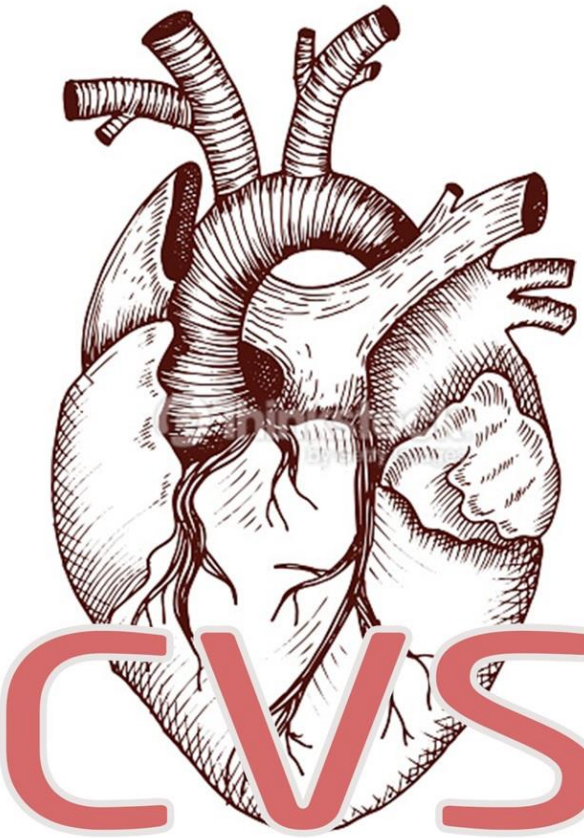

# CVS

## Physiology

♡ Slide Sheet ♥

| | |
|---|---|
| Number: | 9 |
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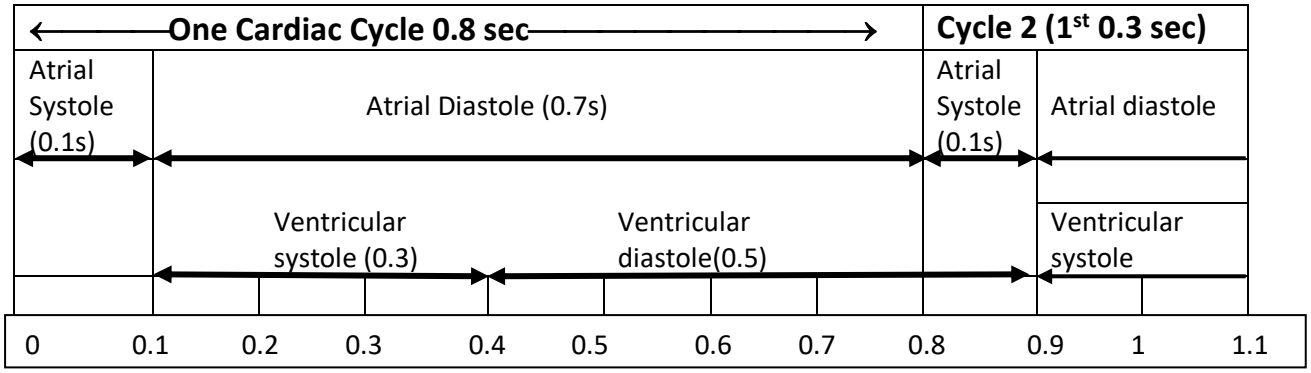
# The cardiac cycle

- The cardiac cycle is similar to any cycle; it represents certain events that repeat themselves with time. As we have mentioned before, the cardiac cycle (if the heart rate is regular=normal) is the time between a P wave and the next P, or R and the next R, or T and next T.

- This period reflects the events that occur from the beginning of one heartbeat to the beginning of the next. It includes a systole (one for atria and one for ventricles) and a diastole (one for atria and one for ventricles). We will focus on these events during a period of one cardiac cycle.

Note: For teaching purposes (we say this because normally there are variations in the duration which are normal), we can say that the period of one cardiac cycle is 0.8 second (remember that this correlates with a heart rate =60s/0.8= 75 beats/min).

- **The mechanical changes taking place in a cardiac cycle from its beginning:**




⇒ **Atrial systole**: takes 0.1 second (both atria contract together for 0.1 sec).

⇒ **Atrial diastole**: one cycle is 0.8 sec, atrial systole is 0.1 sec, so atrial diastole is 0.8 – 0.1= 0.7 sec (during the cycle, the atria relax for 0.7 second).

⇒ Remember the AV delay (delay of conduction of the impulse from the atria to the ventricles to assure that the atria and the ventricle won't contract at the same time), so what happens is that *after* atrial systole ends, **ventricular systole** starts, which takes around 0.3 second.

⇒ This means that ventricular diastole period equals 0.8 (period of a cardiac cycle) Minus 0.3 (the period during which the ventricles are contracted) = 0.5 sec (the period during which the ventricles are relaxed).

⇒ If you look at the cardiac cycle above, you would find that because ventricular systole already started late by 0.1 sec from the beginning of the cycle, all

that's left for the ventricles to relax is 0.4 sec (to reach the end of this cycle) not 0.5 sec.

