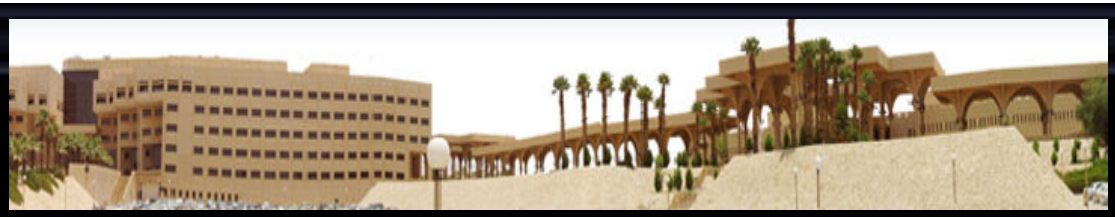
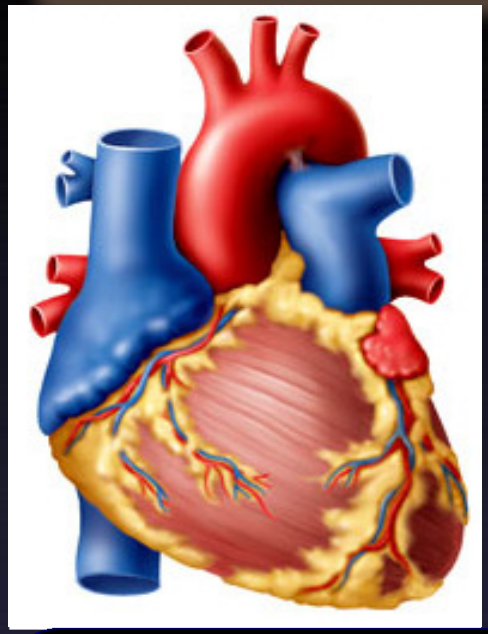
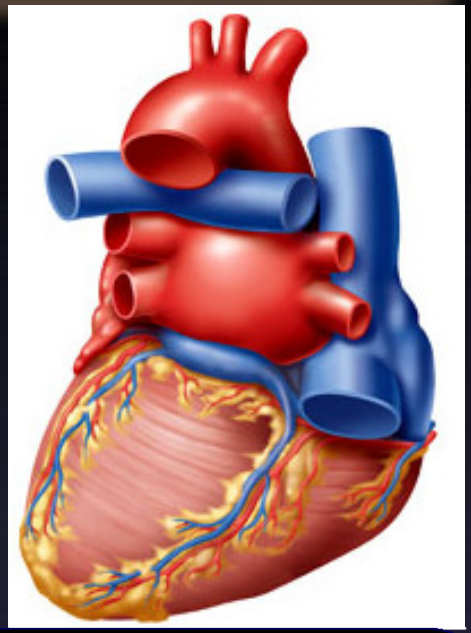


CARDIOVASCULAR SYSTEM

CARDIAC CYCLE





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OBJECTIVES

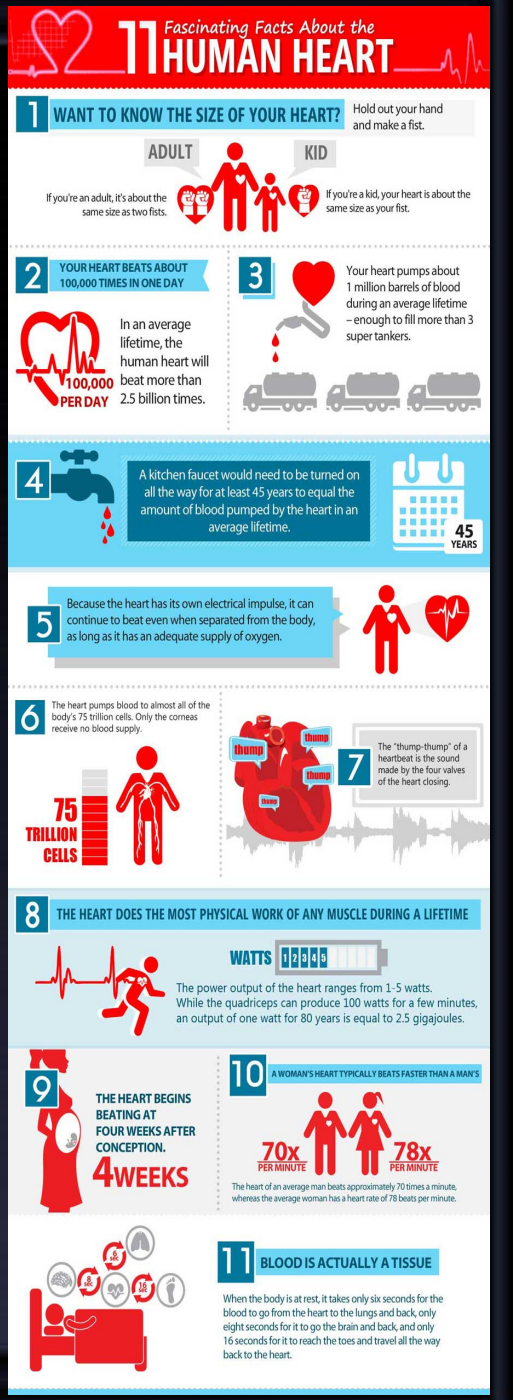
❖ **At the end of the lecture you should be able to …..**

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 2,500 million times and pumps 110 million gallons of blood.
- 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?

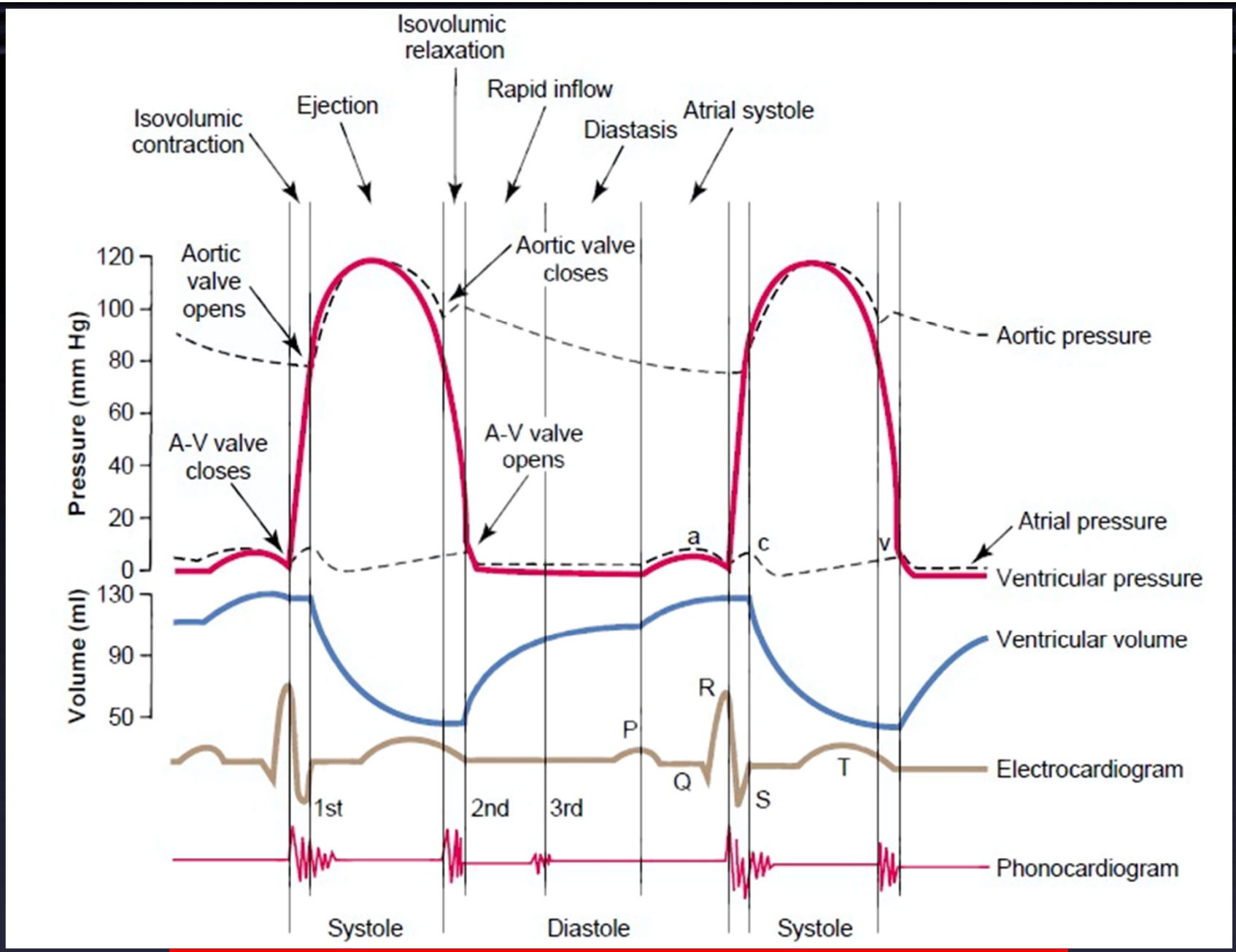
EVENTS OF CARDIAC CYCLE

Mechanical changes:

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

Electrical Changes

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

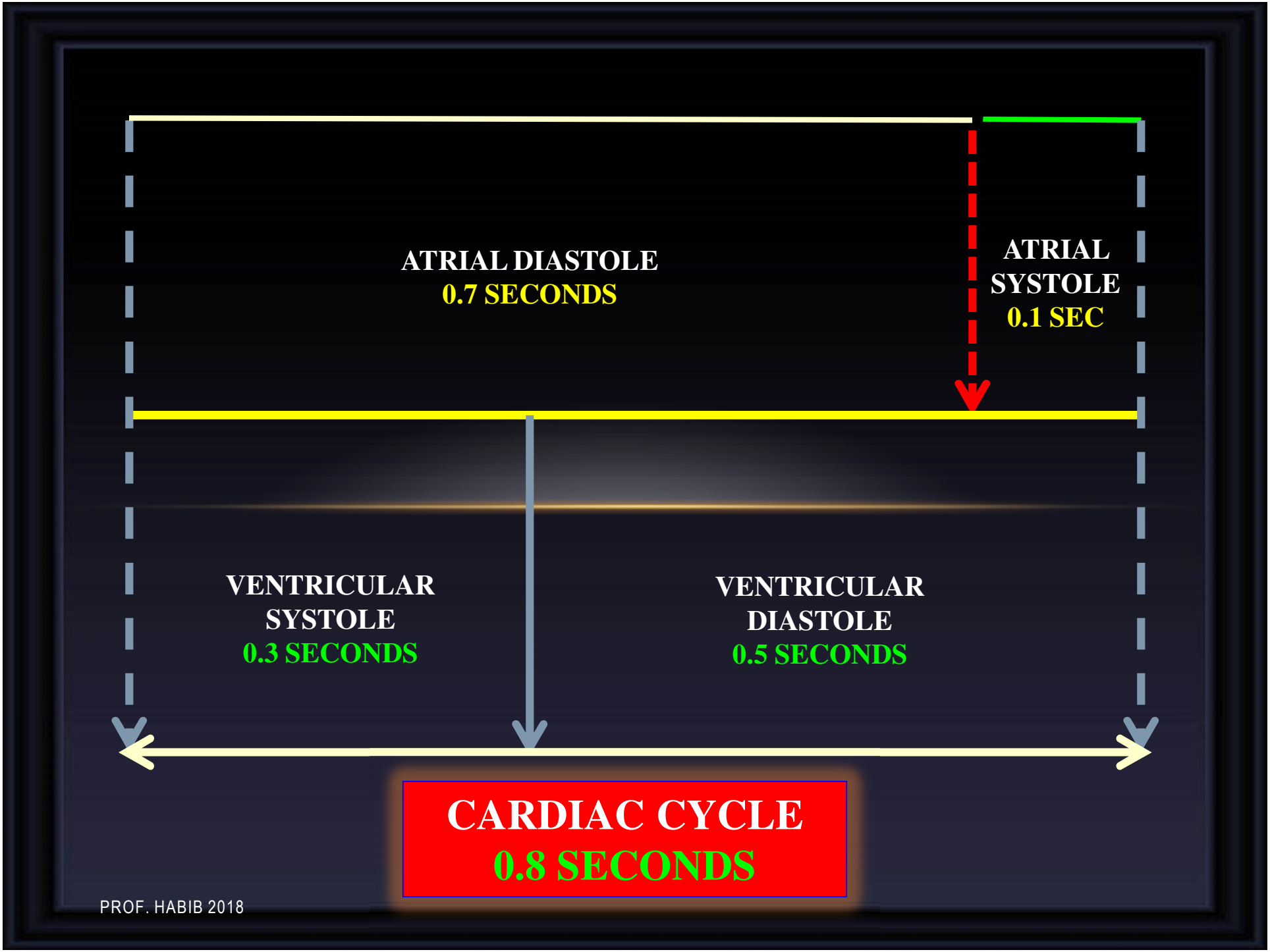

ATRIAL DIASTOLE
0.7 SECONDS
ATRIAL
SYSTOLE
0.1 SEC
VENTRICULAR
SYSTOLE
0.3 SECONDS
VENTRICULAR
DIASTOLE
0.5 SECONDS
CARDIAC CYCLE
0.8 SECONDS
PROF. HABIB 2018

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.

