This lecture may NOT include all information we need for the exam, If you're studying for the exam.. Better you study real slides first then revise and organize your thoughts here.

Physiology Team 434

Cardiac Cycle

I & II

Physiology Team 434
contact us : physiology434@gmial.com

Color index

- Important
- Further Additions

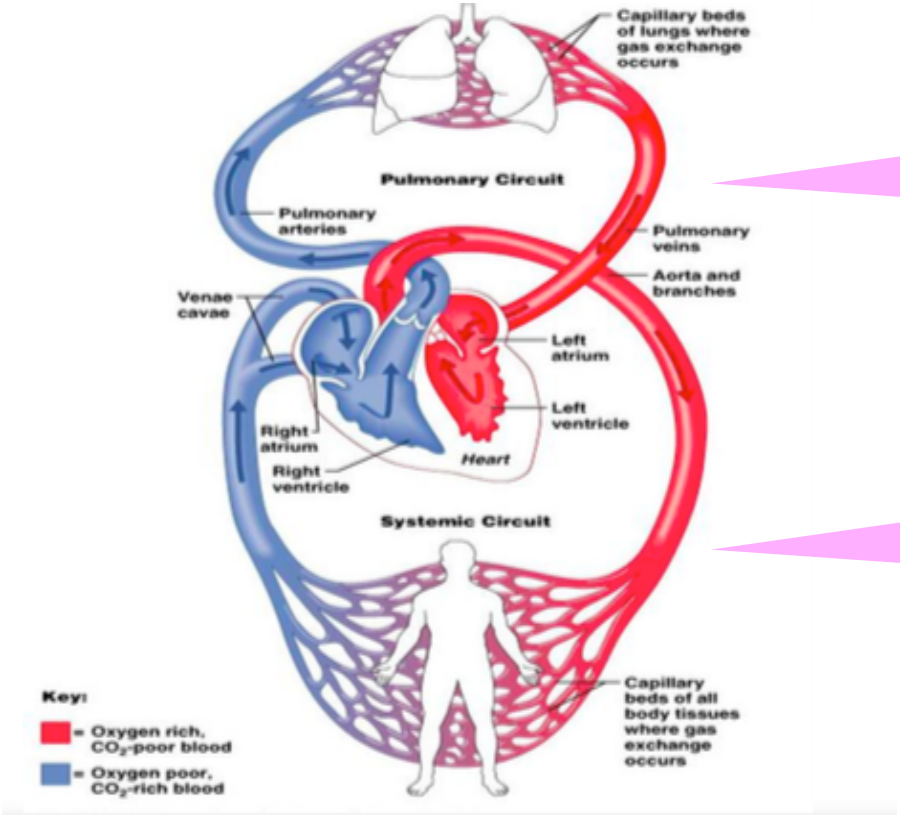
Only in Boys' Slides

Only in Girls' Slides

Explained in:
-Guyton Ch.9 P.104
-Linda's Ch.4 P.148
-Dr. Najeeb's videos for this lecture are highly recommended!

Pulmonary & Systemic Circulations

The heart contains two pumps (left and right) that divide the circulation of blood into :



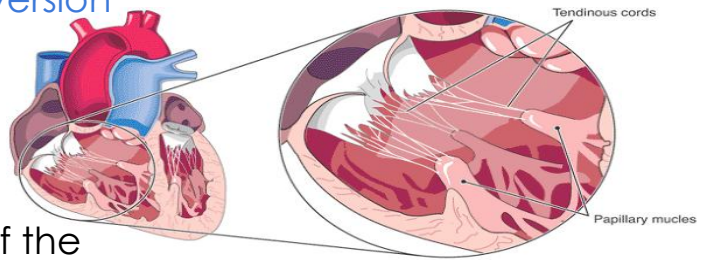
Pulmonary Circulation
Through the right pump moves the blood to the lungs

Systemic circulation
Through the left pump moves the blood to body tissues
That's why left side have more pressure

✧ Each pump consist of one atrium and one ventricle

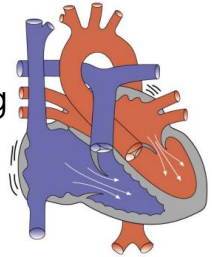
Valves of The Heart

- ✧ Found at entry & exit of each ventricle ➔ Allow blood to flow in ONLY ONE direction.
- ✧ Opening & closing of valves occur as a result of pressure gradient across the valves
- ✧ A-V cusps are held by chordae tendinea to muscular projections called Papillary muscles:
  - ✓ Papillary muscles limit valve movements & prevent eversion
  - ✓ Papillary muscles don't open or close the valve.



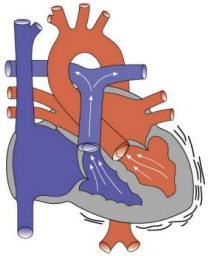
Atria of The Heart

- ✧ Atrial counteraction causes an additional filling (20%) of the ventricles. Therefore the atria simply functions as **a primer pumps** that increases the ventricular pump effectiveness.
- ✧ In some phases atrium passively add blood to ventricle(80%)acting as "Link or tunnel" passing the blood. (Rapid and reduced filling Phases)



Ventricles of The Heart

- ✧ Main **pump** for the cardiac cycle



Here are some great videos you may want to watch to get a proper understanding of the cardiac cycle =)

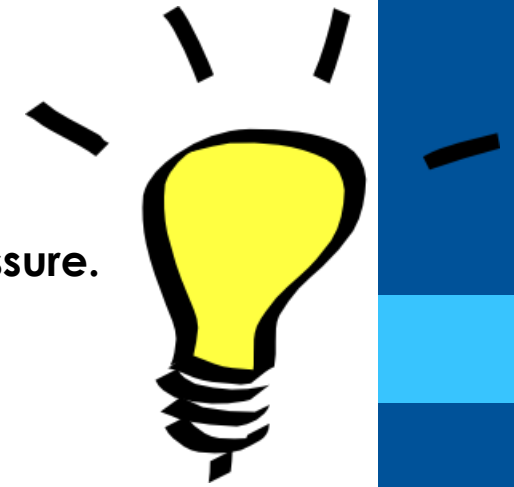
Youtube link for dr.Najeebs' cardiac cycle videos:
http://youtu.be/XbivIaFPoQI

Videos done by Med433:
http://youtu.be/5iqxRhfuKT4 Diastole
http://youtu.be/o2y8e5-qbxc Systole

To help you imagine the circulation:
https://www.youtube.com/watch?v=jLTdgrhpDCg
https://www.youtube.com/watch?v=5tUWOF6wEnk

General Principles

- ✧ Contraction of the heart **generates pressure changes.**
- ✓ Resulting in orderly blood movement.
- ✧ Blood flows from an **area of high pressure to an area of low pressure.**
- ✧ Events in the right & left sides of the heart are the same,
- ✓ **But with lower pressures in the right side.**
- ✧ When AV valve open, semilunar valve close & vice versa,
- ✧ Heart is a double pump (right & left sides) that work together.

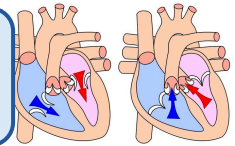


Cardiac Cycle

It's the sequence of events that place in the heart in each beat

The cardiac cycle last 0.8 seconds* (when heart rate 72 bpm)

Mechanical Events



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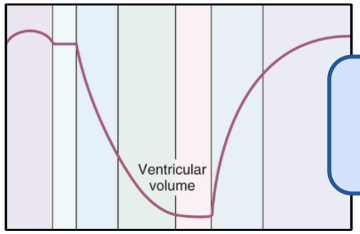
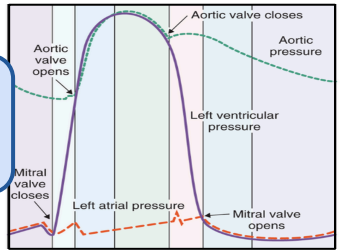
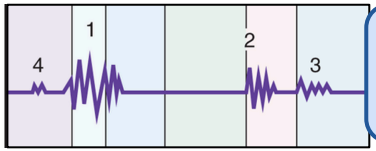
Volume Changes



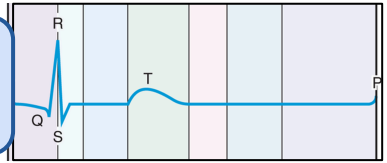
Pressure Changes



Heart Sounds



Electrical Events (ECG)