⇒ Remember that the heart doesn't stop beating, and it can't afford to wait, so the last 0.1 sec of ventricular diastole coincides (overlaps) the atrial systole of the nest cycle. So ventricular diastole equals 0.4 sec (of this cycle) + 0.1 sec (the first 0.1 sec of the next cycle), which equals 0.5 sec. So, the atrium contracts and the ventricle relaxes in the same time , but we will not see both atrium and ventricle contract at the same time.

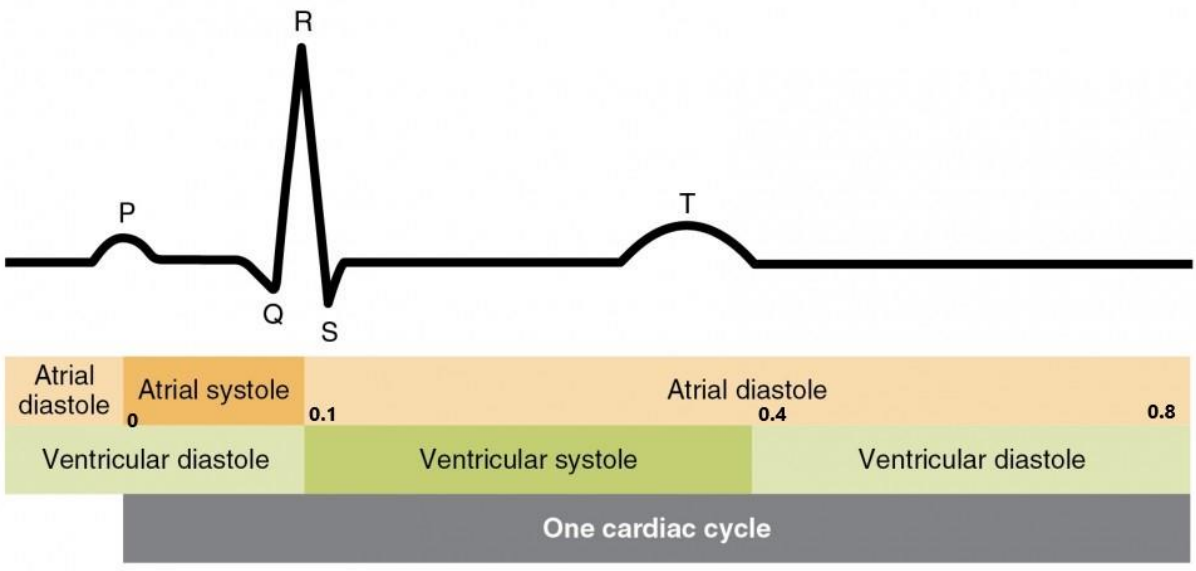
❖ **The ECG changes during the cardiac cycle:**

Remember that electrical changes **PRECEDE** mechanical changes, so depolarization precedes contraction, and repolarization precedes relaxation.

✓ Thus, we can say that:

- P wave occurs slightly **before** (prior to) atrial systole.
- QRS complex occurs slightly **before** ventricular systole.
- T wave occurs slightly **before** ventricular diastole.

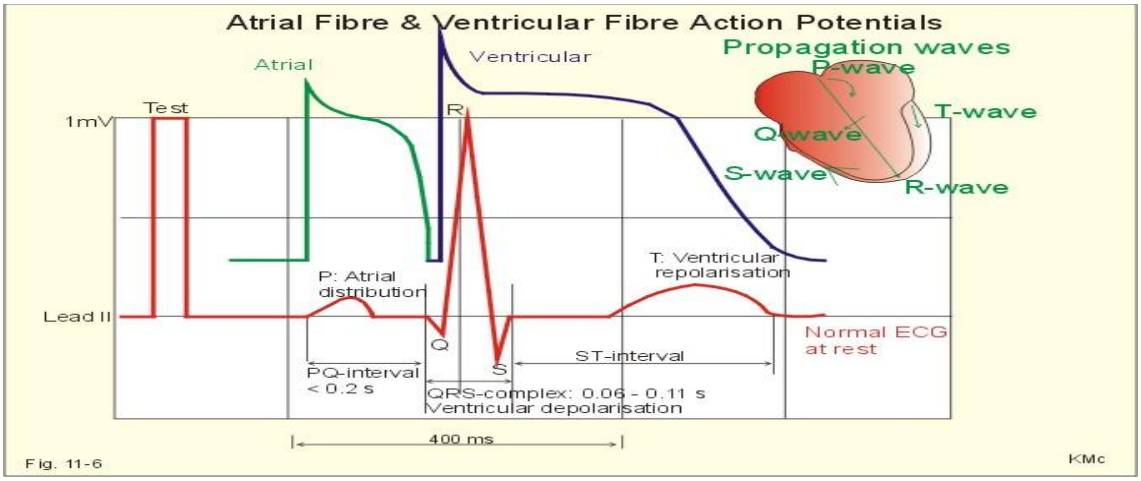
*The figure below shows an ECG superimposed on the mechanical changes occurring during a cardiac cycle. Note that the numbers inside roughly point out the time (start is 0, atrial systole to 0.1, ventricular systole lasts 0.3 sec (from 0.1-0.4 sec)…etc).