VENTRICULAR EVENTS

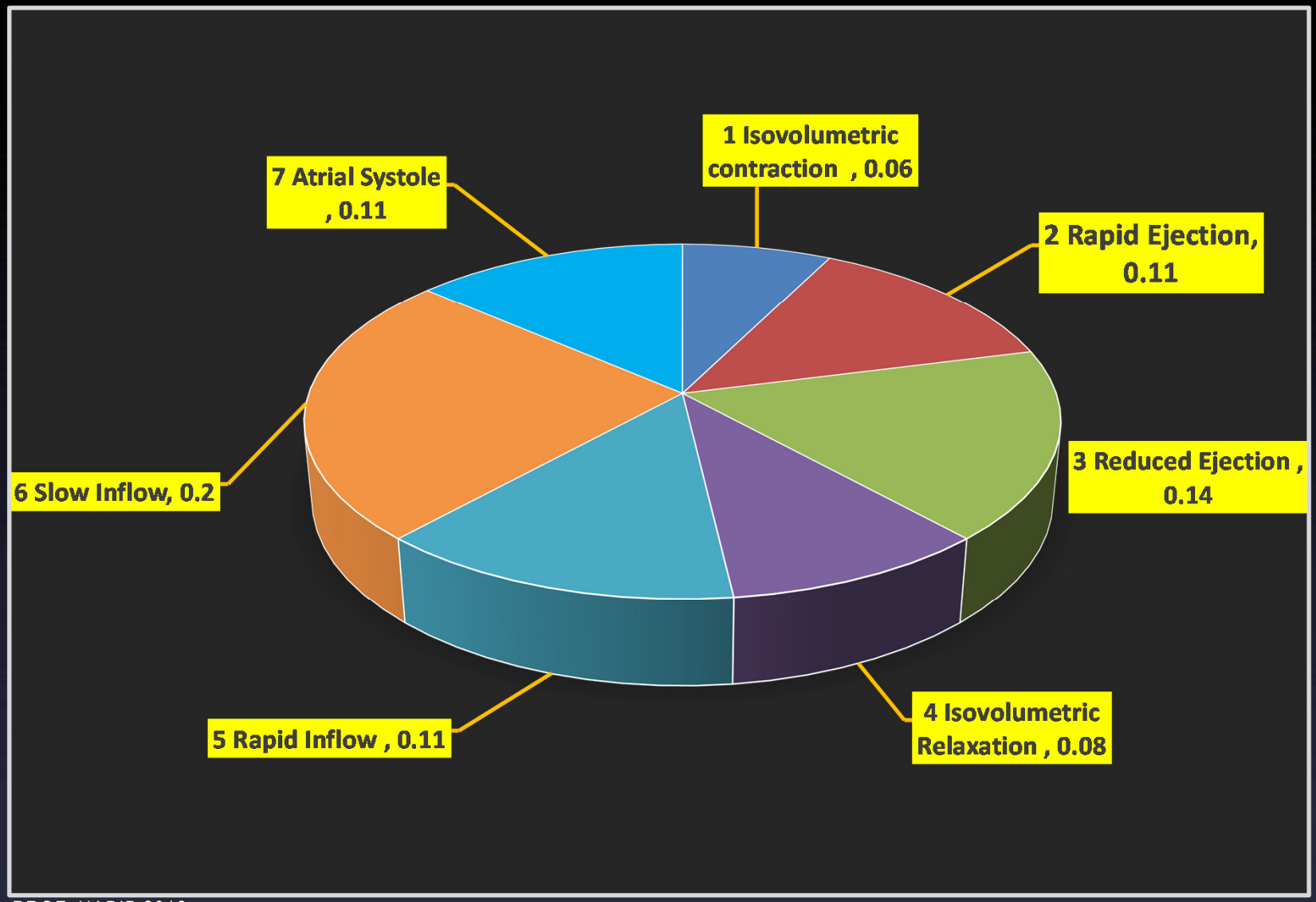
- **Ventricular systole**

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

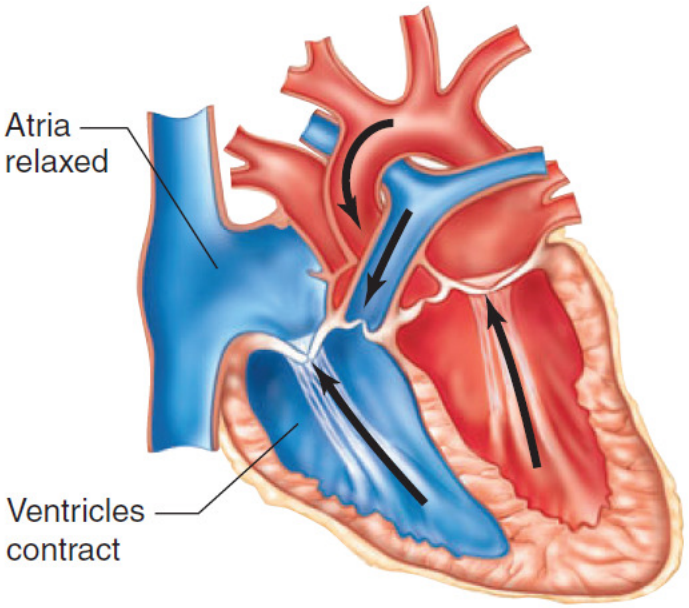


VENTRICULAR SYSTOLE (Peak of R wave of QRS complex to the end of T wave)	**0.31 sec**
ISO-VOLUMETRIC CONTRACTION	0.06 sec
MAXIMUM EJECTION (2/3, 70%)	0.11 sec
REDUCED EJECTION (1/3, 30%)	0.14 sec
VENTRICULAR DIASTOLE (End of T wave to the peak of R wave of QRS complex)	**0.52 sec**
ISO-VOLUMETRIC RELAXATION	0.06 sec
RAPID INFLOW	0.11 sec
SLOW INFLOW / DIASTASIS	0.2 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

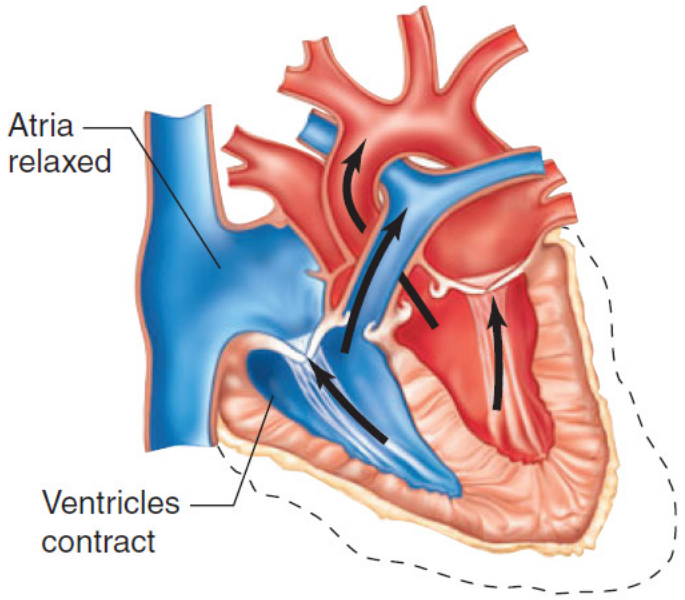
A Systole

Isovolumetric ventricular contraction



Ventricular ejection

Blood flows out of ventricle



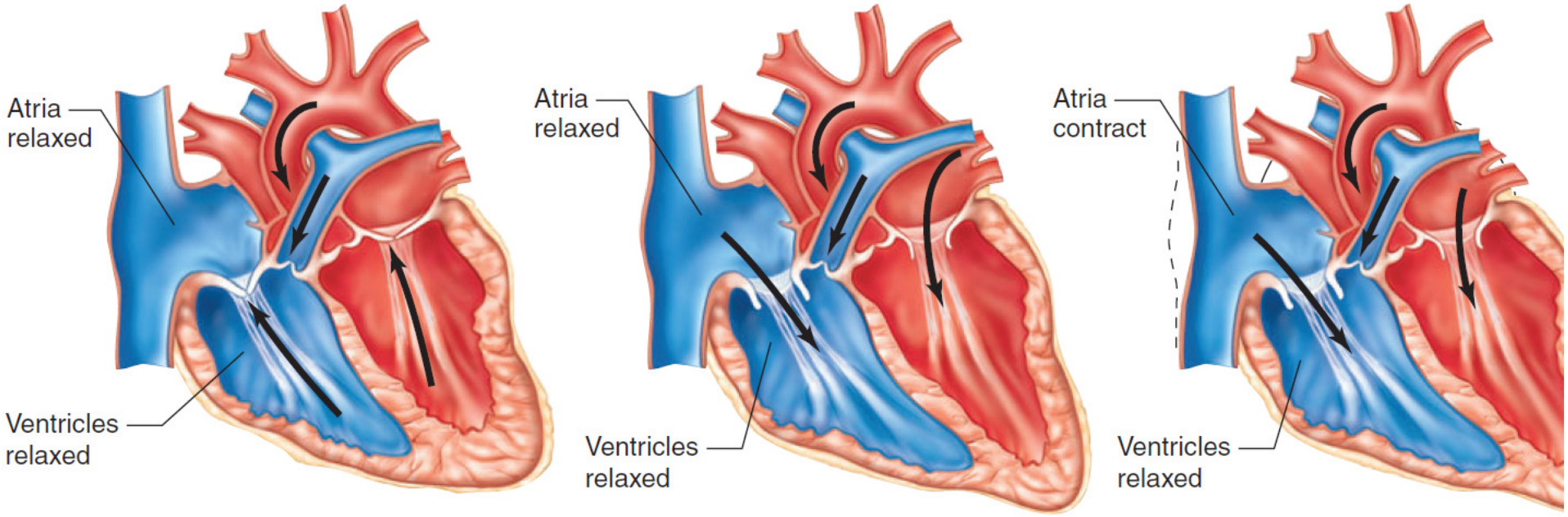
AV valves:	Closed	Closed
Aortic and pulmonary valves:	Closed	Open

B Diastole

Isovolumetric ventricular relaxation

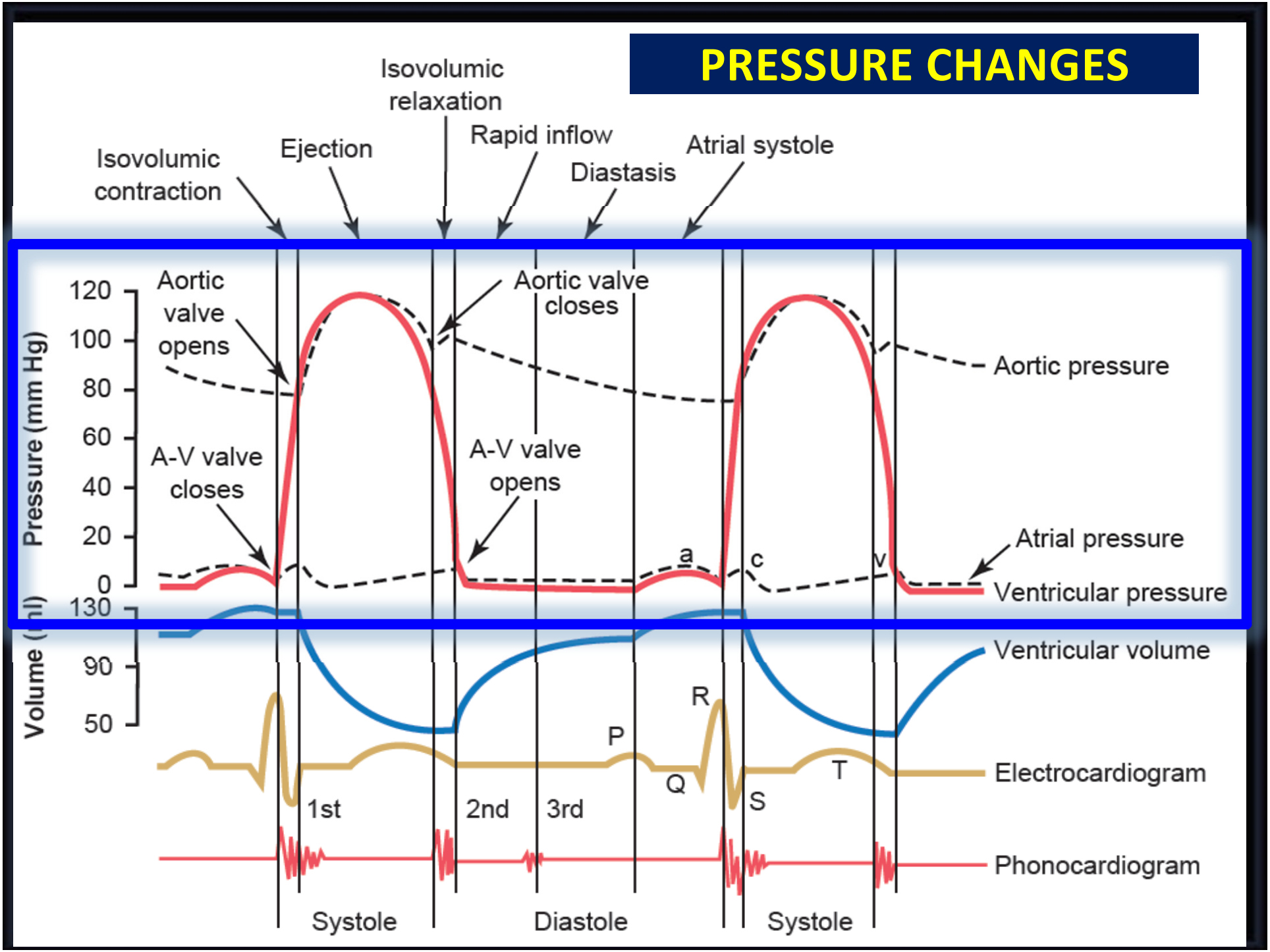
Ventricular filling
Blood flows into ventricles

