CARDIAC CYCLE AND PULSE CURVES

MEDICAL PHYSIOLOGY DEPARTMENT

ILOs

- Identify the cardiac cycle and its phases. Correlate cycle events with heart sounds, and ECG.
- Identify heart sounds (normal and abnormal, characters and causes).
- Define arterial pulse wave (pulse pressure curve) and its significance.

Definition of cardiac cycle

- It is the period from the beginning of one heart beat to the beginning of next beat
- Each cycle consists of systole & diastole
- Atrial systole precedes ventricular systole
- If heart rate is 75/min, the duration of each cycle = $\frac{60}{75}$ = 0.8 sec
- For atria: - Atrial systole = 0.1sec
  - Atrial diastole = 0.7 sec
- For ventricles: - Ventricular systole = 0.3 sec
  - Ventricular diastole = 0.5 sec

Phases of cardiac cycle

1. Atrial systole phase (i.e. ASP) or late ventricular diastole = 0.1 sec.
2. Isometric contraction phase (ICP) = 0.05 sec.
3. Maximum ejection phase (MEP) = 0.15 sec.
4. Reduced ejection phase (REP) = 0.1 sec.
5. Protodiastolic phase (PDP) = 0.04 sec.
6. Isometric relaxation phase (IRP) = 0.06 sec.
7. Maximum filling phase (MFP) = 0.1 sec.
8. Reduced filling phase (RFP) or mid ventricular diastole = 0.2 sec.

During each phase of cardiac cycle different changes of parameters are recorded:

1-Pressure changes:

-Atrial pressure

-Ventricular pressure

-Aortic pressure

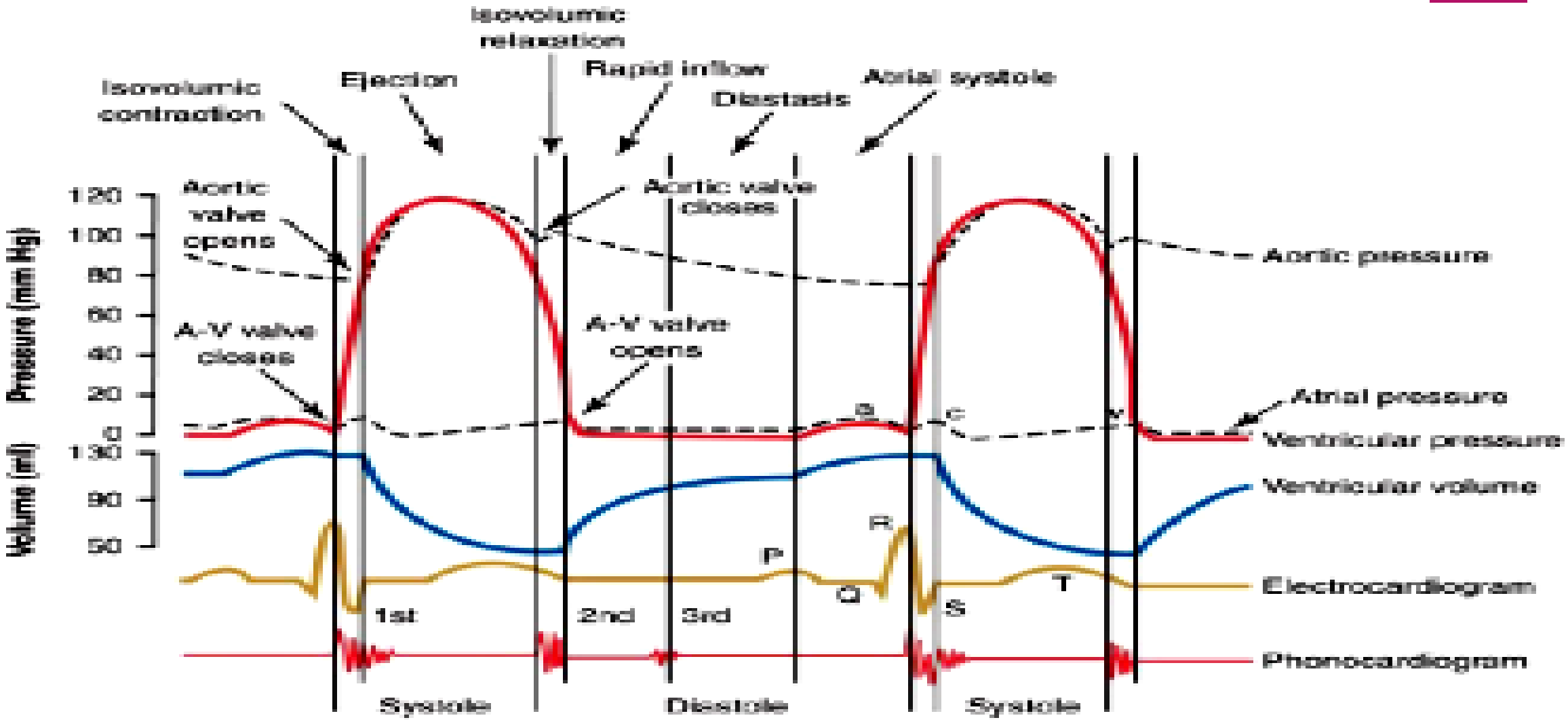
-Pulmonary pressure

2-Ventricular volume

3-Heart sounds

4-Electrocardiogram (ECG)