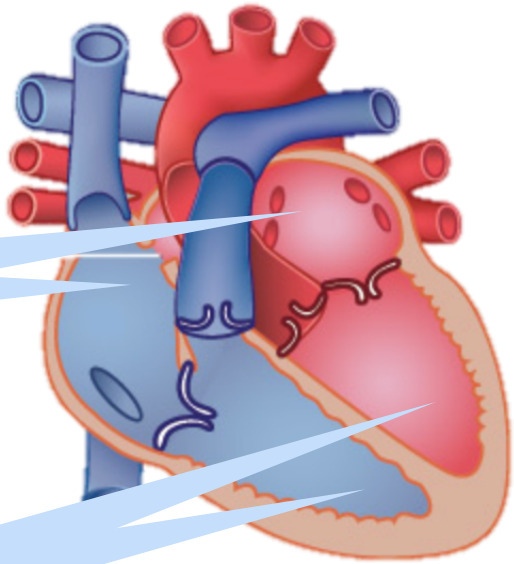


*The cardiac cycle is shortened (< 0.8 s) when the heart rate increases

Mechanical Events

- ✧ Each heartbeat consists of two major periods:
- ✓ **Systole** = Contraction
- ✓ **Diastole** = Relaxation

Atrial
Systole = 0.1 sec
Diastole = 0.7 sec



- ✧ The importance of **long** ventricular diastole:
  - ✓ coronary blood flow.
  - ✓ ventricular filling

Ventricular
Systole = 0.3 sec
Diastole = 0.5 sec

*Adding systole and diastole will give you the total amount of cardiac cycle 0.8

✧ Detentions:

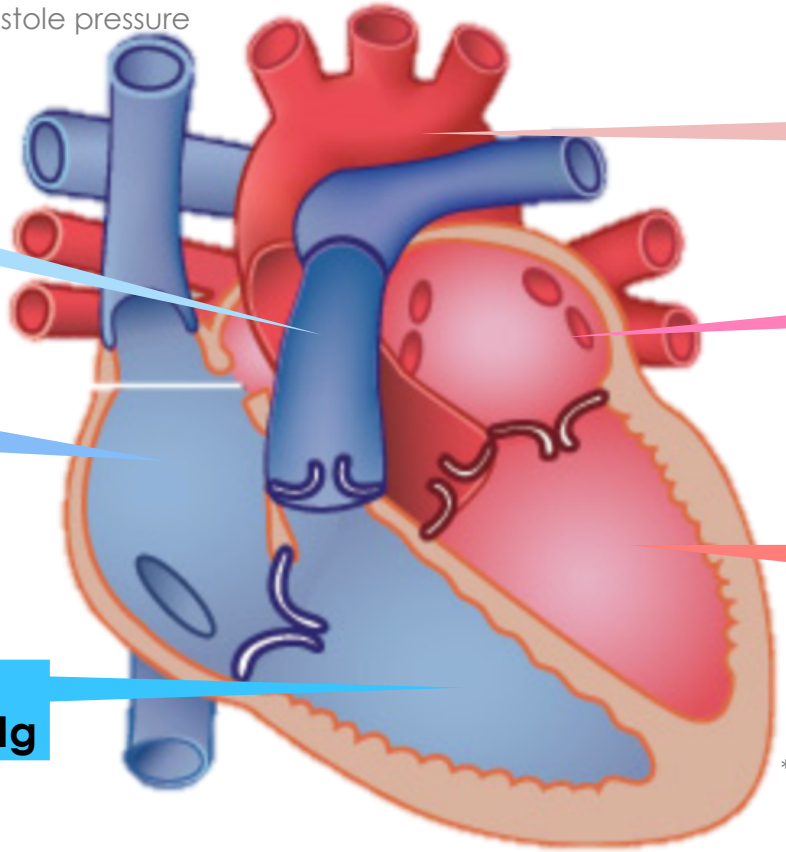
- ✓ End-diastolic volume (EDV): Volume of blood in ventricles at the end of diastole 110-130 ml
- ✓ Stroke volume (SV): Amount of blood ejected from ventricles during systole 70 ml/beat
- ✓ End-systolic volume (ESV): Amount of blood left in ventricles at the end of systole 40-60 ml
- ✓ Ejection fraction (EF): Fraction of end-diastolic volume that is ejected 60-65 %

Mechanical Events

IMPORTANT

Intra-Cardiac Pressures

*All have Systole pressure /Diastole pressure
Atrium *only systole pressure



Pulmonary trunk
25-30/4-12 mmHg

Aorta
120/80 mmHg

Left atrium
2-10 mmHg

Right atrium
2-8 mmHg

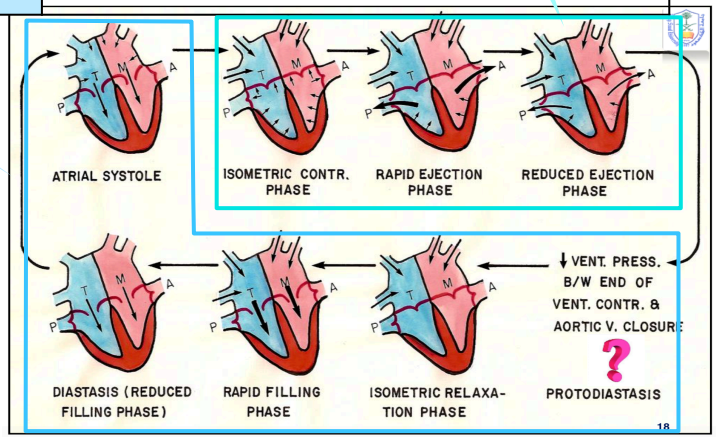
Left ventricle
100-120/3-12mmHg

Right ventricle
25-30/2-3 mmHg

Remember:
*Systole has more pressure cause less volume
*atrium has no diastole pressure cause very little or no pressure
*Ventricle always have pressure in systole and diastole cause it never pump all blood it has (the is always remaining blood).

Mechanical Phases:

Ventricular Diastole		Ventricular Systole
Early Ventricular Diastole		1- Isometric contraction phase
0- Protodiastolic Phase (is no longer mentioned)		2- Rapid ejection phase
1- Isometric relaxation phase	2- Rapid filling phase (Passively from atrium)	3- Reduced ejection phase
Mid Ventricular Diastole		
3- Reduced filling phase (Passively from atrium)		
Late Ventricular Diastole		
3-Atrial systole		



Protodiastolic Phase

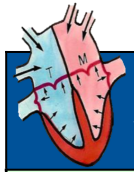
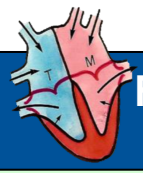
Very short Period between the end of ventricular systole and aortic valve closure.

(As the ventricle relax the pressure is reduced so the blood tend to flow back from aorta but prevented by closure of aortic valve)

PROTODIASTASIS

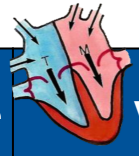
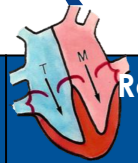
Mechanical Phases (Systole)

Major events are in **bold**

	 Isovolumetric Ventricular Systole	 Rapid Ventricular Ejection	 Reduced Ventricular Ejection
Valves	**A-V are closed**	A-V are closed	A-V are closed
	Semilunar closed	**Semilunar are opened**	Semilunar are opened
Atria	-Diastole -Receiving blood from lungs.	-Diastole -Receiving blood from lungs. -Pressure slowly increases.	-Diastole -Receiving blood from lungs -Pressure slowly increases.
Ventricles	-**Depolarization** **-Contraction** -No change in volume=(EDV) -Pressure increases↑ higher than atrial pressure (which caused AV valve to close), it will increase until reaching 80mmhg (aortic pressure)	**-Contraction** **-75% of ventricular blood is ejected.** -Volume of ejected blood = Stroke Volume = 70ml **-Volume Decreases↓** **-Pressure increases↑** (maximum) -Aortic pressure increases	-Repolarization **-25% of ventricular blood is ejected in slow rate** **-Volume decreases slowly** -Pressure decreases ↓< aortic Pressure -Aortic pressure increases
	1st heart sound	-	-
	0.04 sec	-	-

Mechanical Phases (Diastole)

Major events are in **bold**

	 **Isovolumetric Ventricular Diastole**	 **Rapid Ventricular Filling**	 **Reduced Ventricular Filling (Diastasis)**	 **Atrial Systole**
Valves	A-V valves are closed	**A-V valves are opened**	A-V valves are opened	**A-V are opened**
	Semilunar valves closed	Semilunar valves are closed	Semilunar valves are closed	Semilunar closed
Atria	-Still receiving blood -**Increased pressure** ↑	-60%-70% of **blood moves passively** to ventricles -Pressure start to decrease ↓↓	-10% of blood trickles to ventricles -Pressure decreases ↓	-**Depolarization** -**Contraction** -20%= 40ml atrial blood to ventricles **actively** -**Pressure increases**↑
Ventricles	-**Repolarization** -**Relaxation** -**No change in volume** = (ESV) -**Decreased pressure** ↓ (minimum)	**-Relaxation** -Receiving blood -**Volume increases** ↑↑ - Pressure start to increase ↑↑	**-Relaxation** -Still receiving blood -Volume increases↑ -Pressure increases↑ -Aortic pressure decreases	-Relaxation -Receiving blood -Increase volume↑ -(pressure increases)↑
	2nd heart sound	**3rd** heart sound (Mainly in **children**)	-	**4th** heart sound (In **elderly** & pathological conditions)
	0.04 sec	-	-	0.1 sec

Cardiac Cycle Timing

Although the events of the cardiac cycle on the two sides of the heart are similar, they are somewhat **asynchronous**[1].