Atrial contraction



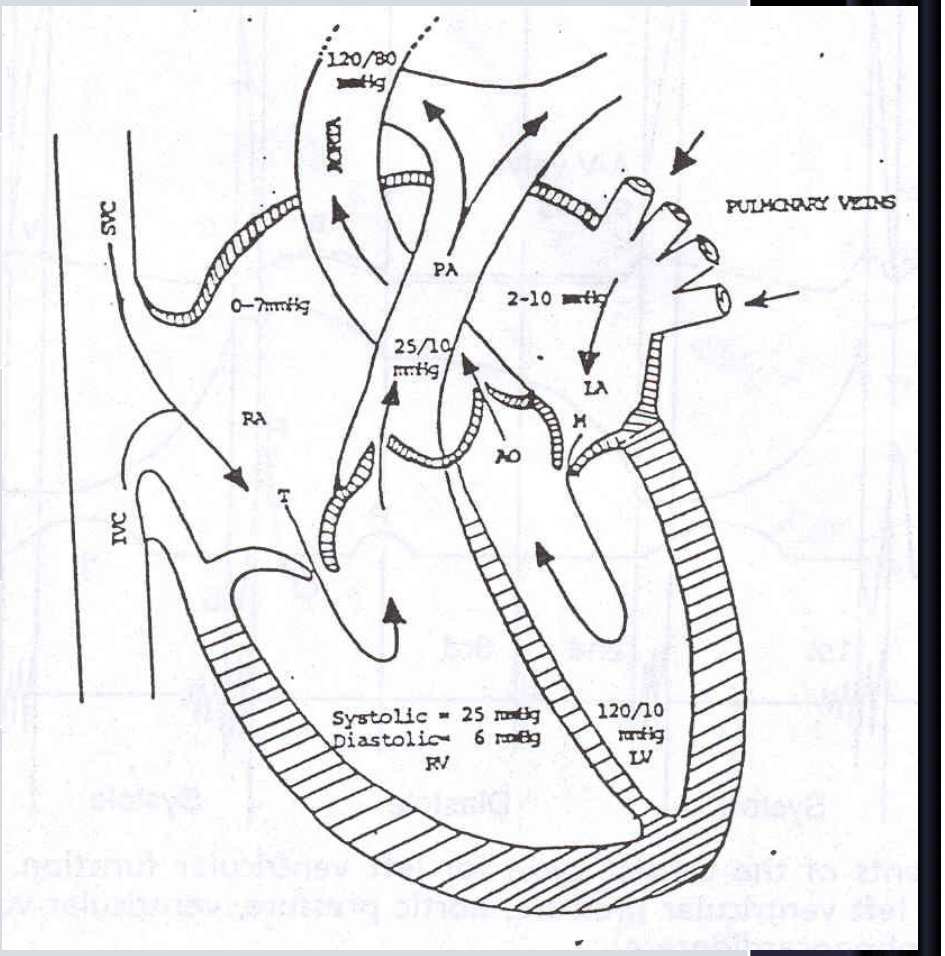
AV valves:	Closed	Open	Oper
Aortic and pulmonary valves:	Closed	Closed	Clos

PRESSURE CHANGES

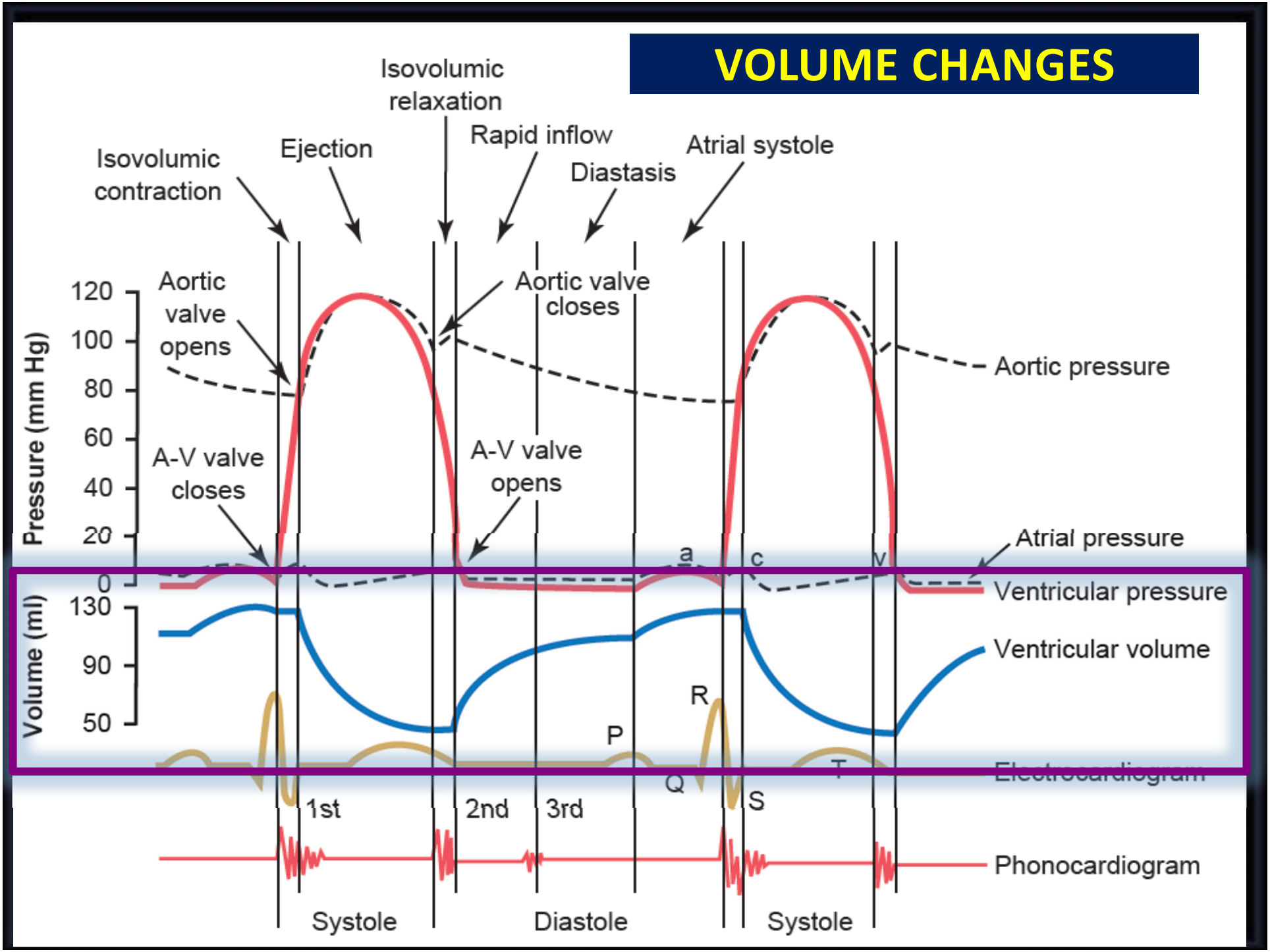


VARIOUS PRESSURE VALUES

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



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

↓

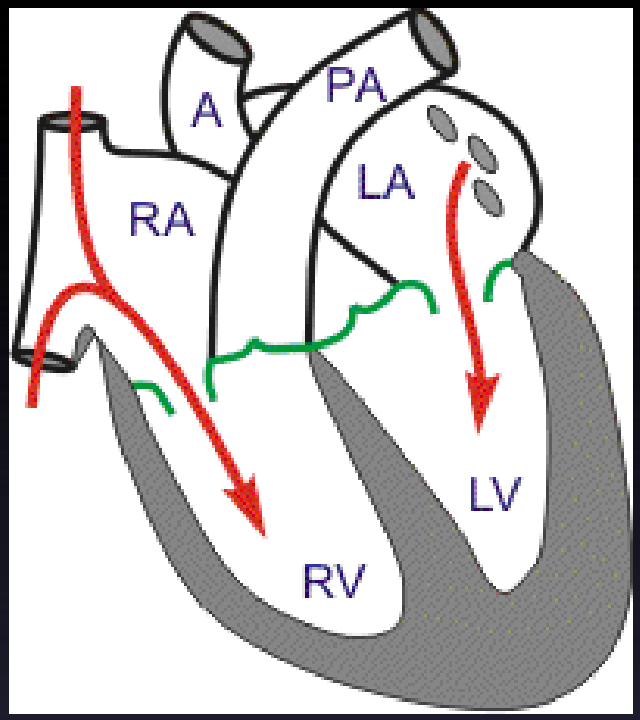
Atrial contraction

↓

Atrial pressures rise

↓

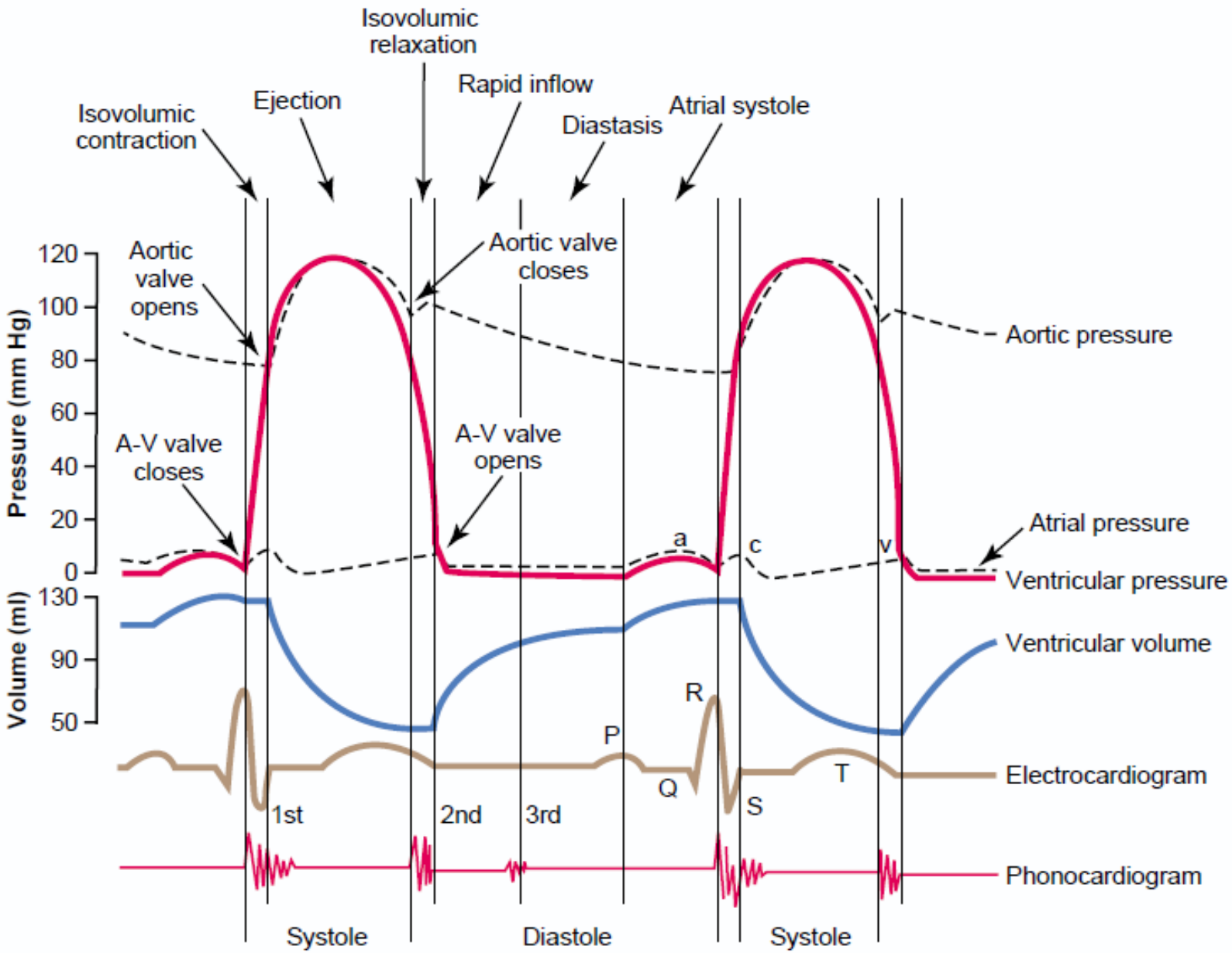
Blood flows across AV valves



ATRIA = PRIMER PUMPS .

Ventricular filling :

- 80% - direct flow from SVC & IVC
- 20% - atrial contraction.


Isovolumic relaxation
Ejection
Rapid inflow
Isovolumic contraction
Diastasis
Atrial systole
Aortic valve opens
Aortic valve closes
Aortic pressure
A-V valve closes
A-V valve opens
Atrial pressure
Ventricular pressure
Ventricular volume
Electrocardiogram
Phonocardiogram
Pressure (mm Hg)
120
100
80
60
40
20
0
Volume (ml)
130
90
50
a
c
v
R
P
Q
S
T
1st
2nd
3rd
Systole
Diastole
Systole

ISOVOLUMETRIC CONTRACTION

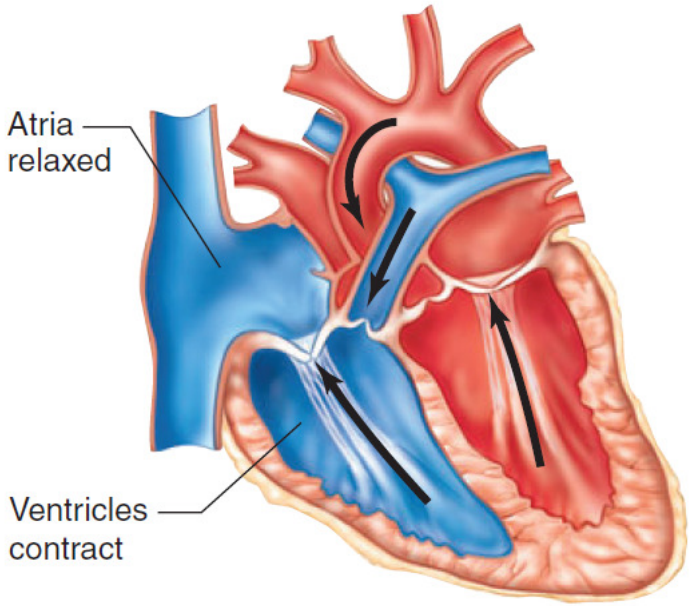
Increase in ventricular pressure > atrial pressure → AV valves close

After 0.02s, 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

Isovolumetric ventricular contraction



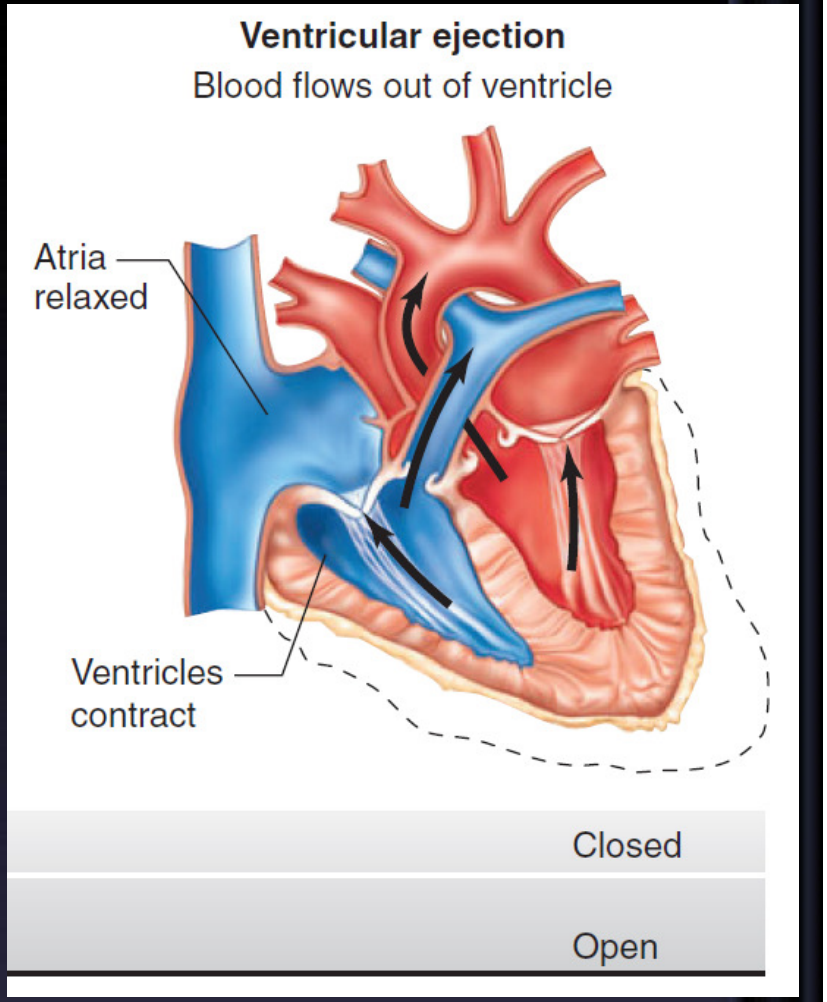
AV valves:	Closed
Aortic and pulmonary valves:	Closed

