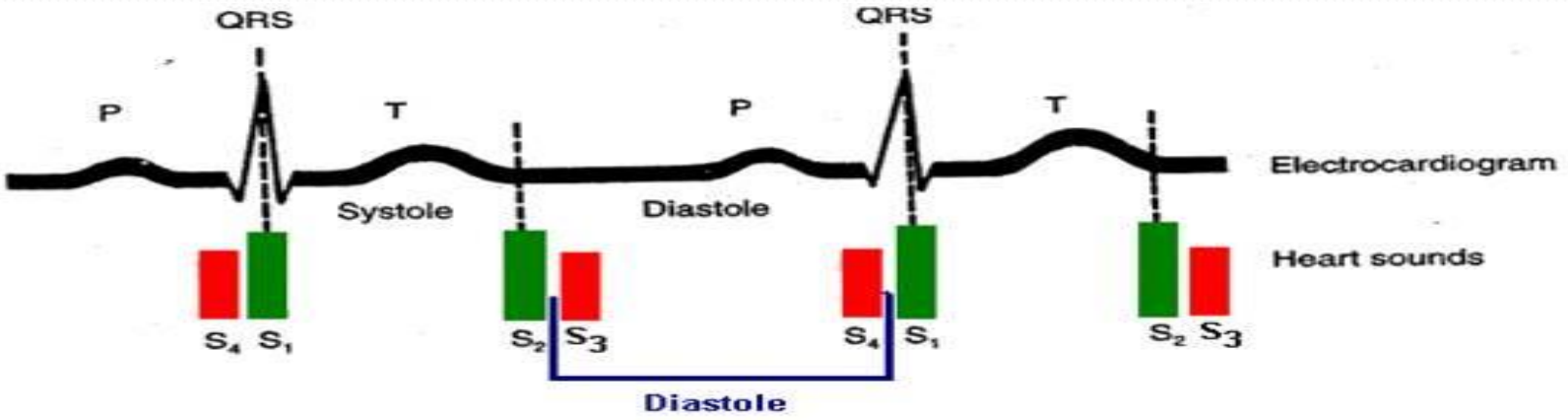
# *Events in the cardiac Cycle*

1. Mechanical events
2. Volume changes
3. Pressure Changes
4. Heart Sounds
5. Electrical Events (ECG)

# *Heart Sounds*

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

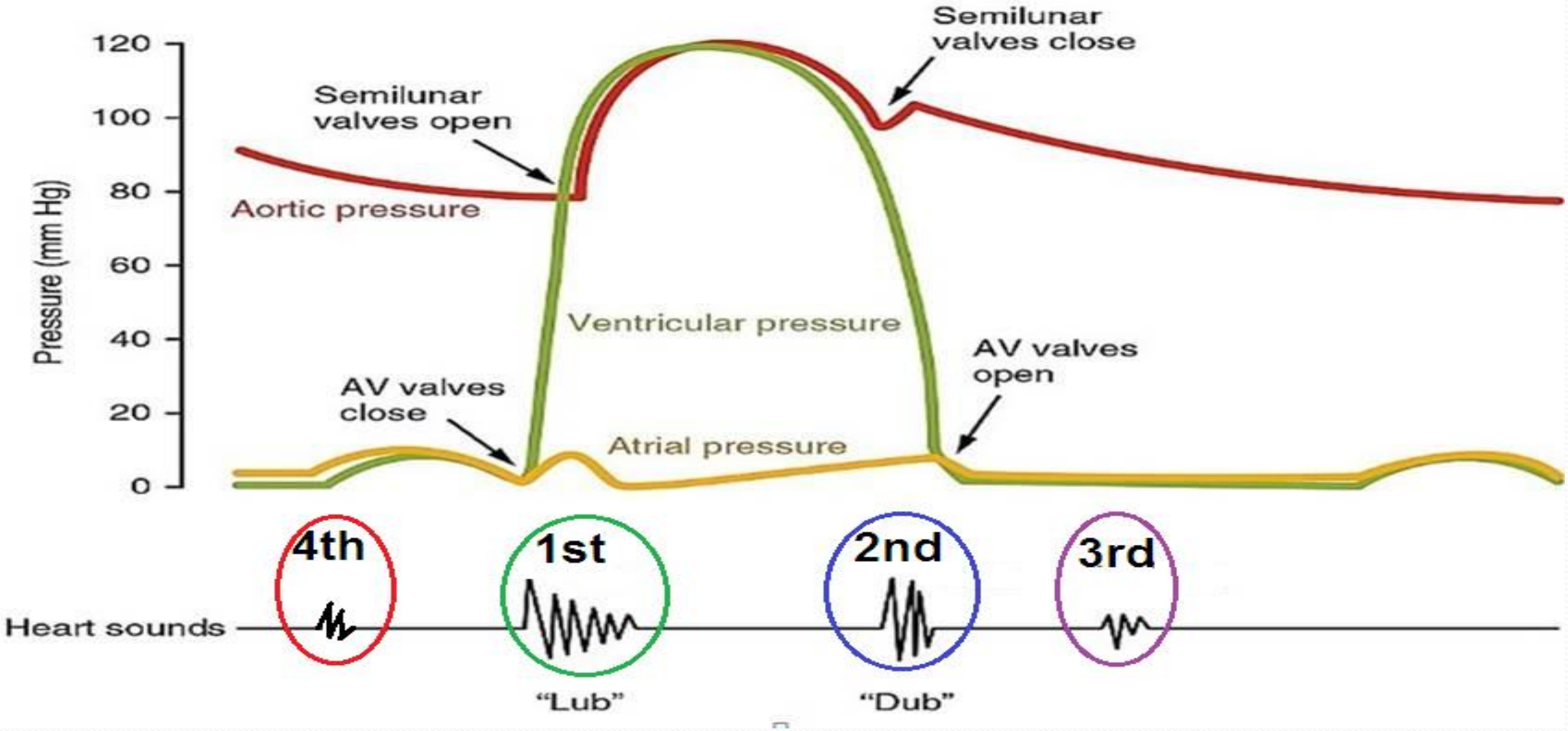
- Four heart sounds can be detected:
  - 1st & 2nd heart sounds … (usually audible)
  - 3rd & 4th heart sounds … (of low pitch, usually not audible)
- Important for diagnosis of valvular heart diseases (murmurs)