5-Valves (opened or closed)



Events of the cardiac cycle for left ventricular function, showing:

① Changes in left atrial pressure

② Left ventricular pressure

③ Aortic pressure

④ Ventricular volume

⑤ Electrocardiogram

⑥ Phonocardiogram

Phases of cardiac cycle

❶ Atrial systole (Atrial contraction) 0.1 sec

- Atrial contraction: Evacuates 25 - 30 % of blood into ventricles
- NB: 70 % of ventricular filling occurs passively during diastole

.....Atrial systole

1. **Atrial pressure** (AP): ↑ few due to atrial contraction . Then returns back to zero by the end of this phase due to evacuation of atrial blood.

2. **Ventricular pressure** (VP): ↑ slightly due to entry of blood from the atrium. **Then** ↓ due to dilatation of the ventricles.

3. **Ventricular volume** (VV): ↑ slightly **due to** entry of blood from the atrium.

4. **Aortic pressure** (Ao P): ↓ **due to** escape of blood from aorta to arteries.

5. **Aortic valve** (Ao V): closed.

6. **AV valve: opened**.

7. **Heart sounds** (HS): **4th HS** produced by atrial contraction **.**

8. **ECG**: P wave (which occurs **0.02 sec before** the beginning of atrial systole).

❷ Isometric Contraction Phase …. 0.05 sec

Ventricular contraction while all valves are closed

1. Atrial pressure (AP): slightly increased due to bulging of AV cusps towards the cavity of the atrium by the sudden increase in intraventricular pressure.

2- Ventricular pressure (VP): rapidly increased and becomes higher than atrial pressure.

3. Ventricular volume (VV): **NO** change (constant).

4- Aortic pressure (Ao P): **decreased** due to escape of blood from aorta to arteries. At the end of this phase VP is slightly higher than Ao P.

5- Aortic valve (Ao V): still closed.

6- AV valve: suddenly closed.

7- Heart sounds (HS): **1st HS** (early part) due to by sudden closure of AV valves .

8- ECG: QRS complex (Q wave starts **0.02 sec before** the beginning of this phase).

3) Maximum Ejection Phase (MEP) = 0.15 sec.

During this phase, blood is ejected at high rate out of the ventricle to the aorta.

1. **Atrial pressure** (AP): sharp decrease due to downward displacement of the AV ring. Then gradual increase due to venous return and upward displacement of the AV ring to its normal position.
2. **Ventricular pressure** (VP): increased from 80 to 120 mmHg.
3. **Ventricular volume** (VV): decreased rapidly due to ejection of most ventricular blood to aorta.
4. **Aortic pressure** (Ao P): increased from 80 to 120 mmHg because the pumped blood by the ventricle is greater than blood escaping from the aorta to arteries.
5. **Aortic valve (**Ao V): opened
6. **AV valve: closed**
7. **Heart sounds** (HS): **1st HS** continues.
8. **ECG:** origin of **T wave** is somewhere in this phase.

4) Reduced Ejection Phase (REP) = 0.1 seconds.

In this phase, blood ejection occurs at a **slower** rate than MEP.

1. **Atrial pressure** (AP): gradual increase due to VR.
2. **Ventricular pressure** (VP): slightly decreased due to decreased force of pumping blood to aorta.
3. **Ventricular volume** (VV): still decreasing.
4. **Aortic pressure** (Ao P): decreased because blood leaving aorta is **more** than blood pumped by the ventricle.
5. **Aortic valve** (Ao V): opened.
6. **AV valve**: still closed.
7. **Heart sounds** (HS): **NO** HS.
8. **ECG:** top of **T wave.**

5) Proto diastolic Phase (PDP) = 0.04 sec.

It denotes the **end of systole** and the **beginning of diastole**.

1. **Atrial pressure** (AP): gradual increase due to VR.
2. **Ventricular pressure** (VP): rapidly decreased till become lower than aortic pressure due to relaxation of the ventricle.
3. **Ventricular volume** (VV): **NO** change (constant).
4. **Aortic pressure** (Ao P): the aortic pressure follows that of the ventricle until the sudden closure of the Ao V which causes sharp decrease of the aortic pressure **called** "Incisura" or "Dicrotic Notch".
5. **Aortic valve** (Ao V): open.
6. **AV valve**: still closed.
7. **Heart sounds** (HS): **NO** HS.
8. **ECG:** **T** wave continues.

6) Isometric Relaxation Phase (IRP) = 0.06 sec.