EJECTION

- When LV pres > 80 mm Hg

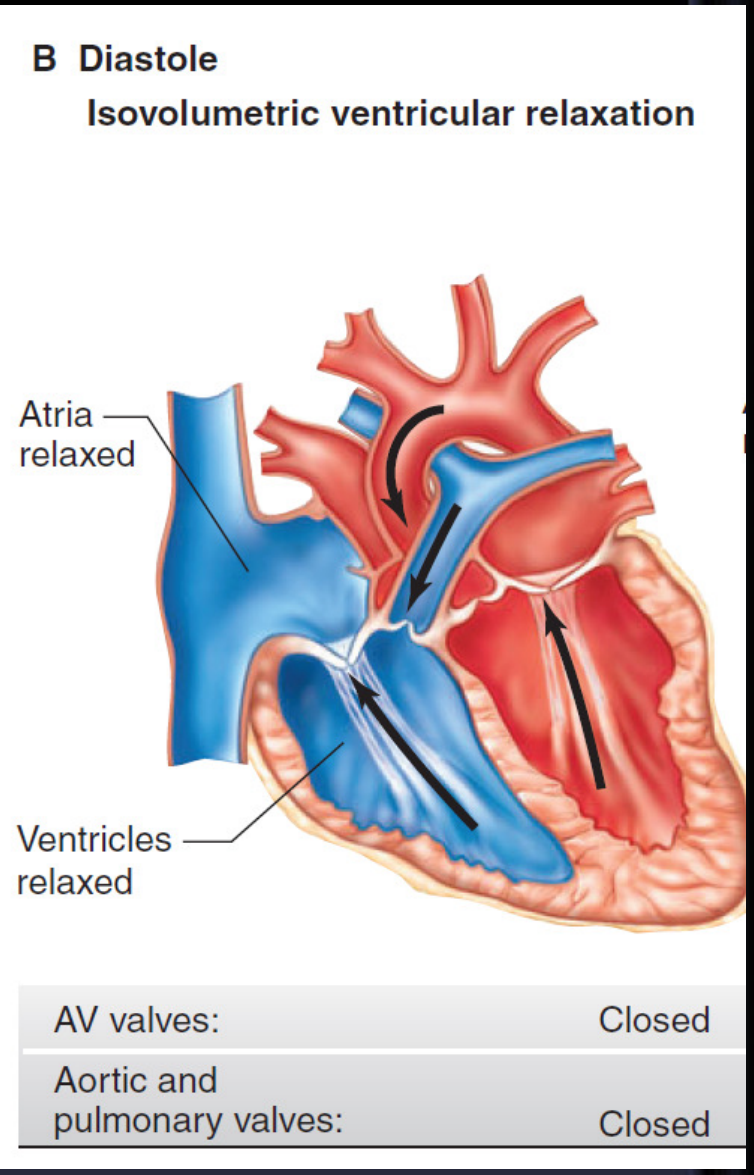
  RV pres > 8 mm Hg,

  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



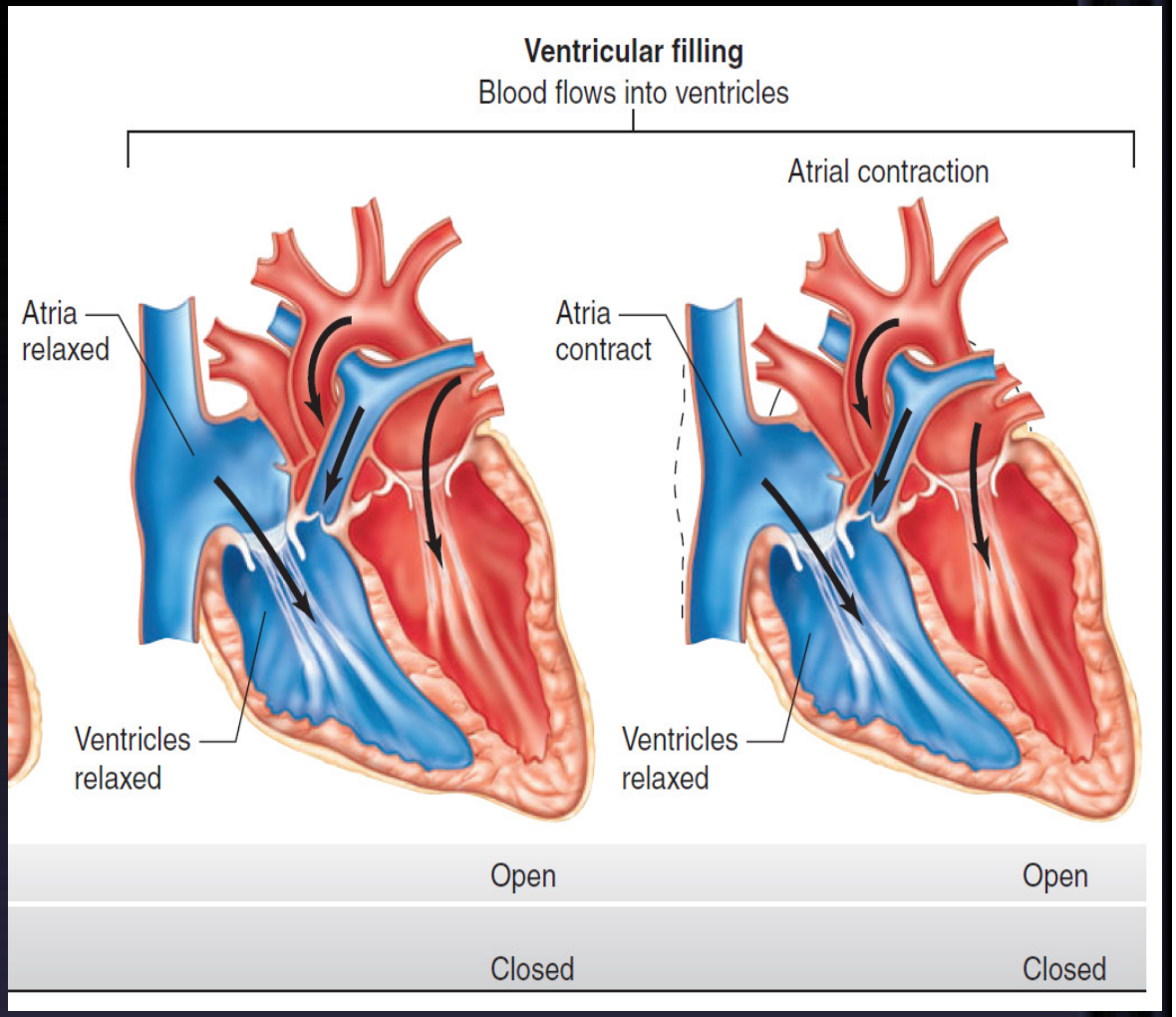
ISOVOULUMETRIC RELAXATION

- When ventricle pressure < arterial pressure→ backflow of blood → forces semilunar valves to close.
- For 0.03-0.06 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



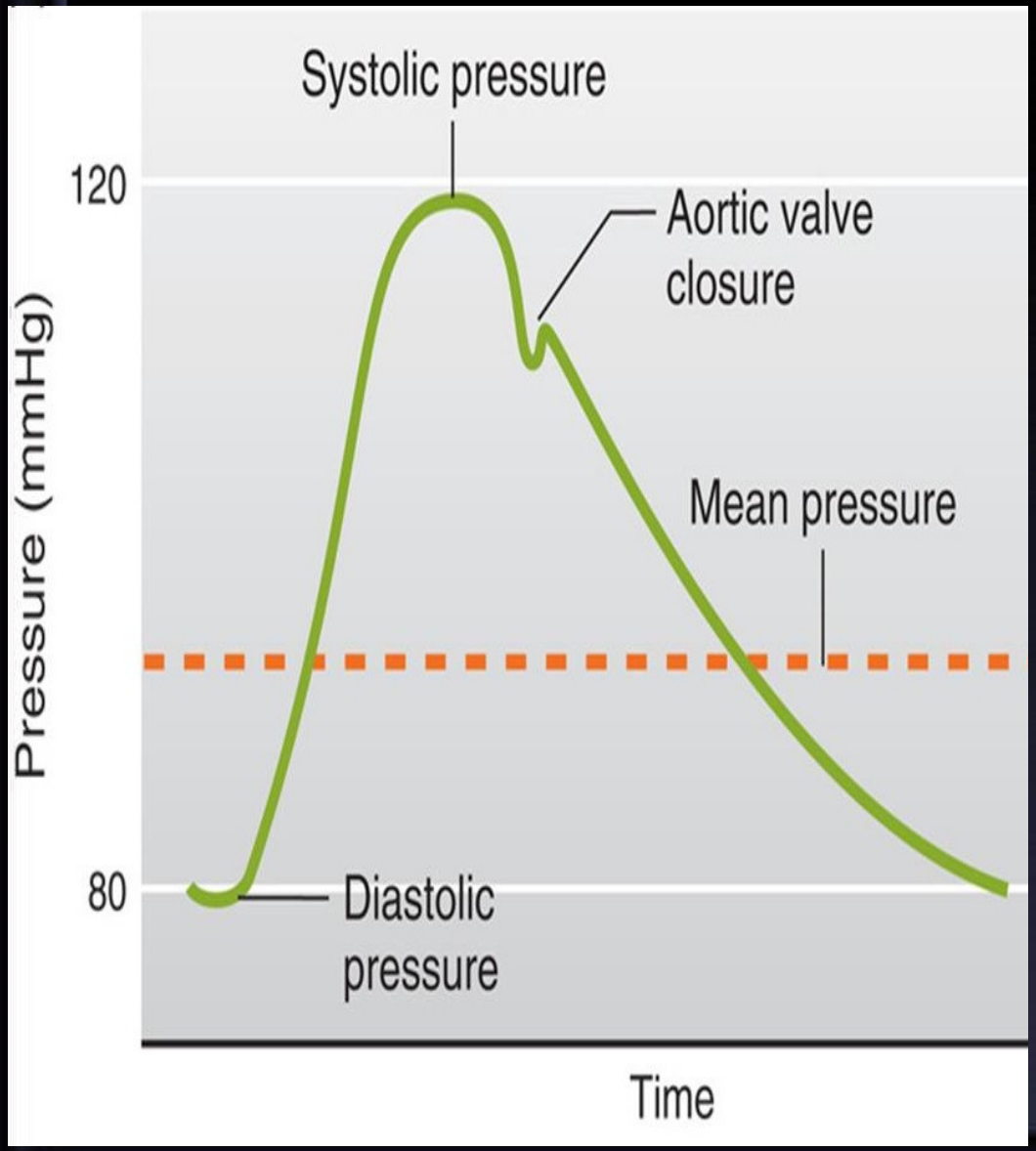
VENTRICULAR FILLING

- 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
- **Atrial contraction** – last 1/3 of diastole **(27-30% blood)**



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

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 but with difference in magnitude. Normal pulmonary artery pressure during the cardiac cycle ≈ 25-30/4-12 mmHg

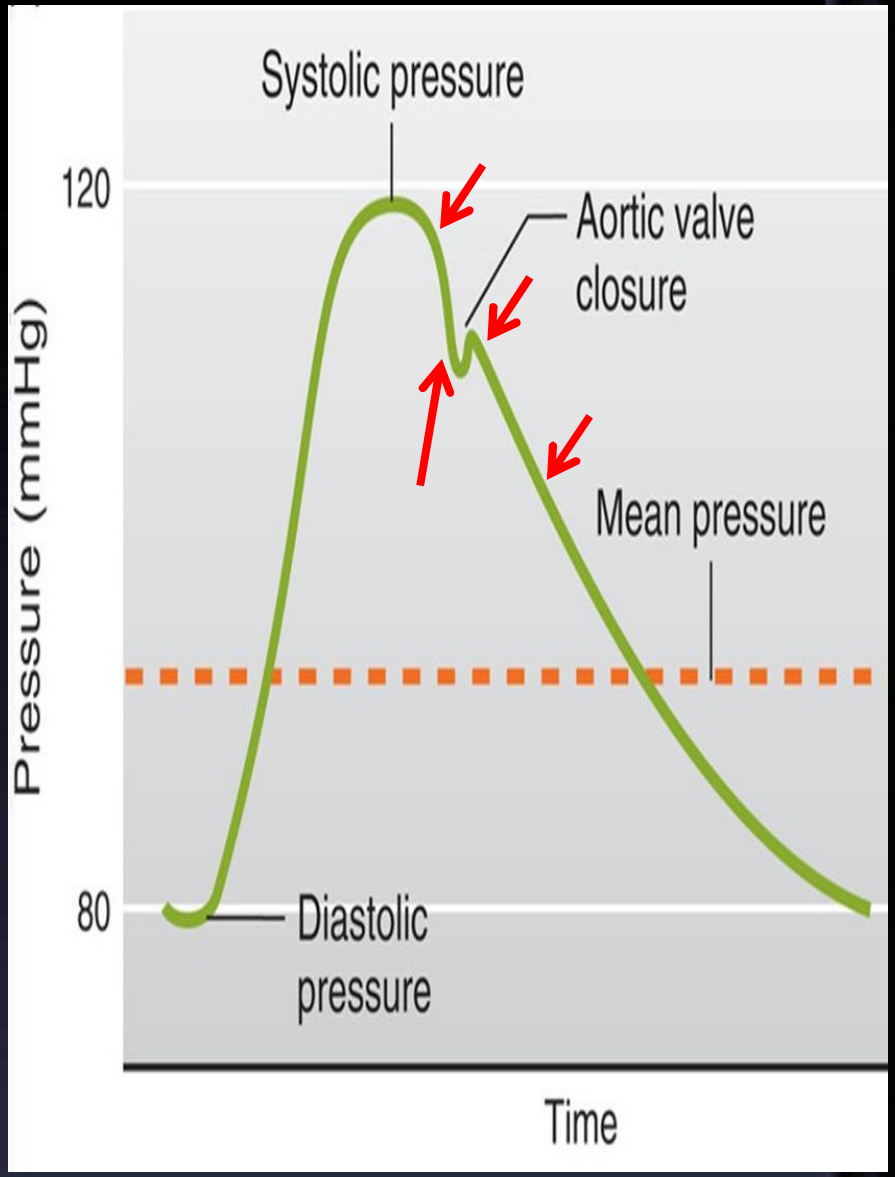
Descending / catacrotic limb - 4 STAGES

1. ↓ Aortic pressure:
   - ❑ This coincides with the 'reduced ejection phase'
   - ❑ The amount of blood enters aorta < leaves

