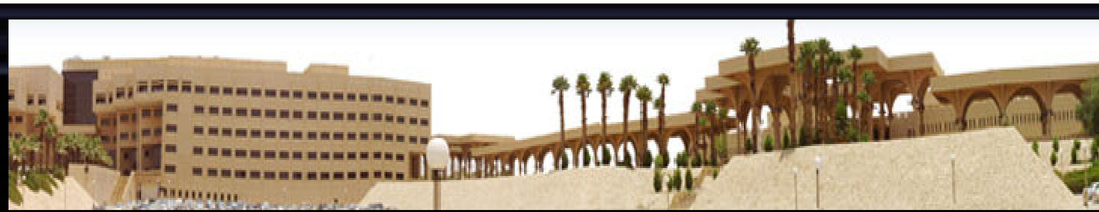
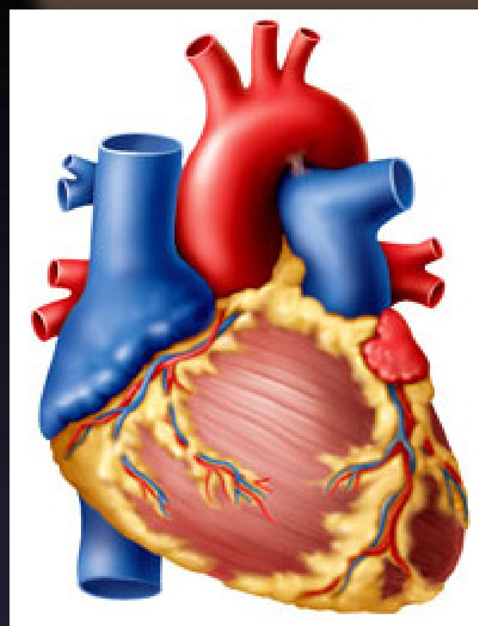
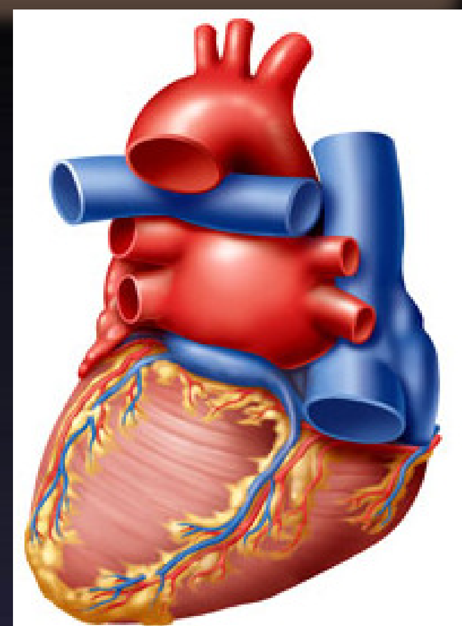


CARDIOVASCULAR SYSTEM

CARDIAC CYCLE





Dr Syed Shahid Habib
Professor & Consultant Clinical Neurophysiology
Dept. of Physiology
College of Medicine & KKUH
King Saud University

2/3/2019

OBJECTIVES

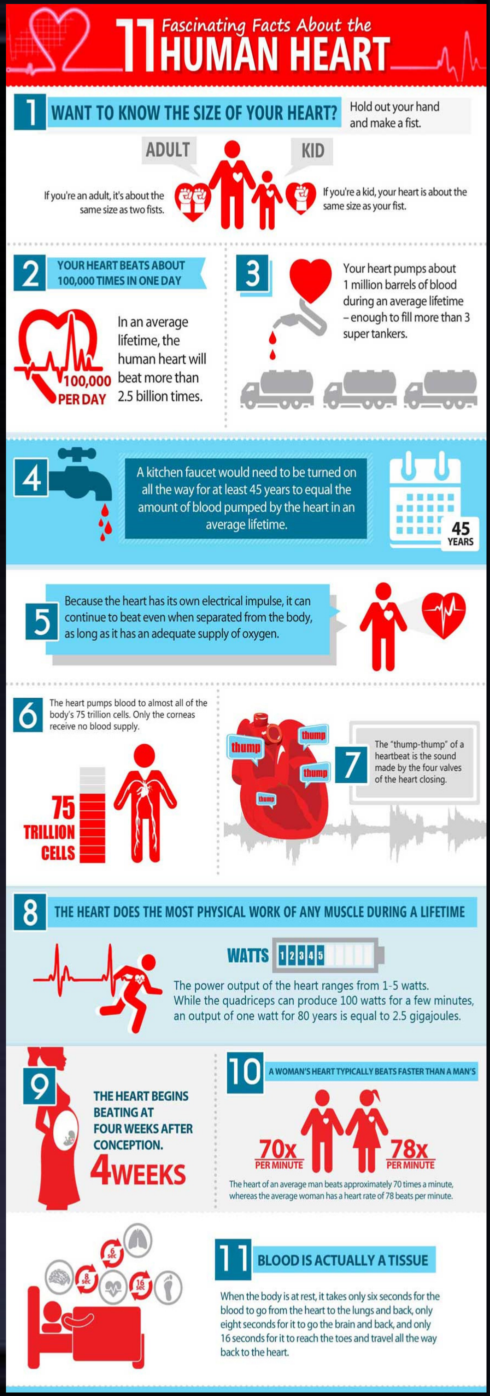
❖ At the end of the lecture you should be able to …..

1. Enumerate the phases of cardiac cycle
2. Explain the effect of heart rate on duration of systole and diastole
3. Recognize the pressure, electrical, sound and volume changes during cardiac cycle
4. Correlate different phases of cardiac cycle with various changes in events.
5. Compare and contrast left and right ventricular pressures and volumes during the normal cardiac cycle.
6. Describe atrial pressure waves & their relationship to cardiac cycle
7. Describe the use of the pressure-volume loop in describing the phases of the cardiac cycle

SOURCE GUYTON 13TH ED. CHAPTER9: PAGE:113-119

FACTS ABOUT OUR HEART

- Size of a fist and weighing about 250 grams
- In lifetime beats 3 billion times and pumps 110 million gallons of blood (2000 gallons/day).
- Every day, your heart creates enough energy to drive a truck for 20 miles (32 km).
- In a lifetime, that is equivalent to driving to the moon and back
- Our heart has its own electrical impulse, it can continue to beat even when separated from the body, as long as it has an adequate supply of oxygen



CARDIAC CYCLE

- Definition: Cardiac Cycle is the time duration comprising all the events from beginning of one heart contraction to the beginning of next heart contraction.
- At heart rate of 75 beats per minute duration of one Cardiac cycle is 0.8 second.

What are the Events?

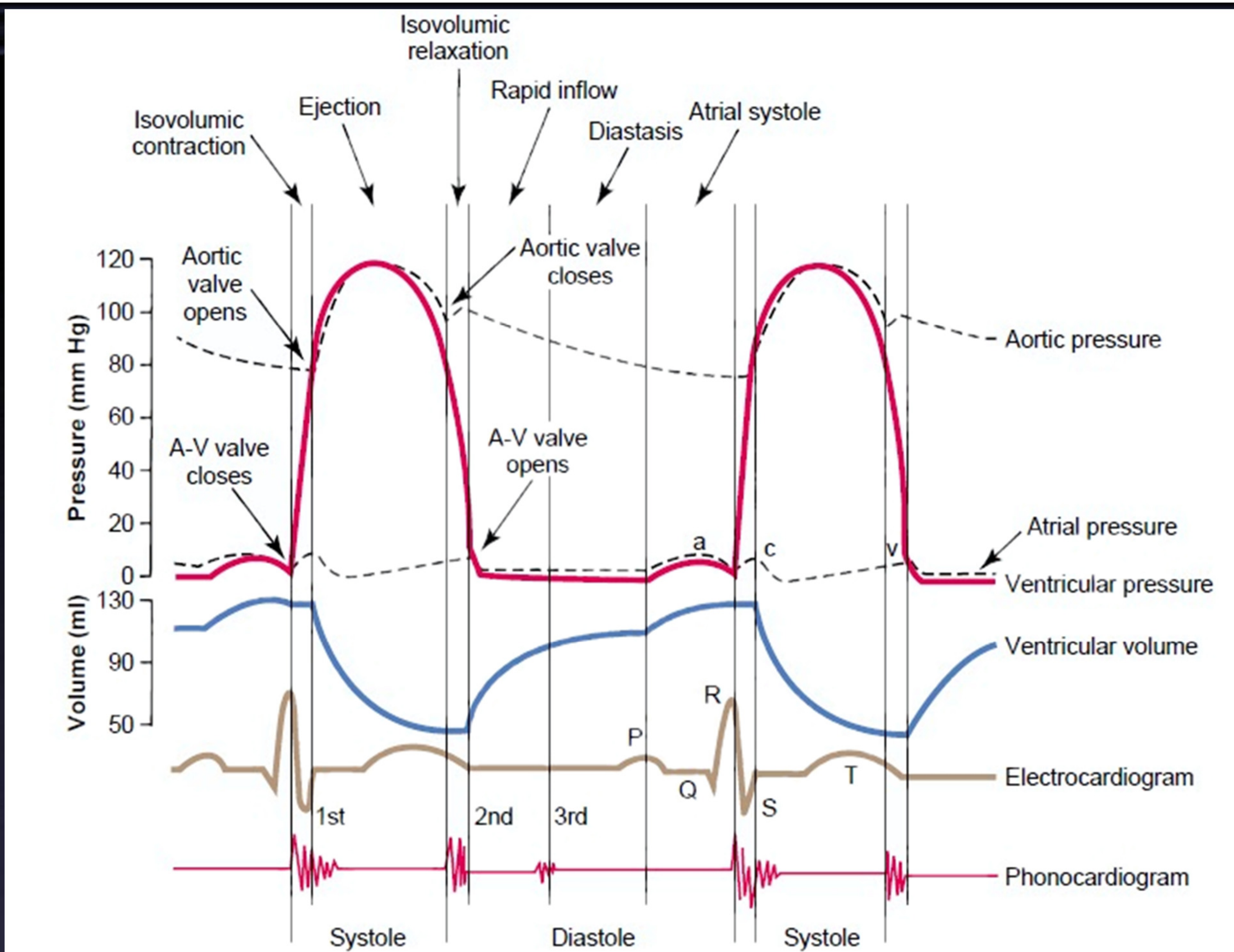
EVENTS OF CARDIAC CYCLE

Mechanical Events:

1. Pressure changes during cardiac cycle
2. Volume changes during cardiac cycle
3. Heart sounds

Electrical Events

5. Electrocardiogram (ECG)



The Events of the Cardiac Cycle

PHASES OF CARDIAC CYCLE

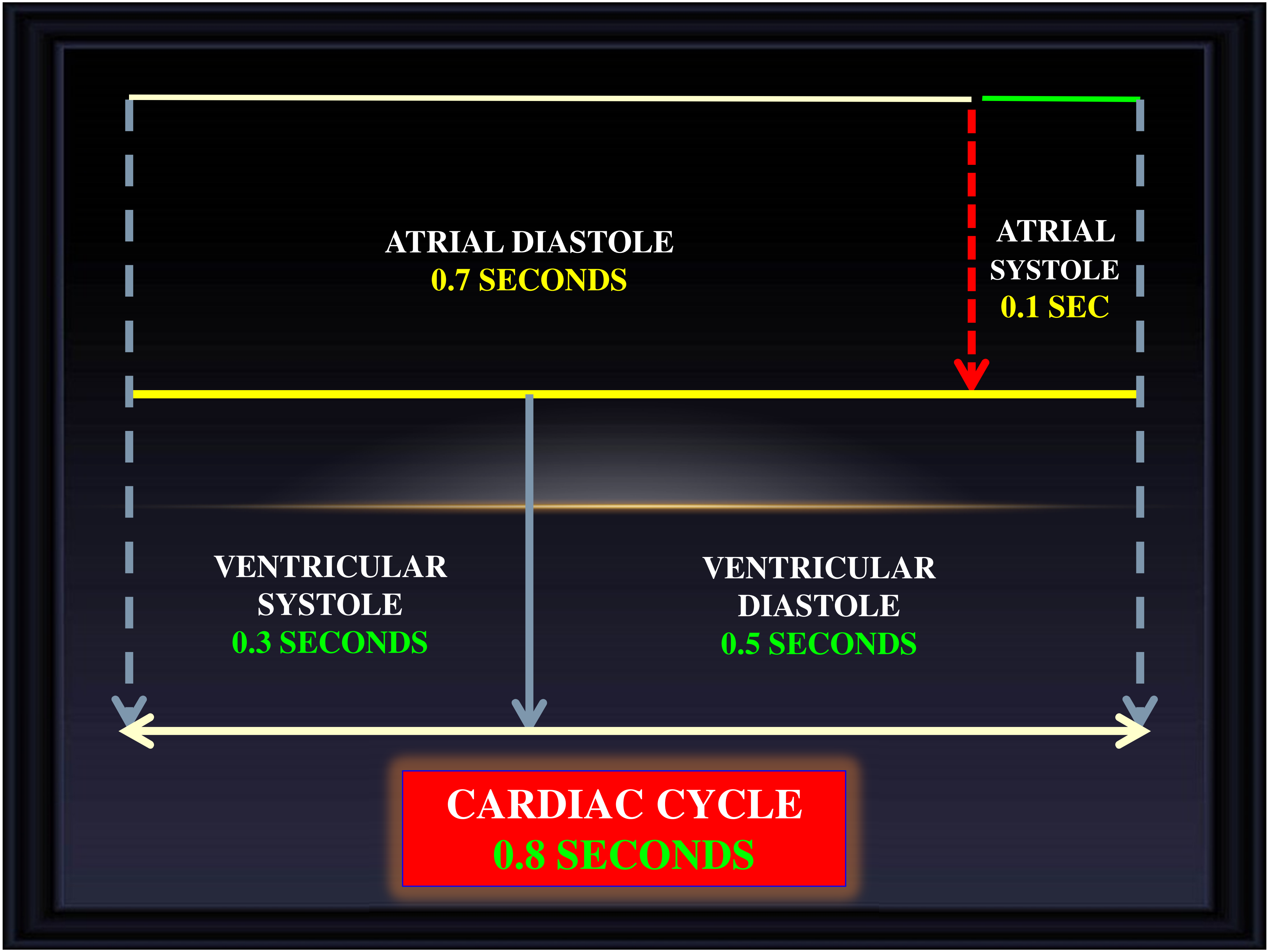
Atrial Events

- Atrial systole: 0.1 second
- Atrial diastole : 0.7 seconds

Ventricular Events

- Ventricular systole : 0.3 seconds
- Ventricular diastole : 0.5 seconds

CARDIAC CYCLE
0.8 SECONDS

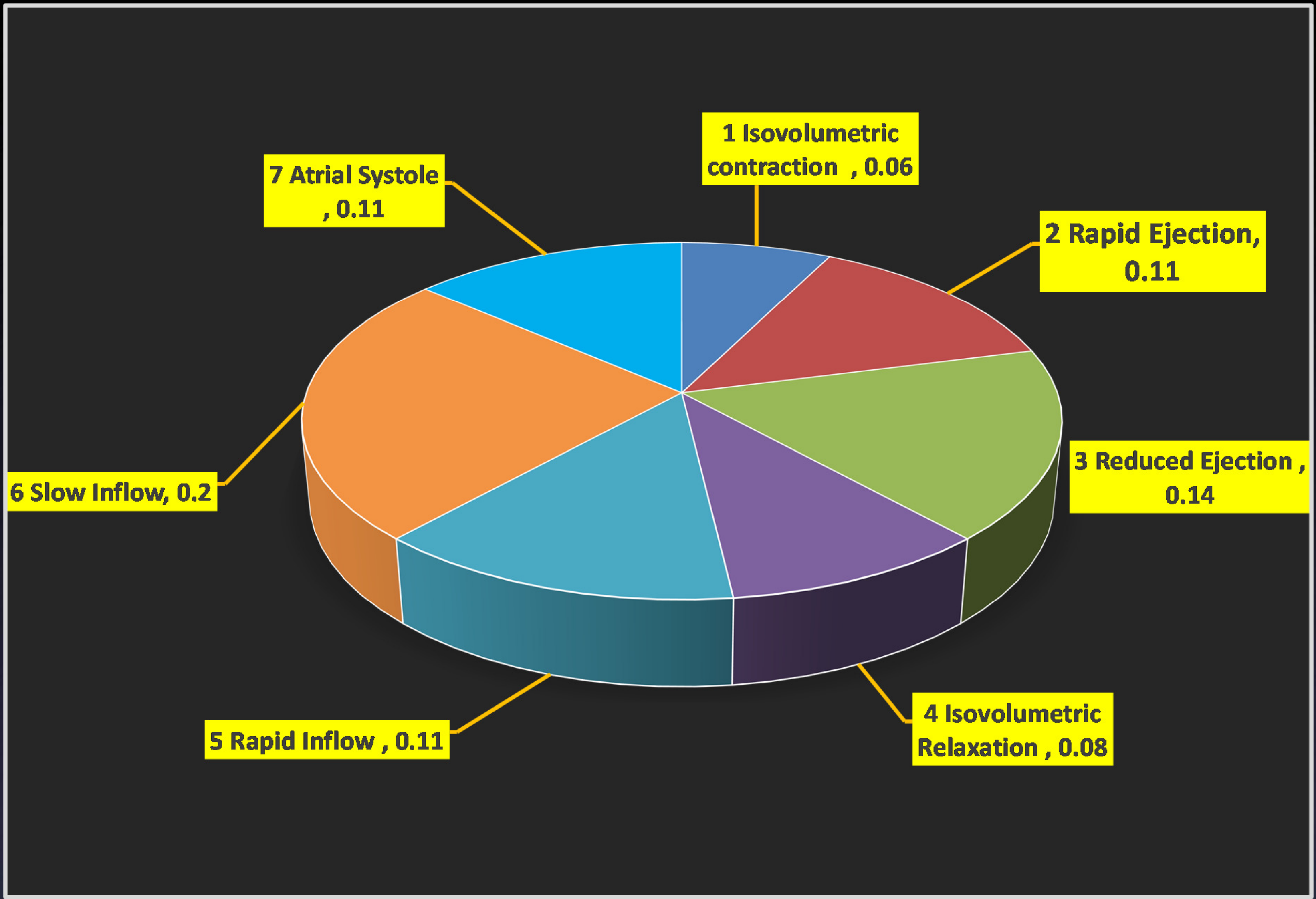


ATRIAL DIASTOLE
0.7 SECONDS
ATRIAL
SYSTOLE
0.1 SEC
VENTRICULAR
SYSTOLE
0.3 SECONDS
VENTRICULAR
DIASTOLE
0.5 SECONDS
CARDIAC CYCLE
0.8 SECONDS

VENTRICULAR EVENTS

- **Ventricular systole**
  1. Isovolumetric contraction
  2. Ejection phase
     - ✓ Rapid ejection
     - ✓ Slow ejection
- **Ventricular Diastole**
  1. Isovolumetric relaxation phase
  2. Filling phase
     - ✓ Rapid filling
     - ✓ Slow filling (Continued filling)
     - ✓ Last rapid filling (Atrial Systole)

PHASES OF CARDIAC CYCLE

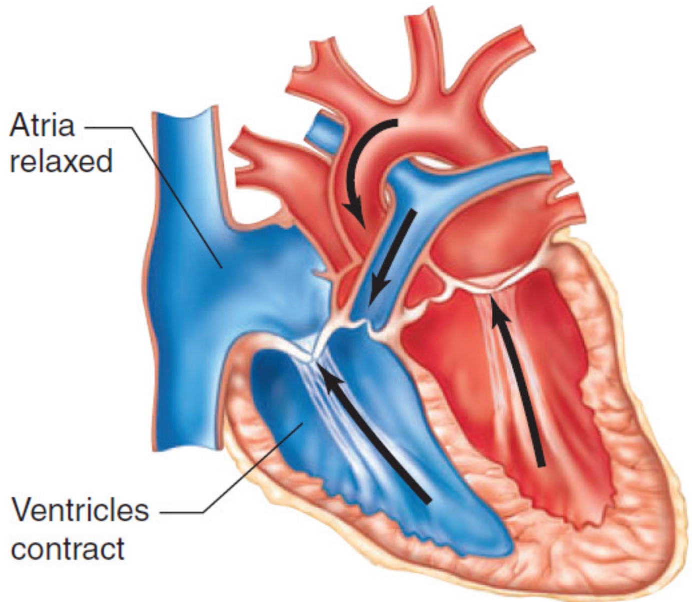


VENTRICULAR SYSTOLE (Peak of R wave of QRS complex to the end of T wave)	**0.30 sec**
ISO-VOLUMETRIC CONTRACTION	0.05 sec
MAXIMUM EJECTION (2/3, 70%)	0.10 sec
REDUCED EJECTION (1/3, 30%)	0.15 sec
VENTRICULAR DIASTOLE (End of T wave to the peak of R wave of QRS complex)	**0.50 sec**
ISO-VOLUMETRIC RELAXATION	0.06 sec
RAPID INFLOW	0.11 sec
SLOW INFLOW / DIASTASIS	0.22 sec
ATRIAL SYSTOLE (after P wave)	0.11 sec
7 Phases of CARDIAC CYCLE	**0.8 sec**

Importance of the long ventricular diastole? This is important for:
Coronary blood flow & Ventricular filling

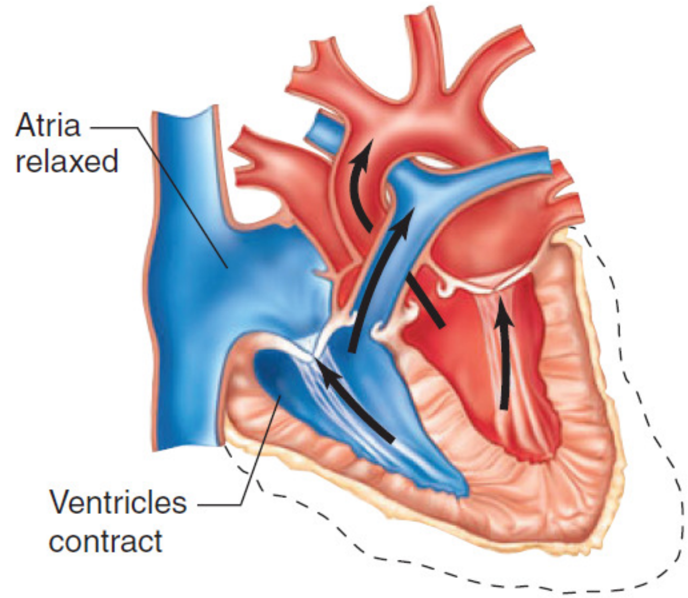
A Systole

Isovolumetric ventricular contraction



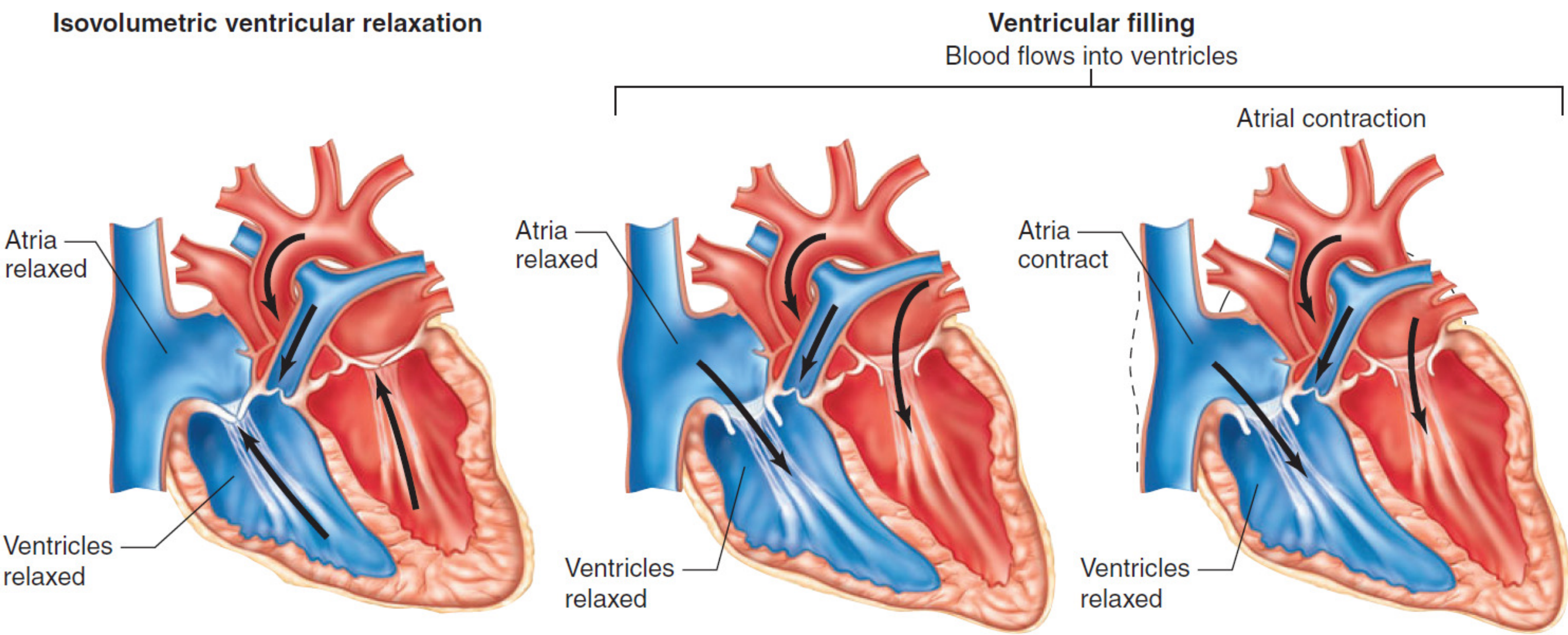
Ventricular ejection

Blood flows out of ventricle



	Isovolumetric ventricular contraction	Ventricular ejection
AV valves:	Closed	Closed
Aortic and pulmonary valves:	Closed	Open

B Diastole



	Isovolumetric ventricular relaxation	Ventricular filling	Atrial contraction
AV valves:	Closed	Open	Open
Aortic and pulmonary valves:	Closed	Closed	Closed

ISOVOLUMETRIC CONTRACTION

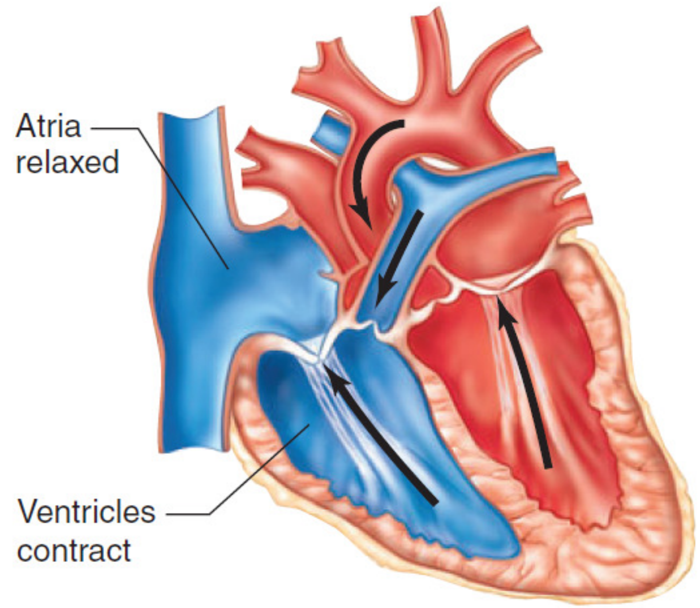
Increase in ventricular pressure > atrial pressure → AV valves close

After 0.06s, semilunar valves open

Period between AV valve closure and semilunar valve opening → heart prepares for contraction without shortening→ occurs **without emptying**

Tension develops without change in muscle length (Isometric/Isovolumetric)

Isovolumetric ventricular contraction



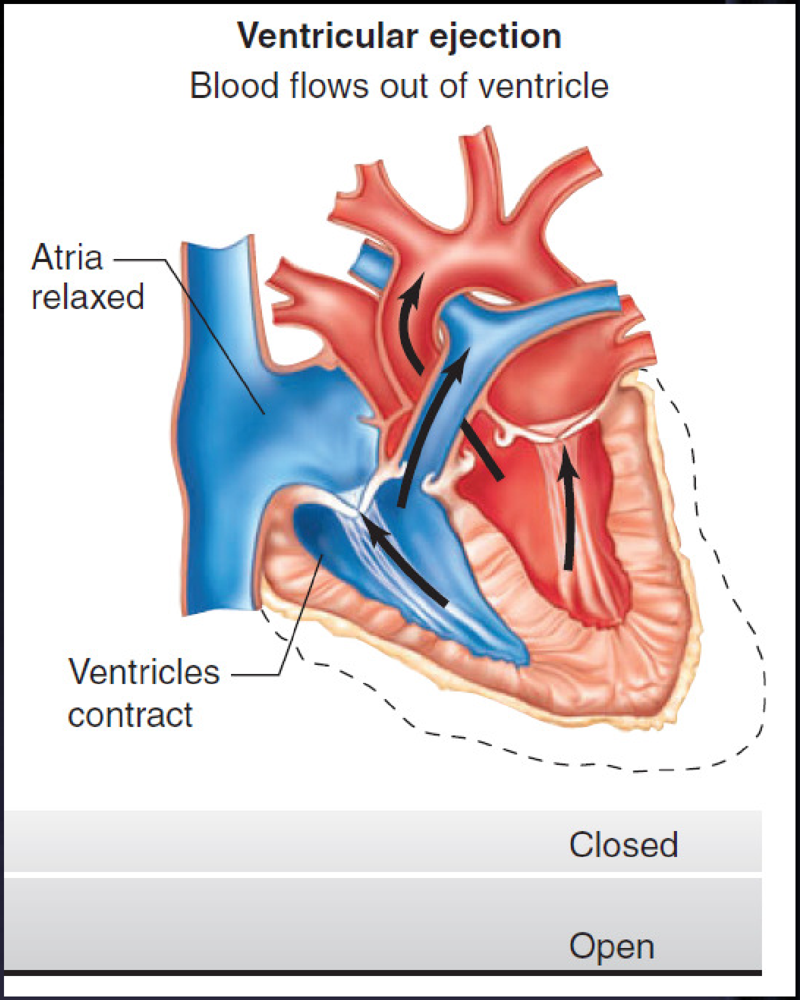
AV valves:	Closed
Aortic and pulmonary valves:	Closed