1. **Atrial pressure** (AP): gradual increase due to VR.
2. **Ventricular pressure** (VP): rapidly decreased.
3. **Ventricular volume** (VV): **NO** change.
4. **Aortic pressure** (Ao P): shows dicrotic notch due to sudden closure of aortic valve. This is followed by dicrotic wave due to elastic recoil of the aorta.
5. **Aortic valve** (Ao V): suddenly closed.
6. **AV valve**: still closed.
7. **Heart sounds** (HS**): 2nd HS.**
8. **ECG**: **T wave** ends during this phase.

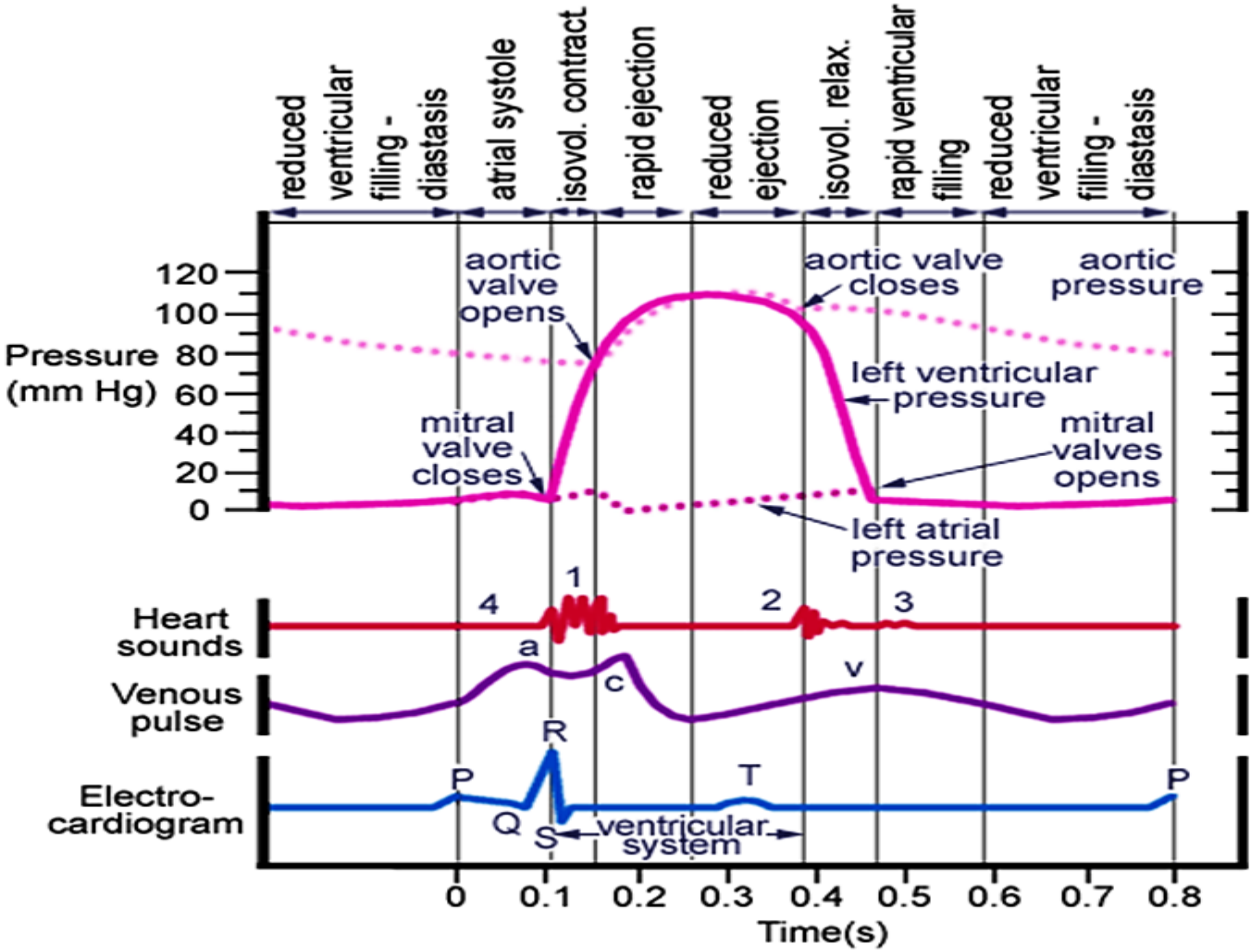
7) Maximum Filling Phase (MFP) = 0.1 sec.

1. **Atrial pressure** (AP): is higher than ventricular pressure at the beginning of this phase, then drops due to rush of blood into the ventricle.
2. **Ventricular pressure** (VP): around zero due to progressive vent. relaxation.
3. **Ventricular volume** (VV): increases rapidly as blood flows from the atria into the ventricles.
4. **Aortic pressure** (Ao P): decreasing
5. **Aortic valve** (Ao V): closed.
6. **AV valve**: opened
7. **Heart sounds** (HS): **3rd HS** (S3) is usually abnormal and is due to rapid passive ventricular filling. It occurs in dilated congestive heart failure, severe hypertension, myocardial infarction, or mitral incompetence.