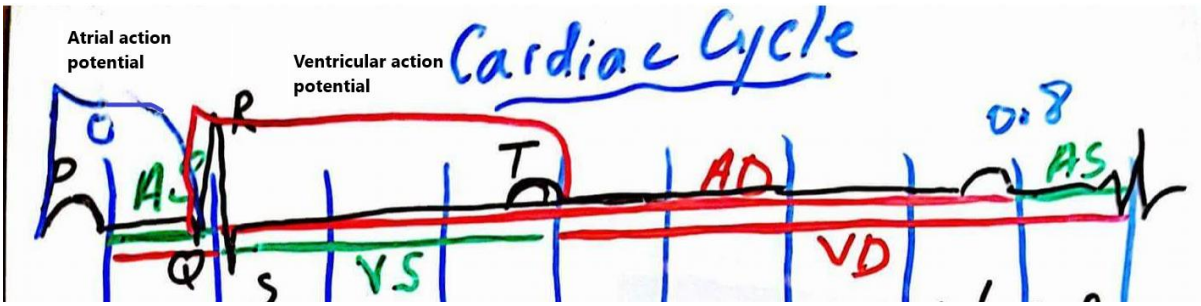
❖ **The action potentials:**

- The action potential of the ***atria*** happens as the ECG is recorded. Phase 0 (rapid depolarization) coincides with the P wave; repolarization is not shown because it's masked by the QRS complex.
- The ***ventricular*** action potential: happens in a similar manner but a longer period. Depolarization→ QRS, plateau→ return to isoelectric line, Repolarization→ T wave.

This figure shows Action potentials and their events in relation to ECG waves:




**_If we were to superimpose this picture over the mechanical changes in the heart, we'd clearly see that phase 2 (plateau) of atrial action potential coincides "يتزامن" with atrial systole, and that phase 2 (plateau) of ventricular action potential coincides with ventricular systole._



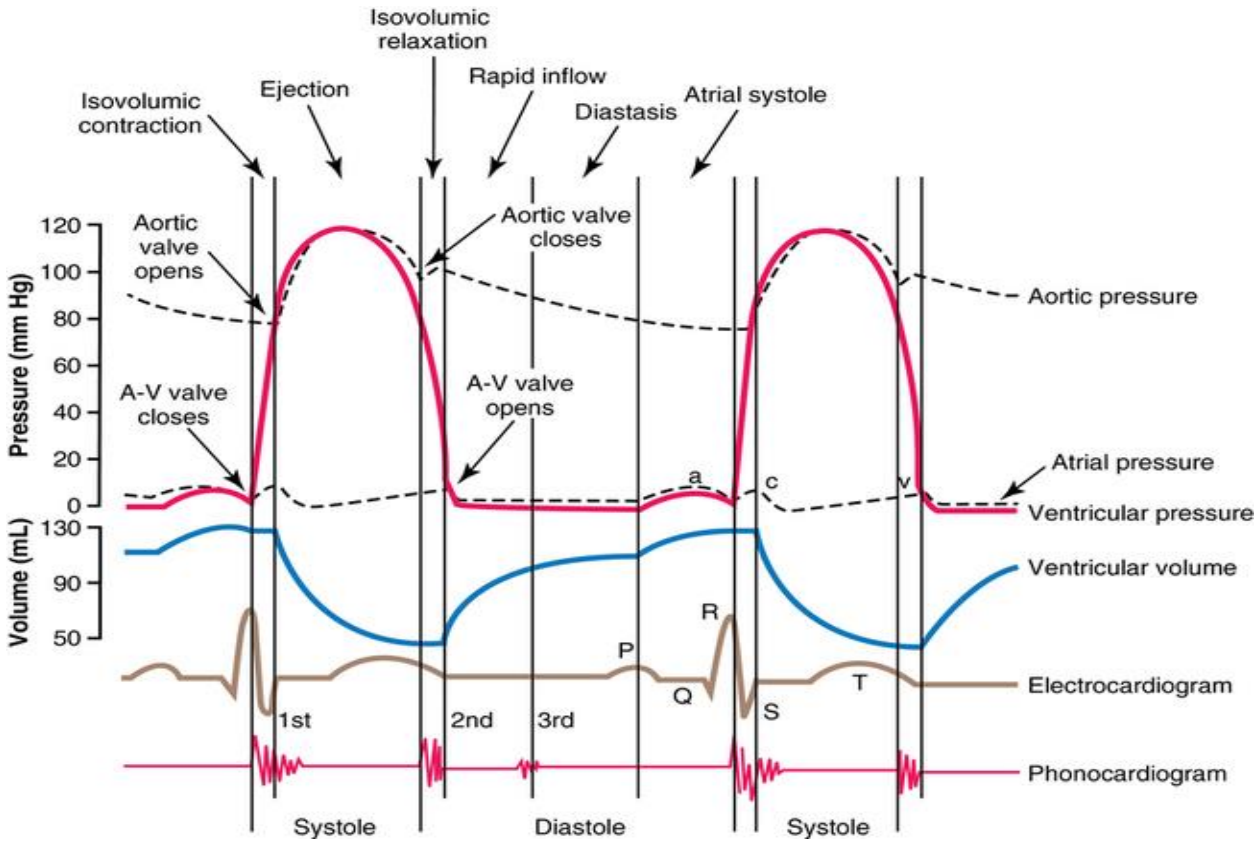

AS= atrial systole, VS= ventricular systole, AD= atrial diastole, VD= ventricular diastole.
Black = ECG waves//Red=VD, AD, and ventricular action potential//blue: atrial action potential.