EJECTION

- When LV pres > 80 mm Hg

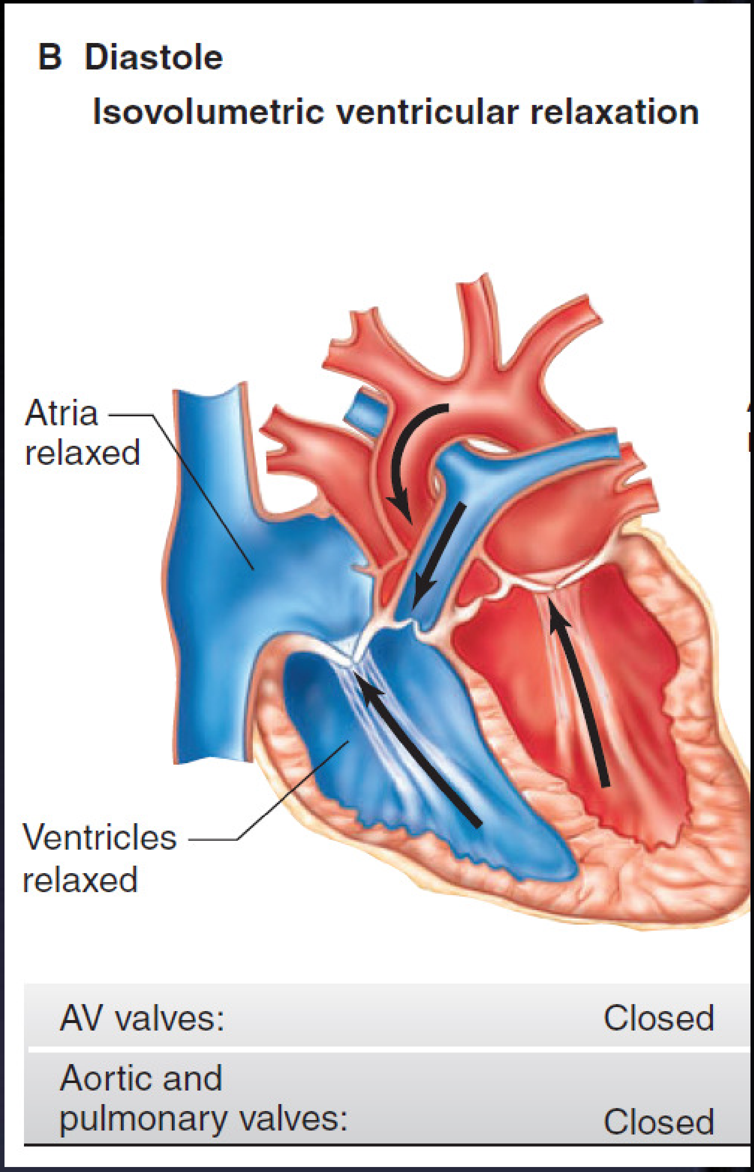
  RV pres > 8 mm Hg,

  The semilunar valves open.
- Rapid Ejection – 70% emptying in first 1/3 duration
- Slow Ejection – 30% in last 2/3 time
- The pressure in the ventricle keeps decreasing until it becomes lower than that of the great vessels



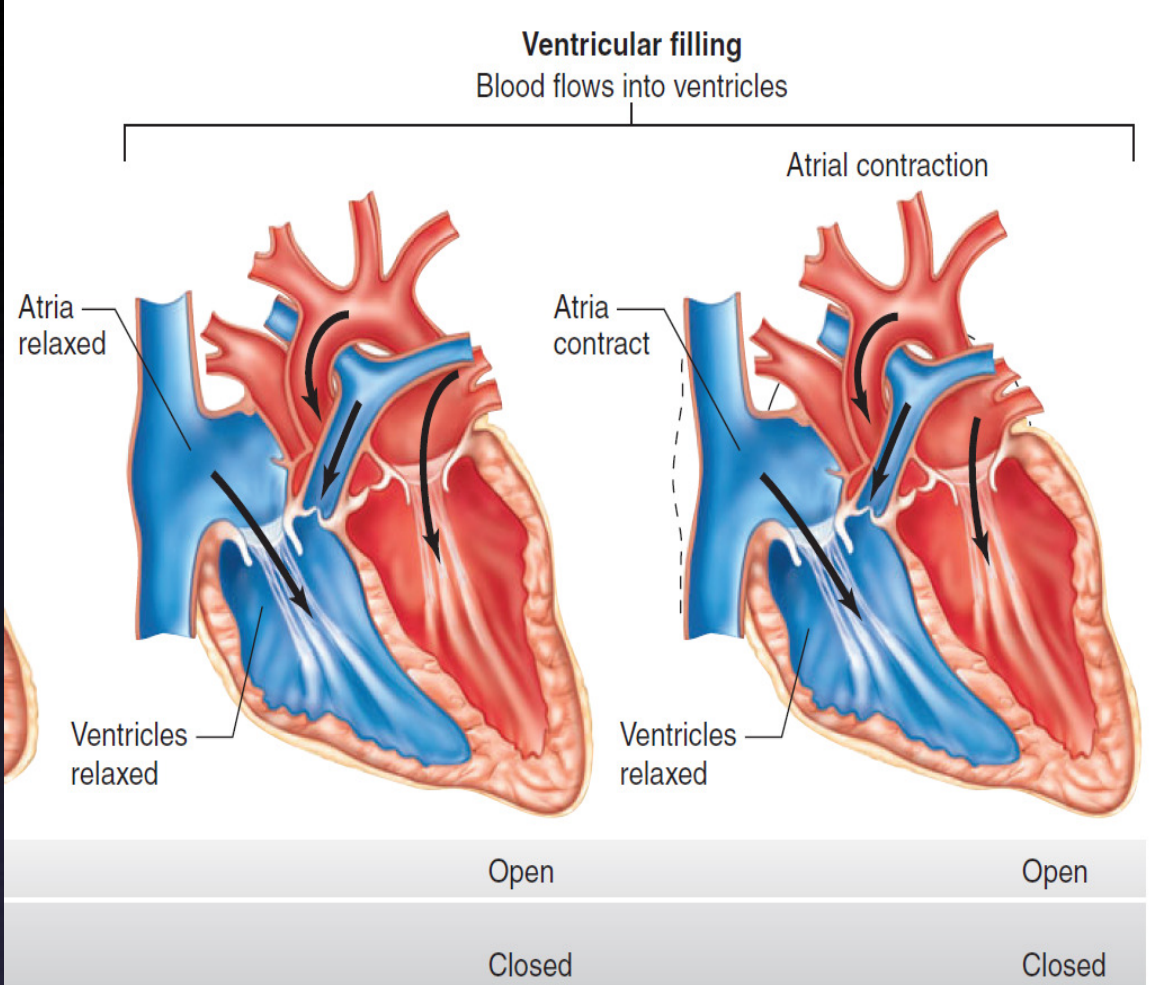
ISOVOULUMETRIC RELAXATION

- When ventricle pressure < arterial pressure→ backflow of blood → forces semilunar valves to close.
- For 0.06 s, ventricle relaxes despite no change in its volume
- AV and Semilunar valves are closed
- Meanwhile, atria fill up and atrial pressure gradually rises
- Pressures in ventricle keep falling till it is < atrial pressure



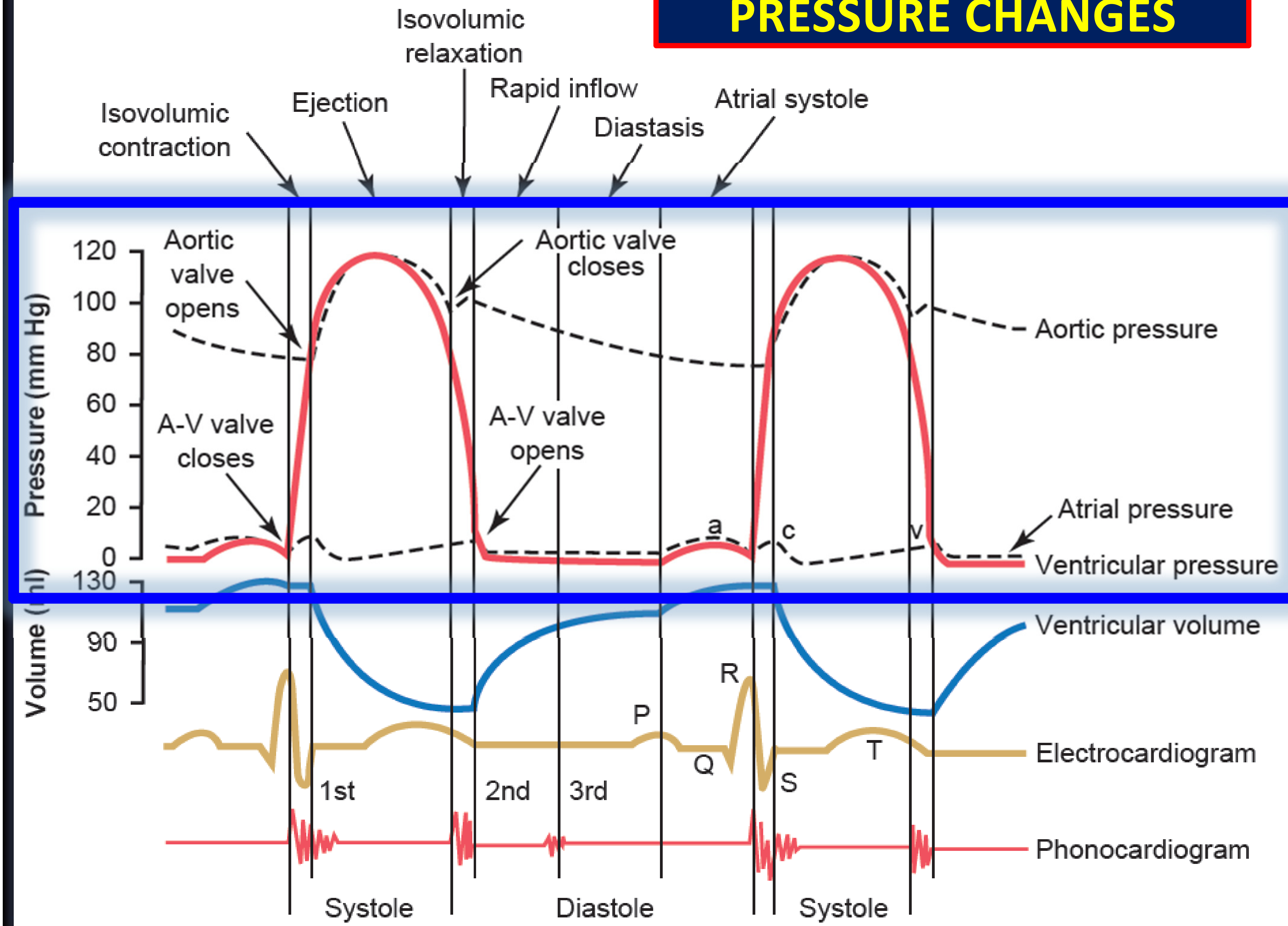
VENTRICULAR FILLING

- Begins with the opening of AV valves
- Rapid filling – first 1/3 of diastole (60-70% blood)
- Reduced filling (Diastasis) – middle 1/3 of diastole (<5% bood)
- Atrial contraction – last 1/3 of diastole (25 % blood)



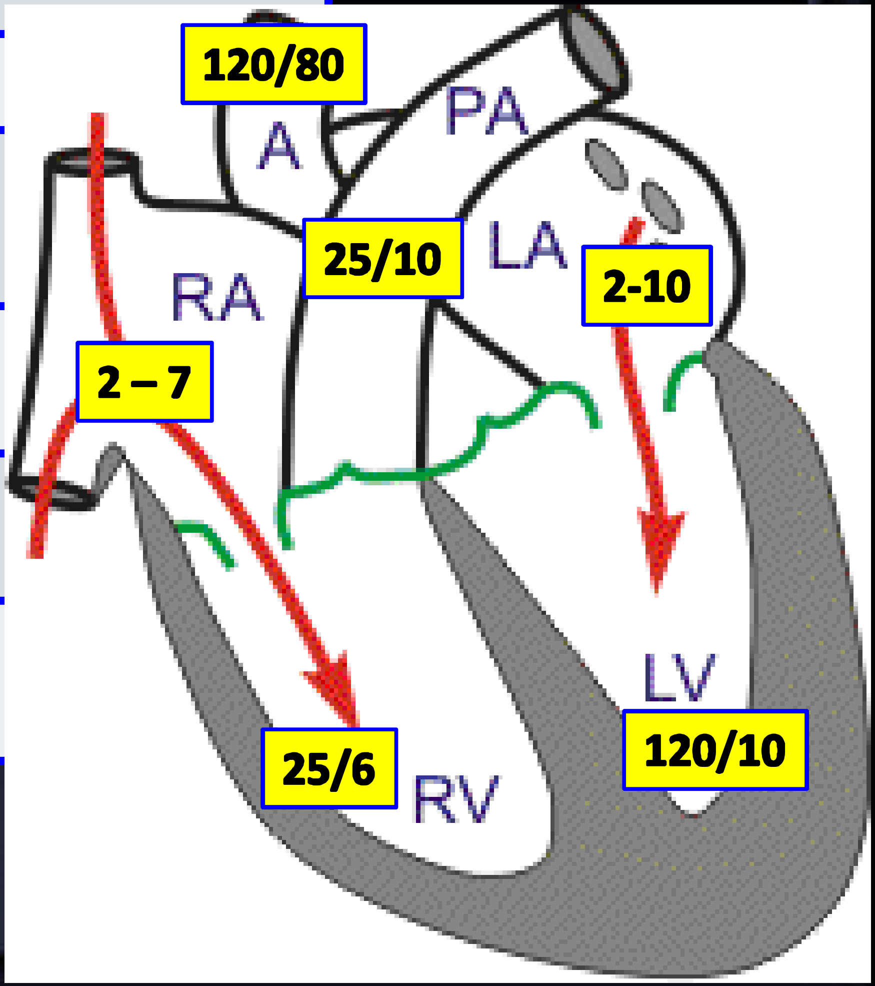
As the atrial pressures fall, the AV valves close and left ventricular volume is now maximum → EDV (120 ml in LV)