8. **ECG**: **NO** waves (i.e. **isoelectric**).

8) Reduced Filling Phase (RFP) = 0.2 sec.

1. **Atrial pressure** (AP): around zero but **higher** than the ventricles.
2. **Ventricular pressure** (VP): around zero but **less** than the atria.
3. **Ventricular volume** (VV): increases.
4. **Aortic pressure** (Ao P): still decreasing due to escape of blood to peripheral tissues
5. **Aortic valve (**Ao V): closed.
6. **AV valve**: opened.
7. **Heart sounds** (HS): **NO** HS.
8. **ECG**: beginning of **p** wave of the next cycle.


reduced ventricular filling - diastasis
atrial systole
isovol. contract
rapid ejection
reduced ejection
isovol. relax.
rapid ventricular filling
reduced ventricular filling - diastasis
aortic valve opens
aortic valve closes
aortic pressure
left ventricular pressure
mitral valve closes
mitral valves opens
left atrial pressure
Pressure (mm Hg)
120
100
80
60
40
20
0
Heart sounds
1
2
3
4
Venous pulse
a
c
v
Electro-cardiogram
P
Q
R
S
T
P
ventricular system
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time(s)

NB:

- Changes in heart rate affects mainly diastole which is important because the following occurs during diastole:

1- Ventricular filling (during early diastole)

2- Maximum coronary blood flow

3- The heart rests

Parameter / Phase	Valves		Heart sounds	Intra-atrial P (JPC)	Ventricular P	Ventricular volume	Aortic P (RPC)	ECG
1-Atrial systole (0.1 Second)	A&P closed	AV open	4th HS	a wave ↑ (systole) then ↓ (evacuation of blood) x wave	Transient ↑	Rapid ↑	Gradual ↓ (Catacrotic Limb)	P & Q waves
2-Isometeric contraction phase (0.05 Second)	Closed	closed	1st HS	↑ c wave	Sharp ↑ (0-80)	No change	Gradual ↓ (Catacrotic Limb)	R and S waves
3-Maximum Ejection phase (0.15 Second)	open	closed	1st HS	Sharp drop x1 wave then ↑	Maximum ↑ (120)	Rapid ↓	(Anacrotic Limb) ↑	beginning of T wave
4-Reduced ejection phase (0.1 Second)	open	closed	No sound	↑ v wave	Slow drop to 110	Slow ↓	Slow↓ to 110 (catacrotic Limb)	T wave
5-Protodiastolic phase (0.04 Second)	A&P Open	AV closed	No sound	Gradual ↑ V wave	Rapid ↓ to 95	No change	At its end sharp ↓ (Dicrotic notch)	T wave
6-Isometeric relaxation phase (0.06 Second)	Closed	closed	2nd HS	Gradual ↑ V wave	Sharp ↓ to 5	No change	↓→Dicrotic notch & ↑→Dicrotic wave	T wave ended
7-Rapid filling phase (0.1 Second)	closed	open	3rd HS	Sharp drop y wave then ↑	Rapid ↓ to zero or –ve then gradual ↑	Rapid ↑	(catacrotic Limb) gradual↓	u wave may be present
8-Reduced filling phase (0.2 Second)	closed	open	No sound	Around zero but higher than the ventricular P	Around zero but less than the atrial P	Slow ↑	(catacrotic Limb) gradual↓	Beginning of P wave

Remarks on cardiac cycles:

- Atrial systole =0.1 second, while atrial diastole =0.7 second.
- Ventricular systole =0.3 second, while ventricular diastole =0.5 second.
- 70% of ventricular filling occurs passively during rapid and reduced filling phases by blood weight. Only 30% of blood is actively pumped into ventricle during atrial systole.
- Aortic valve opens at 80 mmHg pressure in the left ventricle.
- Pulmonary valve opens at 10 mmHg pressure in the right ventricle.
- Highest pressure in the left ventricle is 120 mmHg.
- Highest pressure in the right ventricle is 30 mmHg.

The Jugular Pulse Curve (JPC)

ILOs:

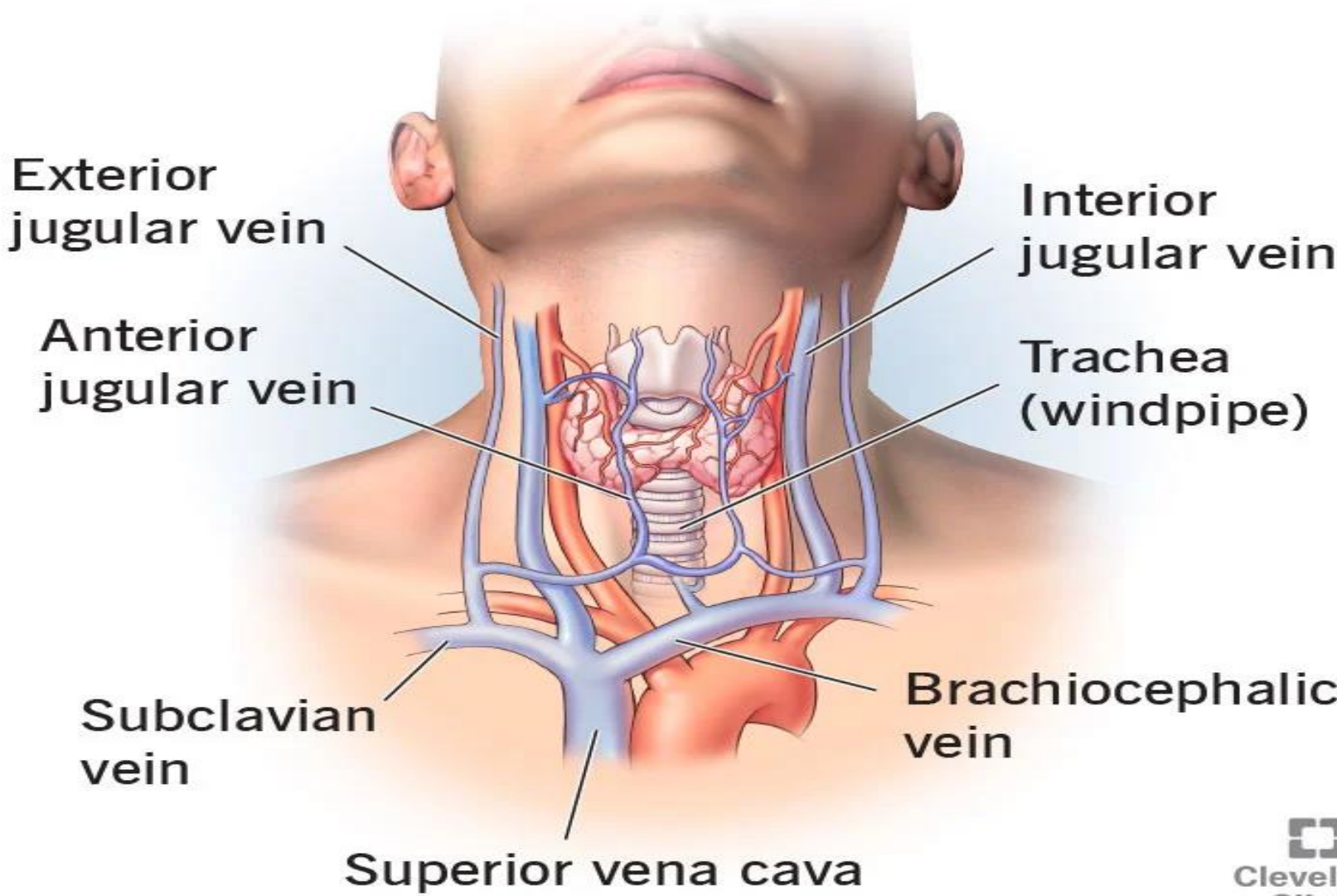
1. After the lecture, students should be able to:

2. Define arterial pulse wave (pulse pressure curve) and its significance.

3. Describe the jugular venous pulse and its significance.

4. Identify heart sound (normal and abnormal, characters and causes).

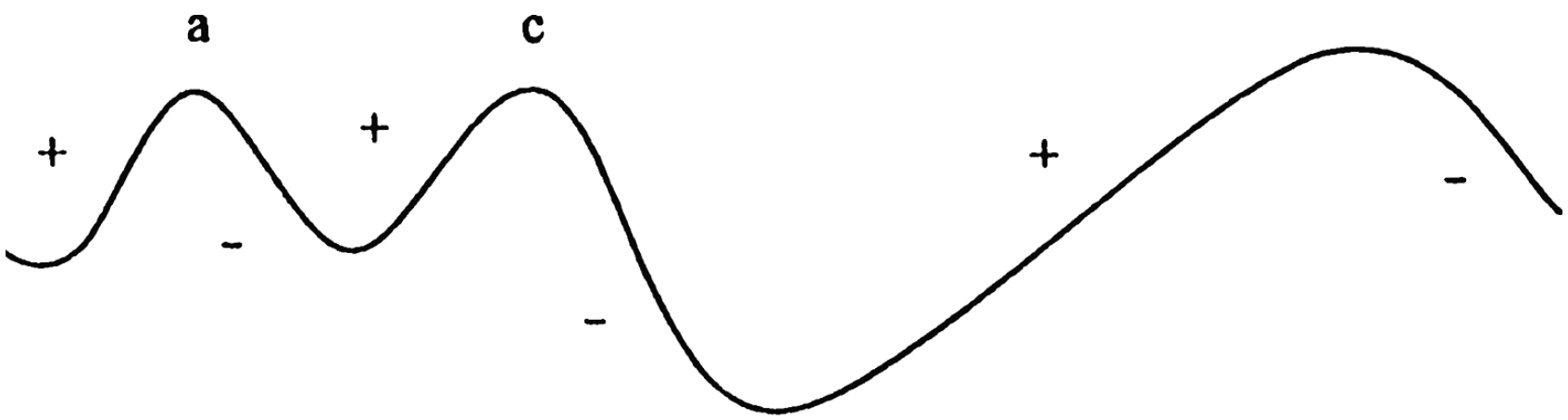
Jugular Veins

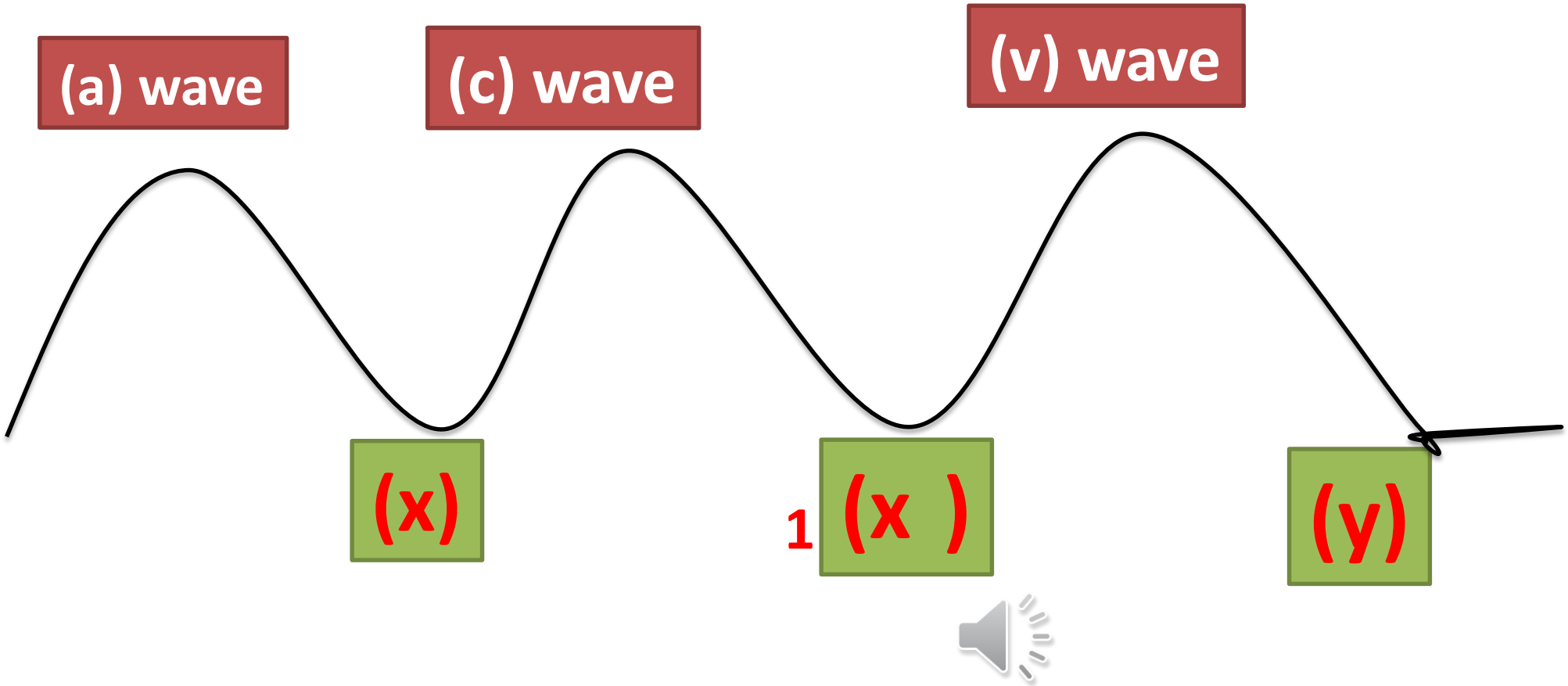


❖ Jugular pulse curve :

Pressure changes in right atrium during cardiac cycle are transmitted to right external jugular vein are recorded in the form of a curve (jugular venous pulse curve) composed of:

- Three positive waves (a, c and v).
- Three negative waves (x, x1 and y)




(a) wave
(c) wave
(v) wave
(x)
1 (x)
(y)

The Cause Of The Positive Waves:

The (a) wave is due to atrial systole contraction of the muscle sleeves around the mouth of SVC ↑ its pressure positive a wave.

The (c) wave is due to early ventricular contraction (ICP) ↑ intraventricular pressure bulging of AV cusps into the right atrium ↑ pressure in jugular vein positive c wave.

The (v) wave is due to ↑ venous return ↑ intraatrial pressure ↑ pressure in jugular vein positive v wave.