# Heart Sounds during Cardiac cycle

| Phase | Heart Sound | Causes of the Sound |
|---|---|---|
| 1- Atrial systole | 4th heart sound | 1- Contraction of atria<br>2- Blood rush from atria to ventricles. |
| 2-Isovolumetric contraction | 1st heart sound | 1- Sudden closure of A-V valves<br>2- Vibration of chordae tendinae of papillary muscles. |
| 3-Maximum Ejection | 1st heart sound continues | 1- Contraction of ventricles.<br>2- Vibration of walls of aorta & pulmonary artery. |
| 4-Reduced ejection | No sound | |
| 5-Isovolumetric relaxation | 2nd heart sound | Sudden closure of semilunar valves |
| 6-Rapid filling | 3rd heart sound | Rush of blood into ventricles and vibration in ventricular wall |
| 7-Reduced filling | No sound | |

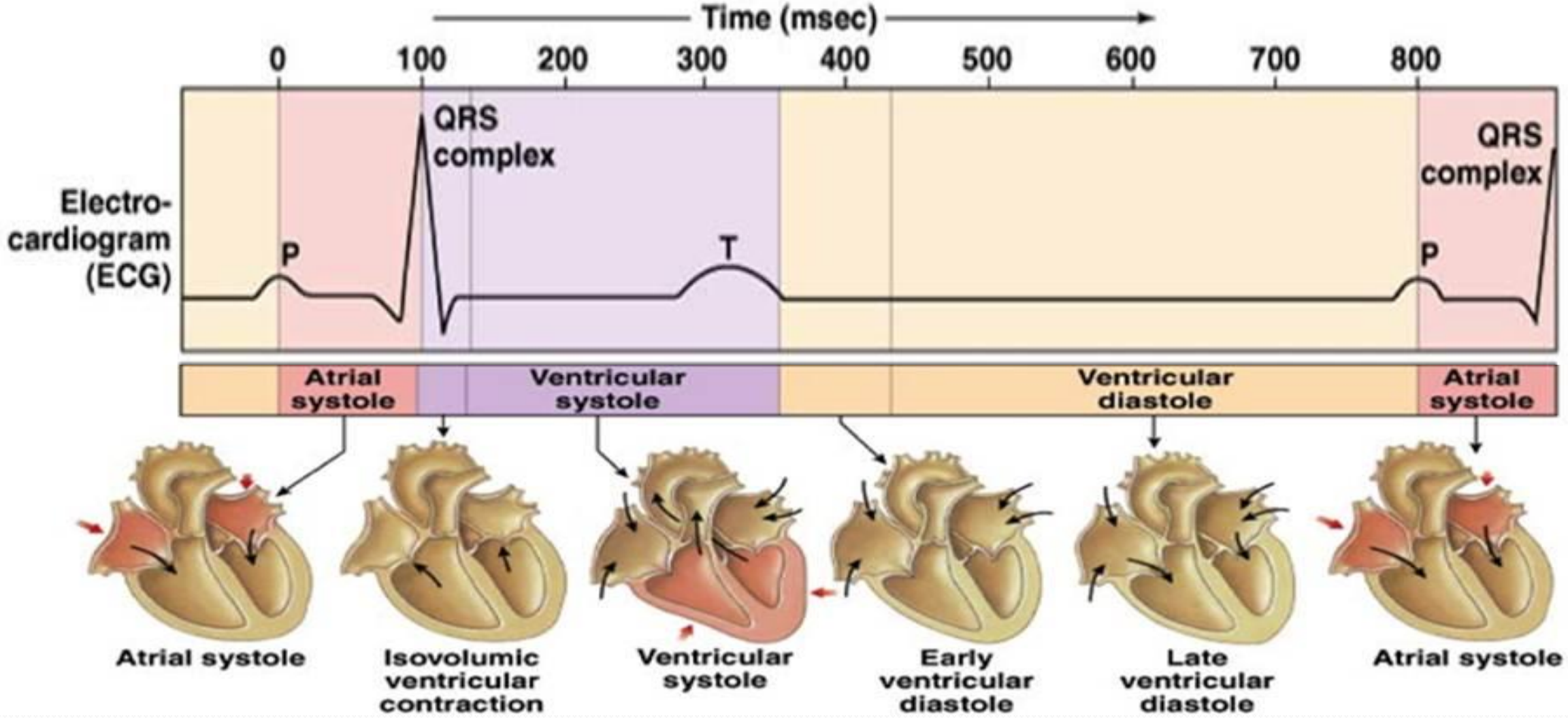
# Cardiac Cycle VS Heart Sounds



# *Events in the cardiac Cycle*

1. Mechanical events
2. Volume changes
3. Pressure Changes
4. Heart Sounds