PRESSURE CHANGES

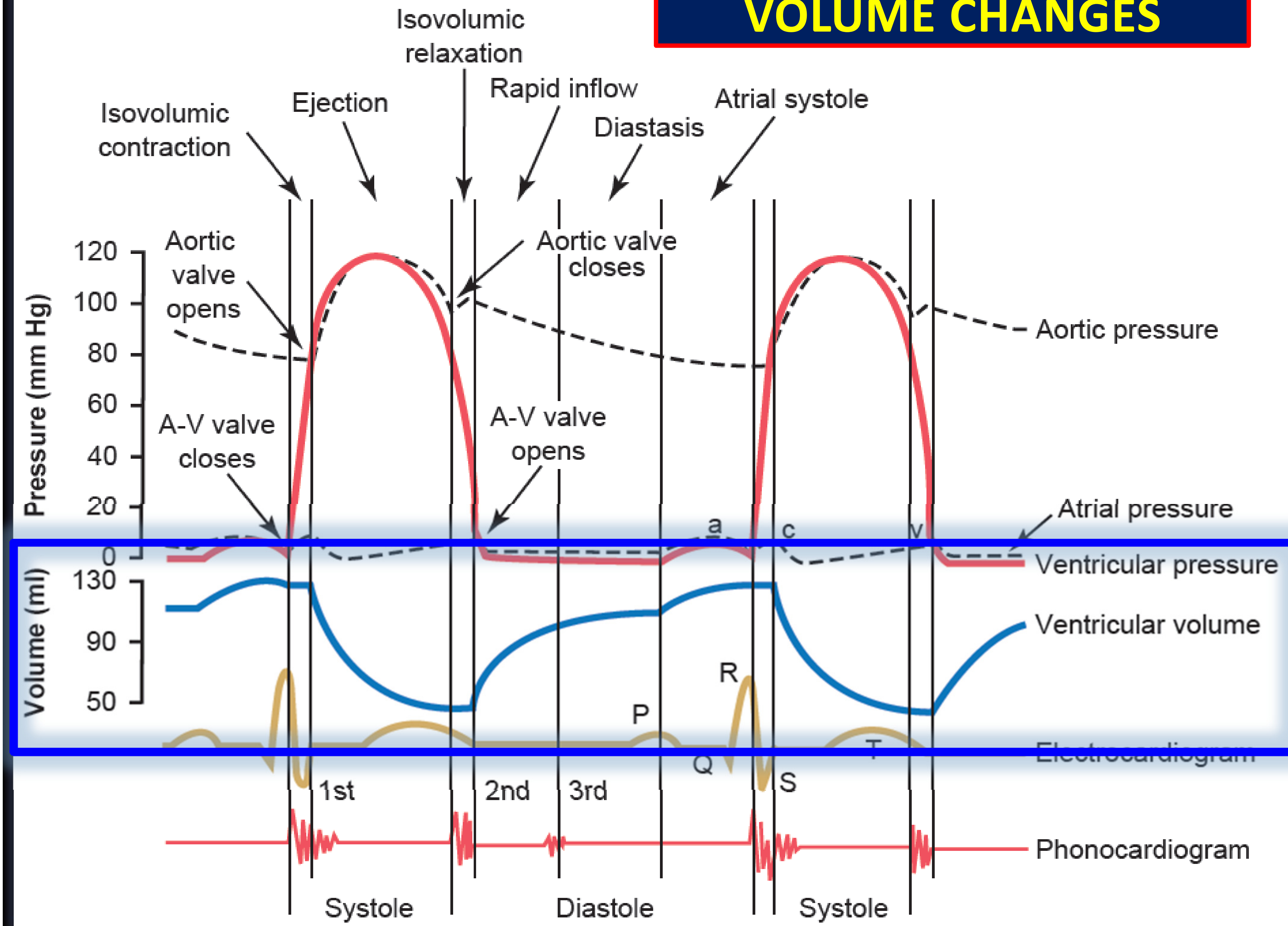


PRESSURE CHANGES IN CARDIAC CYCLE

CHAMBERS	NORMAL RANGE (mm of Hg)
Right Atrium	**2 – 7**
Left Atrium	**2-10**
Right Ventricle (systolic) (diastolic)	**15 – 25 2 -8**
Left Ventricle (systolic) (diastolic)	**100 – 120 2 – 10**
Pulmonary Artery (systolic) (diastolic)	**25 10**
Aorta (systolic) (diastolic)	**120 80**



VOLUME CHANGES



- **End Diastolic Volume:** Volume of blood in each ventricle at the end of diastole.

  It is about 110 – 120 ml.

- **End Systolic Volume:** Volume of blood in each ventricle at the end of Systole. It is about 40 to 50 ml

- **Stroke Volume:** It is a volume of blood pumped out by each ventricle per beat. It is about 70 ml.

  Stroke volume (SV) = EDV – ESV

EJECTION FRACTION (EF) is the percentage of ventricular end diastolic volume (EDV) which is ejected with each stroke.

$$EF = \frac{SV \text{ or } (EDV - ESV)}{EDV} \times 100$$

$$\frac{75}{120} \times 100 = 62.5\%$$

Normal ejection fraction is about 60 – 65 %.
Ejection fraction is good index of ventricular function.

ATRIAL SYSTOLE

Atrial Depolarization

↓

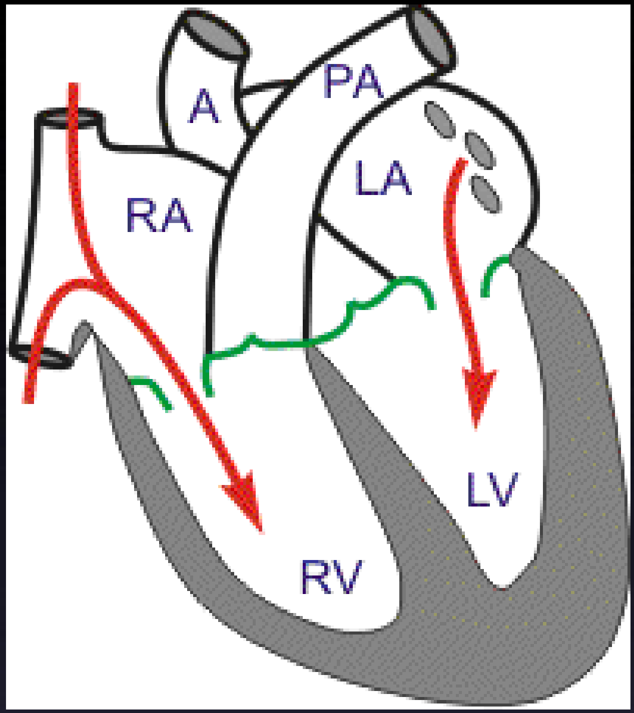
Atrial contraction

↓

Atrial pressures rise

↓

Blood flows across AV valves



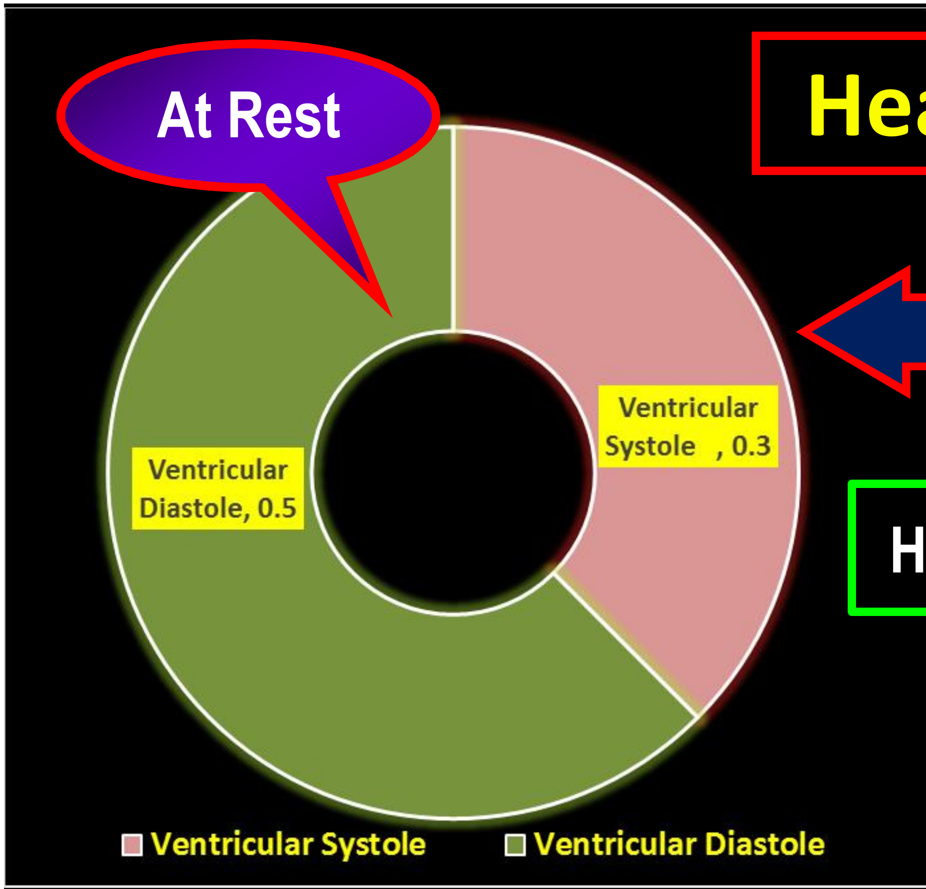
ATRIA act as PRIMER PUMPS

& increase the ventricular pumping effectiveness as much as 20-25%

Ventricular filling :

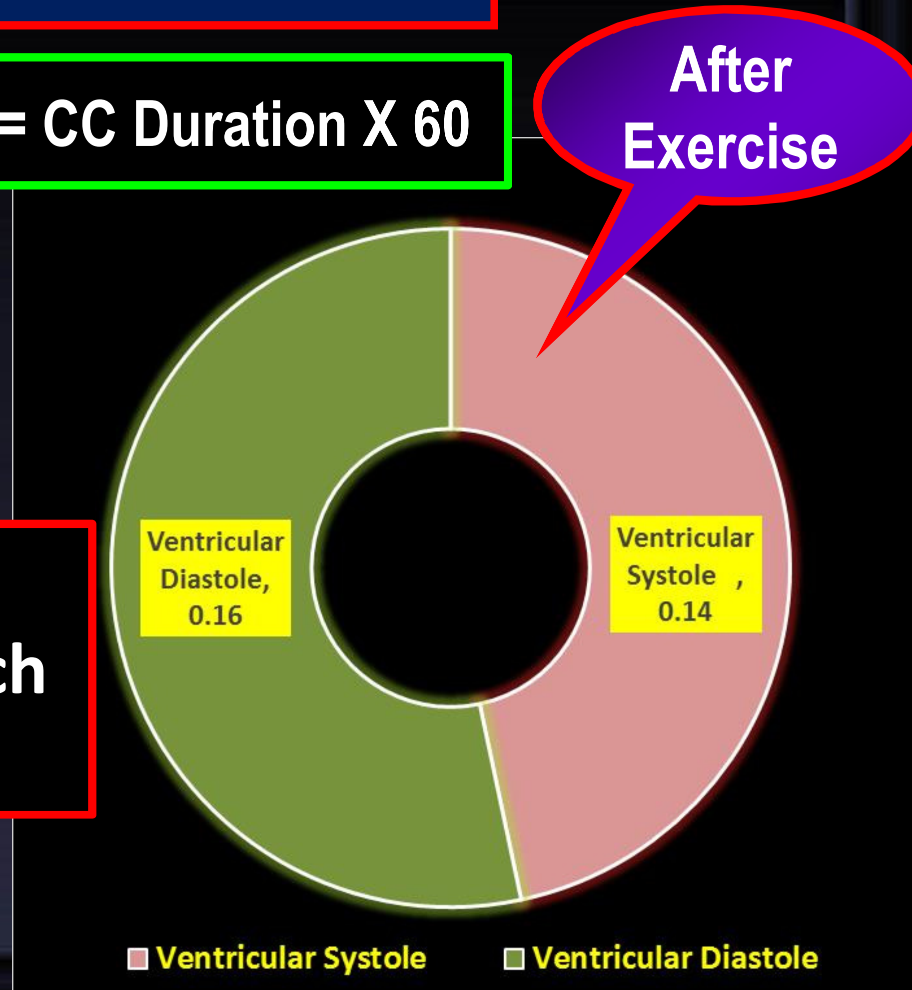
- **60-70% - direct flow from VR**
- **25% - atrial contraction.**

Hear Rate & Cardiac Cycle



What is the HR??

HR = CC Duration X 60



When the heart rate is ↑ diastole is shortened to a much greater degree than systole.

Heart Rate & Cardiac Cycle

- Higher the rate lesser is duration of Cardiac cycle.
- However, the duration of systole is much more fixed than that of diastole.

Physiologic and clinical implications of shortened diastole:
The heart muscle rests during diastole. Coronary blood flows to the subendocardial portions of the left ventricle only during diastole. Furthermore, most of the ventricular filling occurs in diastole.

Up to about 180/min, filling is adequate as long as there is enough venous return, and cardiac output per minute is increased by an increase in rate. However, at very high heart rates, filling may be compromised to such a degree that cardiac output per minute falls.

TABLE 30–1 Variation in length of action potential and associated phenomena with cardiac rate.[a]

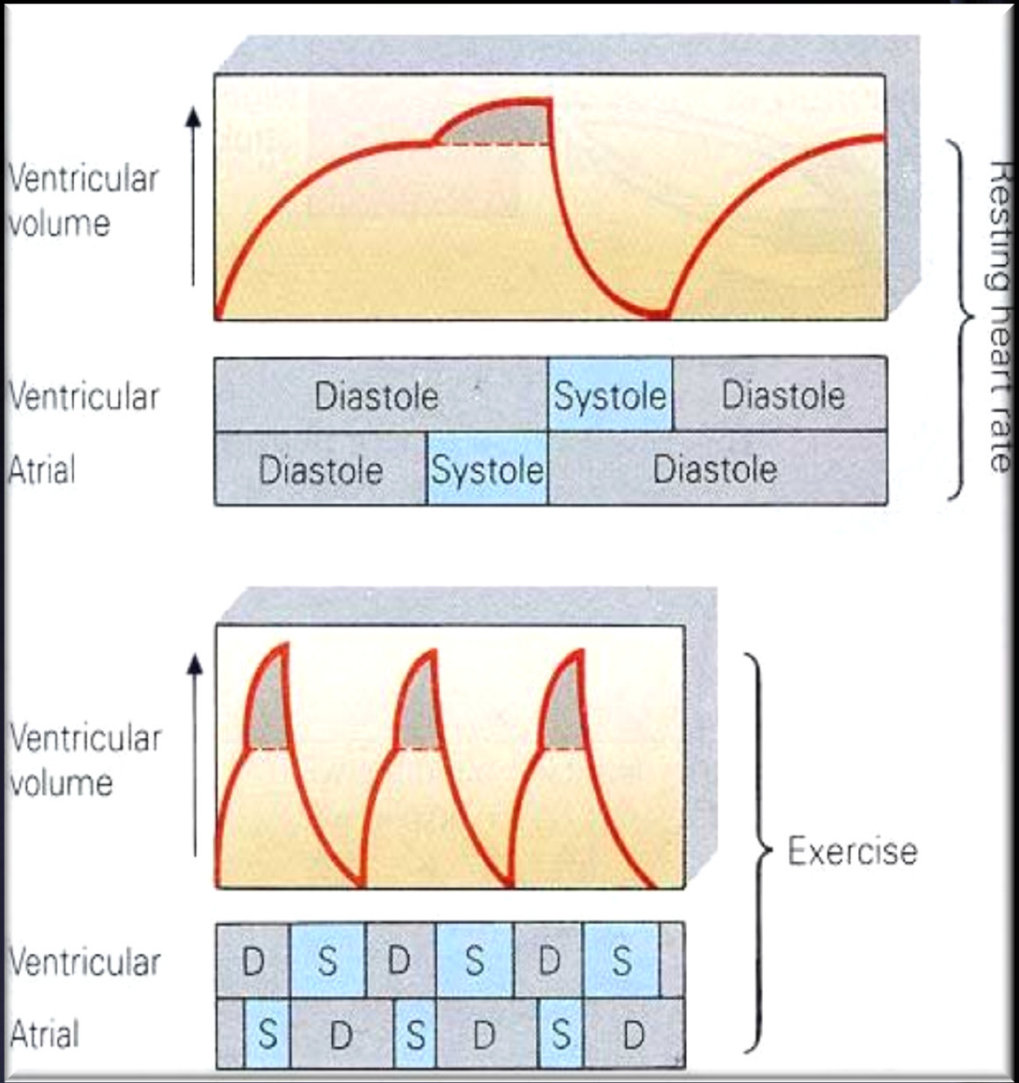
	Heart Rate 75/min	Heart Rate 200/min	Skeletal Muscle
Duration, each cardiac cycle	0.80	0.30	…
Duration of systole	0.27	0.16	…
Duration of action potential	0.25	0.15	0.007
Duration of absolute refractory period	0.20	0.13	0.004
Duration of relative refractory period	0.05	0.02	0.003
Duration of diastole	0.53	0.14	…

[a]All values are in seconds.