- ✓ Right atrial systole precedes left atrial systole.
- ✓ Contraction of the right ventricle starts after that of the left

Why? Since pulmonary arterial pressure is lower than aortic pressure.

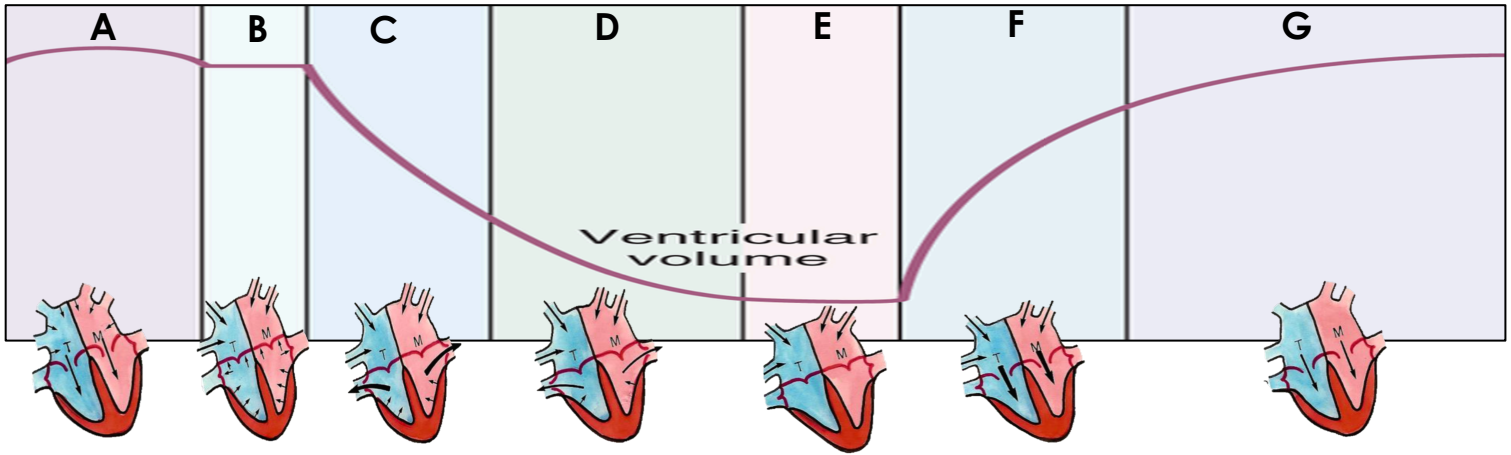
- ✓ **During inspiration**: The aortic valve closes slightly before the pulmonary. **Why?** Due to lower impedance of the pulmonary vascular tree

- ✓ When measured over a period of minutes, the outputs of the two ventricles are equal. **BUT** transient[2] differences in output during the respiratory cycle occur in normal individuals.

1: Not existing or occurring at same time
2: Last for a short time.

Volume Changes in Cardiac Cycle

		Phase	Ventricular Volume
SYSTOLE	A	Atrial Systole	**Increases ↑**
	B	Isovolumetric Ventricular Contraction Phase	**Constant**
	C	Rapid Ventricular Ejection Phase	**Rapidly decreases ↓↓**
	D	Reduced Ventricular Ejection Phase	**Slowly decreases ↓**
DIASTOLE	E	Isovolumetric Ventricular Relaxation Phase	**Constant**
	F	Rapid Ventricular Filling Phase	**Rapidly increases ↑↑**
	G	Reduced Ventricular Filling Phase	**Slowly increases ↑**



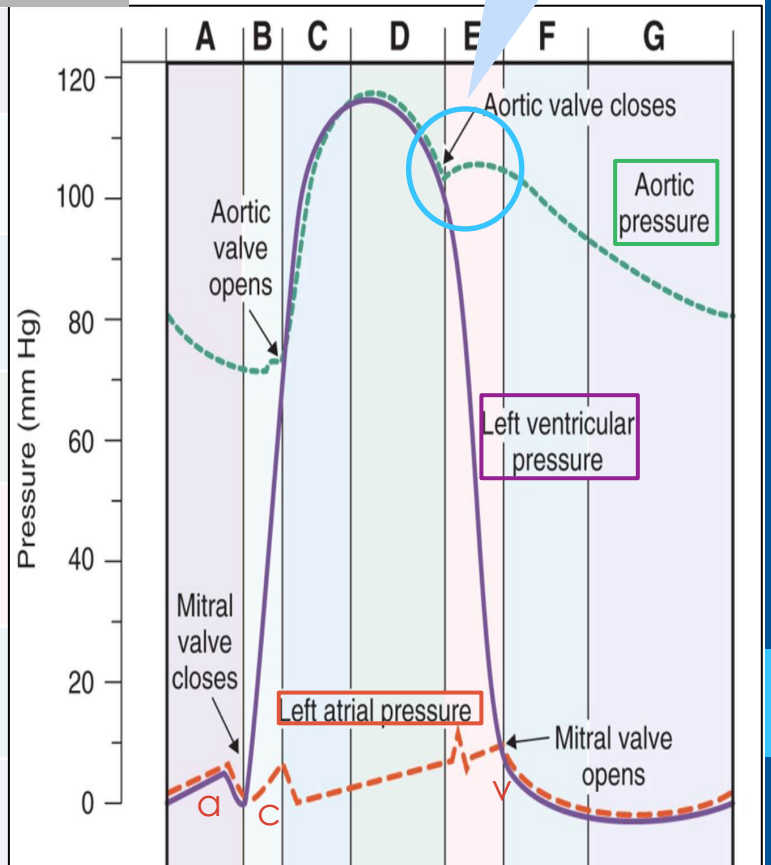
Pressure Changes in Cardiac Cycle

- ✧ Ventricular pressure changes (VP)
- ✧ Aortic Pressure changes
- ✧ Atrial pressure changes (AP)

Read the table and follow on the graph

A	**Atrial Systole**	VP : Starts from 3 mmHg up to 15 mmHg Aortic P: Constant (80 mmHg) AP: Start from 3 mmHg up to 15 mmHg (a wave)
B	**Isovolumetric Ventricular Contraction**	VP: 15-80 mmHg Aortic P: Constant (80 mmHg) AP: A slight increase (c wave)
C	**Rapid Ventricular Ejection**	VP: 80-120 mmHg Aortic P: Ascending or **anacrotic limb** (80-120 mmHg) **Why?** due to the opening of the aortic valve AP: Continuous increase (v wave)
D	**Reduce Ventricular Ejection**	VP: Slowly decreases (120-110 mmHg) Aortic P: Descending or **catacrotic limb** (120-111 mmHg) AP: Continuous increase (v wave)
E	**Isovolumetric Ventricular Relaxation**	VP: Rapid decrease (110-15 mmHg) Aortic P: Dicrotic notch **(incisura)** **Why?** due to the closure of the aortic valve AP: continuous increase (v wave)
F	**Rapid Ventricular Filling Phase**	VP: A slight decrease (15-3 mmHg) Aortic P: **Dicrotic wave** **Why?** Due to the elastic recoil of the aorta AP: A slight decrease (end of v wave)
G	**Reduce Ventricular Filling**	VP: A slight increase Aortic P: Decrease up to 80 mmHg AP: A slight increase