5. **Electrical Events (ECG)**

# ECG changes during the Cardiac cycle



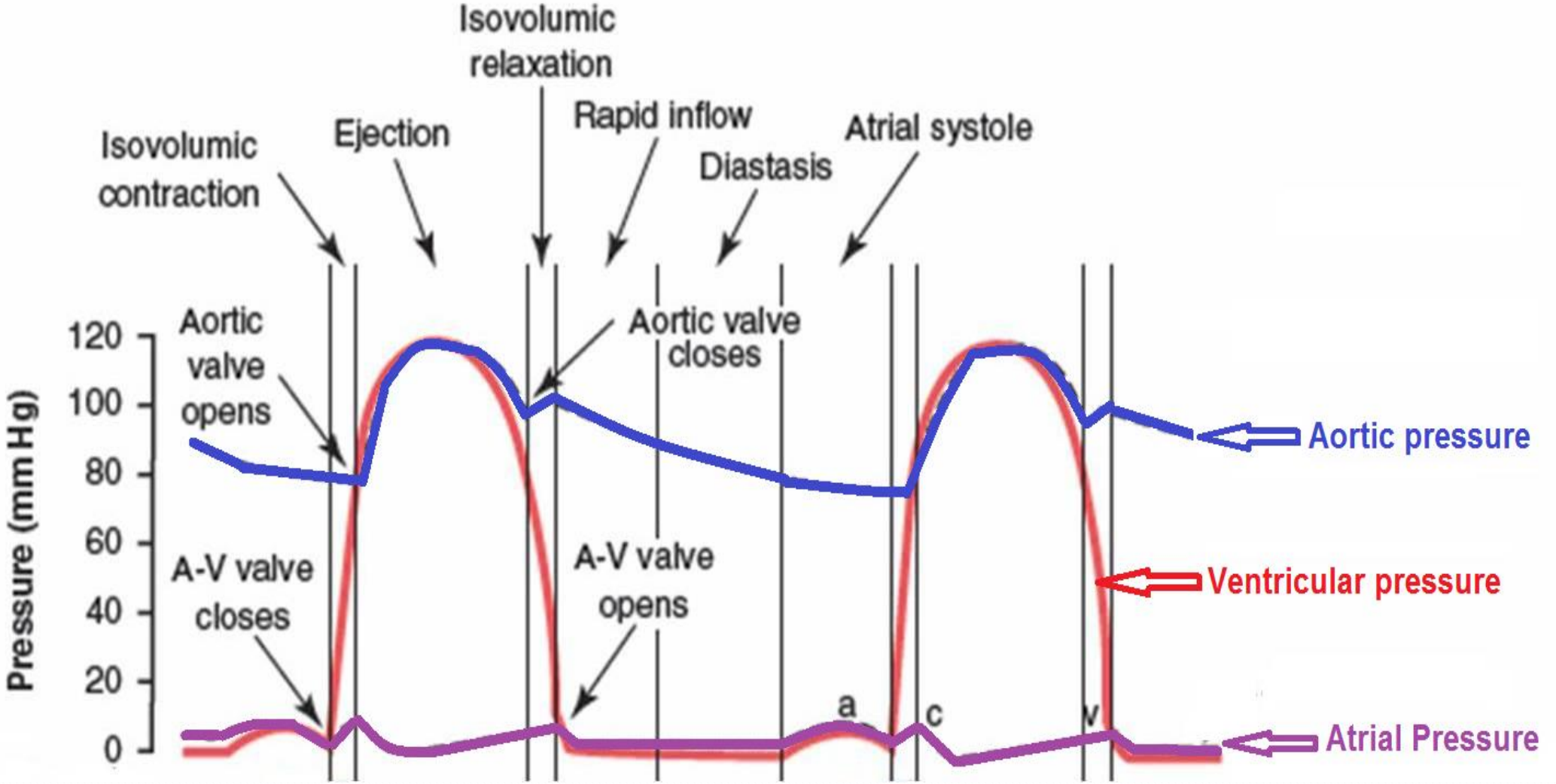
# ECG changes during the Cardiac cycle

| Phase | ECG Changes |
|---|---|
| 1- Atrial systole | P- wave starts 0.02 sec. before atrial systole & continues.<br>Q- wave occurs at the end of this phase. |
| 2-Isovolumetric contraction | Q- wave starts 0.02 sec. before this phase.<br>R & S- waves occur during it. |
| 3-Maximum Ejection | T- wave starts at the last part of it. |
| 4-Reduced ejection | T- wave continues |
| 5-Isovolumic relaxation | T- wave ends |
| 6-Rapid filling | T-P segment. |
| 7-Reduced filling | P- wave of the next cycle starts at the end of this phase. |

# *Left Ventricular Pressure – Volume Diagram (Loop)*

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

# Left Ventricular Pressure Curve
## "The Complete Picture"



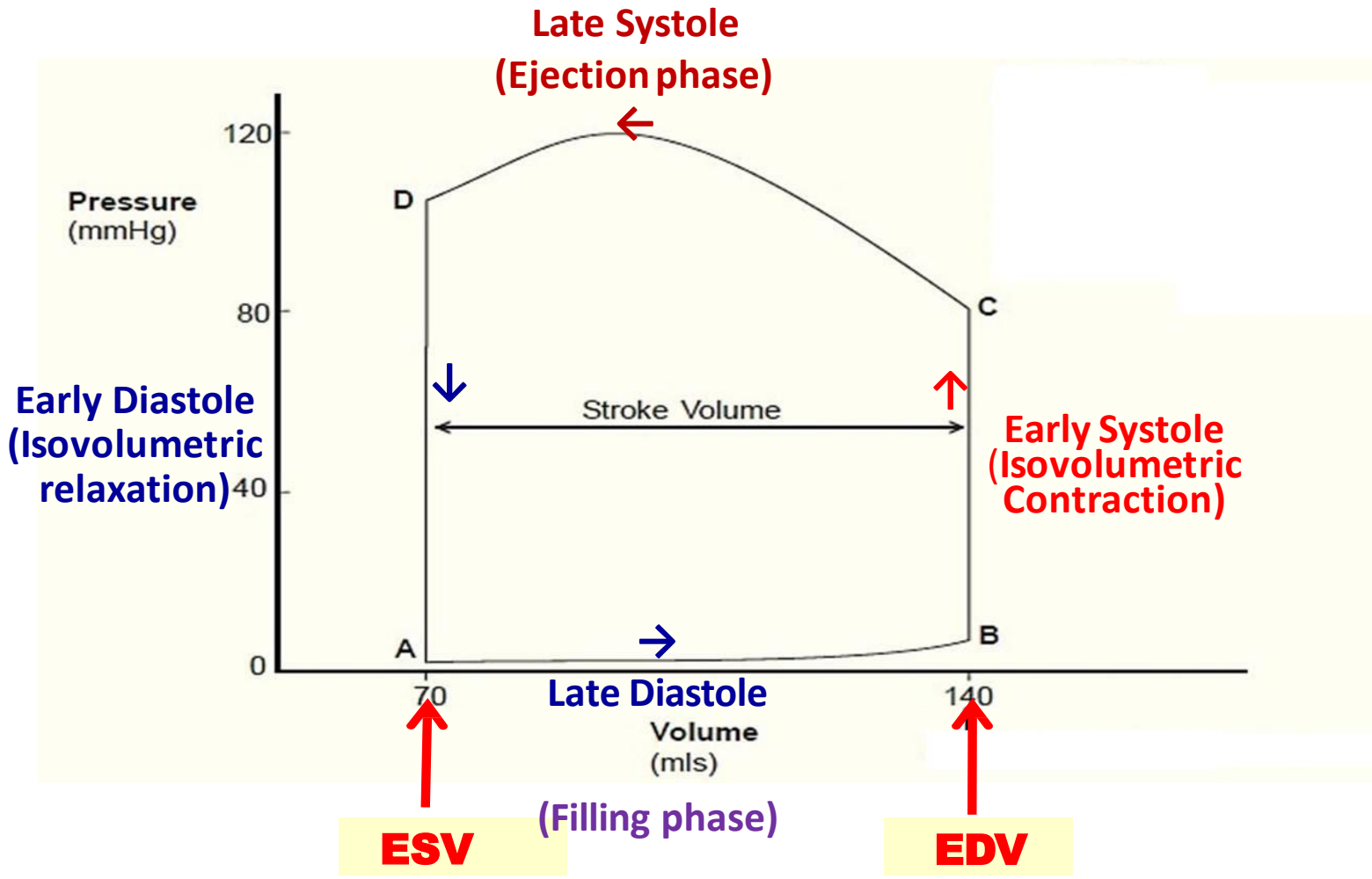
# Basic Myocardial Muscle Mechanics:

- Both ventricular systole & diastole can be divided into early & late phases.
- Systole:
  - Early systole = 'Isovolumetric Contraction.'
  - Late systole = Isotonic Contraction 'Ejection Phases.'

- Diastole:
  - Early diastole = 'Isovolumetric Relaxation.'
  - Late diastole = Isotonic Relaxation 'Filling Phases.'

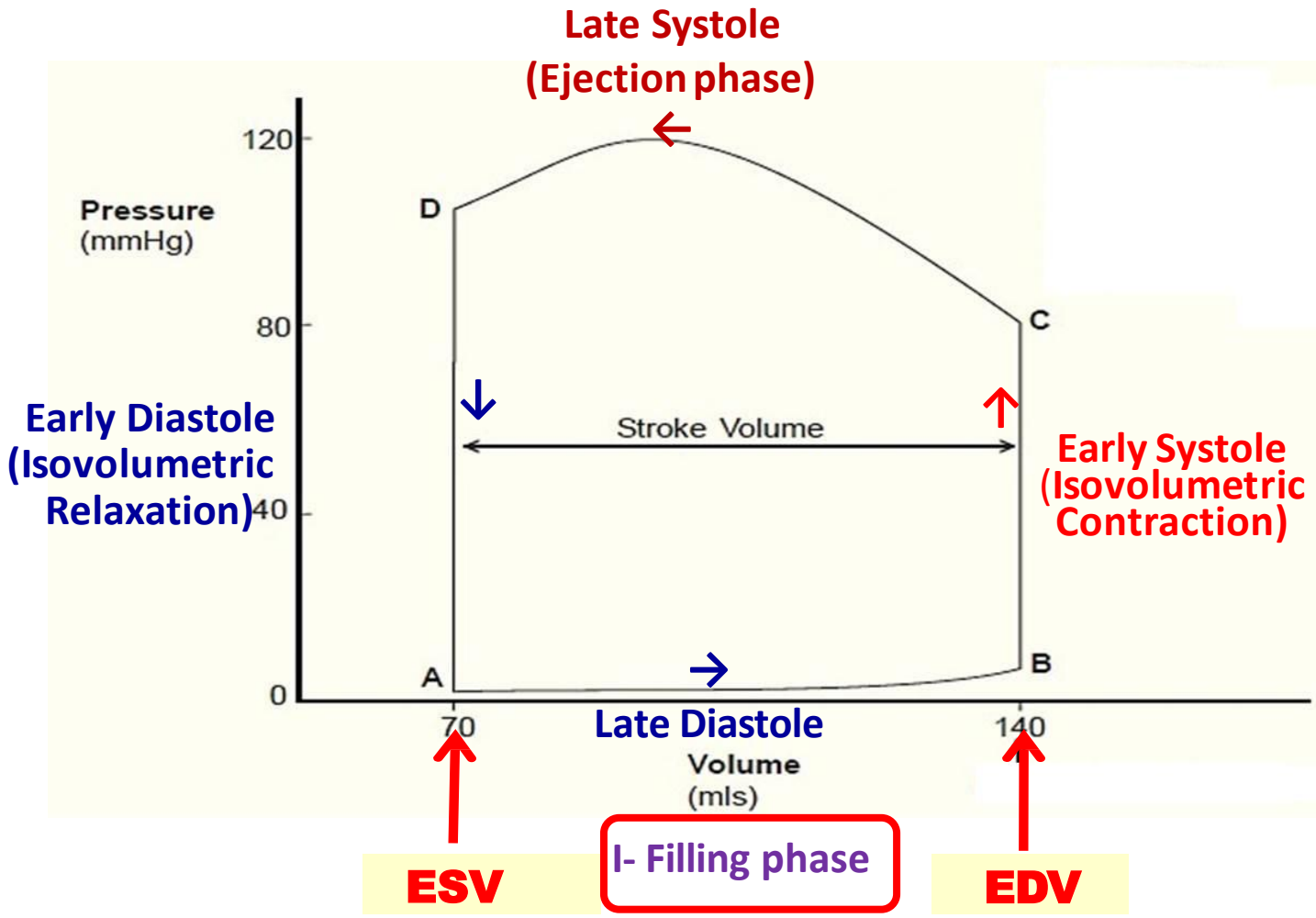
# Ventricular Pressure - Volume Loop

- Plots LV pressure against LV volume through one complete cardiac cycle
- It is divided into four phases.