❖ **The changes in the volume of blood in the ventricles during the cycle:**

-The volume of blood in the right ventricle = the volume of blood in the left ventricle (meaning that the two ventricles store an equal amount of blood, and eject an equal amount of blood, and that the cardiac output of the right ventricle equals that of the left). However, the difference between them is in the **pressure** values –as we'll see-; the pressure in the left ventricle is much higher than that of the right ventricle.

-Side note not mentioned by Dr.Faisal: What determines the peripheral vascular resistance (resistance to blood flow) is the arterioles by vasoconstriction of their wall smooth muscles. The pulmonary circulation's arterioles have little smooth muscles in their walls→ little resistance to blood flow within them→ no need to have high pressure in the right ventricle to eject the blood, its lower pressure is enough to pump it, so the right ventricle is a low pressure pump (pumps blood against low resistance) and that's why its pressure is lower than that of the left.

-Since the volume is the same, we'll study the left ventricular volume changes but also keeping in mind that all of this applies to the right. The following picture will be used throughout the rest of the sheet, so please keep referring to it as we proceed (**very important**).



For now, keep your eyes over the Ventricular volume line.

-Let us say that before the atria start their systole, the left ventricle contains around 100 ml blood. At this moment, the pressure in the atria (here we are concerned with the left atrium, but as we said, this applies to the right side as well) is higher than the pressure in the ventricle, so the AV valve is open. The atrial pressure is around 0, and the ventricular pressure is around -1 or -2 (or say that the atrial pressure = +2, ventricular = 0). (A zero pressure means that this pressure equals that of the atmospheric pressure, which equals 760 mmHg. So a pressure of 762 mmHg would be +2, and a pressure of 0 equals 760 mmHg, and a pressure of 758 mmHg equals -2). Since the AV valve opens and closes passively due to pressure gradient; a zero pressure is higher than -2 pressure, so it will be opened.

-When the atria undergo systole, they push a certain amount of blood to the ventricle very fast, so the left ventricular volume increases to 125 ml. This tells us that the atrial systole contributed to the ventricular volume as much as 25%. The real contribution of atrial systole is actually less, because the AV valve are already opened before atrial contraction, and the blood that the atria receive is pouring inside the ventricle without that contraction (that's why we say the contribution reaches 25% at its best state but it's less). So even without this contraction, as much as 15ml (instead of 25ml) will pass to the ventricles and fill it (indicating that the real contribution is less than 25%). This means that atrial systole *is not essential* for the normal function of the heart, and this implies that atrial fibrillation is actually compatible with life, whereas ventricular fibrillation, which leads to loss of the pumping activity, is lethal.

-So the heart will function almost normally in cases of atrial fibrillation, and what actually is prescribed for such patients is none other than anticoagulants (our only fear is that some stagnation "stasis" of blood occurs in the atria leading to thrombus formation). The rest of volume changes is after the pressure changes; so have fun…

- **Pressure changes in the ventricles:**

-We study the left ventricular pressure, which is higher than the right.
-Keep your eye on the ventricular pressure in the picture above.

* Before atrial systole, it was around zero (less than atrial pressure, but roughly zero considering the atrial as +2), when the atria contract and push the blood to the ventricle, the left ventricular pressure rises a bit –around +5. ***Remember that when atrial systole ends, ventricular systole starts***, and when the ventricle starts to

contract, the pressure inside it increases. This increase causes ventricular pressure to become higher than the atrial pressure (zero) → AV valve closes.

-Note that the semilunar valve during all of this is closed (opens when blood is ejected to the aorta), so for now it is still closed.

-So, at the beginning of ventricular systole, the AV valve closes, while the semilunar valves are already closed. During this period, the 2 valves are closed, so there is no blood inflow nor blood outflow, so the volume of blood in the ventricle doesn't change → no volume change + very fast rising pressure due to ventricles initiating their systole = **Isovolumic contraction**.

Note: The pressure in the ventricle increases very fast until the pressure in the ventricle is higher than the pressure in the aorta (keep an eye on the picture, the aortic pressure during ventricular diastole equals 80 mmHg). This causes *the semilunar valve to open and blood to be ejected into the aorta* when ventricular pressure > 80mmHg. After that, the pressure in the ventricle keeps rising (due to Vt.contraction) to reach as much as 120 mmHg, then it decreases.

- During this ejection phase, the **pressure** in the ventricle must be higher than the **pressure** in the aorta, why? To allow the flowing of blood from the ventricle to the aorta. This applies to most of the ejection period except at its end, where the aortic pressure exceeds the ventricular pressure, but to your surprise :) , the blood will not flow backward (remember, we're still in the ejection phase, we didn't reach Vt. Diastole yet), because during the *whole* of the ejection period the blood is flowing in a certain direction (Vt → aorta). In order to make it flow backwards, you must overcome its ***momentum*** first (you'll need to stop the flowing current that's been going forward for quite some time) and this is hard, so blood keeps flowing forward.