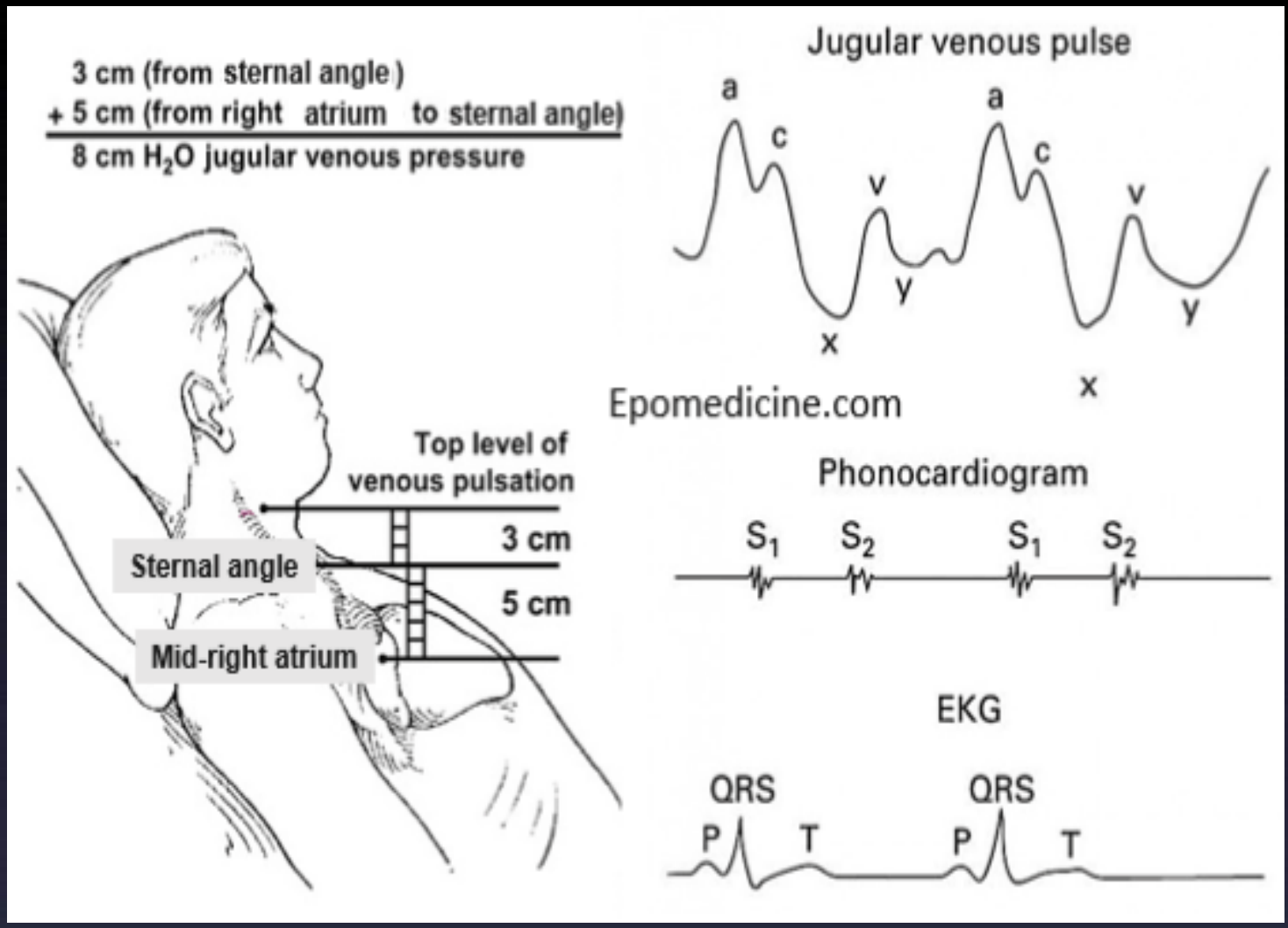
2. Dicrotic notch (incisura):
   Due to closure of aortic valve
   - ❑ There is sudden drop in aortic pressure
   - ❑ This notch is seen in the aortic pressure curve at end of ventricular systole

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)



Practical Box 13.2 Measurement of jugular venous pressure

The patient is positioned at about 45° to the horizontal (between 30° and 60°), wherever the top of the venous pulsation can be seen in a good light.

The jugular venous pressure is measured as the vertical distance between the manubriosternal angle and the top of the venous column.

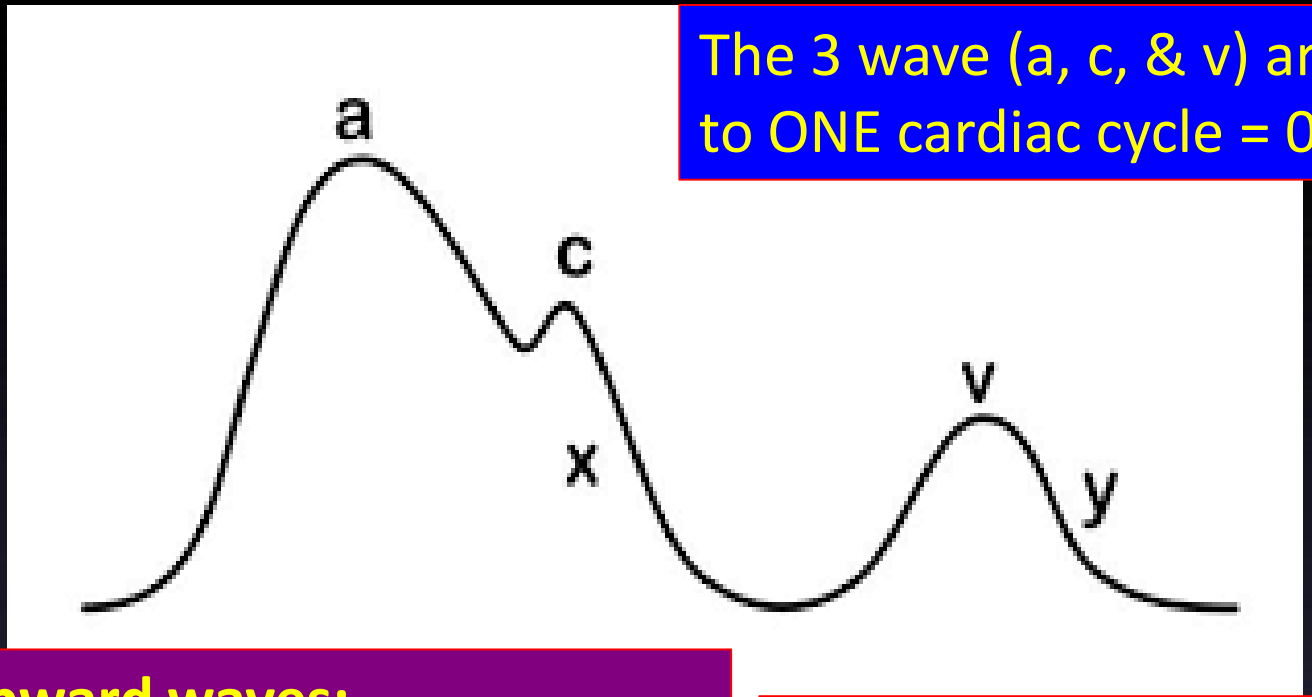
The normal jugular venous pressure is usually less than 3 cmH_2O, which is equivalent to a right atrial pressure of 8 cmH_2O when measured with reference to a point midway between the anterior and posterior surfaces of the chest.

The venous pulsations are not usually palpable (except for the forceful venous distension associated with tricuspid regurgitation).

Compression of the right upper abdomen causes a temporary increase in venous pressure and makes the JVP more visible (hepatojugular reflux).

Atrial pressure changes during the cardiac cycle

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



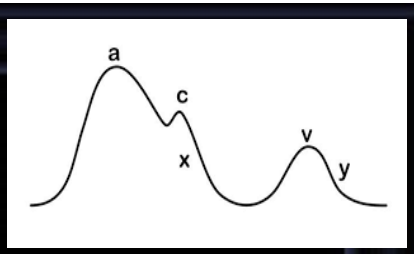
3 upward waves:

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

2 downward deflection (waves):