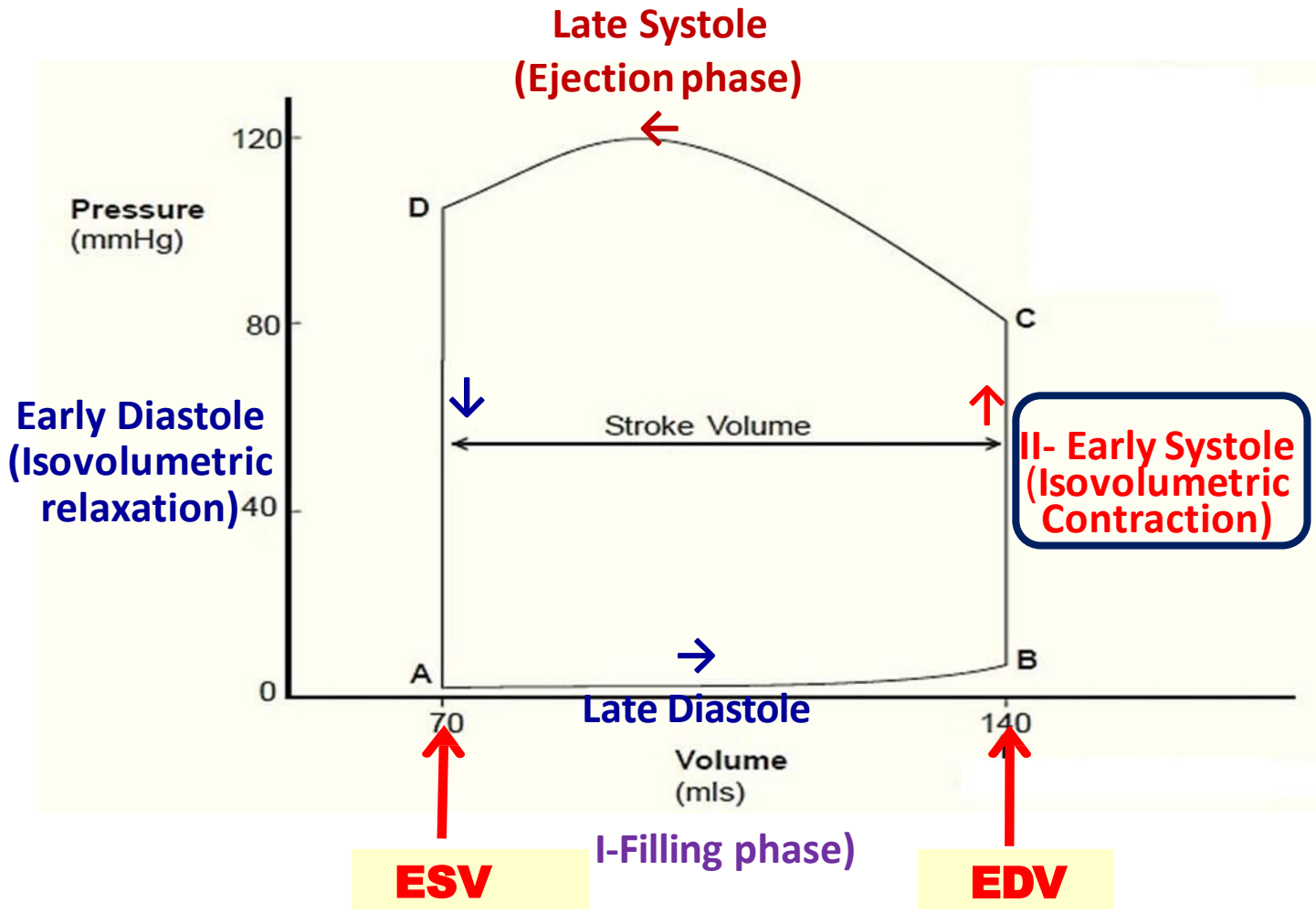
# Ventricular Pressure - Volume Loop…..Cont

- ***Phase I (filling phase):***
  - Begins at a ventricular volume of about 70 ml (the amount of blood that remains in the ventricle, the ESV), and a diastolic pressure of 2 to 3 mm Hg (point A).
  - The ventricular volume normally increases to 140 milliliters EDV (point B).



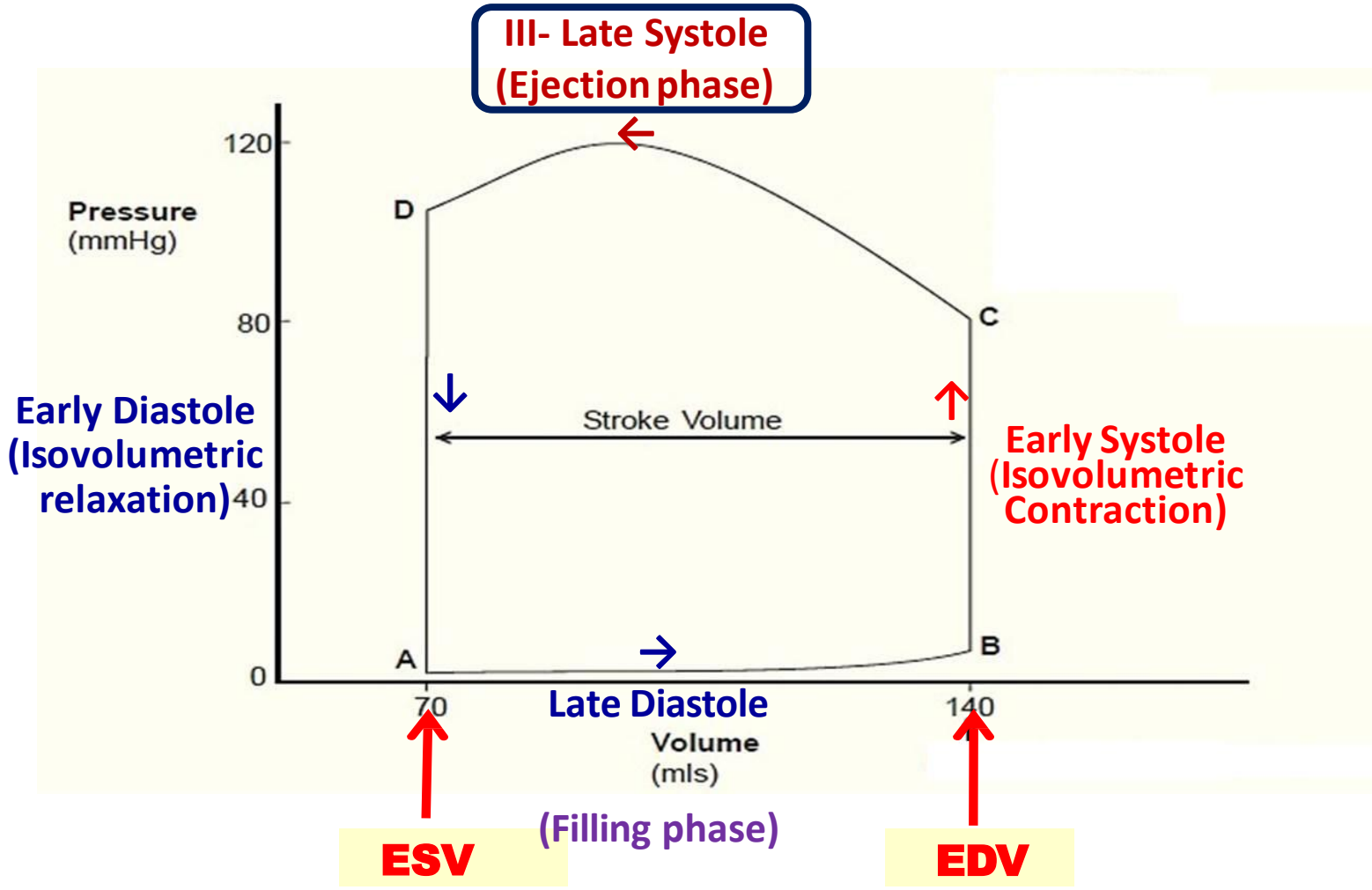
# Ventricular Pressure - Volume Loop…..Cont