The cause of the negative waves:

1. The –ve wave (x) is due to atrial diastole relaxation of the muscular sleeves around the mouth of SVC - ve wave "x".

2. The –ve wave (x_1) is due to the downward displacement of the AV ring during the MEP decreased pressure in right atrium and external jugular vein -ve wave "x_1".
3. The –ve wave (y) is due to opening of the AVV during RFP and rush of blood from the atrium to ventricle decreased atrial and external jugular vein pressure - -ve wave "y".

Aortic pressure changes during cardiac cycle

Pressure changes in aorta during cardiac cycle are recorded in the form of a curve composed of:

Anacrotic limb

- **It coincides with maximum ejection phase of left ventricles.**
- Aortic pressure:
  - Increases (As blood coming to aorta is more than that leaving it)
  - Reaches of 120 mmHg (SBP "Systolic Blood Pressure)

Catacrotic limb

❶ Beginning of catacrotic limb:

- Coincides with reduced ejection phase & Protodiastole
- Aortic pressure: Starts to decrease (As blood coming to aorta is less than that leaving it)

On catacrotic limb: There is diacrotic notch & diacrotic wave

❷Diacrotic

1- Diacrotic Notch = Incisura

Aortic pressure: - Sharp small drop

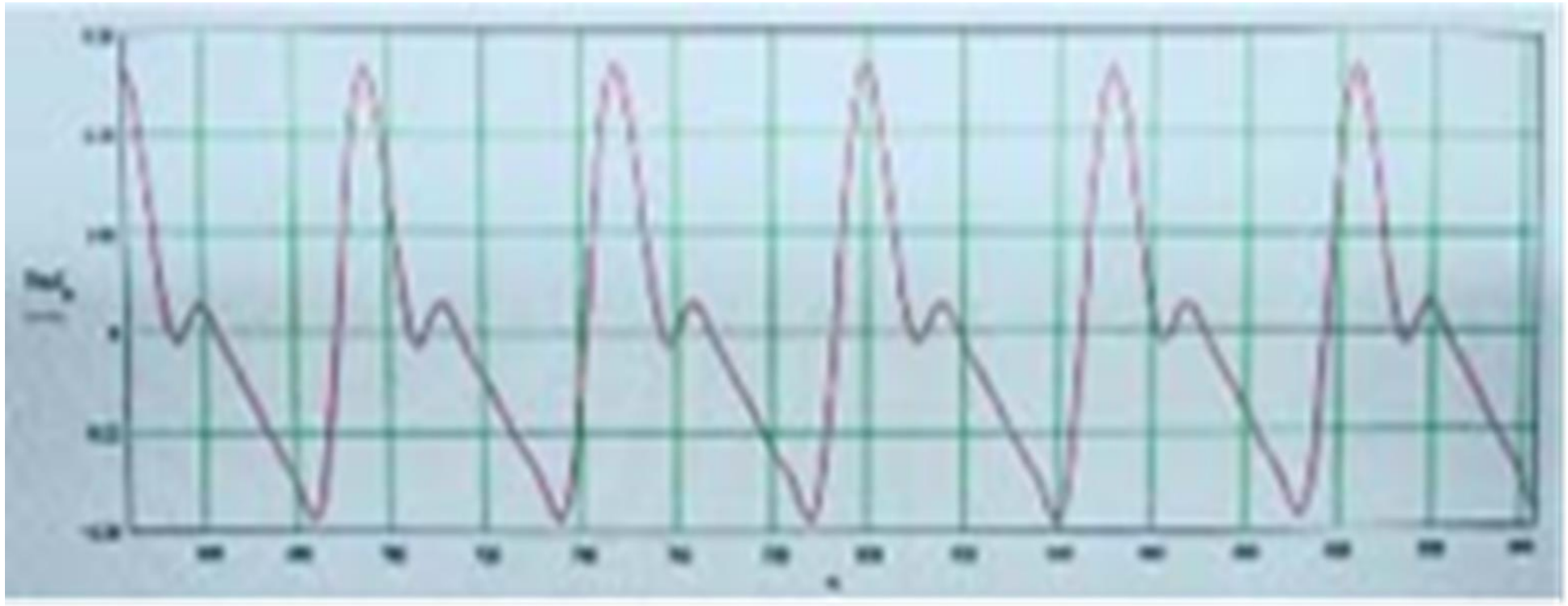
- Due to Sudden closure of aortic valve at beginning of isometric relaxation phase