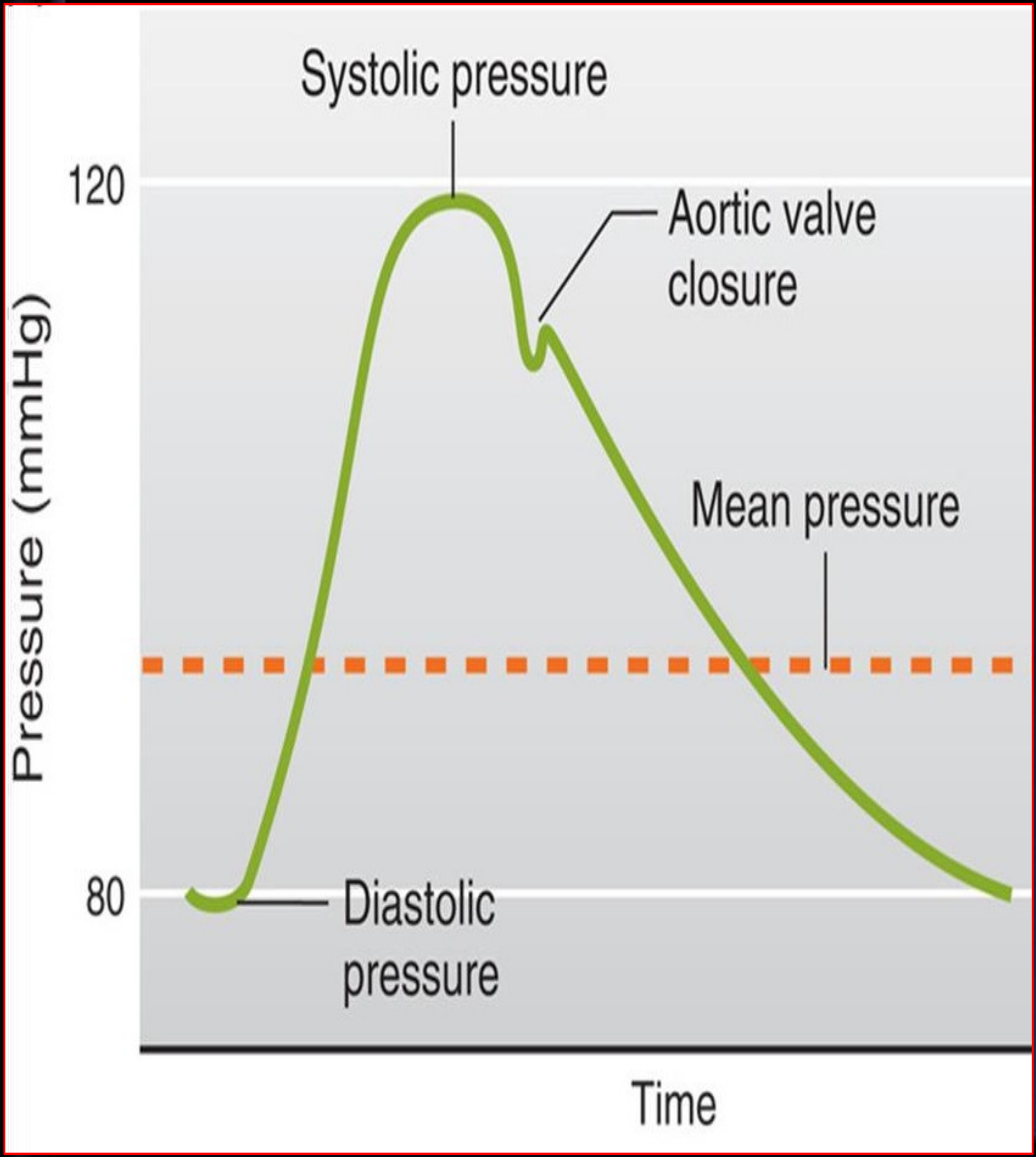
Courtesy of AC Barger and GS Richardson.

EFFECT OF ATRIAL CONTRACTION ON VENTRICLE FILLING

- At rest, atrial contraction adds little extra blood to the ventricles.
- When the heart rate is high, ventricle filling time is reduced.
- During exercise, atrial contraction adds a MORE amount of blood to the ventricles.



Aortic Pressure Curve



a. Ascending or anacrotic limb:

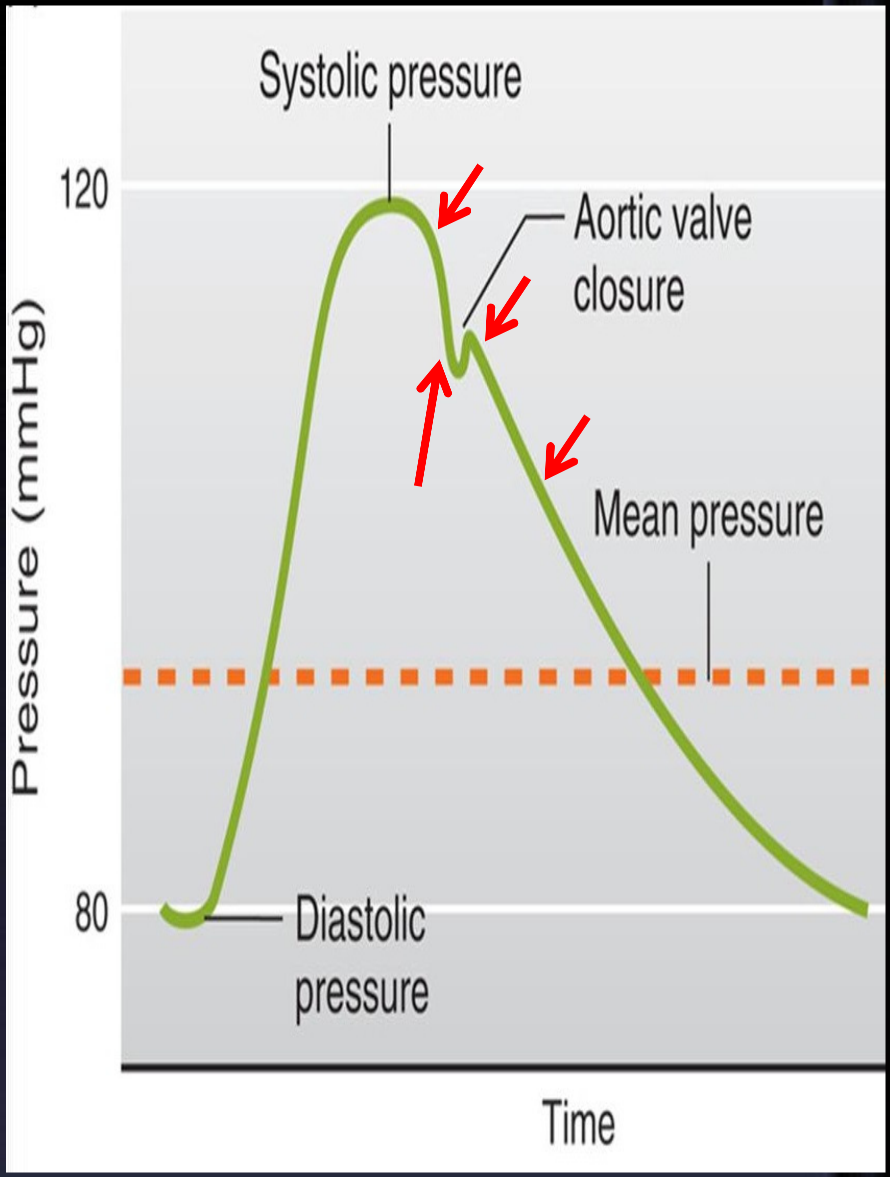
- ❑ This coincides with the 'rapid ejection phase'
- ❑ The amount of blood enters aorta > leaves
- ❑ Aortic pressure ↑ up to 120 mmHg

b. Descending or catacrotic limb: (Has 4 stages)

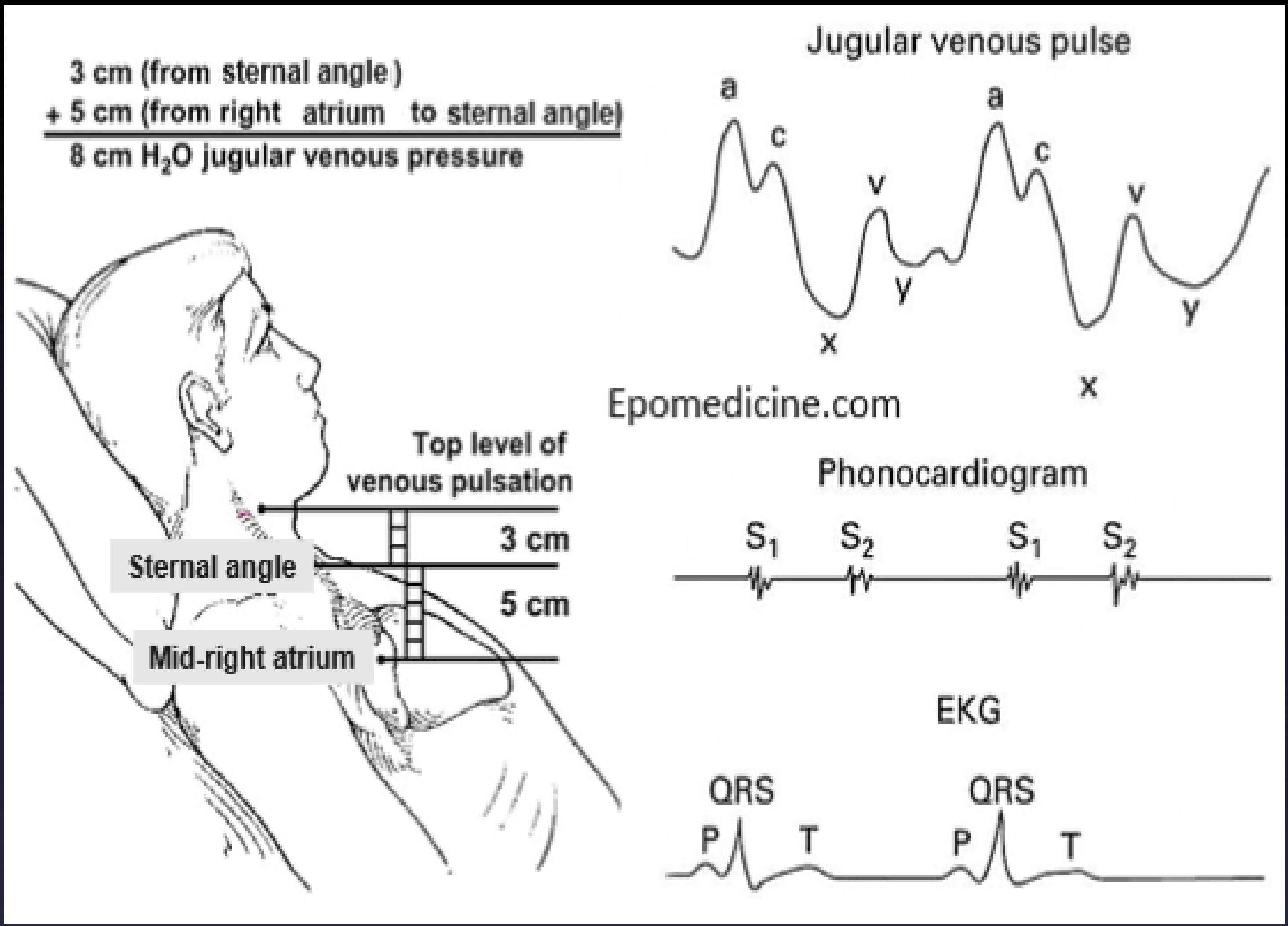
Pulmonary artery pressure changes are similar to the aortic pressure changes [Magnitude 3-4 times Less]. Normal pulmonary artery pressure during the cardiac cycle ≈ 25-30/4-12 mmHg

Descending / catacrotic limb - 4 STAGES

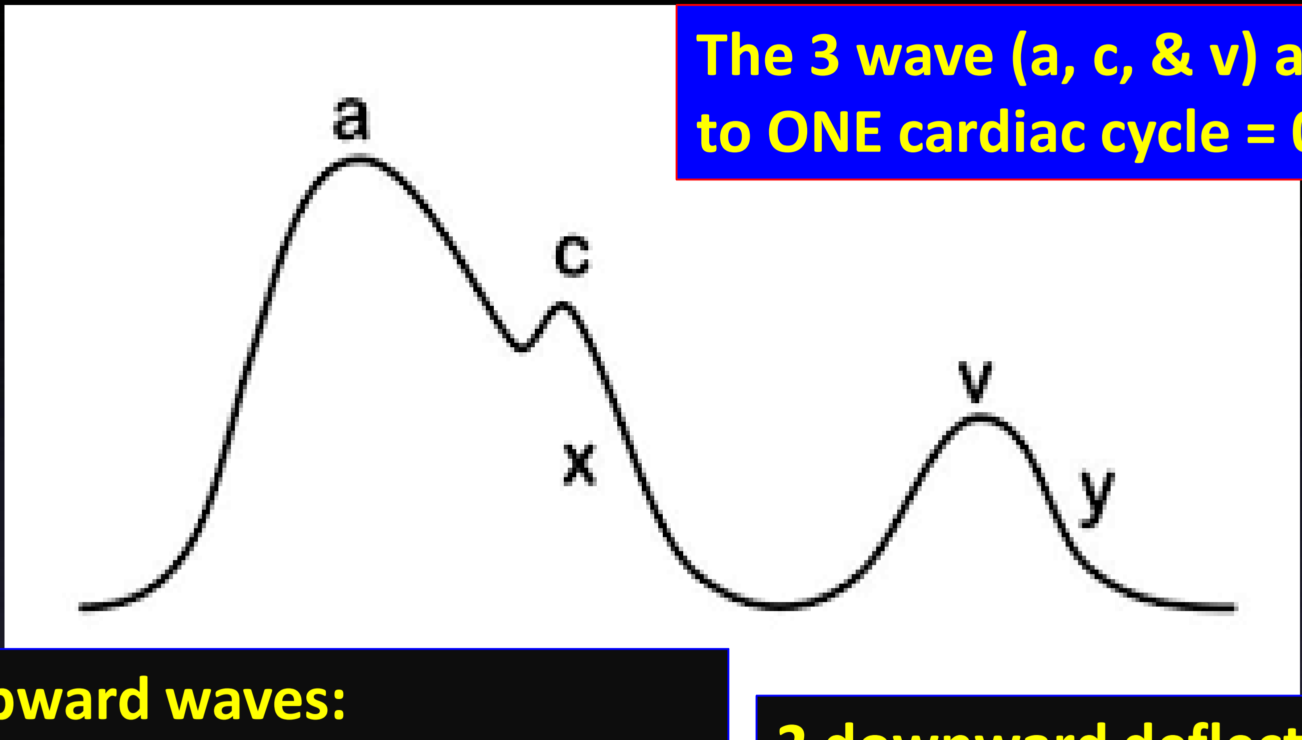
1. ↓ Aortic pressure:
   - ❑ This coincides with the 'reduced ejection phase'
   - ❑ The amount of blood enters aorta < leaves
2. Dicrotic notch (incisura):
   Due to closure of aortic valve
   - ❑ There is sudden drop in aortic pressure
   - ❑ This notch is seen in the aortic pressure curve at end of 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