- *Phase II (isovolumic contraction phase):*
- The volume of the ventricle does not change.
- Ventricular pressure rises to about 80 mm Hg (point C).



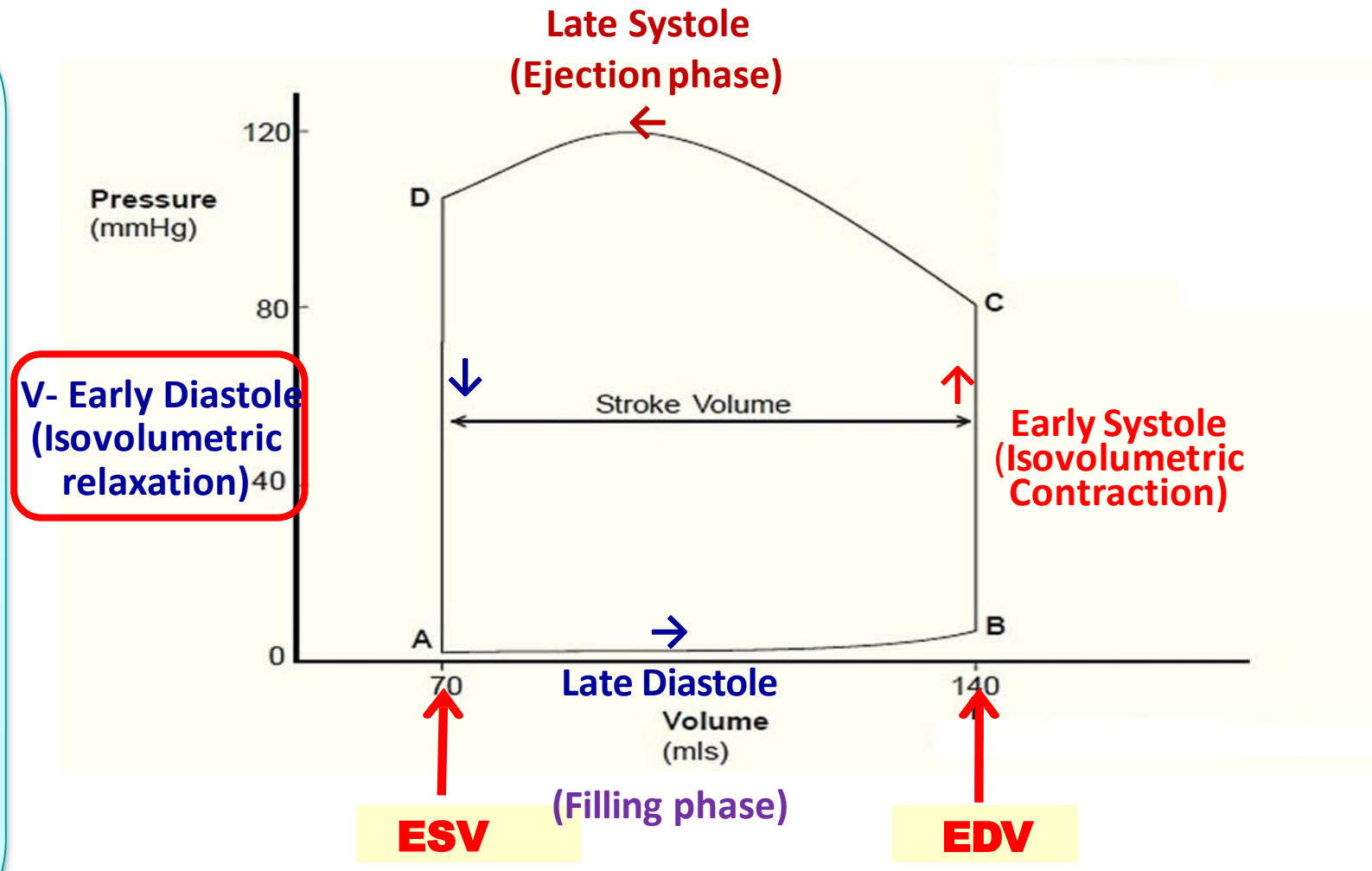
# Ventricular Pressure - Volume Loop…..Cont

- ***Phase III (Ejection phase):***
- Systolic pressure rises (from 80 to 120 mmHg).
- The volume of the ventricle decreases because blood flows out of the ventricle into the aorta.