Notice at the end of this phase, the AP is higher than the VP (Aortic valve closes)

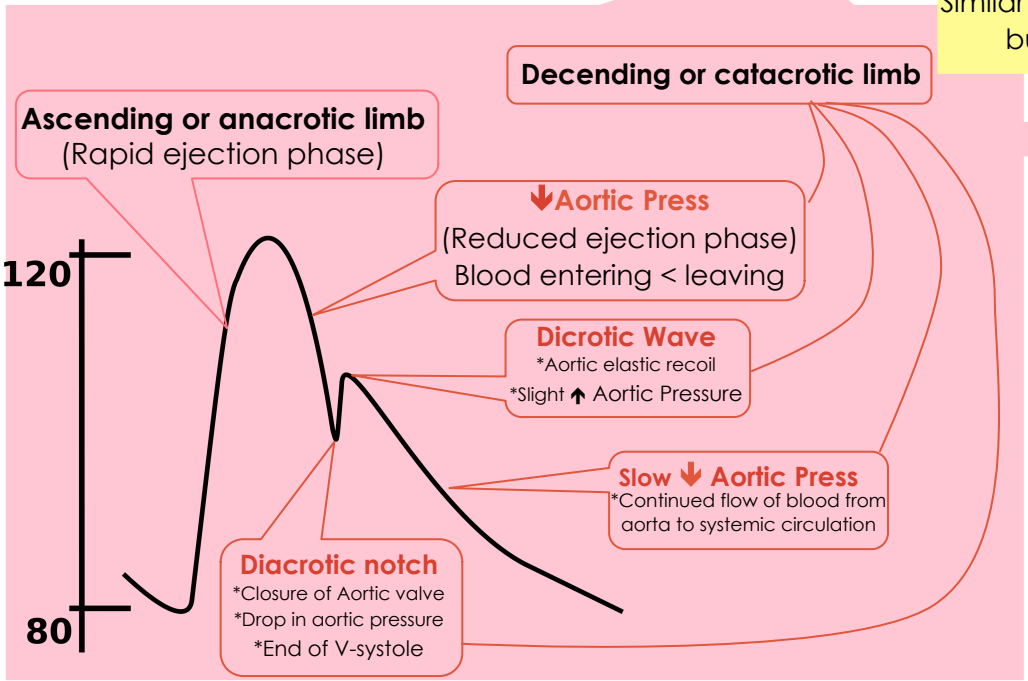


Pressure Changes in Cardiac Cycle

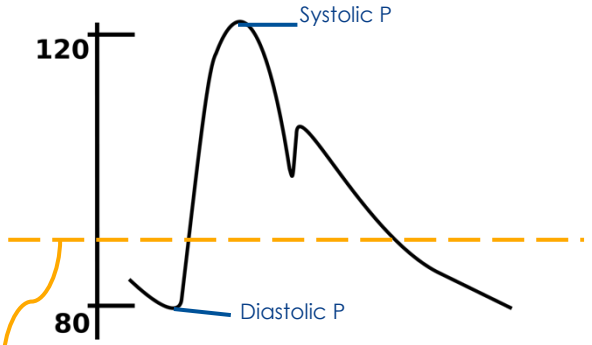
	Left Ventricles	Aorta	Pulmonary Artery	Peripheral Arteries
Maximum Systolic	120 mmHg	120 mmHg	25-30 mmHg	110-130 mmHg
Minimum Diastolic	3-15 mmHg	80 mmHg	4-12 mmHg	70-85 mmHg

Similar to aortic pressure waves but diff. in **magnitude**

Similar to aortic pressure waves but **sharper**



Mean & Pulse Pressure

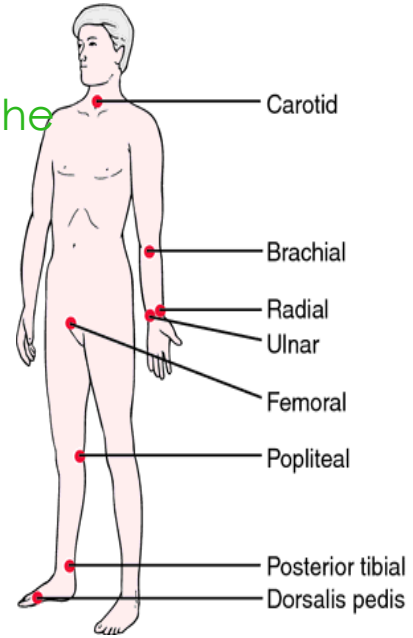


- **Mean Pressure** = diastolic P + ⅓ (pulse pressure)
- **Pulse pressure** = Systolic P – Diastolic P

Arterial Pulse

Forcing of the blood into the aorta during systole not only moves the blood in the vessels forward but also sets up a pressure wave that travels along the walls of the arteries.

- ✧ The pressure wave expands the arterial walls as it travels, and the expansion is palpable as the **pulse.**
- ✓ The rate at which the wave travels is independent and much higher than the velocity of blood flow.
- ✓ the pulse is felt in the radial artery at the wrist about 0.1 s <u>after the **peak of systolic ejection into the aorta**</u>.
- ✓ With advancing age, the arteries become more rigid, and the pulse wave moves faster.
- ✓ The strength of the pulse is determined by the pulse pressure bears little relation to the mean pressure.

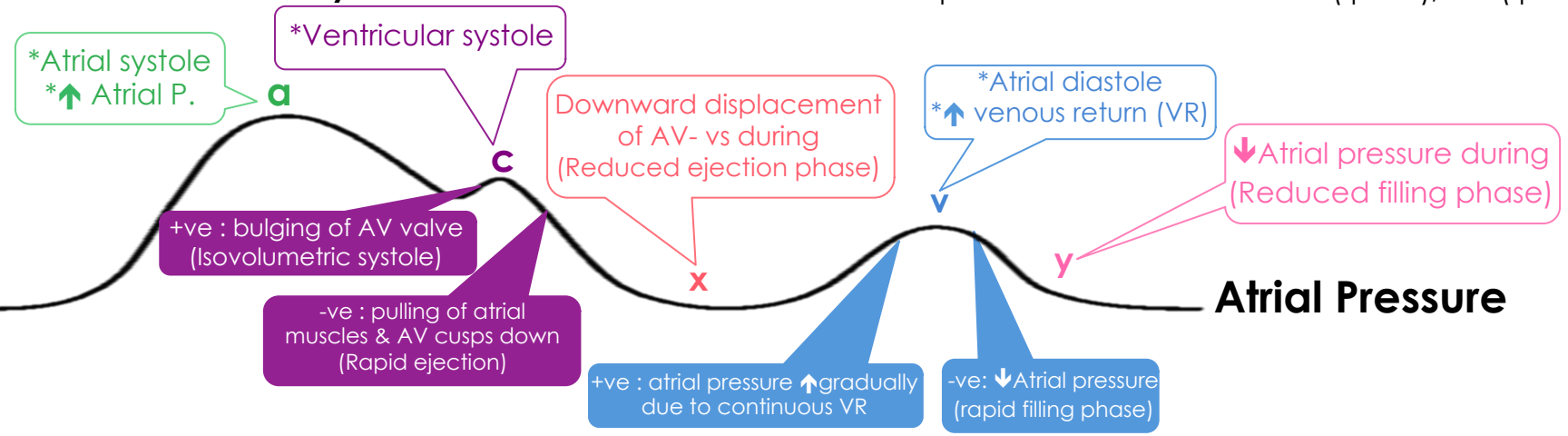


- ✧ When the aortic valve is incompetent (aortic insufficiency), the pulse is particularly strong, and the force of systolic ejection may be sufficient to make the head nod with each heartbeat. The pulse in aortic insufficiency is called a collapsing, Corrigan, or water-hammer pulse.

Pressure Changes in Cardiac Cycle

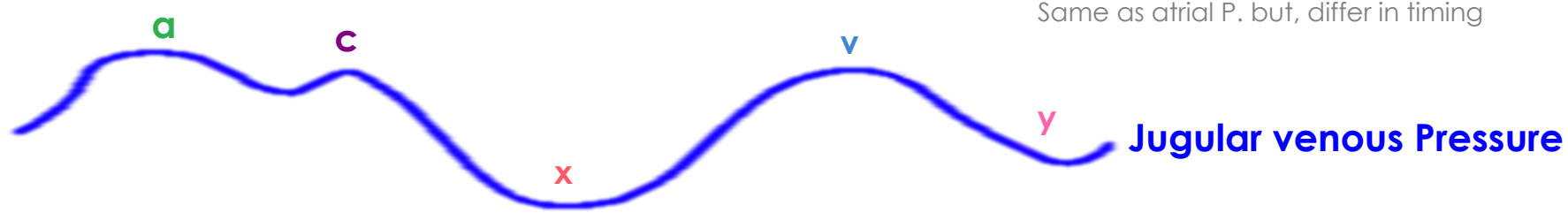
Atrial Pressure Changes results in:
- 2 **Downward** deflection: x & y
- 3 **Upward** deflection: a, c & v
  - ✓ 2 components in each wave: +ve (press), -ve (press)

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



Jugular venous pulse changes: Also results in recording of transmitted atrial waves.