Atrial pressure changes during the cardiac cycle
THE JUGULAR VENOUS PULSE (JVP)



Atrial pressure changes during the cardiac cycle



The 3 wave (a, c, & v) are equal to ONE cardiac cycle = 0.8 sec

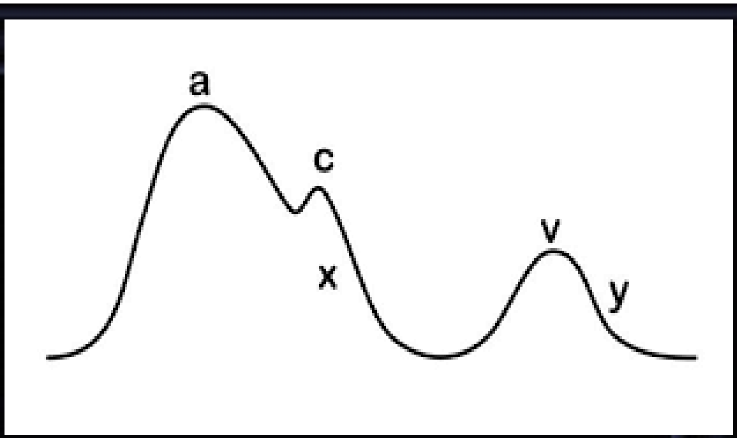
3 upward waves:

- **a, c, & v waves**
- 2 components in each wave: +ve (↑ pr), -ve (↓ pr)

2 downward deflection (waves):

- **x & y waves**

Atrial pressure waves

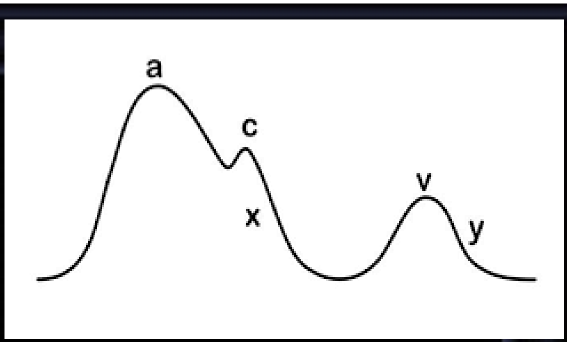


- ‘a’ wave: Atrial systole:

↑ atrial pressure during atrial contraction

- ‘c’ wave: Ventricular systole
    - +ve as a result of bulging of AV valve into the atria during ‘isovolumetric contraction phase’
    - -ve as a result of pulling of the atrial muscle & AV cusps down during ‘rapid ejection phase’, resulting in ↓ atrial pressure

Atrial pressure waves



- 'v' wave: Atrial diastole
  - +ve: atrial pressure ↑ gradually due to continuous VR
  - -ve as a result of ↓ atrial pressure during 'rapid filling phase'
- 'x' descent:
  - Downward displacement of AV valves during 'reduced ejection phase'
- 'y' descent:
  - ↓ atrial pressure during 'reduced filling phase'

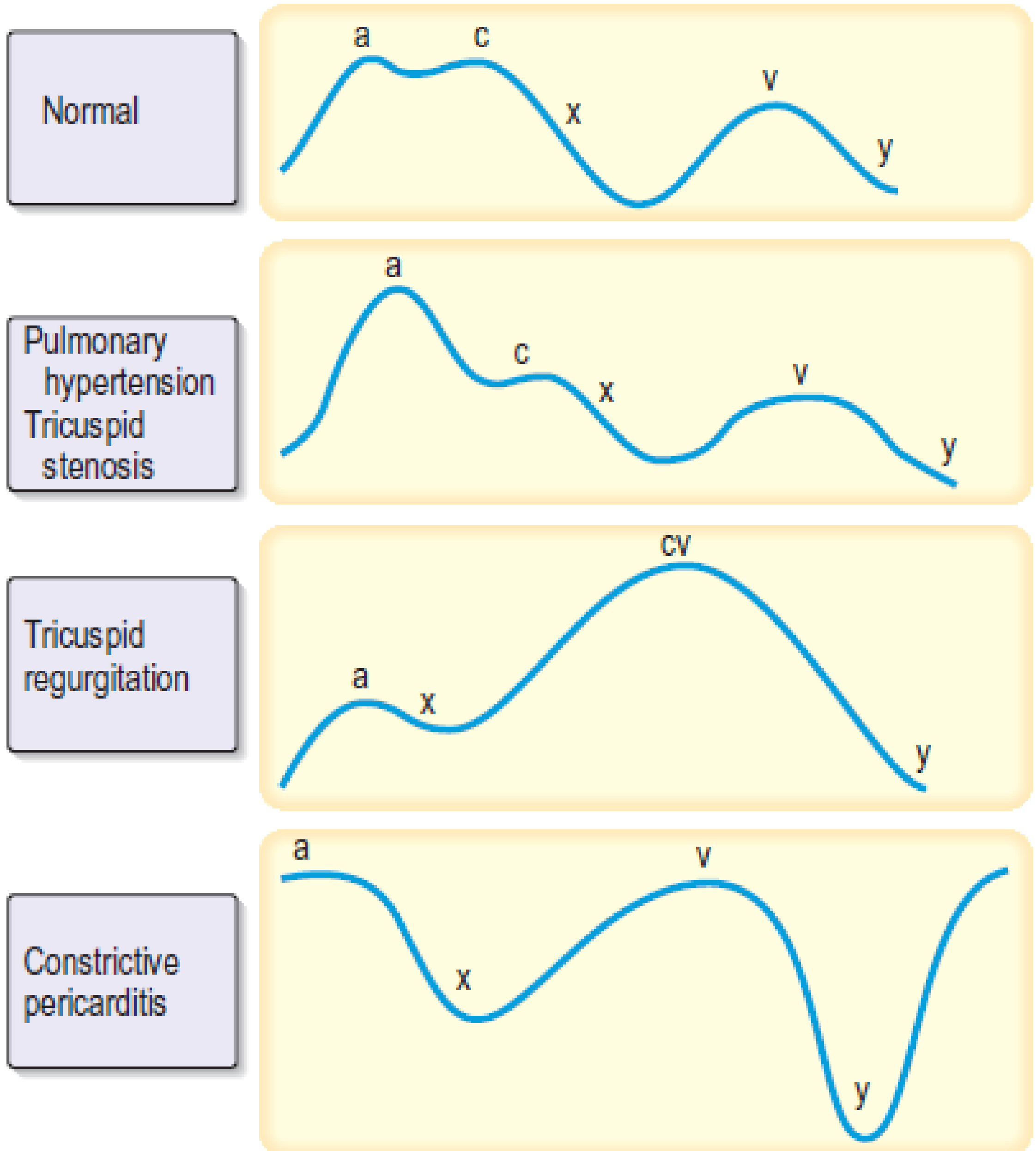


Fig. 13.12 **Jugular venous waveforms.**

ABNORMALITIES OF "a" WAVE

- **Elevated *a* wave**

  Tricuspid stenosis

  Decreased ventricular compliance (ventricular failure, pulmonic valve stenosis, or pulmonary hypertension)

- **Cannon *a* wave**

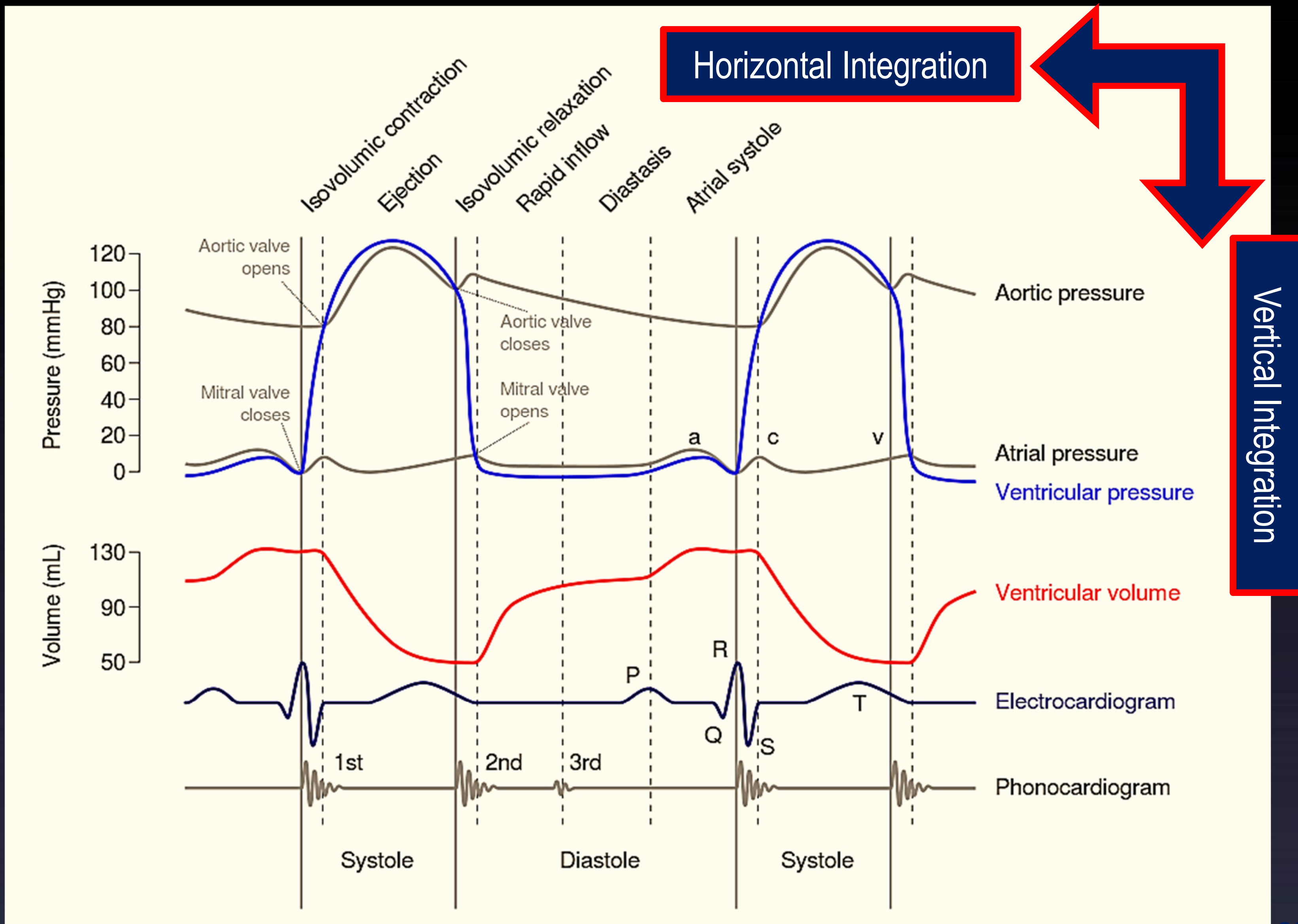
  Atrial-ventricular asynchrony *(atria contract against a closed tricuspid valve)*

  complete heart block, following premature ventricular contraction, during ventricular tachycardia, with ventricular pacemaker

- **Absent *a* wave**

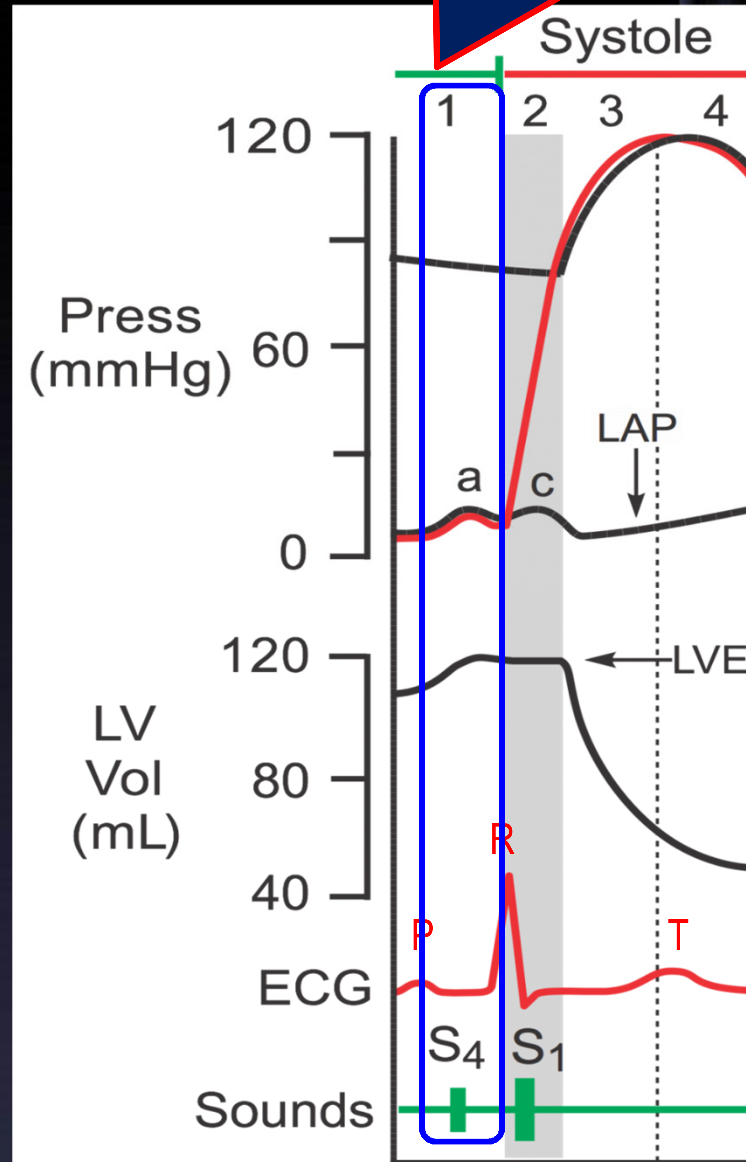
  Atrial fibrillation or atrial standstill
  Atrial flutter