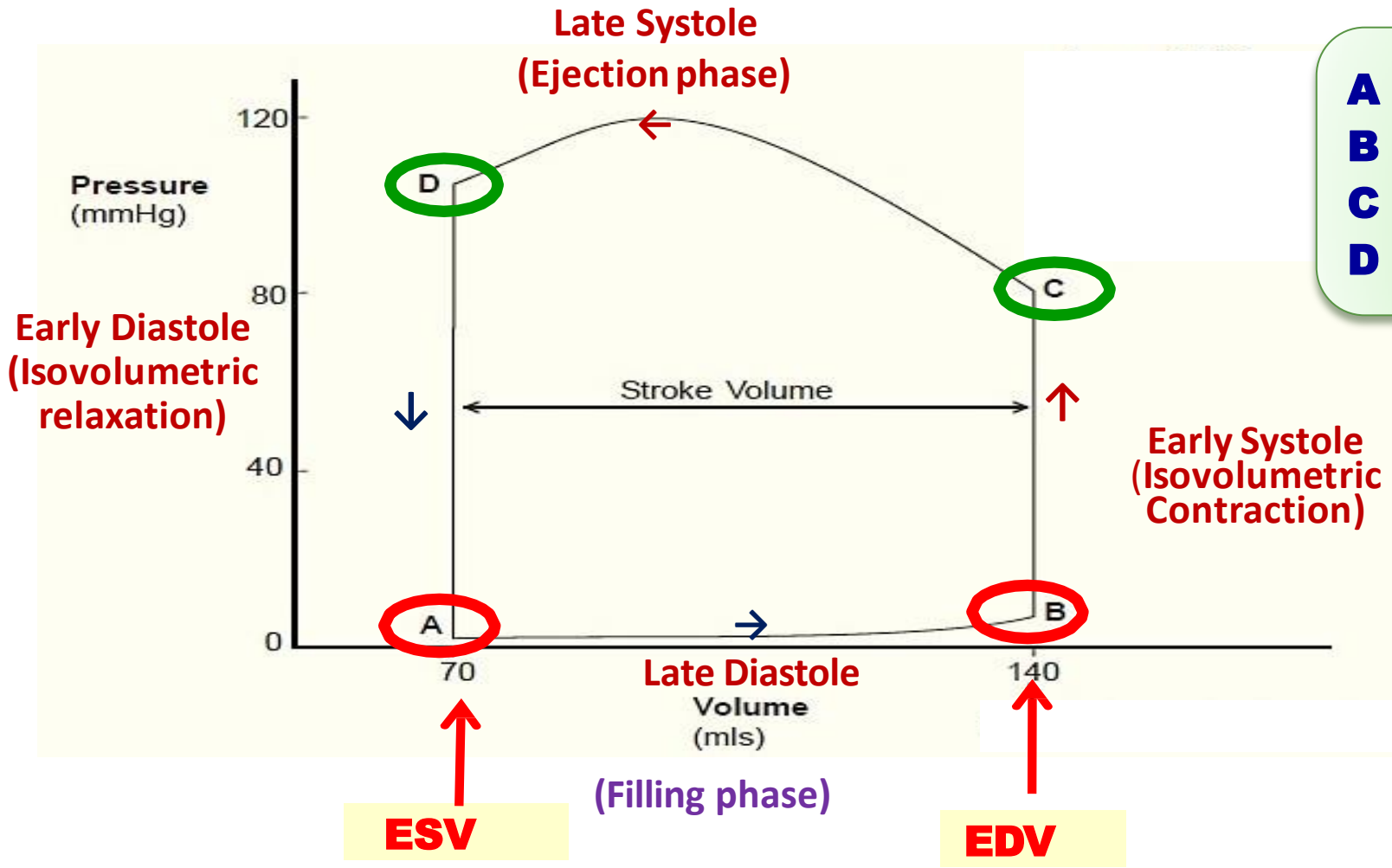


# Ventricular Pressure - Volume Loop…..Cont

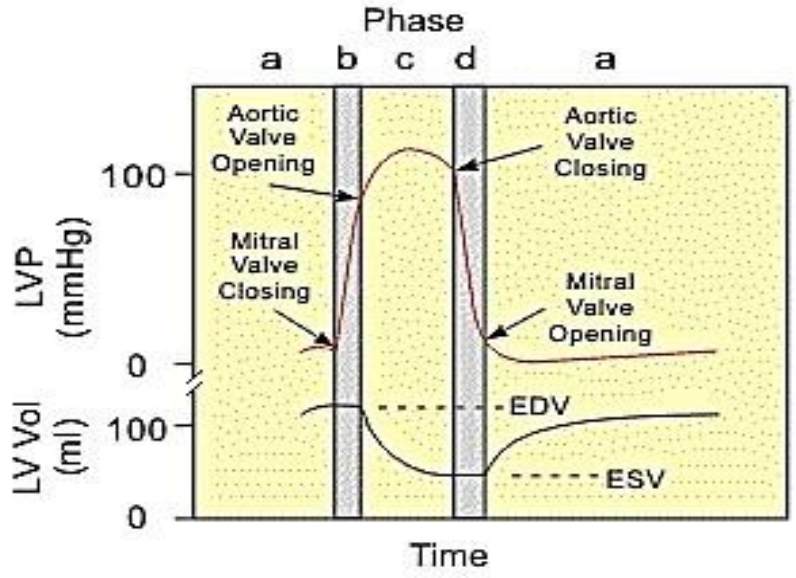
- ***Phase IV (Isovolumic relaxation phase):***
- At the end of ejection period (point D), the aortic valve closes
- Ventricular pressure falls back to the diastolic pressure level.
- The ventricle returns to its starting point (point A).