*The flow of blood between two points is proportional to the difference in pressure between the two points, and is inversely proportional to the resistance to blood flow
Flow = $\Delta P / R$…….. (Ohm's law)

(When the pressure in point A is much higher than point B, blood will flow easily from A→B, and when there's high resistance to blood flow, blood cannot flow). This pretty much looks like physics! Electrical currents flow in the exact same way, so when two points have a high potential difference, a current flows between them, and when there's high resistance to flow between them, it will be hindered to flow. This actually represents *Ohm's law of electricity*, which also applies to blood flow.



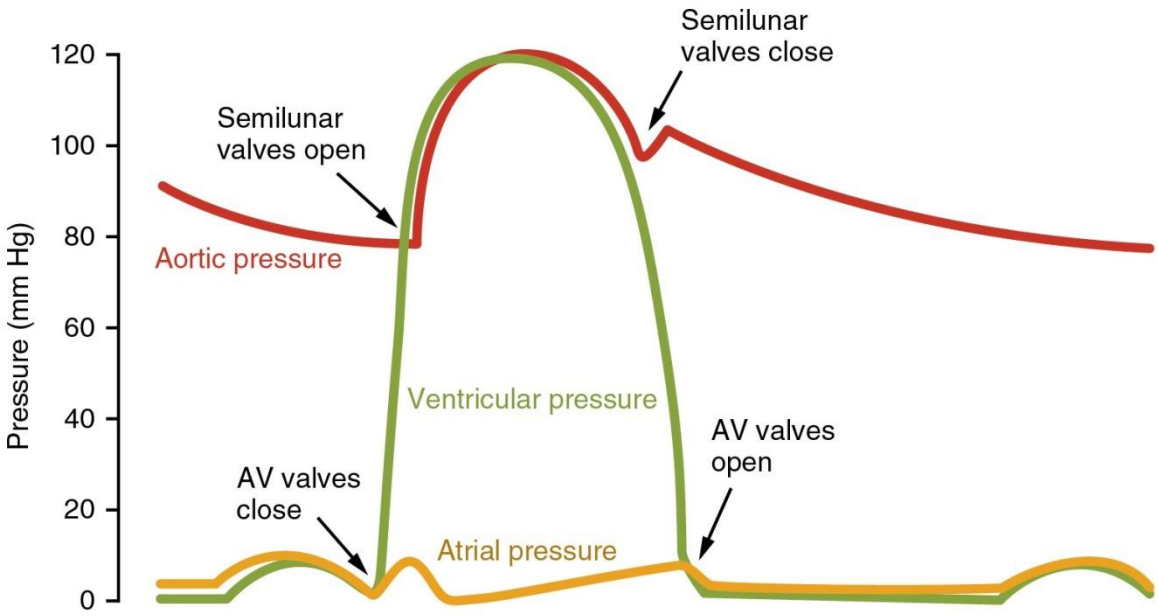
Vt = ventricular.// At = atrial

*In order to keep blood flowing from the ventricle to the aorta, the pressure in the ventricle must be higher than the pressure in the aorta (There must be a pressure gradient). As we said, the pressure in the ventricle equals 120 mmHg (maximum). The aortic pressure equals 118 or 119 mmHg. This is the actual difference, but since it's not that much of a difference, we say that during ventricular systole, aortic pressure reaches 120 mmHg.

*As we said, in the last part of systole; aortic pressure > ventricular pressure, but blood keeps flowing from Vt→ aorta. After this period, ventricular diastole starts. As you can see from the picture above, what happens is the following: after the pressure in the ventricle reaches 120 mmHg, it starts decreasing. This continues (during the ejection period) until the pressure in the ventricle become less than 80 mmHg (aortic diastolic pressure), this causes *closure of the semilunar valve*.

*Now, semilunar→closed, while AV valve???? → Also closed. This means that there is no volume change (no in, no out), while the ventricles are relaxing and the pressure is decreasing fast. This period is the period of **Isovolumic relaxation**.

Another representation of what we said is shown; try to re-summarize everything we've said up until now before going on (and have a little break):




- The pressure in the ventricles is falling, when it becomes less than the atrial pressure (around zero), the AV valve opens, and blood flows from the atria to the ventricle.
- Note that the pressure in the aorta varies between 80 (diastolic) and 120 (systolic), while the ventricular pressure varies between 0 (diastolic) and 120

(systolic). That is why when you measure your blood pressure, you're actually measuring the *arterial pressure (almost like the aorta not the ventricle)*. Also of note, a normal blood pressure would be between 90 – 140 (systolic, this is in the aorta or the ventricle since the systolic pressure isn't that much different between the two), and between 60 – 90 (diastolic, this is the diastolic pressure in the **AORTA** not the ventricle).

**Now let's return to **the volume changes** in the ventricles during all of these events:

We reached 125 ml (just before ventricular contraction). Subsequent events include:

- *Isovolumic contraction* → *no change* in volume.
- Opening of semilunar valve → *Rapid ejection* (this is the first part of ejection, because the pressure in the ventricle was so high that any possible opening like this would lead to excessive, strong, fast ejection) –same as opening a hole in a pressurized balloon. Ejecting blood = volume *decreases* in ventricle.
- After that → *slow ejection* (still in ejection phase but slower because of relief after ejecting the blood rapidly).