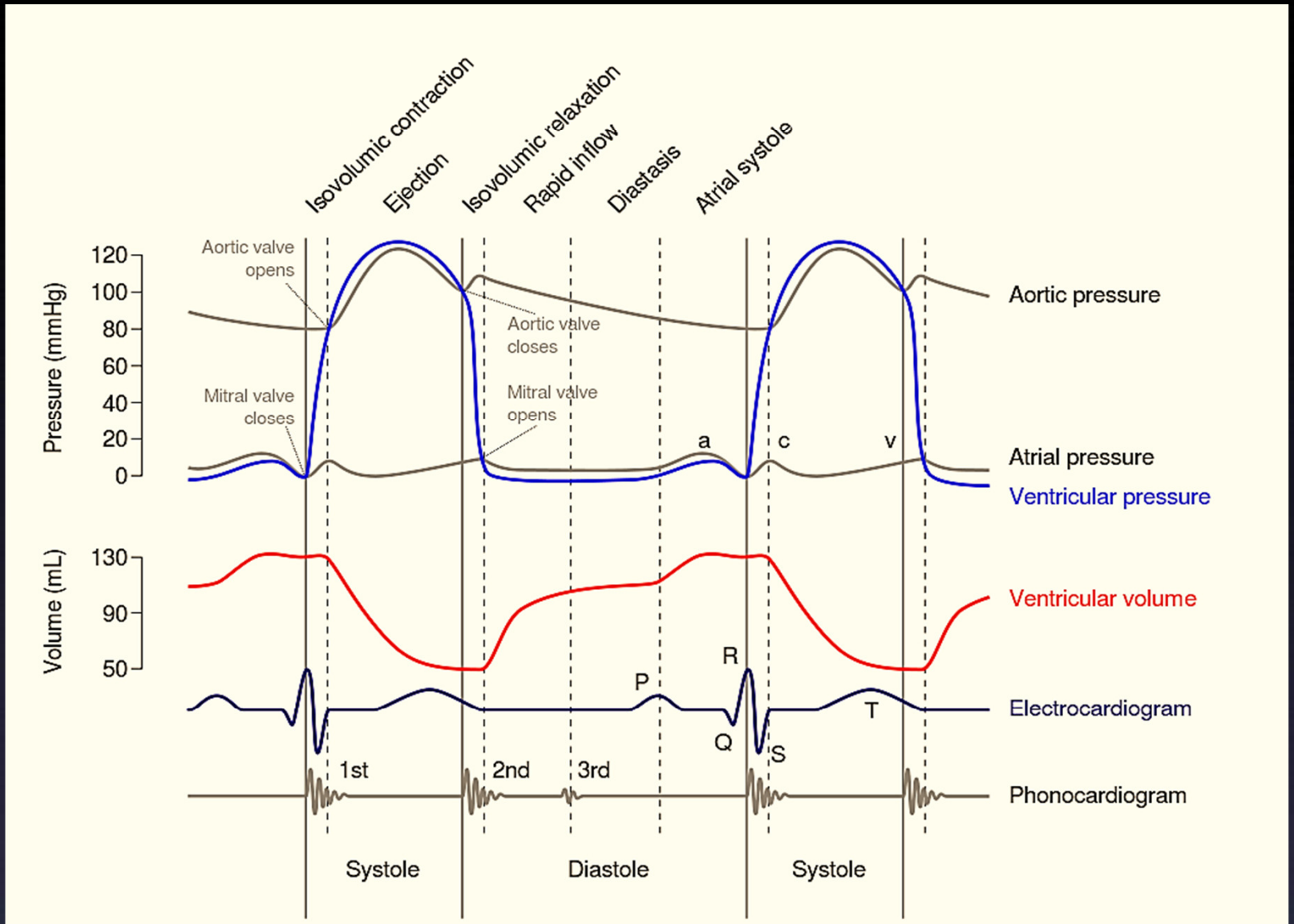
- **x & y waves**

Atrial pressure waves

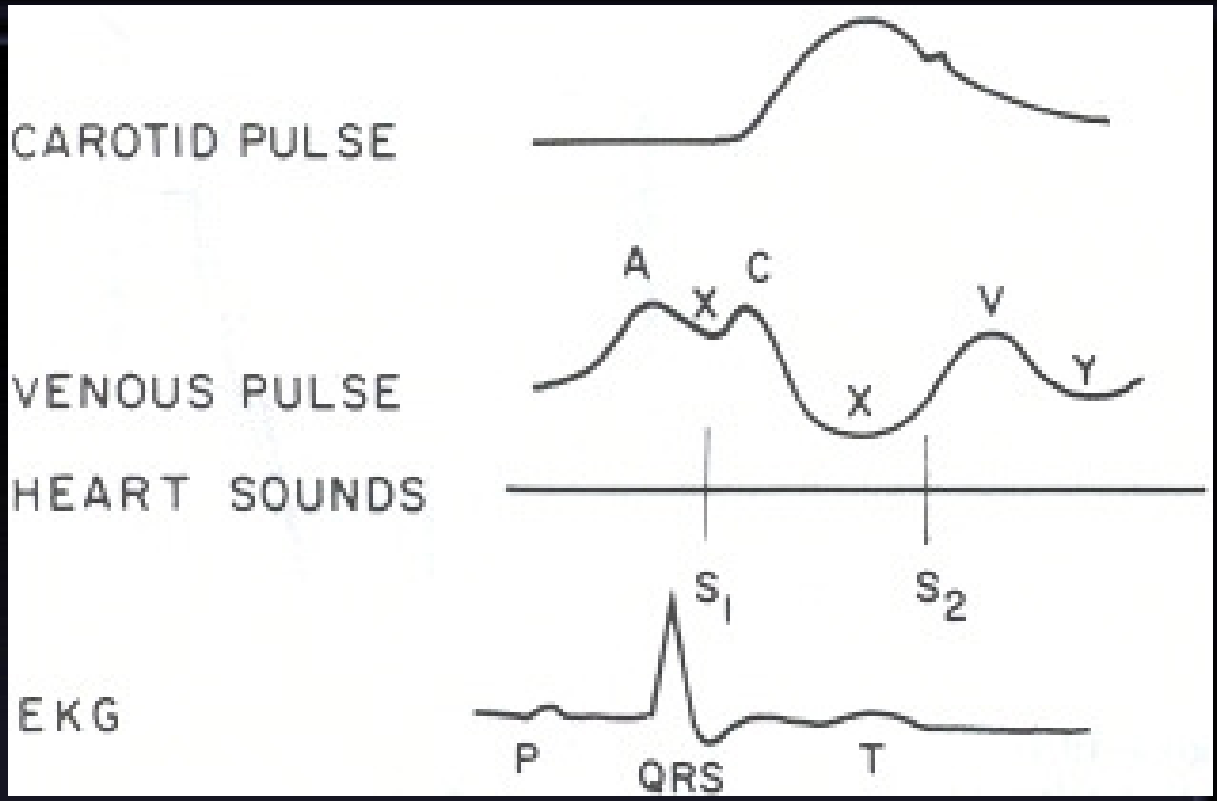


- ‘a’ wave: Atrial systole: ↑ atrial pressure during atrial contraction
- ‘c’ wave: Ventricular systole
  - +ve as a result of bulging of AV valve into the atria during ‘isovolumetric contraction phase’
  - -ve as a result of pulling of the atrial muscle & AV cusps down during ‘rapid ejection phase’, resulting in ↓ atrial pressure
- ‘v’ wave: Atrial diastole or ↑ venous return (VR)
  - +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’

CORRELATING EVENTS TOGETHER



ATRIAL SYSTOLE

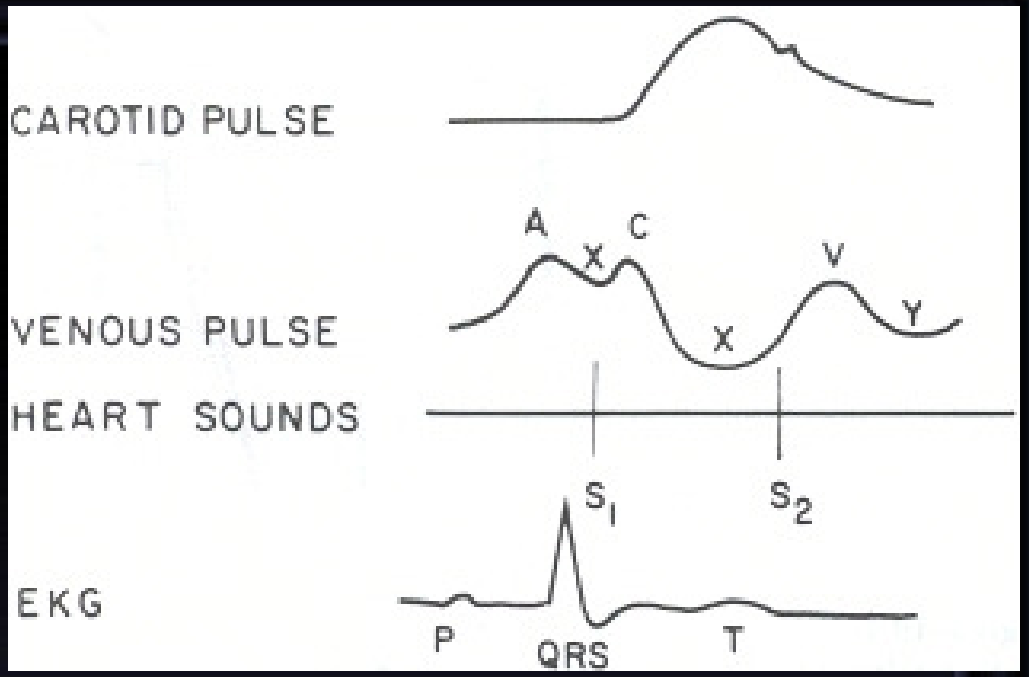


- **JVP** – 'a' wave
- **ECG** – P wave precedes the atrial systole. PR interval – depolarization proceeds to the AVN. The brief pause allows complete ventricular filling
- **Heart sounds** - **S_4 – pathological.** Vibration of the ventricular wall during atrial contraction. Heard in 'stiff' ventricle like in hypertrophy and in elderly. Also heard in massive pulmonary embolism, cor pulmonale, TR

ISOVOLUMETRIC CONTRACTION

Volume does not change

All valves are closed

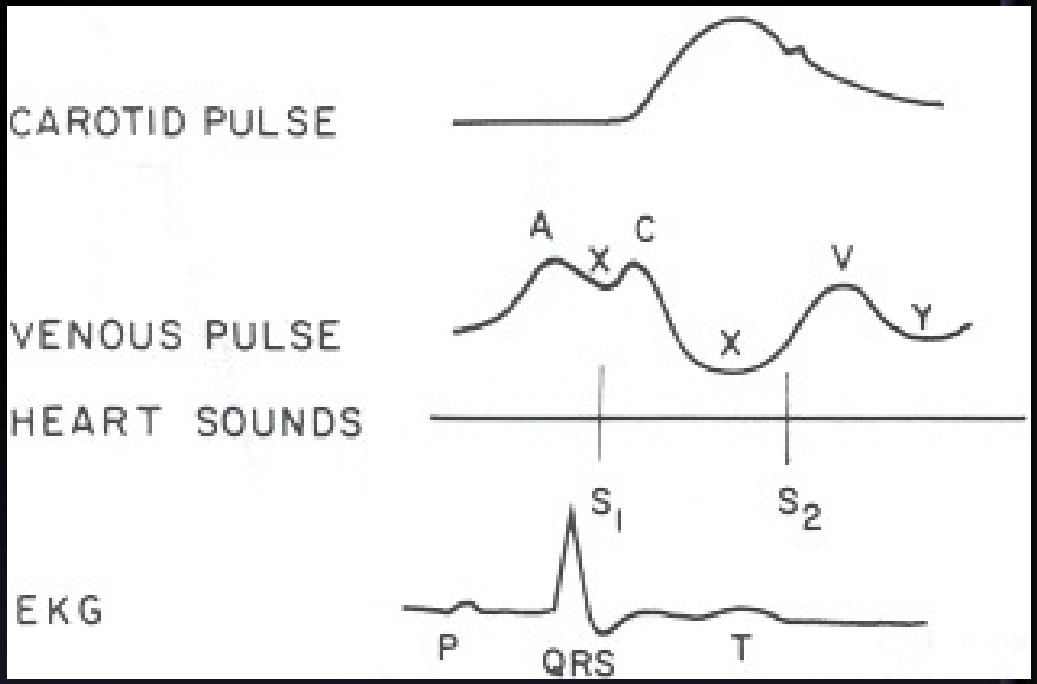


- **JVP** – 'c' wave → due to the bulging of the Tricuspid valve into RA secondary to increased pressure in the ventricle.
- **ECG** – End of QRS complex
- **Heart Sounds** – S_1 : closure of the AV valves.

EJECTION

Rapid

Slow

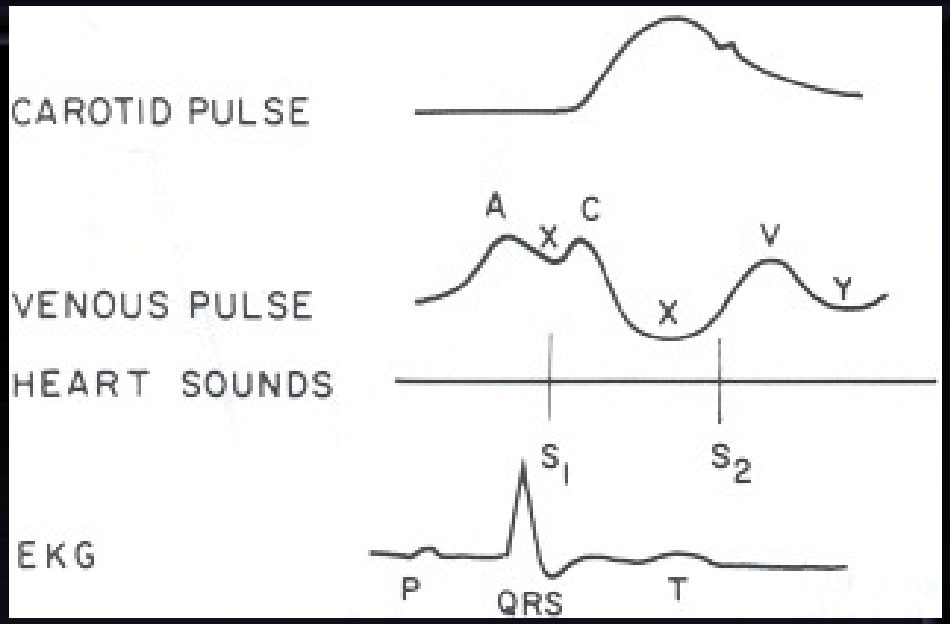


- **JVP** – no waves
- **ECG** – T wave
- **Heart sounds** – none
- **Aortic pressure** - Rapid rise in the pressure = 120 mm Hg. Even at the end of systole pressure in the aorta is maintained at 90 mm Hg because of the elastic recoil

ISOVOLUMETRIC RELAXATION

Volume does not change

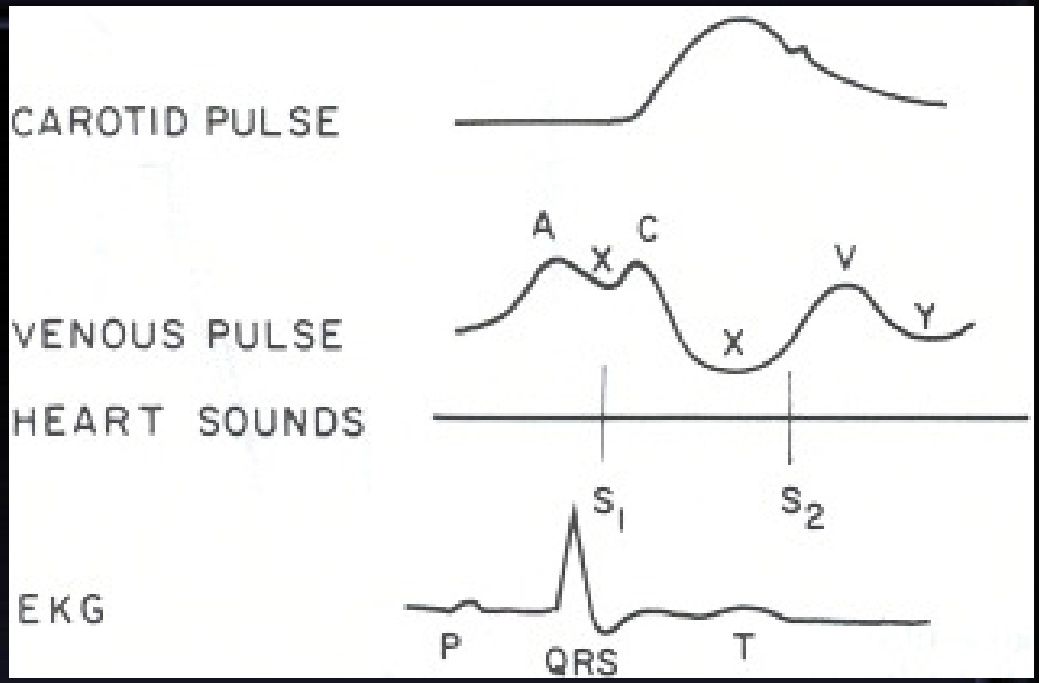
All valves are closed



- **JVP:** 'v' wave – due to venous return to the atria from SVC and IVC
- **ECG:** End of T wave
- **Heart sounds:** S_2 : closure of the semilunar valves coincides with this phase.
- **Aortic pressure curve: INCISURA** - when the aortic valve closes. Caused by a short period of backflow before the valve closes followed by sudden cessation of the backflow when the valve closes.

VENTRICULAR FILLING

- Rapid filling
- Reduced filling
- Atrial contraction



- **JVP** – 'y' descent in first 2/3 & 'a' wave in last 1/3
- **ECG** – P wave before atrial systole
- **Heart sounds - S_3 - Pathological in adults.** Seen in dilated congestive heart failure, MI, MR, severe hypertension. Normal in children.