Same as atrial P. but, differ in timing



The Electrocardiogram

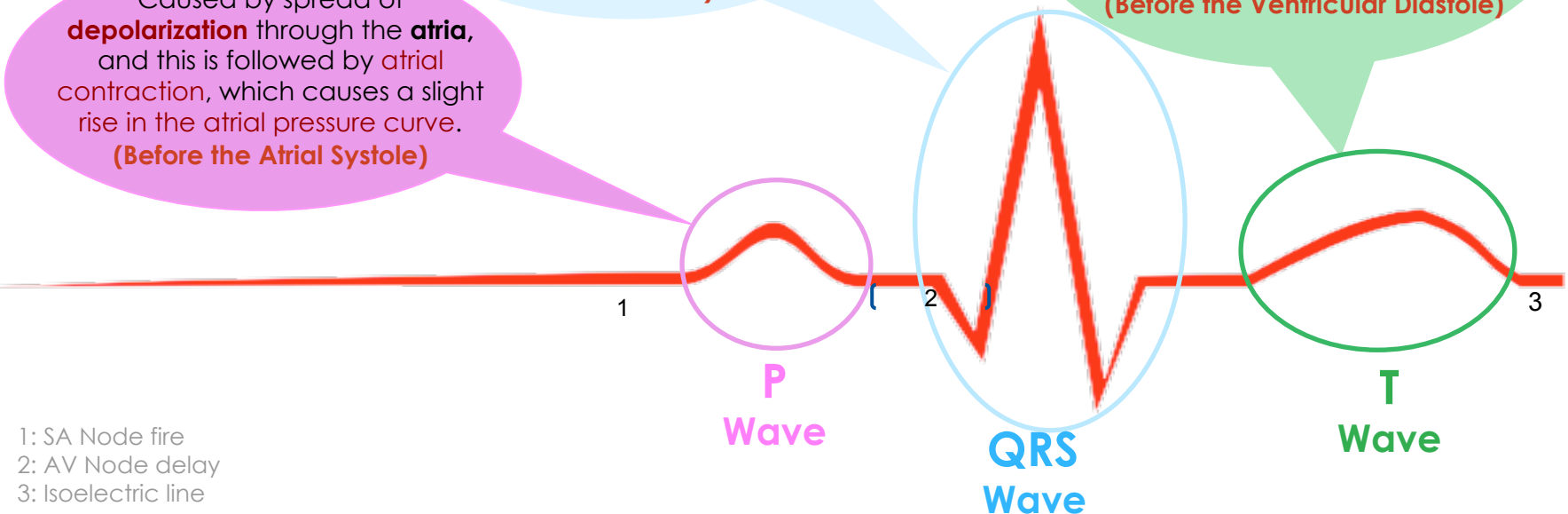
They are electrical voltages generated by the heart and recorded by the electrocardiograph from the surface of the body.

***Where is atrial repolarization?**
Maxed by the QRS complex.

Caused by spread of **depolarization** through the **atria,** and this is followed by atrial contraction, which causes a slight rise in the atrial pressure curve.
(Before the Atrial Systole)

Appear as a result of electrical **depolarization** of the **ventricles**, which initiates contraction of the ventricles and causes the ventricular pressure to begin rising.
(Before the Isovolumetric contraction)

The stage of **repolarization** of the **ventricles** when the ventricular muscle fibres begin to relax. Therefore, the T wave occurs slightly before the end of ventricular contraction.
(Before the Ventricular Diastole)