-At the end of ventricular systole, the ventricle contain around 55 ml blood, which is called End Systolic Volume (ESV), while the 125 ml is called the End Diastolic Volume (EDV) –the volume of blood in the ventricle at the end of diastole/just before systole-.

-The ventricle contained 125 ml before it contracted, and 55 ml after it contracted, so it ejected an amount of blood which equals 125-55 = 70 ml, which is called **Stroke volume** (SV). So the **stroke volume** is the amount of blood that is ejected from *either* ventricle per beat. Note that since volume in Rt. Ventricle= volume in Lt. Ventricle, the SV is the same from either one.

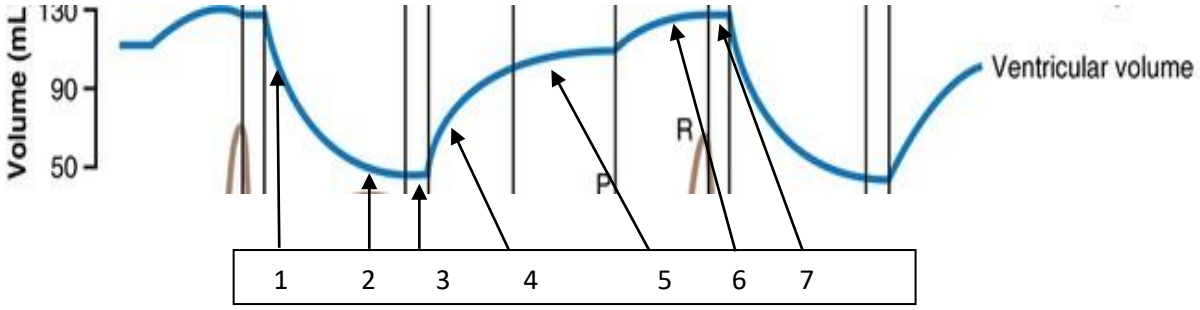
- Stroke volume x heart rate= how much either ventricle ejects per minute = **Cardiac output.**

- After ejection (fast and slow), Isovolumic relaxation → no change in volume.
- During ventricular systole, the AV valve is closed, but blood will be coming to the atria and collecting there, so at the end of Isovolumic relaxation, as soon as the AV valve opens, the stored blood (in atria) will rush to the ventricle → *rapid filling.* Filling = blood volume *increases* in the ventricle.

After that, *slow filling* of the ventricle occurs. This is called ***diastasis,*** which lasts until the ventricular volume reaches 100ml again (so 55 → 100 ml is due to rapid filling and diastasis, while 100→125 ml –last stage- is by At. Systole).

Note: Fast and slow filling fill the ventricle from 55 ml (ESV) to 100 ml. Atrial systole fills to 125ml , but If atrial systole doesn't occur slow filling will take more time so that about 15 ml of blood will pass to ventricle without Atrial contraction, and the EDV will be around 115 ml (not much reduced) so we say that the contribution of Atrial systole is less than 25% of filling.

- After diastasis, everything repeats itself in a new cycle.




This figure shows ventricular volume changes:

1- Rapid ejection. 2- Slow ejection.

3- Isovolumic Relaxation. 4- Rapid filling.

5- Slow filling (diastasis) 6- Atrial systole

7- Isovolumic contraction.

Remember: the first (earliest) part of vt. Systole is Isovolumic contraction.
The first (earliest) part of vt. diastole is Isovolumic relaxation.

❖ **The right ventricle:**

- In terms of volume, it is similar to that of the left.
- In terms of pressure, instead of having a maximum systolic pressure of125 mmHg (in the aorta), the maximum pressure reaches 25 mmHg (in pulmonary artery). In addition, instead of having a diastolic pressure of 80 mmHg (aorta), it is only 8 mmHg (in the pulmonary artery).
- So the pressure in the right pulmonary artery varies between 8 and 25 mmHg, while the pressure in the right ventricle varies between 0 and 25 mmHg.

❖ **The heart sounds:**

- When ***the AV valve closes*** we hear a sound –when using the stethoscope-, which is called ***S1***, or *Lubb.* At the beginning of ventricular systole, pressure in the ventricle is higher than atrial pressure, so the blood tries to flow back to the atria; the AV valve closes to prevent this backflow.