CORRELATING EVENTS TOGETHER



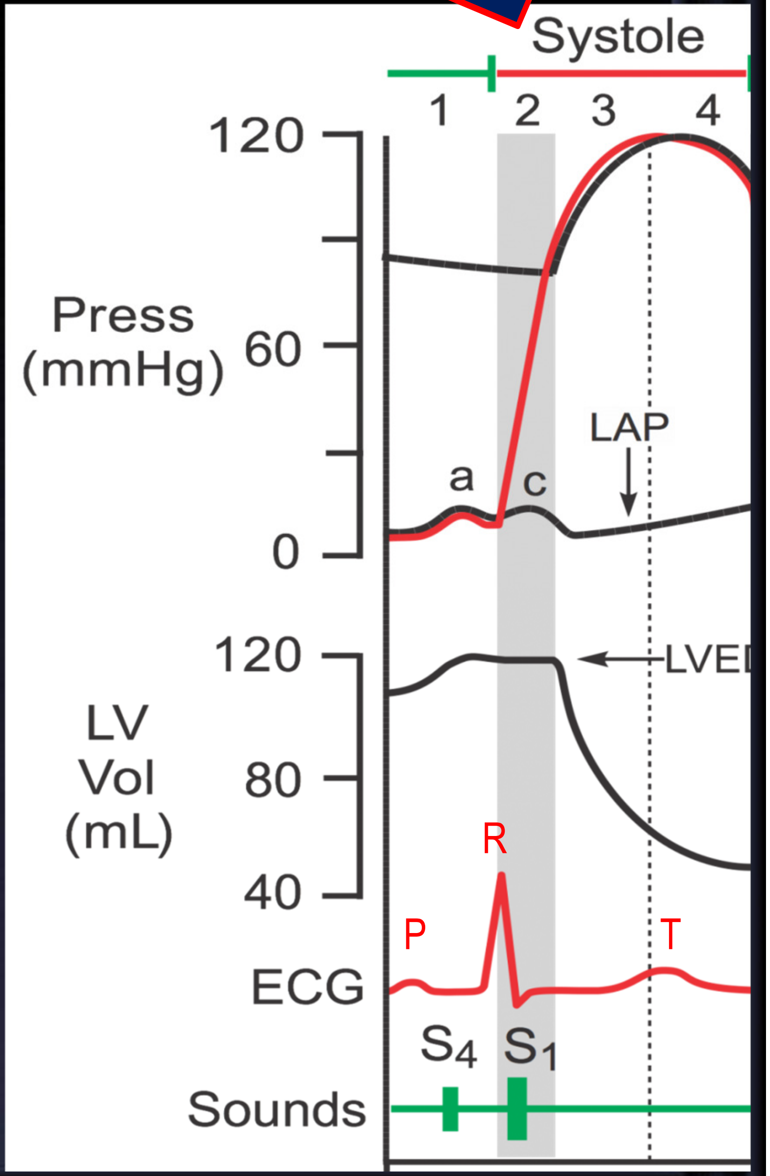
ATRIAL SYSTOLE: 1

- Phase of atrial contraction at end of diastole (JVP – ‘a’ wave) [≈ 0.11 sec]
- Preceded by atrial depolarization (P wave).
- **Valves:** A-V valves open (semilunar valves closed). blood goes from atria to ventricles.
- **Ventricular volume:** up to 130 ml (EDV) .
- **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.
- **4th (S4) Heart sound** heard (Vibration of the vent wall during atrial contraction).



ISOVOLUMETRIC CONTRACTION: 2

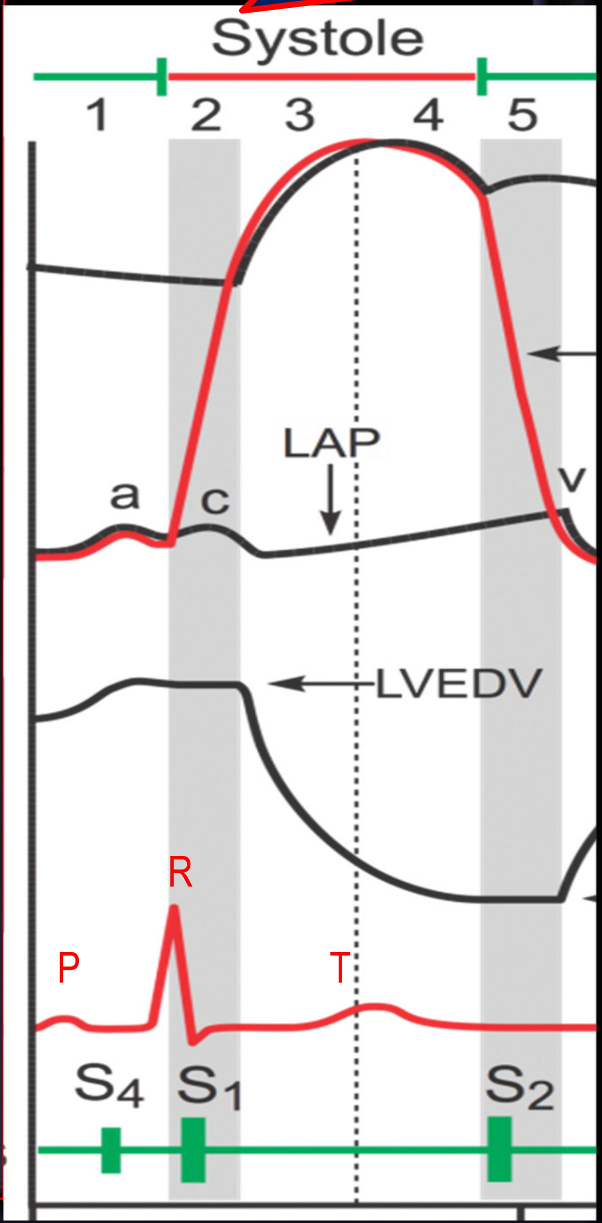
- Start of ventricular systole [≈ 0.04 sec]
- Starts with closure of **A-V valves**.
- **Heart Sounds:** S_1
- **Semilunar valves:** Still closed
- Ventricle contracts with no changes in volume (isometrically, no shortening)
- **ECG:** End of QRS complex
- **Volume in ventricle:** EDV (120 ml)
- **Ventricular 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.
- **JVP** – 'c' wave → due to the bulging of the Tricuspid valve into RA



Rapid

EJECTION 3 Rapid, 4 Slow

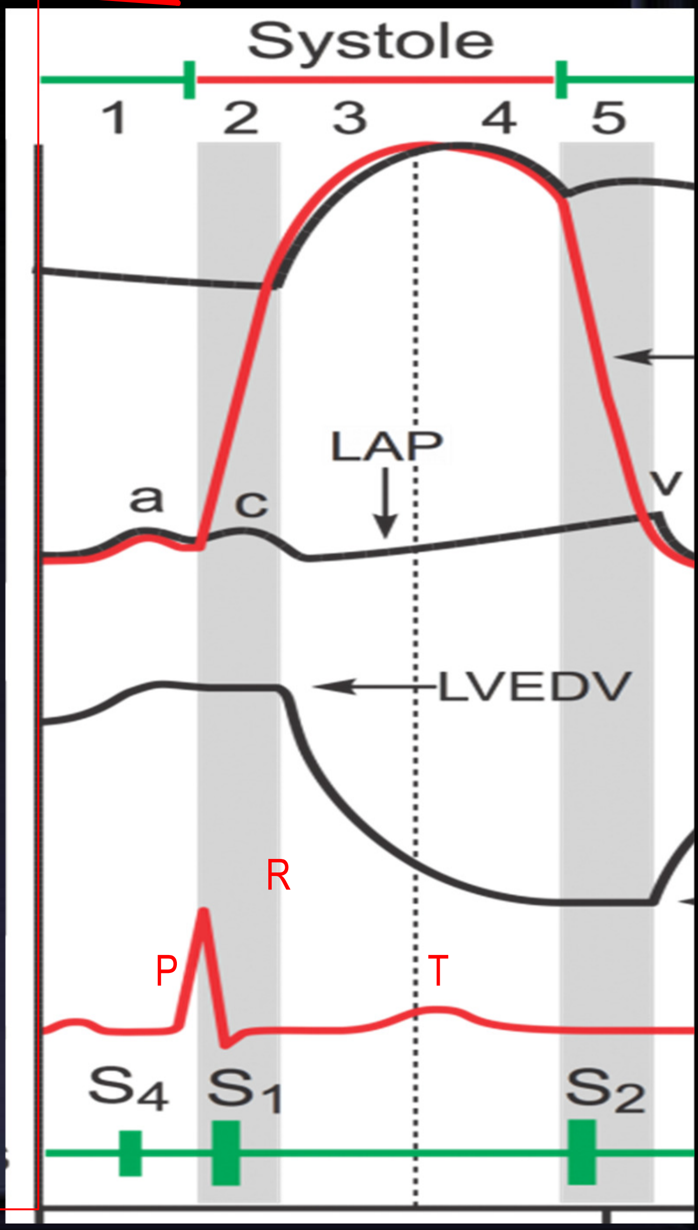
- The ventricles contract isotonically (with shortening) ejecting 75% of stroke volume.
- Duration: ≈ 0.15 sec.
- Semilunar valves open at beginning of this phase when LV pressure exceeds 80 mmHg.
- **AV valves:** Still closed.
- **Ventricular pressure:** ↑
- **Ventricular volume:** ↓
- Atrial pressure: First ↓ because when ventricles contract, they pull fibrous AV ring with AV valves downward
- **Heart sounds:** none
- **Aortic pressure:** ↑
- **ECG** – T wave
- **Heart sounds** – none



Slow

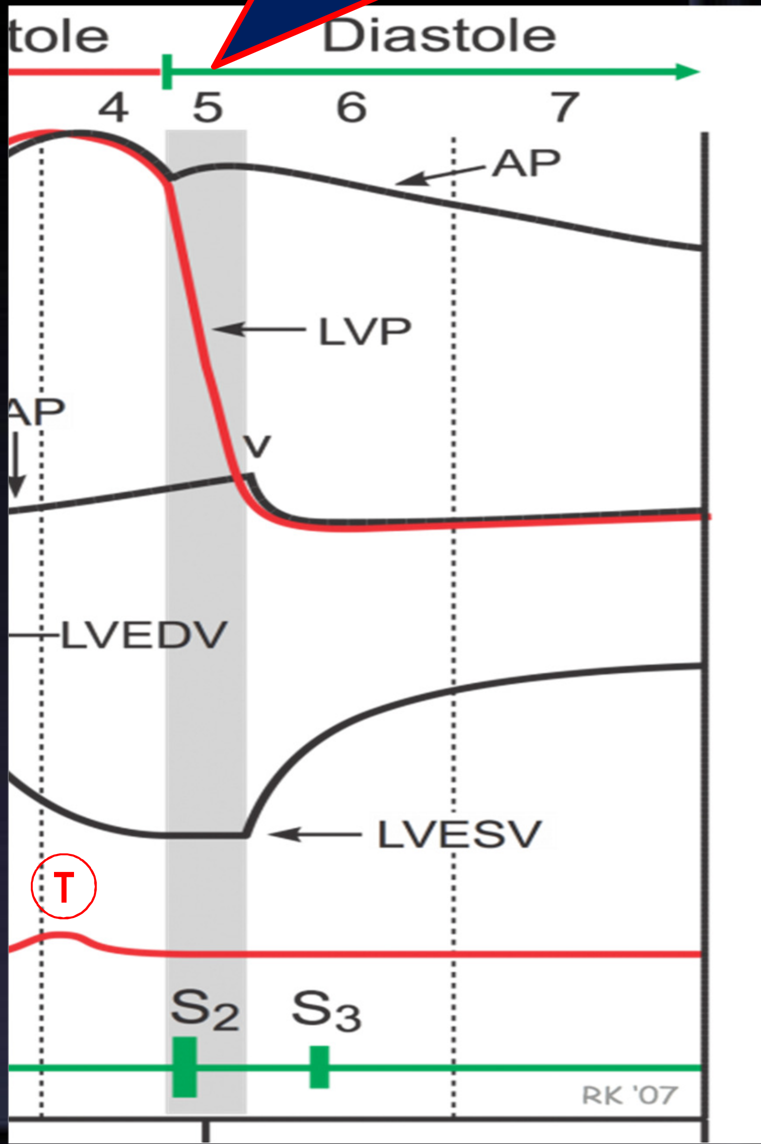
EJECTION 3 Rapid, 4 Slow

- The ventricles contract with lesser force and less blood is ejected (end of systole).
- Almost 25% of Stroke Volume is ejected.
- **Duration:** ≈ 0.10 sec.
- **AV valves:** Still closed.
- Semilunar valves: Still opened.
- Atrial pressure: Still ↑ gradually due to venous return.
- **Ventricular volume:** Continue to ↓.
- **Ventricular pressure:** ↓
- **Heart sounds:** none
- **Aortic pressure:** ↓ Even at the end of systole pressure in the aorta is maintained at 80-90 mm Hg (Why?)
- **ECG:** T wave
- **Heart sounds:** none



ISOVOLUMETRIC RELAXATION: 5

- The ventricles relax at the start of diastole.
- It lasts for ≈ 0.06 sec.
- **Ventricular volume:** is constant at the ESV (60 ml).
- **Semilunar valves:** close at the beginning of the phase (Result in S2).
- **A-V valves:** Still closed.
- **Ventricular pressure:** ↓ rapidly,
- **Atrial pressure:** Still ↑ gradually due to accumulation of venous blood. **(JVP:** ‘v’ wave)
- **ECG:** End of T wave
- **Aortic pressure curve: INCISURA** - backflow of blood coming across a closed aortic valve

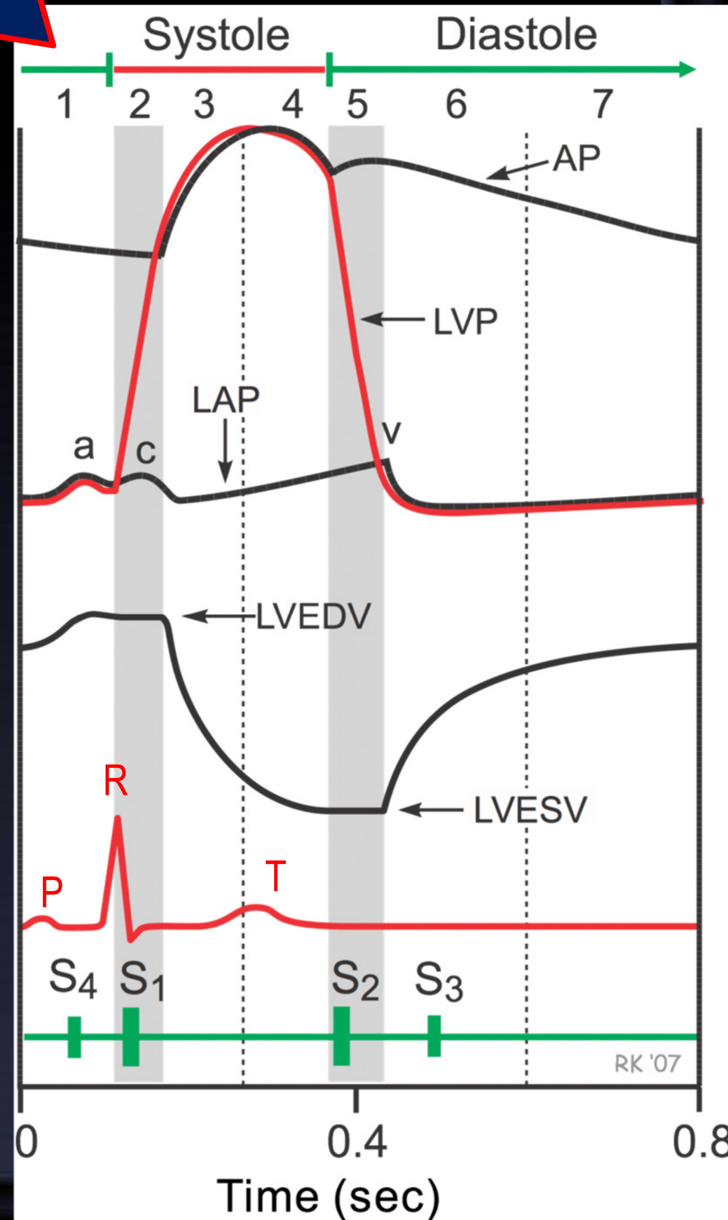


Rapid filing

VENTRICULAR FILLING

Rapid filing 6: Reduced filling 7: Atrial contraction 1

- About **60-70%** of blood passes passively to the ventricles [≈ 0.11 sec].
- **Heart sound:** [S3] 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