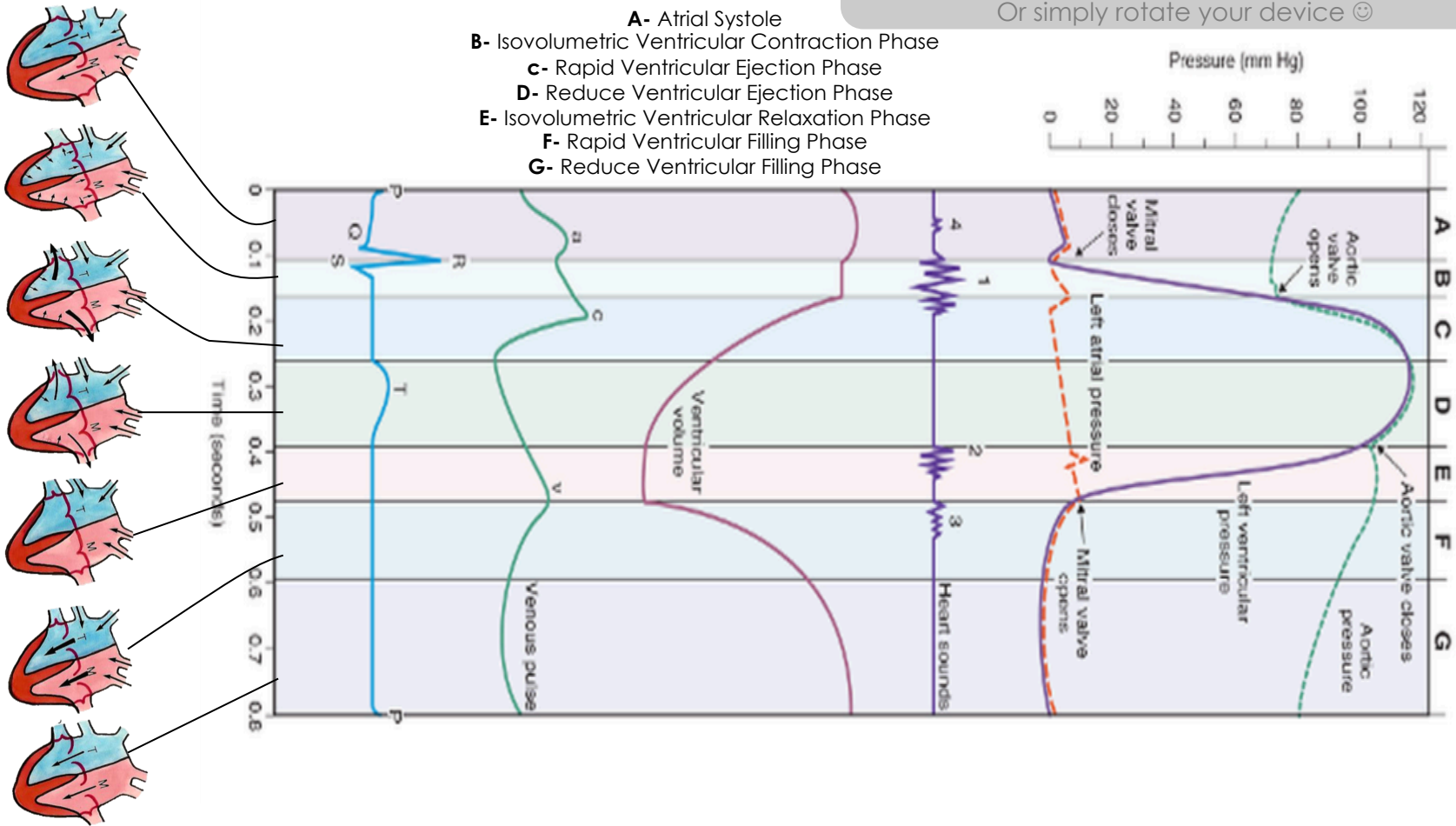


1: SA Node fire
2: AV Node delay
3: Isoelectric line

The complete picture

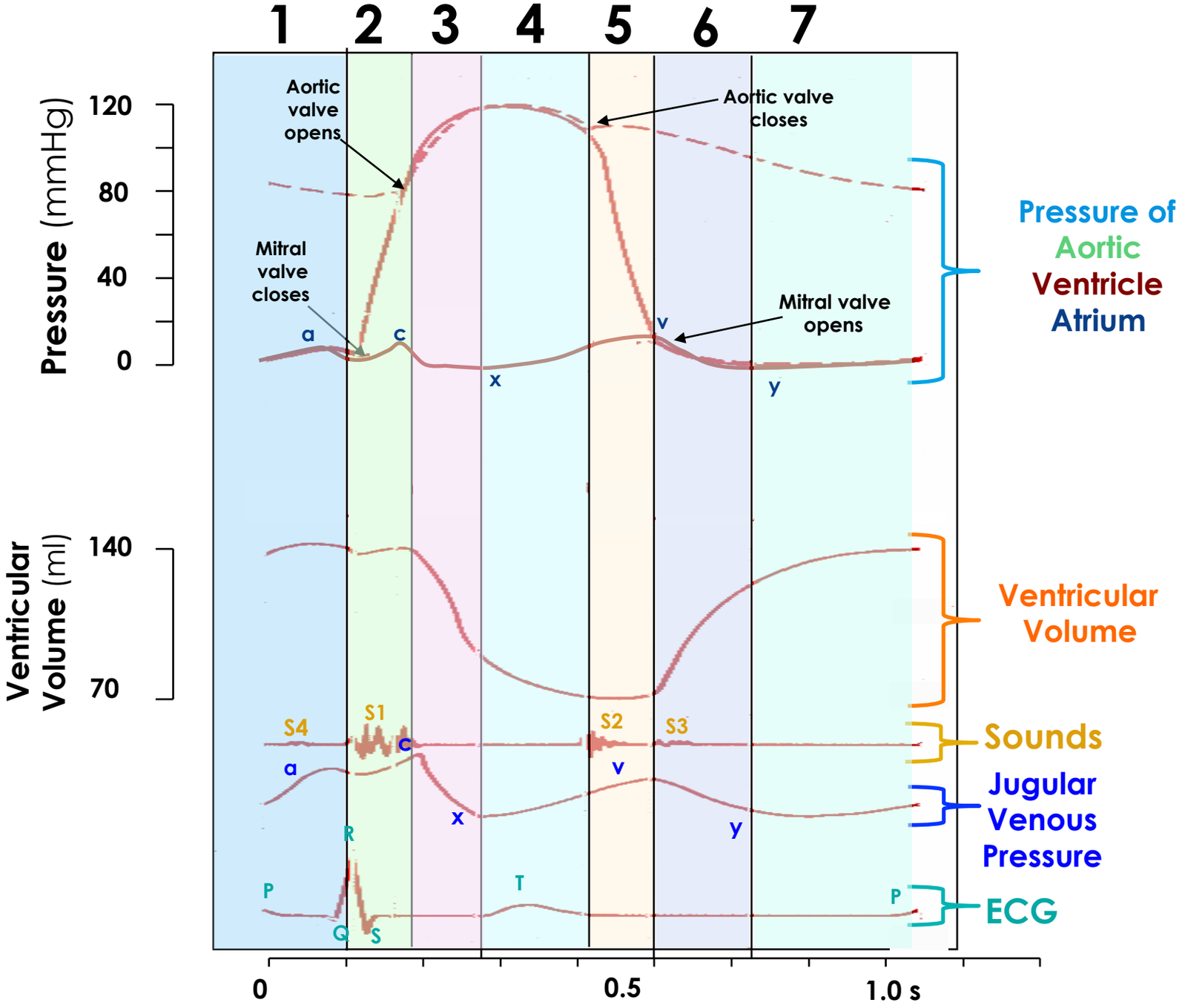
I think you need to do some exercise by rotating your head to the right.
So you can see the complete picture...
Or simply rotate your device ☺

A- Atrial Systole
B- Isovolumetric Ventricular Contraction Phase
c- Rapid Ventricular Ejection Phase
D- Reduce Ventricular Ejection Phase
E- Isovolumetric Ventricular Relaxation Phase
F- Rapid Ventricular Filling Phase
G- Reduce Ventricular Filling Phase



Now you see me!

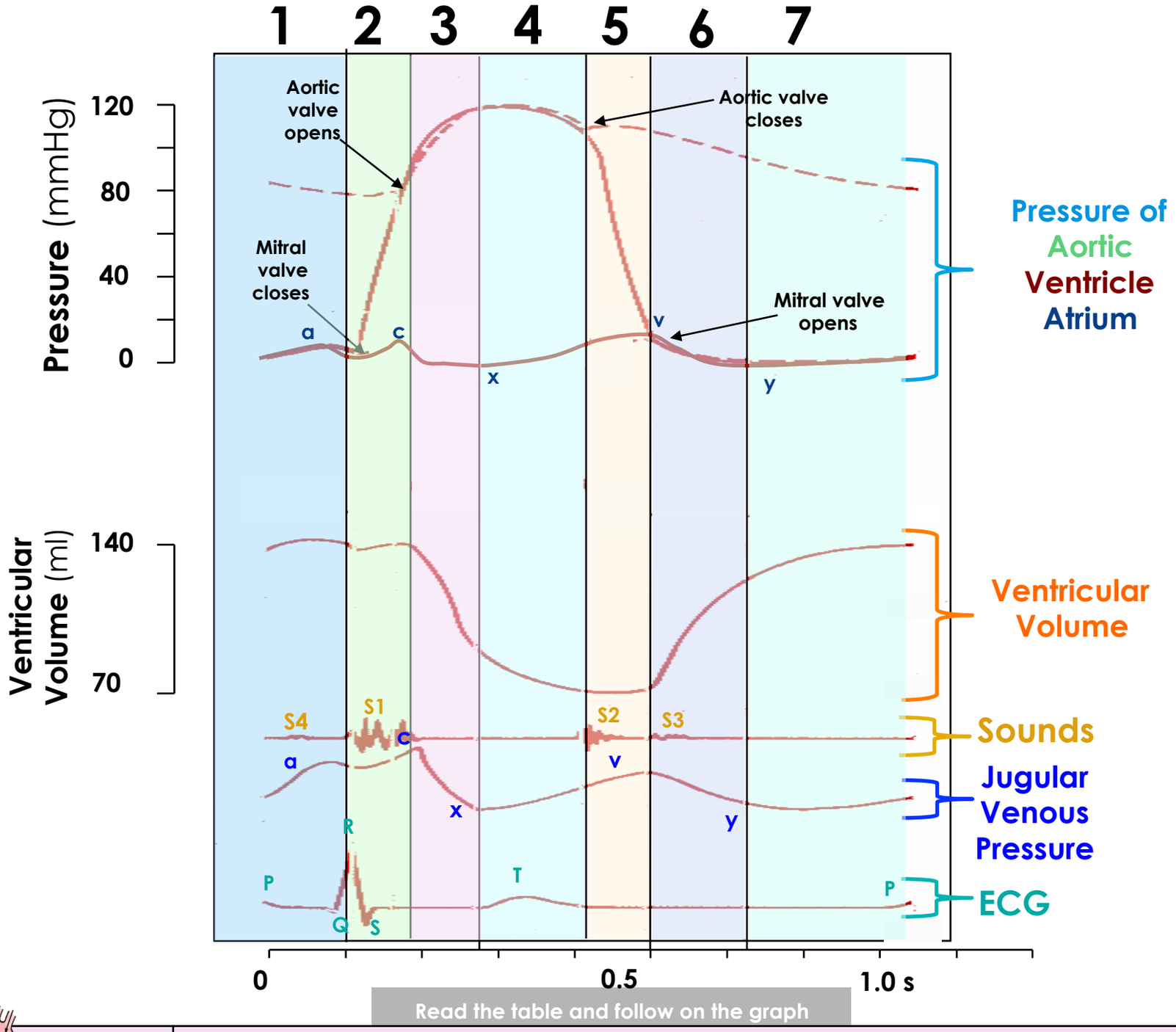
The Complete Picture (Important)



Read the table and follow on the graph

1 Atrial Systole	ECG: P wave due to atrial depolarization just before atrial systole. J.V.P. : (a wave) is produced due right atrial contraction. Sounds: 4th heart sound heard (elderly). Ventricular v.: Ventricles receiving last 27-30% of ventricular filling➔ increase in volume. Atrial P.: (a wave) Increase atrial pressure during atrial systole. exceeds ventricular pressure. Ventricular P.: More blood is squeezed into the ventricle ➔increase in ventricular pressure.
2 Isovolumetric Systole	ECG: QRS complex due to ventricular depolarization just before ventricular systole. J.V.P. : (c wave) during ventricular systole bulging of tricuspid valves into right atrial. Sounds: 1st heart sound (lub) heard due to closure of AV valves. Ventricular v.: Ventricles now are full and closed, volume is constant. 'EDV=110-130 ml' Atrial P.: (c wave ' +ve') during ventricular systole bulging of AV valves into right atrial. Ventricular P.: As ventricles contract the ventricular pressure increases until it exceeds. aortic/pulmonary pressure [80 mmHg], Phase ends with semilunar valves opening.