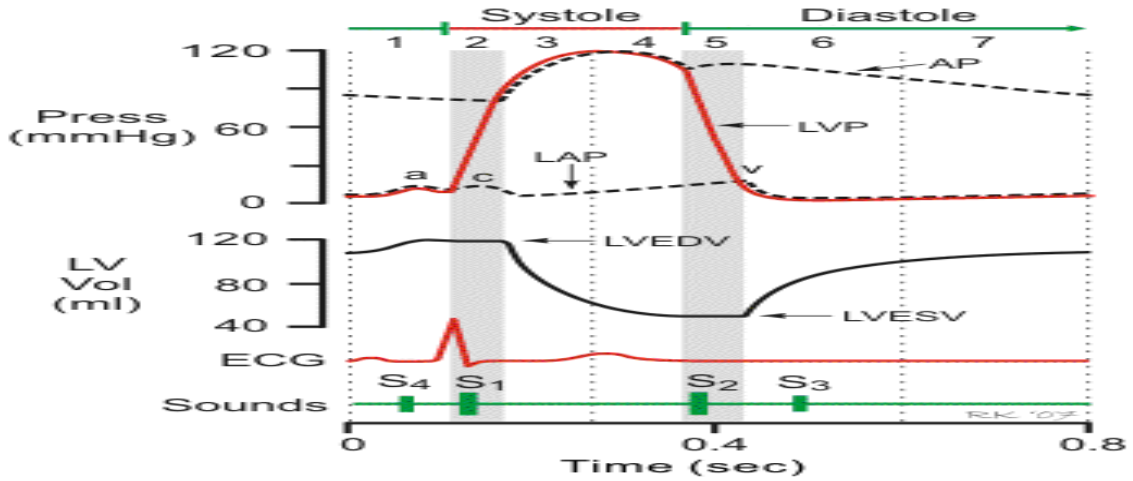
- The blood that was trying to flow back flows around this closed valve (the closed valve causes the back-flowing blood to bounce forward again into the ventricle, and this movement is what gives the sound; so it's not the sound of the cusps closing, because the blood between the cusps cushions the ''slapping'' of these cusps and prevents significant sound).

-So these sounds are due to movement of blood around a closed valve. Note that the AV valve closes, but the pressure in the ventricles is very high, so what prevents this valve from bulging upward and secures its competence? The chordae tendineae which are connected to papillary muscles in the ventricular wall. These muscles contract when the ventricles contract, tightening the chordae tendineae and preventing valve incompetence (AV valve prolapse).

*When ventricular systole ends, and the ventricles start to relax, the pressure in the aorta is higher than the pressure in the ventricle, so the blood tries to flow back towards the ventricle, but the ***semilunar valve closes*** preventing this backflow. The movement of blood around a closed semilunar valve produces a sound, which is called ***S2***, or *Dubb*.

-So S1 →AV closure in order to start ejecting blood towards the aorta (not the atria), and S2→Semilunar closure (end of ejection). *The time between S1 and S2 is the period of ventricular systole (around 0.3 sec), while the time between S2 and the next S1 represents ventricular diastole (0.5 sec).* These two sounds are always heard normally.

-We realized up until now that the heart sounds are produced due to very fast movement of blood (in case of S1/S2→the movement is around closed valves), but this raises the question: when do I also have very fast movement of blood?
→The *RAPID filling* of the ventricles by the blood collected in the atria, this rapid movement produces a sound which is S3 (you might/might not hear it)
→During *atrial systole*, because when the atria contract, they push a certain amount of blood very fast to the ventricle. This produces the sound of S4 (not heard normally). Note S1, S2, S3, and S4 on this figure, their arrangements and the events producing these sounds.




So normally you hear S1 and S2. You can hear abnormal sounds, such sounds are called **Murmurs**. If you hear a murmur between S1 and S2 (during ventricular systole) it is called a systolic murmur. If the murmur is heard between S2 and S1 (during diastole), it is a diastolic murmur.

Note that S1→closure of **BOTH** AV valves at the same time (and movement of blood around both valves), and S2→ both semilunar valves.

This is done now by using technical equipment and a device called Phonocardiogram, which shows all 4 heart sounds as well as any abnormality (murmur).

*If you have musical ears you might hear S3 and S4.

- **The pressure:**

*IMPORTANT NOTE: in the exam, most questions will focus on your ability to link events together and **know what coincides with what**. Let's give an example:
You must keep the important picture above in your mind. You know that:

1- At. systole =0.1s, At. diastole = 0.7s, Vt. Systole = 0.3s, Vt. Diastole = 0.5s
2- We know that P is before At. systole, QRS is before Vt. Systole, T is before Vt.D.
3-Atrial systole is just before Vt. Systole to prevent simultaneous contraction.
4-The arrangement of the heart sounds

The Question is: QRS complex coincides with the first heart sound, True or False?
You'll have to wait till the end of the sheet to know the answer…