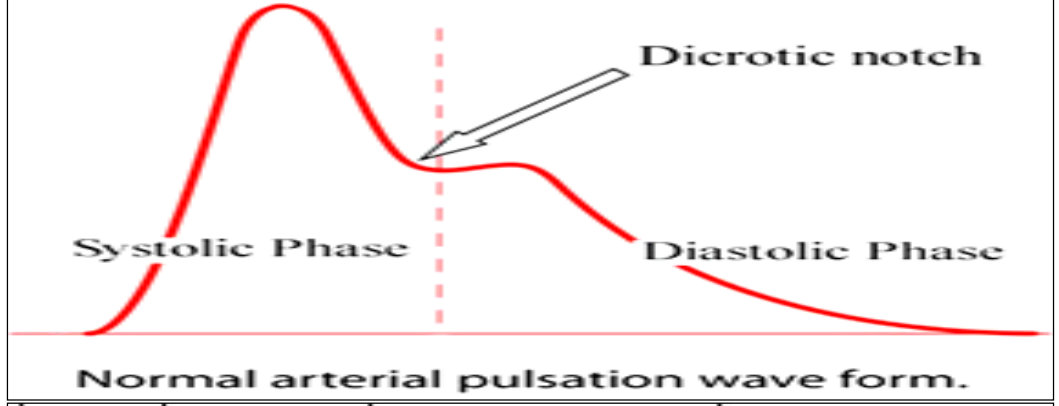
2- Diacrotic wave:

Aortic pressure: - Increases (Due to elastic recoil of distended aorta)

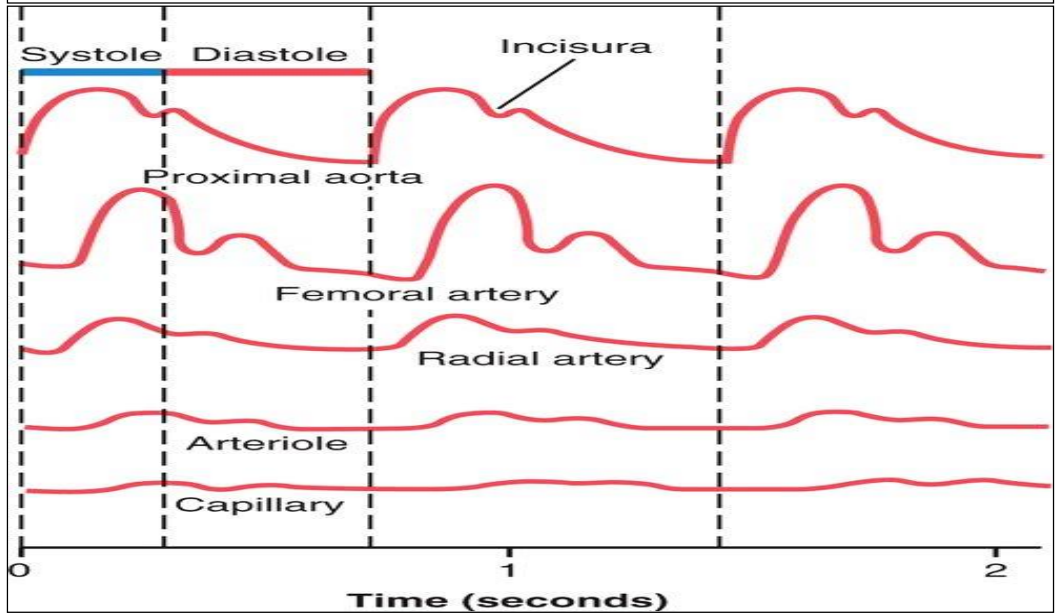
❸ Remaining part of catacrotic limb:

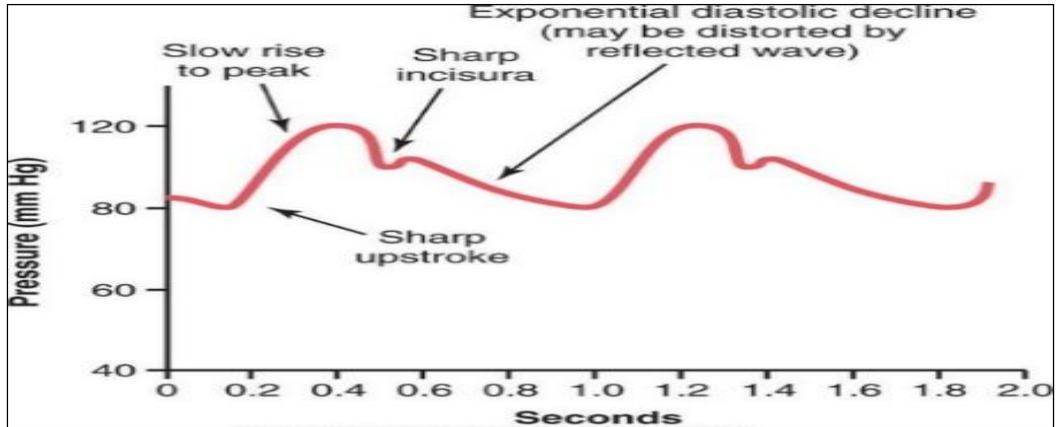
- It coincides with early, mid and late diastole & isometric contraction phase
- Aortic pressure: Decreases (As blood leaves aorta to tissues) reaches 80 mmHg (DBP “Diastolic Blood Pressure”)





Normal arterial pulsation wave form.






Thank
you!