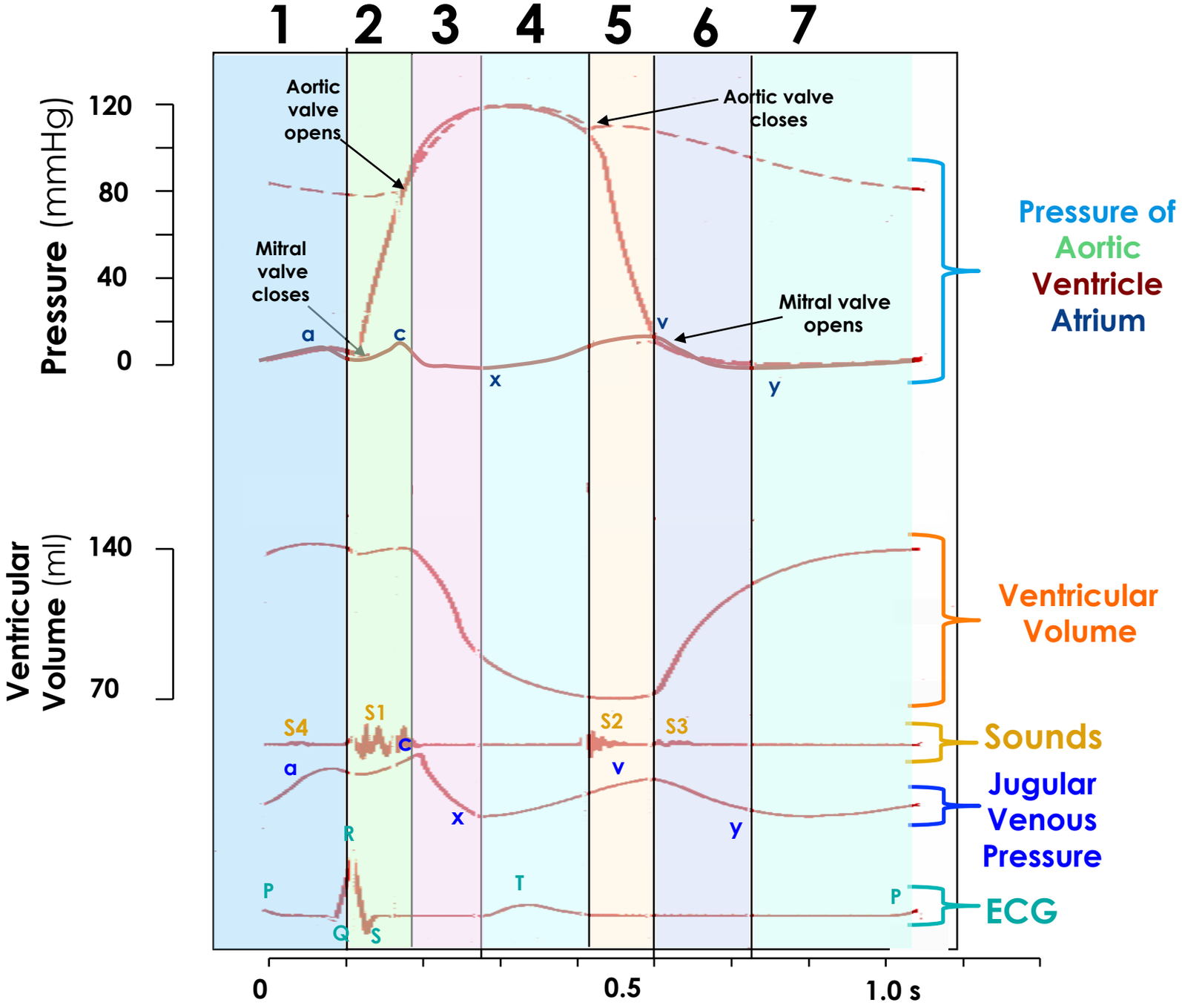
The Complete Picture (Important)



Read the table and follow on the graph

3 Rapid Ejection	**J.V.P. : (x descent) Downward displacement of tricuspid valve.** **Ventricular v.: Almost 75% of ventricular blood in ejected (SV)➔volume rapidly decreases.** **Atrial P.: (c wave '-ve') AV valves cusps down and atrial muscles are pulled ➔ decrease in atrial pressure.** **Ventricular P.: Contraction of ventricles causes the ventricles pressure increase to the maximum** [up to 120 mmHg]. **Aortic P: Aortic pressure increases** [up to 120 mmHg] **'Ascending or anacrotic limb'.**
4 Reduced Ejection	**ECG: T wave due to ventricular repolarization** just before ventricular diastole. **Ventricular v.: Almost 25% of ventricular blood in ejected ➔ volume slowly decreases.** **Atrial P.: (x descent) decrease in atrial pressure due to downward displacement of AV vs.** **Ventricular P.: Decrease of ventricular pressure**[110 mmHg] **= semilunar valves closes.** **Aortic P: : Aortic pressure decreases amount of blood enters < leaves 'Descending or catacrotic limb'**

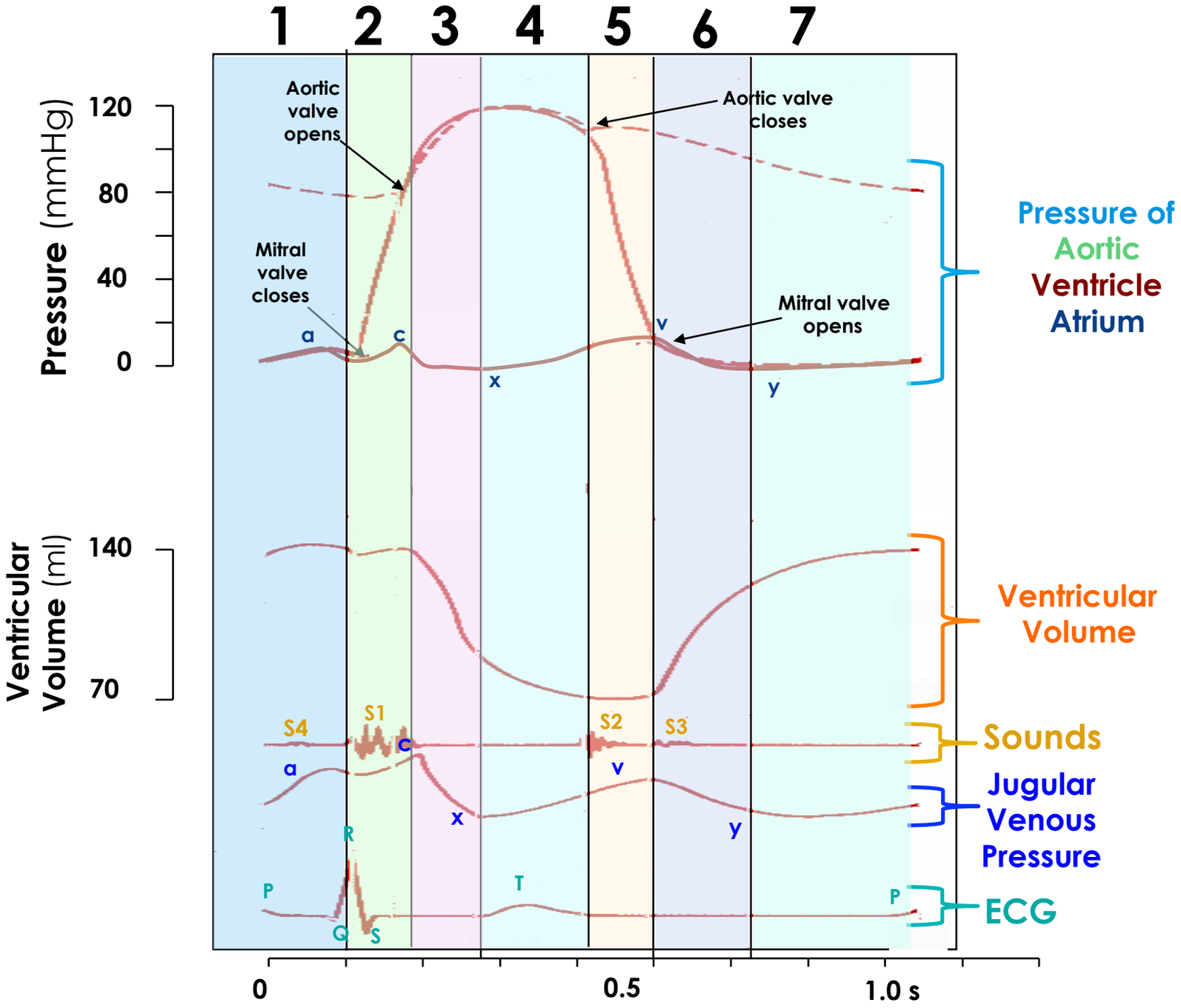
The Complete Picture (Important)