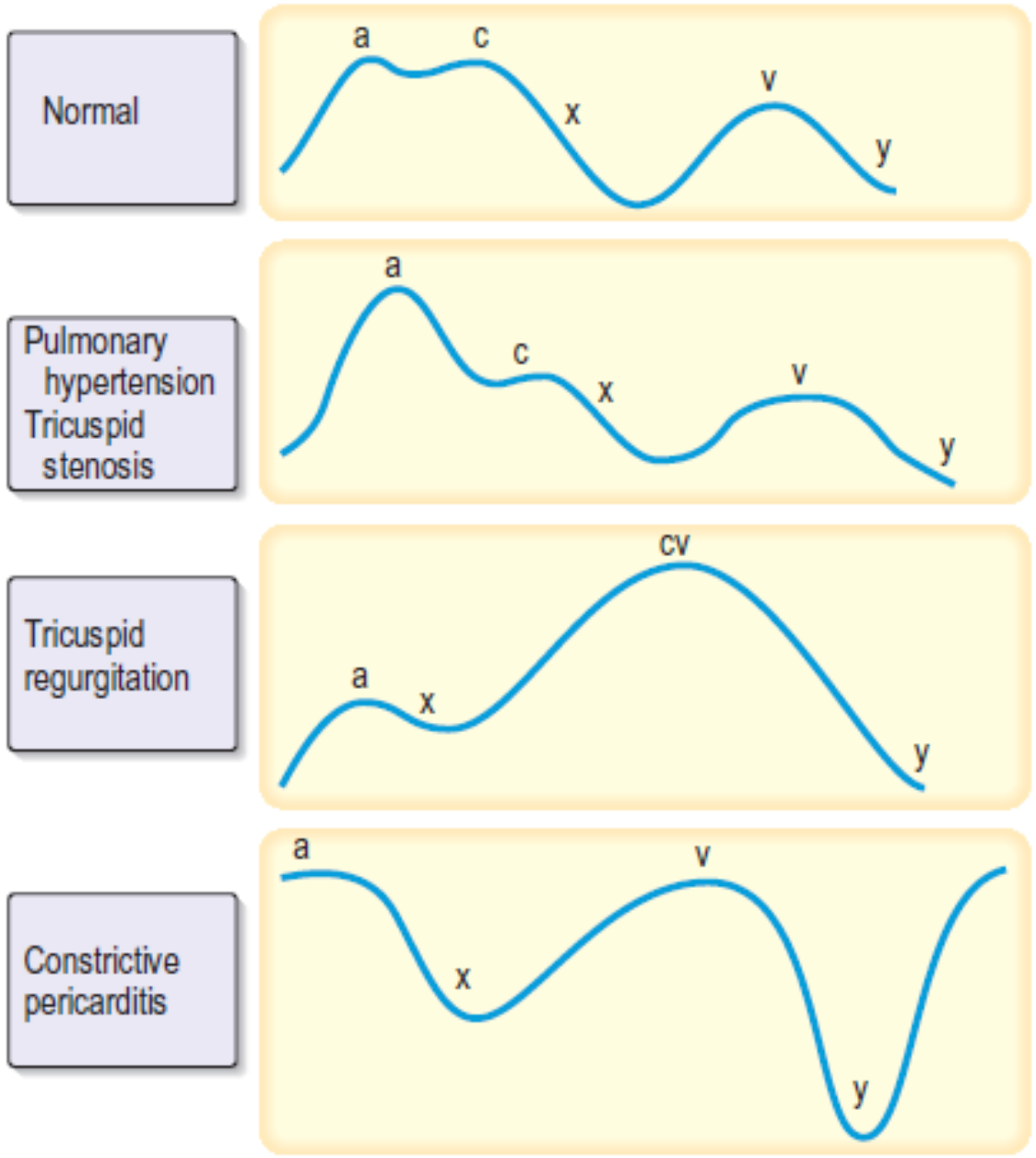


Fig. 13.12 **Jugular venous waveforms.**

ABNORMALITIES OF "a" WAVE

- **Elevated *a* wave**

  Tricuspid stenosis

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

- **Cannon *a* wave**

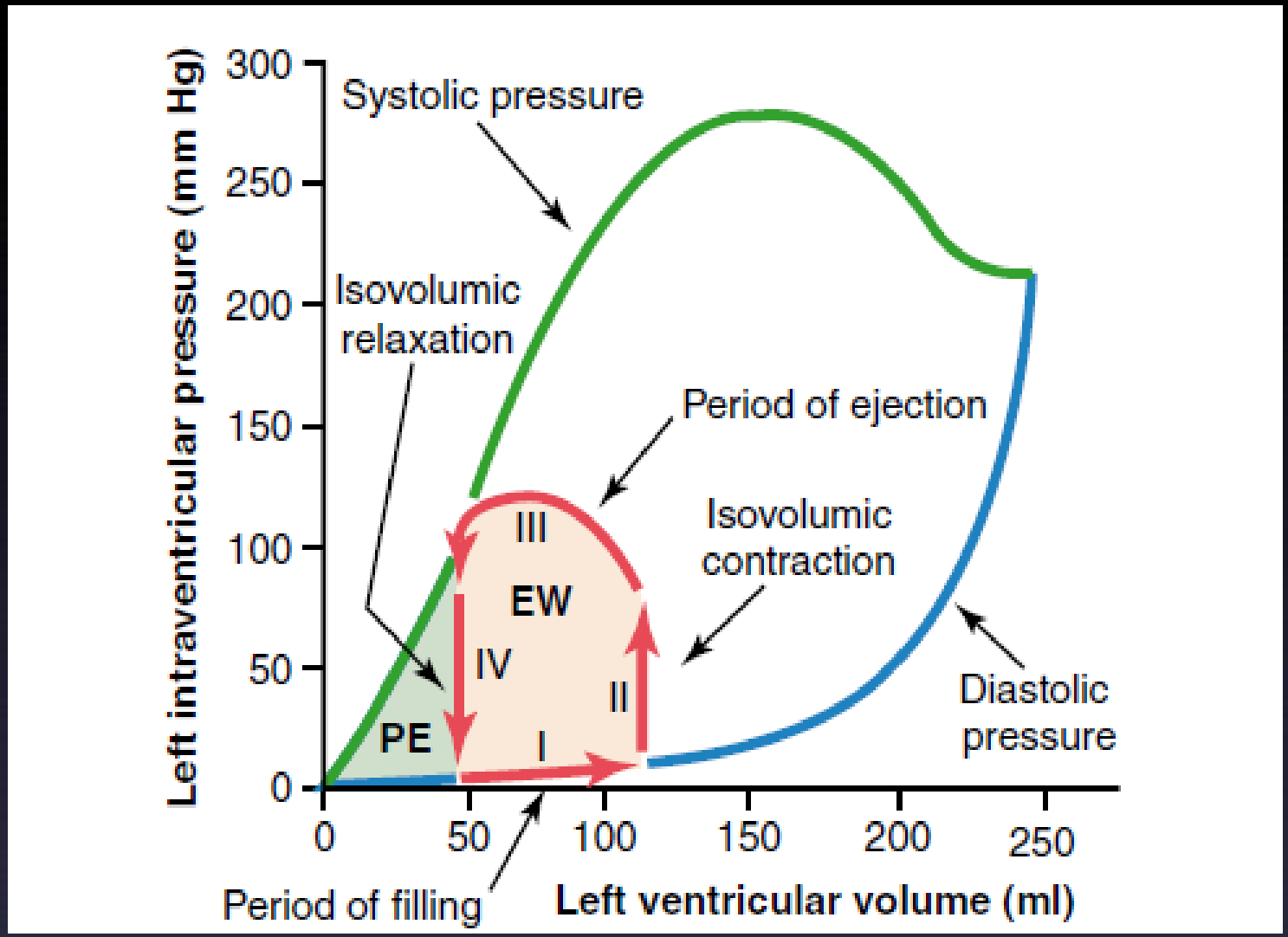
  Atrial-ventricular asynchrony *(atria contract against a closed tricuspid valve)*

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

- **Absent *a* wave**

  Atrial fibrillation or atrial standstill
  Atrial flutter

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



BASIC MYOCARDIAL MUSCLE MECHANICS:

Both ventricular systole & diastole can be divided into early & late phases.

Systole:

Early systole = 'Isovolumetric Contraction'.

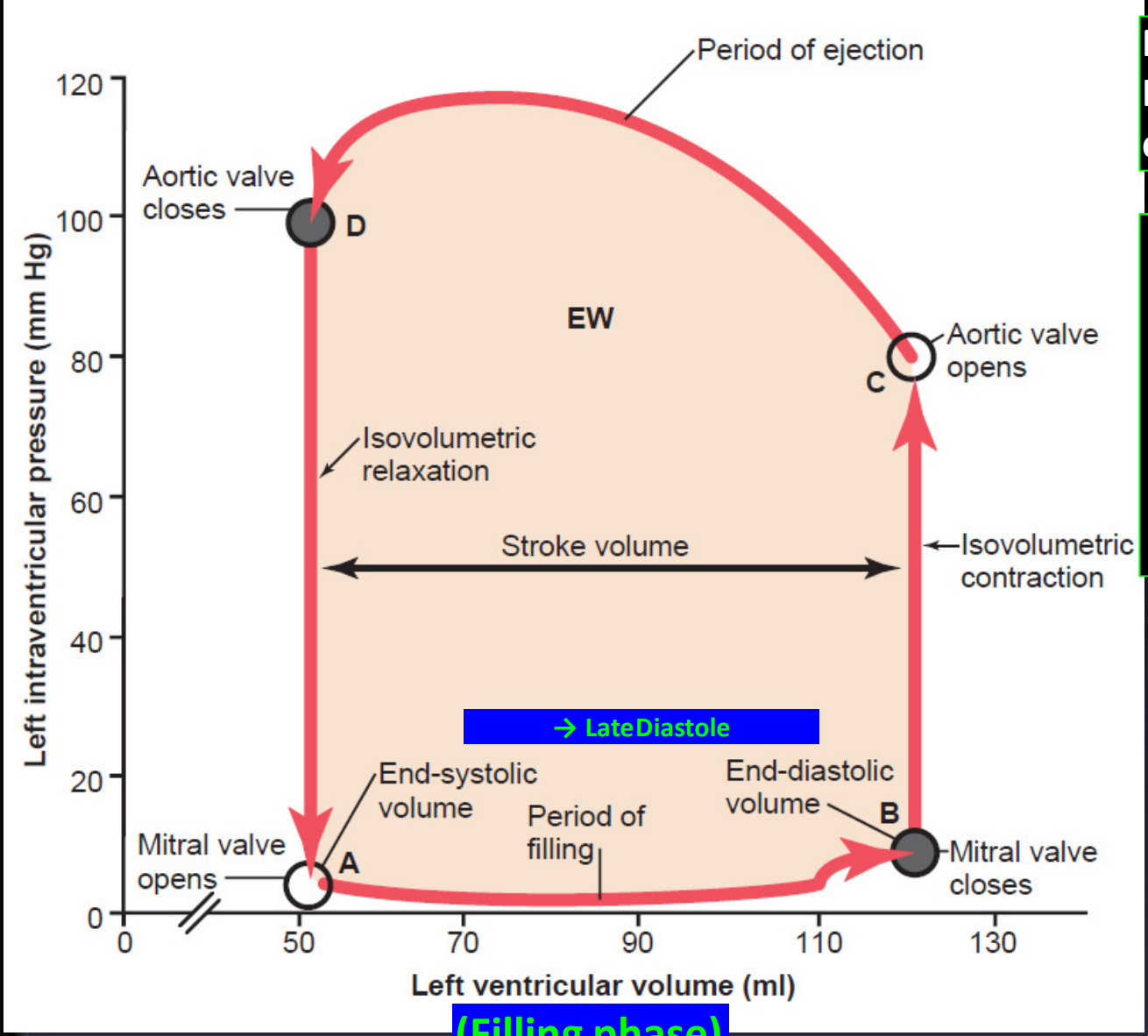
Late systole = Isotonic Contraction 'Ejection Phase'.

Diastole:

Early diastole = 'Isovolumetric Relaxation'.

Late diastole = Isotonic Relaxation 'Filling Phase'.

VENTRICULAR PRESSURE - VOLUME LOOP



Plots LV pressure against LV volume through one complete cardiac cycle

Systole: divided into

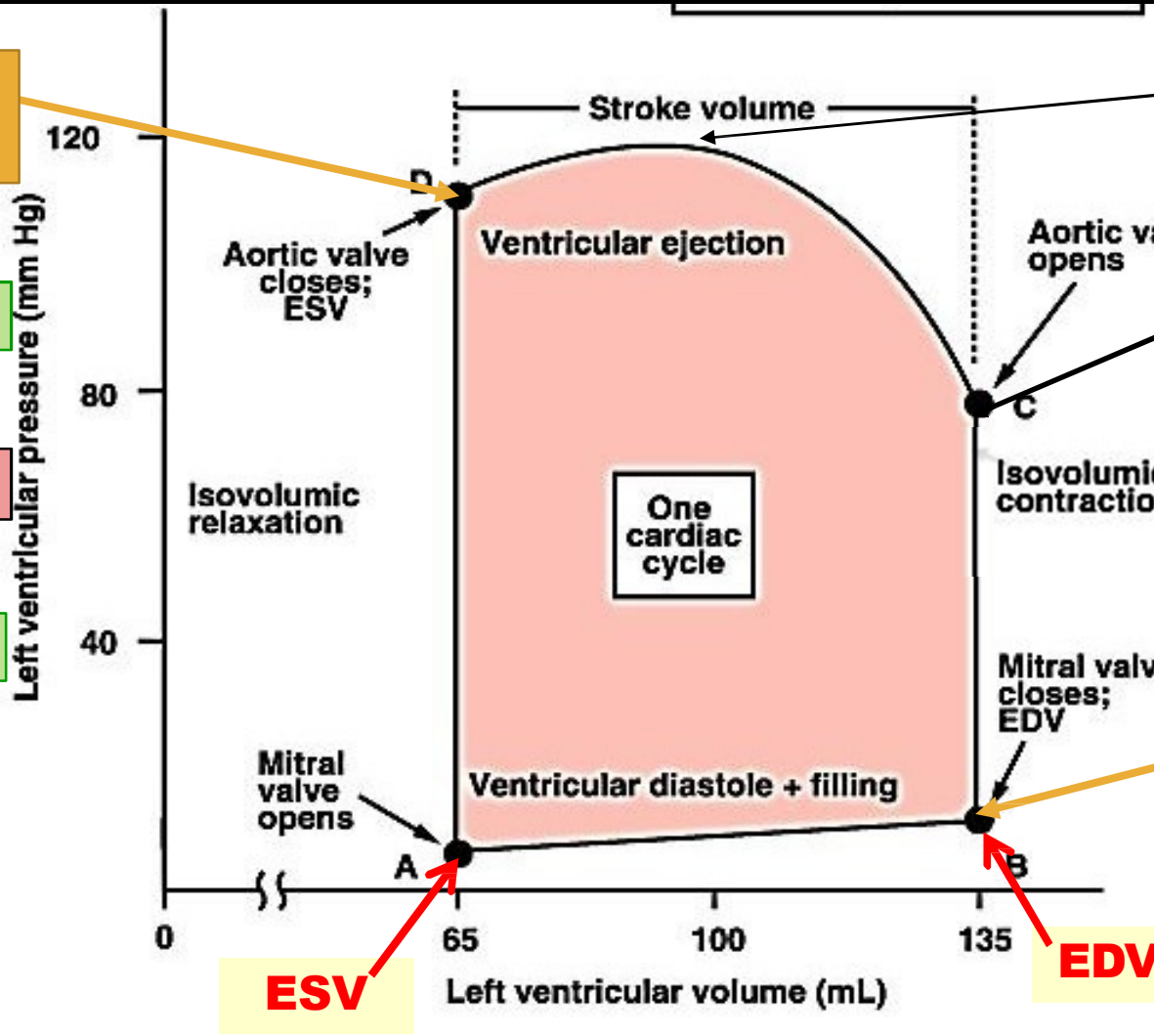
Early systole Late systole

Diastole: divided into

Early diastole Late diastole

(Filling phase)

VENTRICULAR PRESSURE - VOLUME LOOP



End of Systole

Systolic BP

Contractility

Diastolic BP

Area = Work

Compliance

Beginning of Systole

ESV

EDV

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

SV = EDV - ESV

a. Increased preload: n refers to an increase in end-diastolic volume and is the result of increased venous return.
causes an **increase in stroke volume** based on the Frank–Starling relationship….reflected in **increased width** of the pressure–volume loop.

b. Increased afterload refers to an increase in aortic pressure.
n The ventricle must eject blood against a higher pressure, resulting in a decrease in stroke volume….is reflected in decreased width of the pressure–volume loop.
The decrease in stroke volume results in an increase in end-systolic volume.