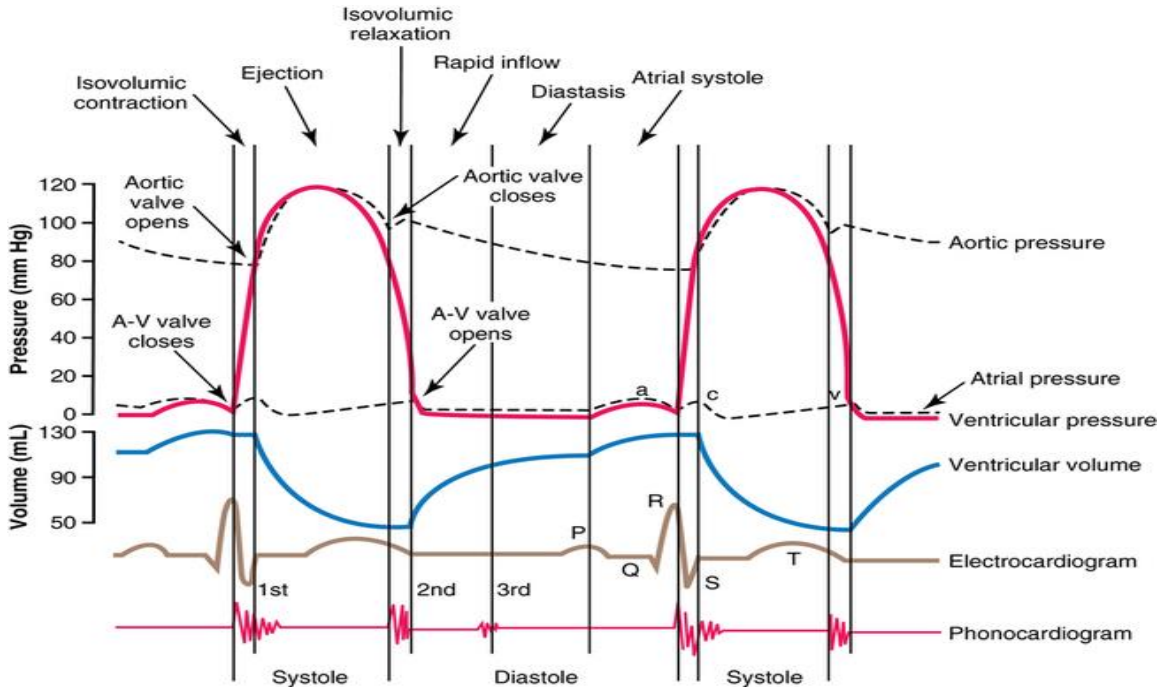
-Note that in the ejection phase, although blood is ejected into the aorta (leading to less blood in ventricles, and we know that blood volume in a space causes a pressure, so whenever you have more blood volume in a space, the higher the pressure in it) the pressure keeps rising (up until 120 mmHg), so why do we have: decreasing

amount of blood in the ventricles due to ejection and rising ventricular pressure?? The answer is that the *strong contraction* of the ventricles is the cause of the rising pressure, which presses on the wall more than the effect of the blood volume.

-The pressure gradient between the ventricle and the aorta during ejection is only about 1-2 mmHg (P vt = 120, P aorta = 118/119). This difference might be higher in cases like aortic valve stenosis, where the ventricular pressure must rise a lot in order to push the blood against a stenosed (narrowed) valve.

Note that aortic diastolic pressure is due to the <u>recoil of the aorta</u> (the blood that is ejected in the aorta during systole causes the aorta to stretch/expand-, now in diastole the aorta tries to go back to its normal diameter by the elastic properties present in it), and <u>the presence of blood in the lumen</u> (volume = pressure, more volume means more pressure) so if less blood is present in the lumen of the aorta, the diastolic pressure in it will be sharply reduced. If you were to measure the aortic pressure and find it very low (like120/0 or 120/10), one cause is *aortic incompetence* (aortic regurgitation), where there is dysfunctionality in the aortic valve which allows backflow of blood from the aorta to the ventricle during diastole, so the aorta recoils on a lumen that's almost hollow (because the blood is flowing backwards), and no volume = sharp reduction in pressure.

At the end of this sheet, we would like to put this picture one more time because of its **importance** (and for you to summarize everything up until now and know what coincides with what):



-As for the question earlier, the answer is **TRUE**, because S1→ happens at AV closure, which slightly precedes ejection . Ventricular contraction is also preceded by QRS complex, so S1 coincides with the QRS complex (see picture).

-The arrangement of the sounds: $4^{th}$→$1^{st}$→$2^{nd}$→$3^{rd}$ (and repeat).

**Questions:**

**1**- If the blood pressure is 110/70, what is correct about cardiac cycle – maximal pressure gradient around aortic valve is :

A-70 mmHG
B-110 mmHG

**2**- Right about cardiac cycle – the largest amount of blood in the ventricle is after:

A- Atrial diastole

B- Atrial systole

c-Ventricle diastole.

**3**- In normal cardiac cycle, isovolumetric contraction phase is associated with the following except:

A- Second heart sound

B-preceded by QRS in ECG .

C-After this phase, rapid ejection will occur.

**4**-During ejection phase , the least difference in the pressure is between :

A- Aorta and left ventricle.

B- Left atrium and left ventricle.

c- Right atrium and right ventricle .

**5-**The atria never need to contract due to passive ventricular filling:

A- TRUE.
B-FALSE.

**6**-The steps of cardiac cycle:

A)isovolumic contraction, isovolumic relaxation, ejection, passive ventricular filling, active ventricular filling.

B)isovolumic relaxation, isovolumic contraction, ejection, passive ventricular filling, active ventricular filling.

C)isovolumic contraction, ejection, isovolumic relaxation, passive ventricular filling, active ventricular filling.

D)isovolumic contraction, ejection, isovolumic relaxation, active ventricular filling, passive ventricular filling.

E)ejection, isovolumic relaxation, passive ventricular filling, isovolumic contraction, active ventricular filling.

**7-**When is the ventricular blood volume higher?

A. At the beginning of the systole

B. At the beginning of the diastole

C. During Mid-to-Late Diastole

D. None of the above

**8-**Which of the following is NOT true for ventricular systole?

A. The ventricles contract
B. The atrioventricular valves close
C. The semilunar valves open
D.The ventricles relax.

**9**-The semilunar valves close during:

A- Ventricular systole.
B- Ventricular diastole.
C- Atrial systole.
D- Atrial diastole**.**

**Answers**

| **Q** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **A** | **A** | **B** | **C** | **A** | **D** | **B** |

Best Luck