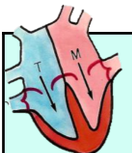
Read the table and follow on the graph

5 Isovolumetric Diastole	J.V.P. : (v wave) increase right atrial press due to filling of atrium with blood (VR). Sounds: 2nd heart sound (dub) heard due to closure of semilunar valves. Ventricular v.: Volume is constant. 'ESV= 40-60ml' Atrial P.: (v wave '+ve') Increase atrial pressure due to continuous VR. Ventricular P.: As ventricles relaxes the ventricular pressure decreases rapidly. Aortic P: Sudden drop in aortic pressure due closure of aortic valve.'Dicrotic notch (incisura)'
6 Rapid Filling	J.V.P. : (y descent) Rapid blood flow from right atrial to right ventricle. Sounds: 3rd heart sound heard (Children). Ventricular v.: As 60-70% of blood is passively filling ventricles➔Volume rapidly increases. Atrial P.: (v wave '-ve') Decrease in atrial pressure. Ventricle P.: It starts to increase as it's receiving blood from atria. Aortic P: is decreasing.

The Complete Picture (Important)



Read the table and follow on the graph



7 Reduced Filling	Ventricular v.: Blood flows slowly to ventricles ➔ volume increases slowly. Atrial P.: (y descent) decrease in atrial pressure. Ventricle P.: Is gradually increasing. Aortic P: Continue to decrease [up to 80 mmHg] due to flow of blood from aorta to systemic circulation.

Left Ventricular Pressure-Volume Loop

It is the measure for the correlation of intra-ventricular changes in volume & pressure that occur during one cardiac cycle

Basic Myocardial Muscle Mechanics	
Systole	**Diastole**
Muscle contracts & generates pressure which cause changes in volume	Muscle is relaxed & venous blood returns to the heart resulting in changes in absolute volume and pressure
✧ Early phase: isovolumetric contraction ✧ Late phase: isotonic contraction = ejection phase	✧ Early phase: isovolumetric relaxation ✧ Late phase: isotonic relaxation = filling phase
Ventricular systole is measured by (contractility)	Ventricular systole is measured by (compliance) = ($C = \Delta V / \Delta P$)
Affected by: ✓ Function of the muscle ✓ Initial volume (preload) 'Directly proportional to it' ✓ Initial pressure (afterload) 'Inversely proportional to it'	**Affected by:** ✓ Connective tissue ✓ Venous pressure ✓ Venous resistance

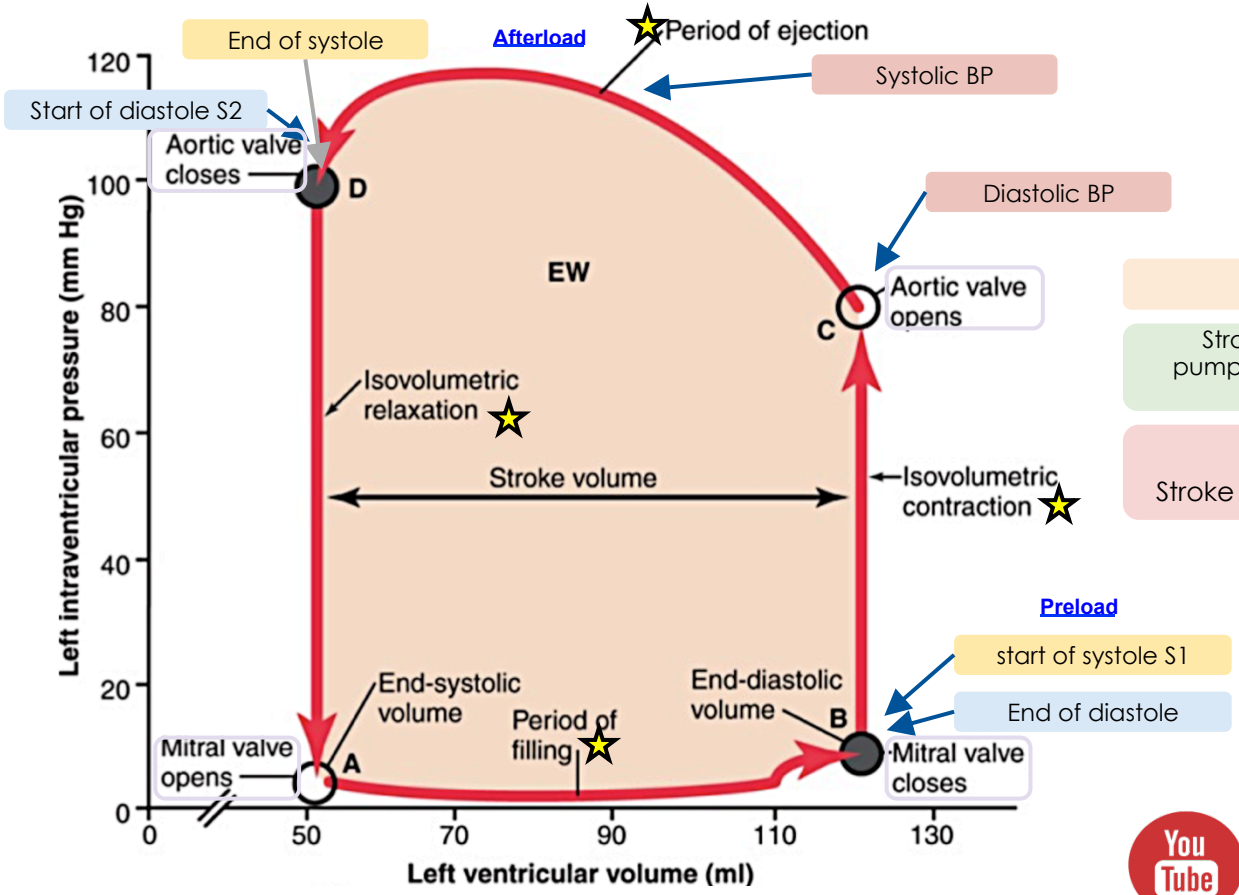
What you should remember about pressure- volume loop?

Beginning of systole (B) & end (D)
- ✓ Early& late systolic periods
- ✓ Ejection occurs between points C&D

Beginning of systole (D) & end (B)
- ✓ Early& late diastolic periods
- ✓ Diastolic filling occurs between points A&B

Systolic and diastolic blood pressure levels

Left Ventricular Pressure-Volume Loop



1 Loop = 1 heart beat

Stroke Volume: It is the volume of blood pumped from one ventricle of the heart with each beat.

SV = EDV - ESV
Stroke Volume = End diastolic - End Systolic

http://youtu.be/11wGp-5jXz0

MCQs

1- During isometric contraction phase the ventricular volume:
A. Increases
B. Rapidly increases
C. Slowly decreases
D. Doesn't change
E. Decreases

2- During the rapid ejection phase the ventricular pressure:
A. 80-120 mmHg
B. 0 mmHg
C. 15-30 mmHg
D. Doesn't change

3- Which pairing is INCORRECT ?
A. 3rd heart sound - Elderly
B. 1st heart sound - closure of AV valves
C. left atrium - pulmonary veins
D. EDV - isometric contraction phase

4- QRS-complex occurs during
A. Atrial depolarization
B. Ventricular depolarization
C. Atrial repolarization

5- Atrial systole accounts for most of the ventricular filling.
A. True
B. False

6- Which one of the following is an early phase of systole?
A. Atrial systole
B. Isovolumeric systole
C. Reduced ejection
D. Rapid filling

1.D
2.A
3.A
4.B
5.B
6.B

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