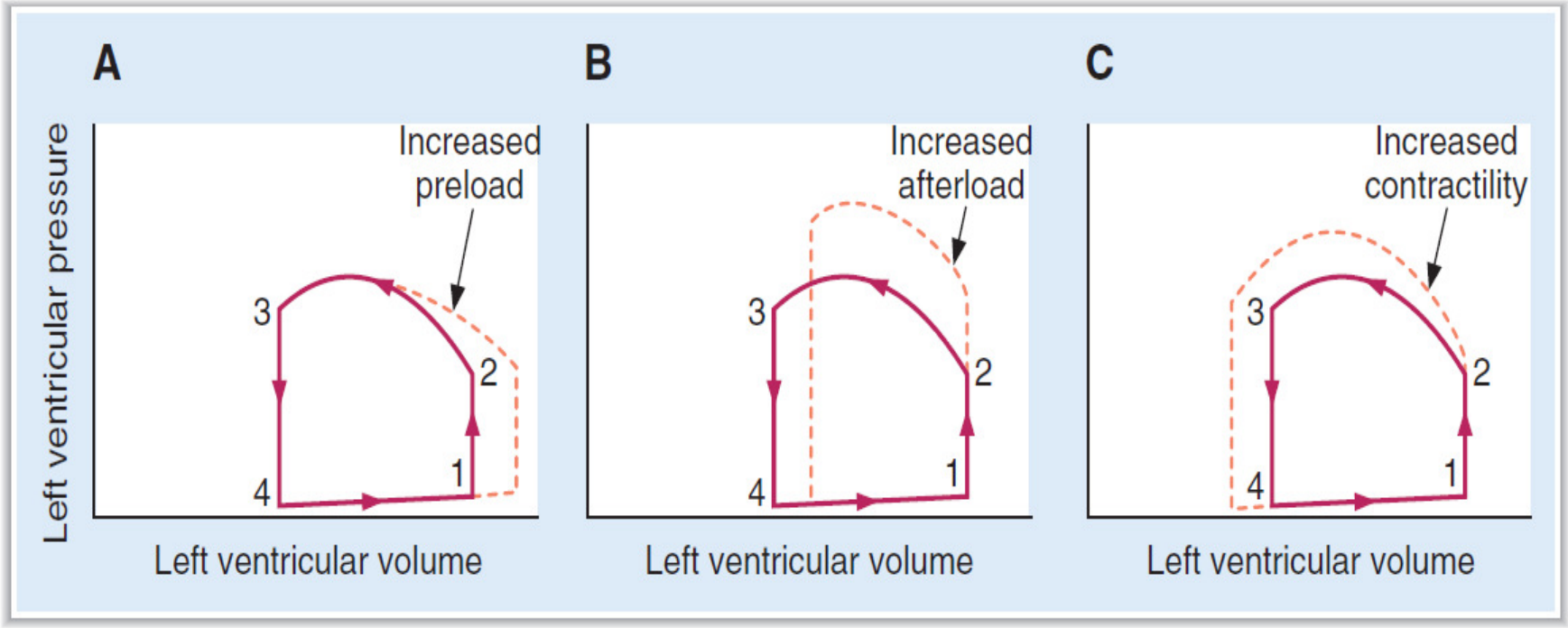
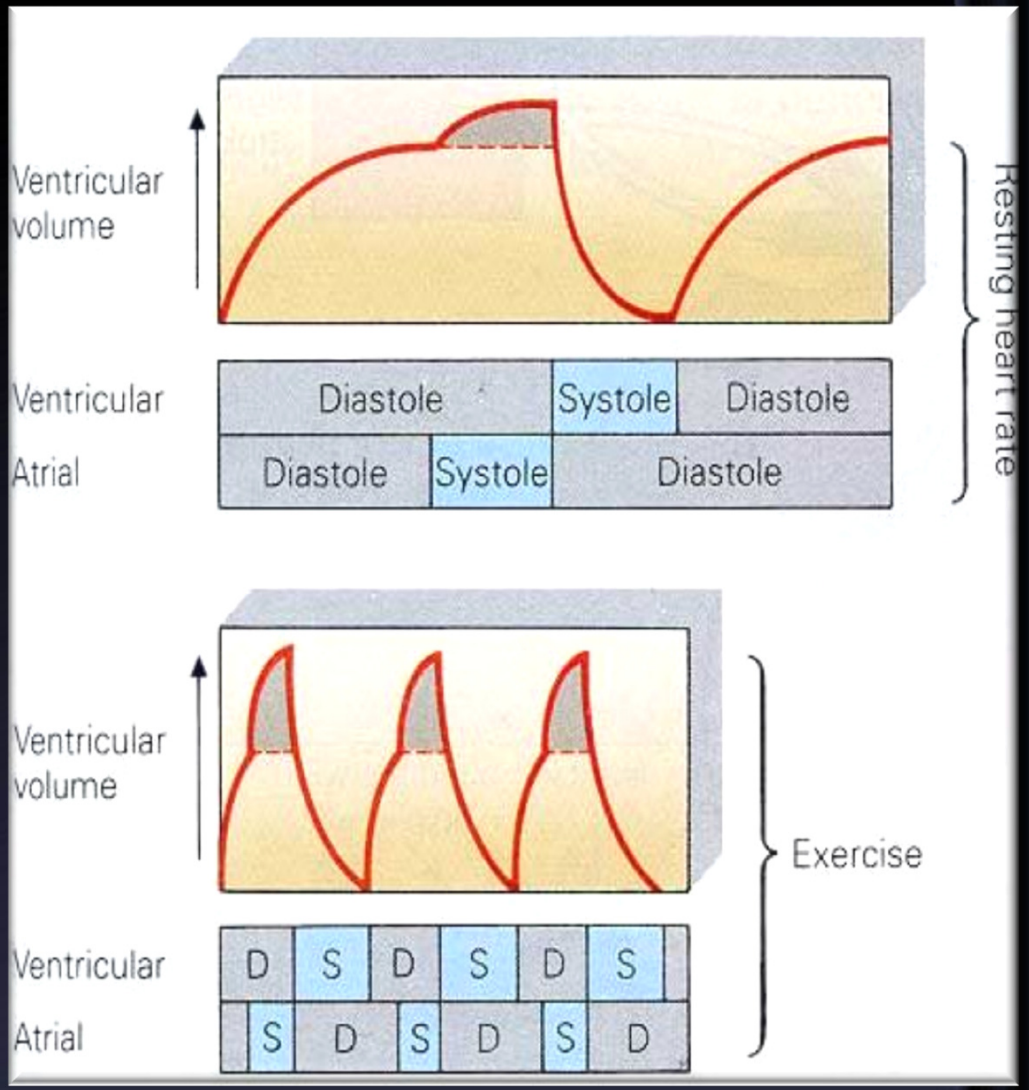


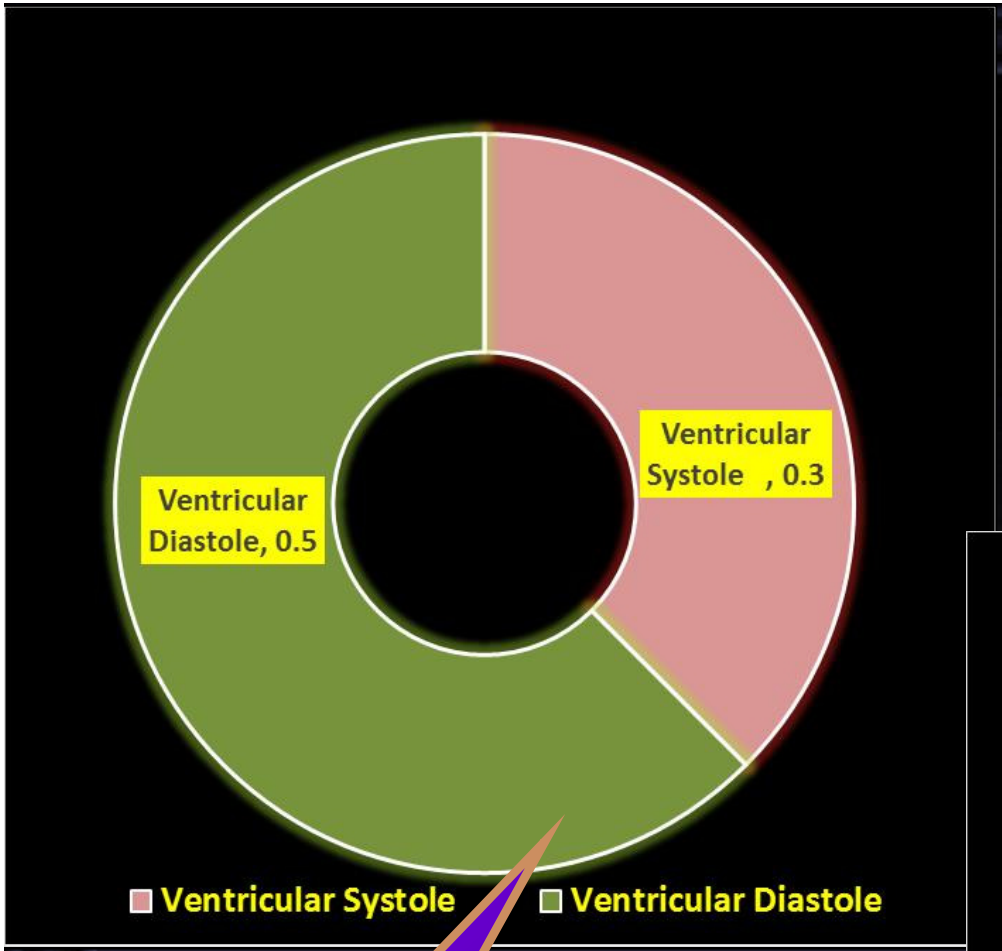
FIGURE 3-10 Effects of changes in (**A**) preload, (**B**) afterload, and (**C**) contractility on the ventricular pressure–volume loop.

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.

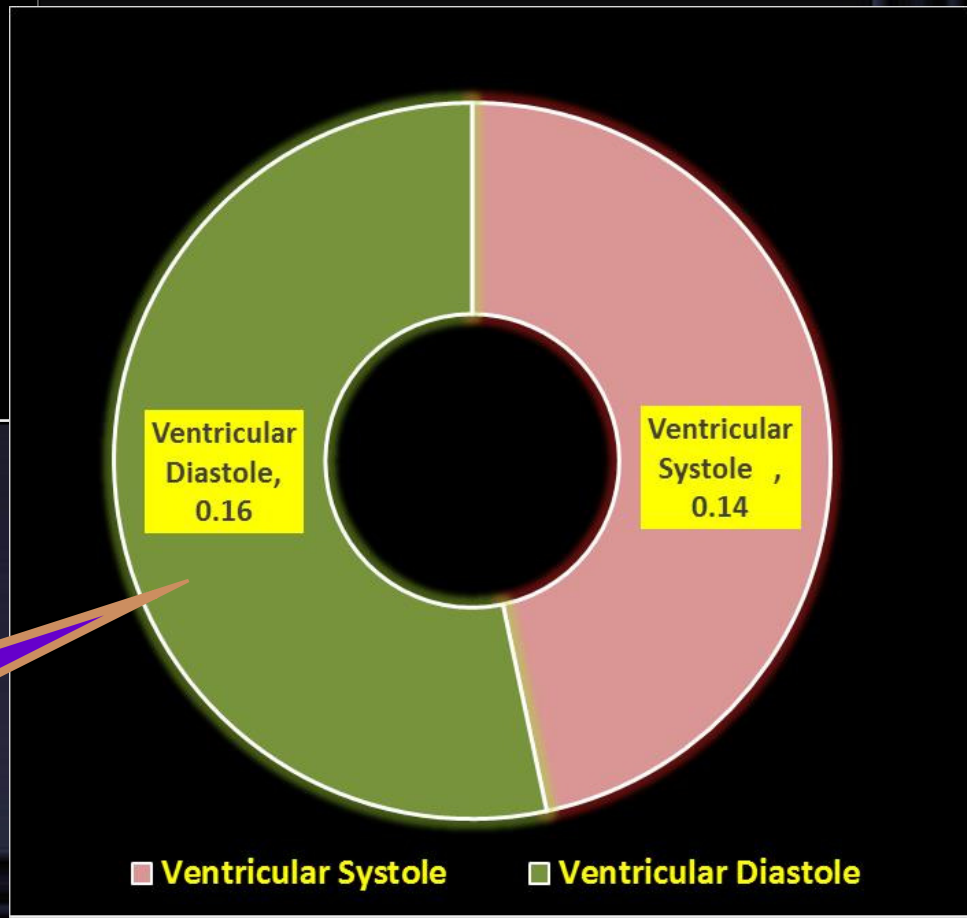


Hear Rate & Cardiac Cycle



At Rest

After Exercise



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Hear 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.
- When the heart rate is increased, diastole is shortened to a much greater degree. For example, at a heart rate of 65 beats/min, the duration of diastole is 0.62 s, whereas at a heart rate of 200 beats/min, it is only 0.14 s.

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.


THANKS