Reduced filling

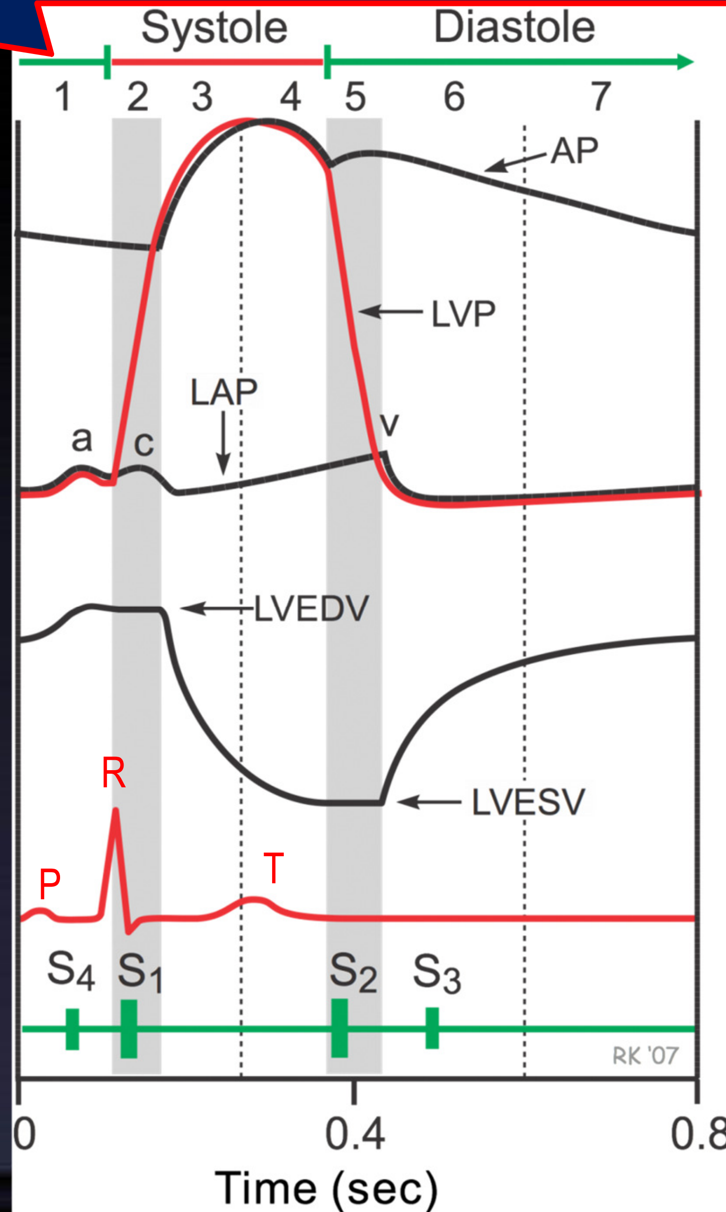
VENTRICULAR FILLING

Rapid filing 6: Reduced filling 7: Atrial contraction 1

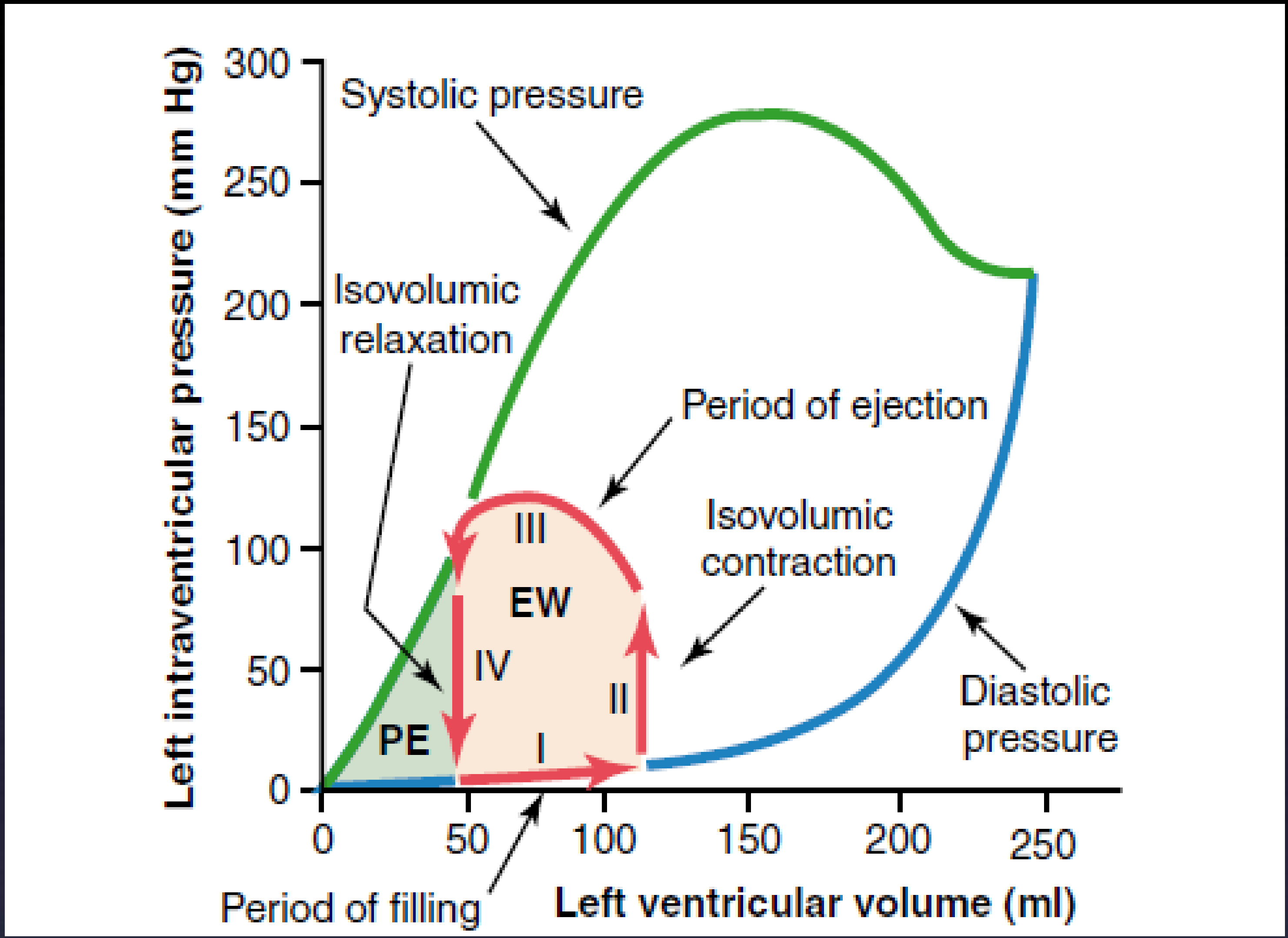
- Remaining atrial blood flows slowly into ventricles by pressure gradient <5%. [≈ 0.22 sec]
- **A-V valves:** still open.
- **Semilunar valves:** Still closed.
- **Atrial pressure:** Still ↑
- **Ventricular volume:** Still ↑
- **Ventricular pressure:** Slightly ↑ gradually

➢**JVP** – ‘y’ descent in first 2/3 & ‘a’ wave in last 1/3

➢**ECG** – P wave before atrial systole

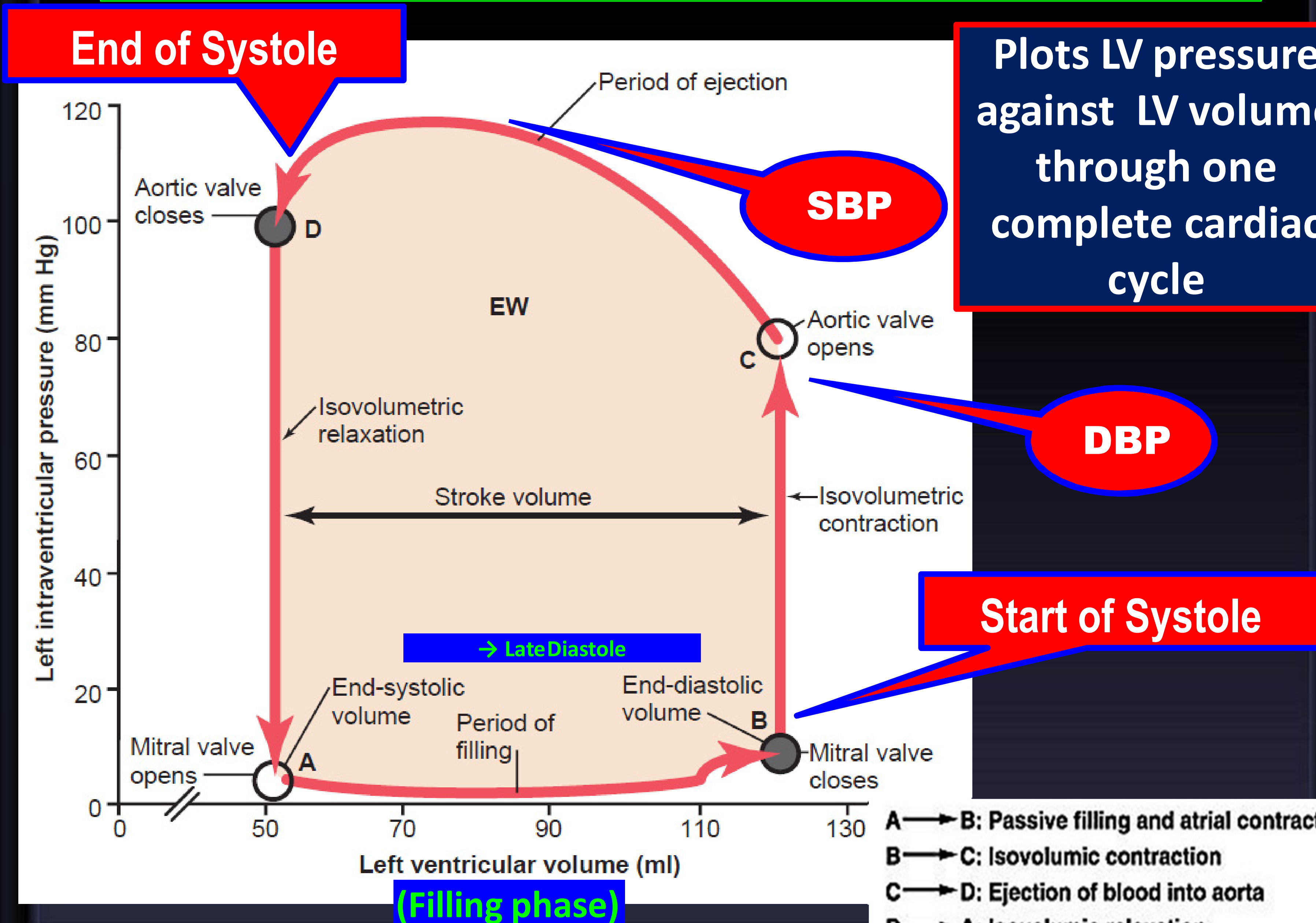


"Volume-Pressure Diagram" During the Cardiac Cycle; Cardiac Work Output.



VENTRICULAR PRESSURE - VOLUME LOOP

Plots LV pressure against LV volume through one complete cardiac cycle



A → B: Passive filling and atrial contraction
B → C: Isovolumic contraction
C → D: Ejection of blood into aorta
D → A: Isovolumic relaxation

A. Increased preload: ↑ venous return → **increase in SV** based on the Frank–Starling relationship….reflected in **increased width** of the PV loop.

B. Increased afterload: due to an increase in aortic pressure → decrease in stroke volume….is reflected in decreased width of the PV loop.

C. Increased contractility: → **increased width & height of the PV loop.**

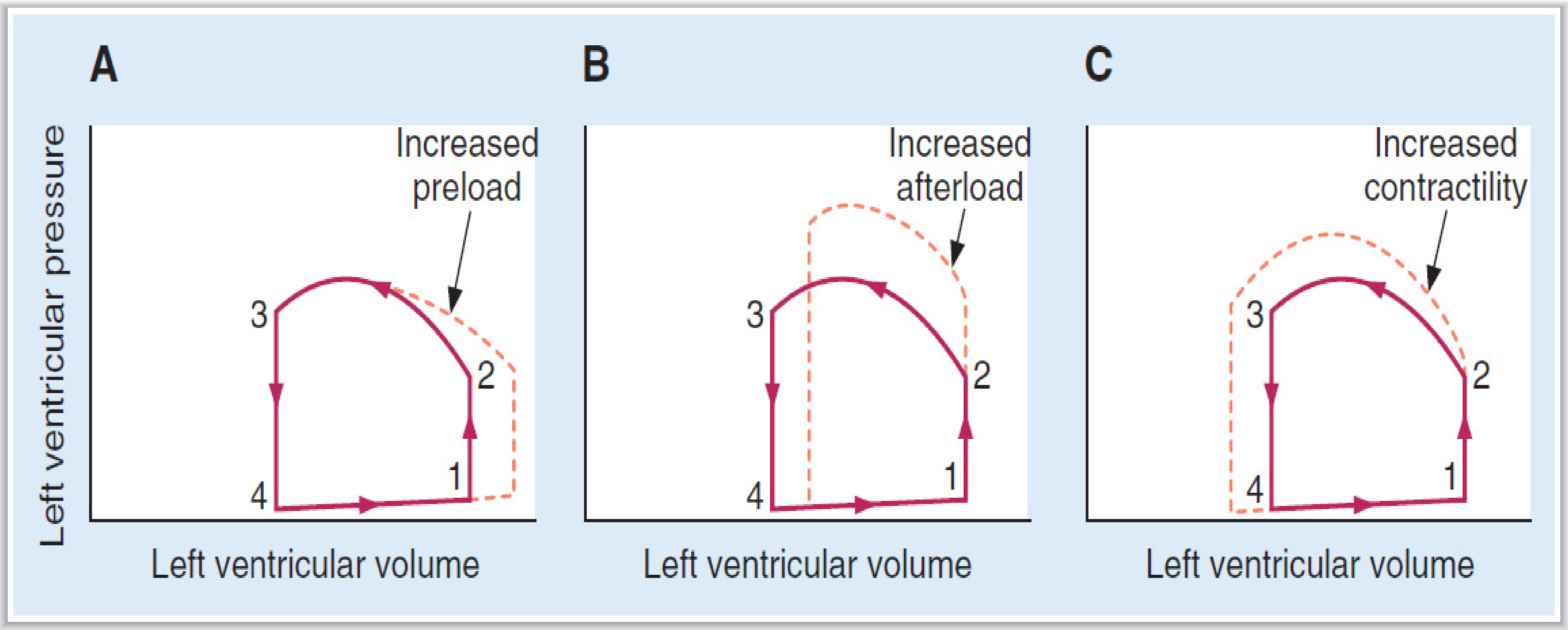


FIGURE 3-10 Effects of changes in (**A**) preload, (**B**) afterload, and (**C**) contractility on the ventricular pressure–volume loop.