# Ventricular Pressure - Volume Loop….Cont.

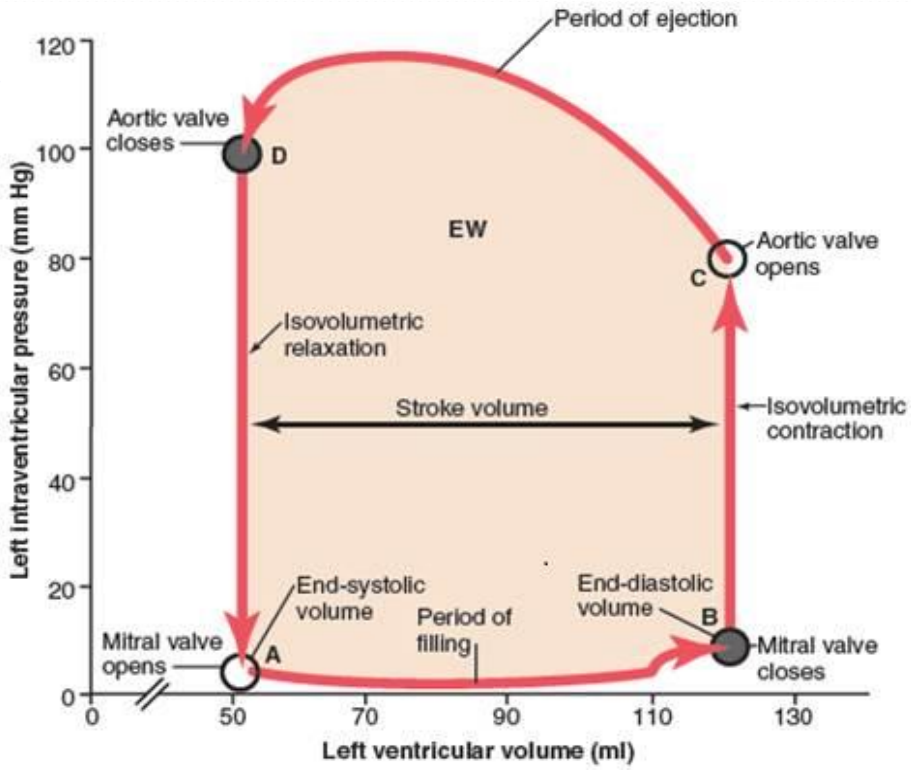



**A – Mitral valve opens**
**B – Mitral valve closes**
**C – Aortic valve opens**
**D – Aortic valve closes**



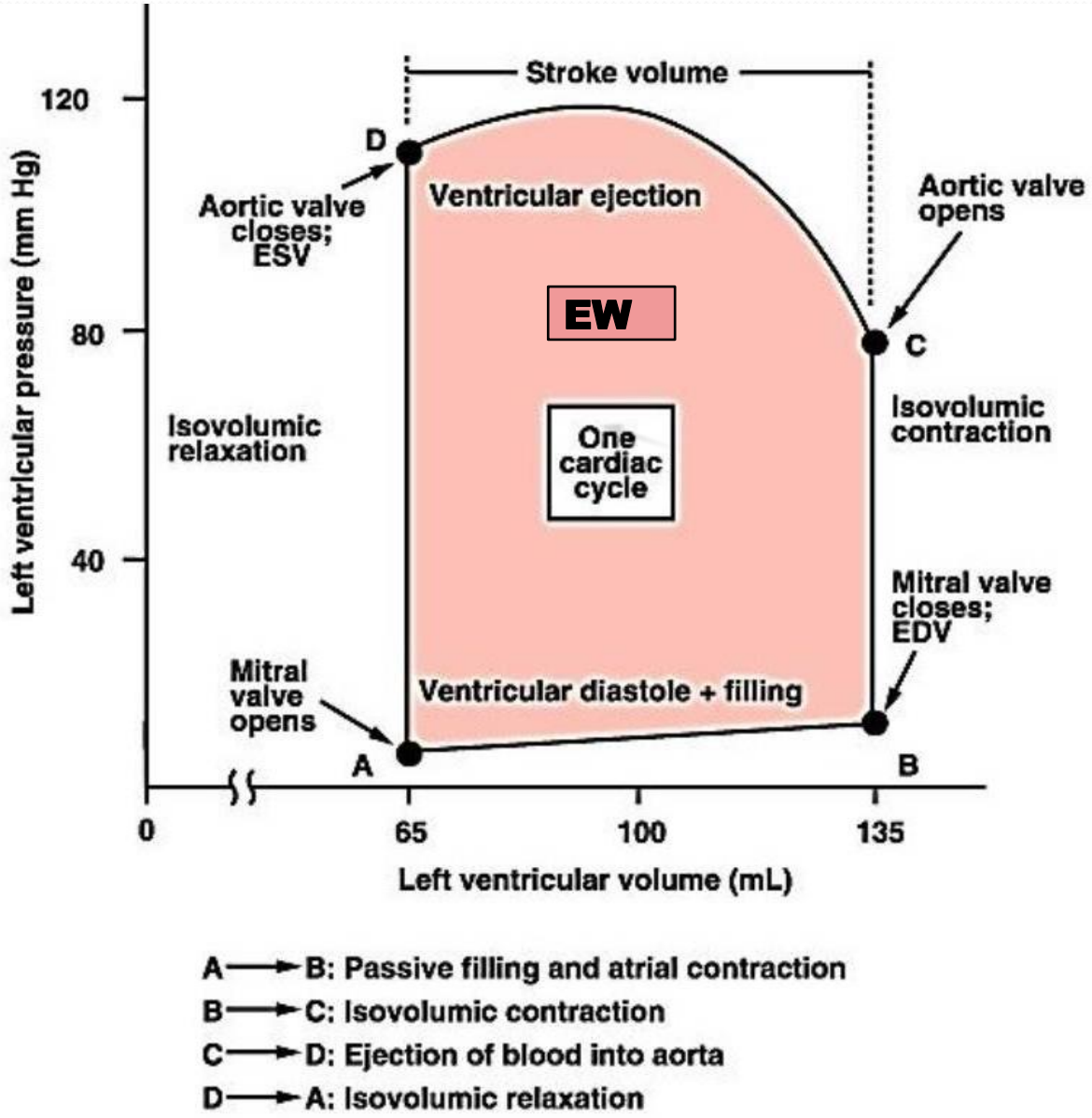
# What you should remember about Pressure – Volume loop?

- Diastolic filling occurs between points A & B.
- Ejection occurs between points C & D.
- Mitral valve open at the beginning of filling phase (point A) and close at its end (point B)
- Aortic valves open at the beginning of ejection phase (point C) and close at its end (point D)



# Importance of Ventricular Volume-Pressure Loop

- This diagram is used for calculating cardiac work output.
- The shaded area, labeled "EW" represents the net external work output of the ventricle during cardiac cycle.
- When the heart pumps large quantities of blood, the area of the work diagram becomes much larger. As during sympathetic stimulation.




Questions