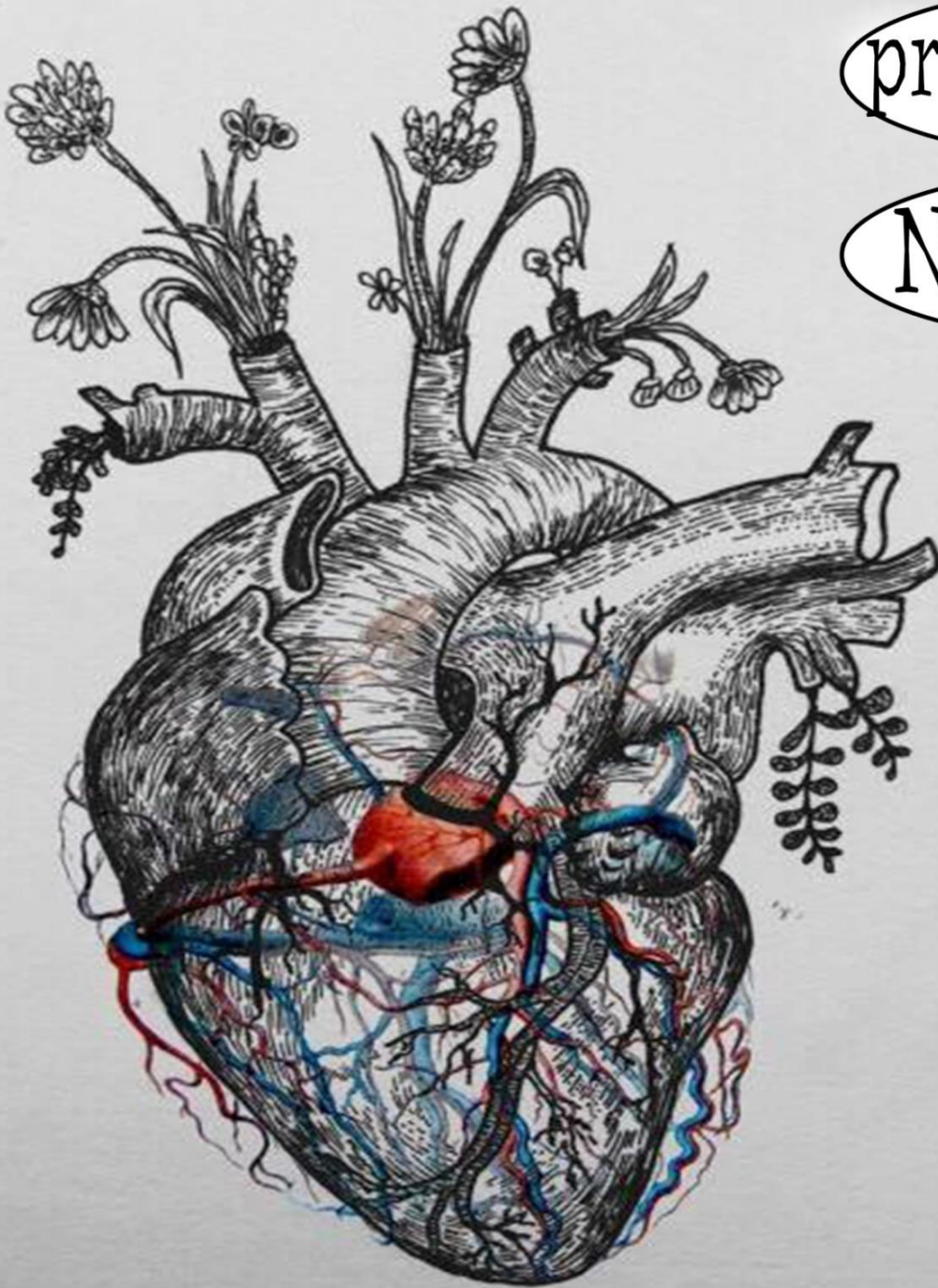


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CVS

sub-system

Physiology #4

lecture

Cardiac cycle

Doctor

د. محمد جعفر

Date

21/3/2016

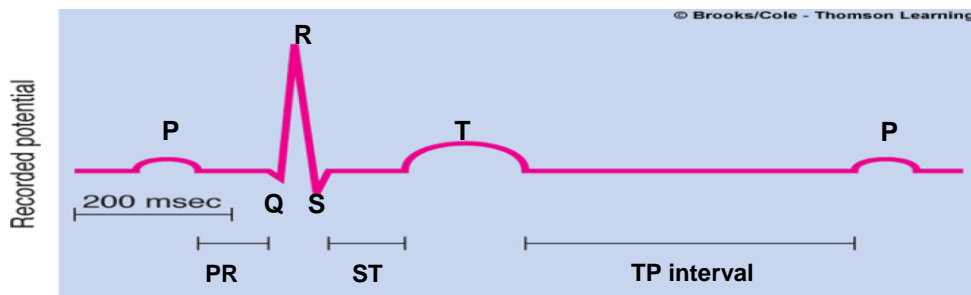
Done by

Turquoise Team



CARDIAC CYCLE

we will start by reviewing the ECG:



- **P wave** ⇒ depolarization of the *atria* (open of sodium channels in the atria).
- **PR segment** ⇒ atrial plateau, contraction of the *atria* (open of sodium & calcium channels in the atria).
- **QRS complex** ⇒ depolarization of the *ventricles* (open of sodium channels in the ventricles & open of potassium channels in the atria).
- **ST segment** ⇒ *ventricles* plateau, contraction of ventricles (open of sodium and calcium channels in the ventricles).
- **T wave** ⇒ repolarization of the *ventricles* (open potassium channels in the ventricles).
- **TP interval** ⇒ resting potential of the heart.

This is called the electrical response (stimulation or action potential) that will cause mechanical response “contraction”.

But what will happen during the mechanical response?

First of all, the blood come from superior and inferior vena cava to the right atrium and from pulmonary veins to the left atrium and collected there. Then the blood must move to the ventricles, but how?

While the blood is in the atria the pressure in the atria will be higher than the pressure in the ventricles, so that will create a **pressure gradient** that will push the AV-valves (bicuspid and tricuspid) and cause the blood to flow to the ventricles (70% of the blood present in the atria will flow to ventricles by pressure gradient before the contraction of the atria).

By the time, the pressure gradient will decrease (because the blood volume decrease in atria and increase in the ventricles) so the blood flow will decrease. At that time the atria will contract to push the remaining (30%) of the blood to the ventricles.

So 70% of the blood will flow to the ventricles by *pressure gradient*

30% of blood will flow to the ventricles by *atrial contraction*

At that point, the pressure in the ventricles is higher than the pressure in the atria so the blood will try to go back to the atria, but AV-valves (bicuspid & tricuspid) will prevent the backflow of the blood.

By now AV-valves and semilunar valves are closed and the blood is in the ventricles
-Note: the pressure in the aorta and pulmonary artery will be higher than the pressure in the ventricles-
so there must be a mechanism to increase the pressure in the ventricles to be more than the pressure in the aorta and the pulmonary artery to open the semilunar valves.

That mechanism is the contraction of the ventricle due to depolarization of it. The contraction starts in the ventricles while all valves are closed this mechanism is called **isovolumic contraction** (*iso*→the same) so there will be contraction without change in blood volume (no pumping).

In muscles there is "isometric contraction" when the muscle contracts it's length will not change because there is origin and insertion but there is contraction.

By that, the pressure in the ventricles will be higher than the pressure in the aorta (and the pulmonary artery). So the semilunar valves will open and the blood will be pushed to the arteries (aorta & pulmonary) and the arteries will be dilated.

After blood flow to arteries the pressure in the arteries will be higher than the pressure in the ventricles for a short period of time, so the blood will try to go back to the ventricles, but the semilunar valves will prevent the backflow.

After the closure of the semilunar valves (AV-valves are still closed because the pressure in the ventricles higher than the pressure in the atria) the ventricles are still contracted, but there is no flow.

So there must be a mechanism to decrease the pressure in the ventricles to open the AV-valves and repeat this cycle again, but what is that mechanism?

This mechanism is called **isovolumic relaxation** (again *iso* mean the same) so there is **NO** change in the volume, but the ventricles are repolarizing "relaxing" that will lead to decrease the pressure in the ventricles and repeat the cycle again.

The only difference between the left and the right side of the heart is in the pressure value.

So this is the mechanical response or the cardiac cycle.



The cardiac cycle is divided into two phases, the **Filling phase** “diastole or resting phase” and the **Pumping phase** “systole or ejection phase”.

The filling phase is related to ventricles, and during it the ventricles will be filled with blood from the atria by the two mechanism (gradient pressure ‘70%’ & atrial contraction ‘30%’).

Note: during pumping phase NOT all the blood will leave the ventricles to the arteries “not as the atria” because we have trabeculation, chordae tendineae & papillary muscle. Even if there is a strong contraction there MUST stay a little amount of blood in the ventricles but the amount will decrease when the contraction force increase.

A student asked: won't the blood go back to the veins during the atrial contraction?

No it will not, because when the atria contract it will squeeze the opening of the vein and it will close it.

✚ Back to the **filling phase** we can subdivide it into two phases:

- ⇒ At the beginning, there will be ‘**rapid filling phase**’ because the blood will rush by pressure gradient to the ventricles.
- ⇒ Then there will be ‘**diastasis** or **late diastole**’ and during this phase the blood will move slowly by atrial contraction to the ventricles.

After late diastole the AV-valves will close and the semilunar valves will open, then there will be **isovolumic contraction phase** (it will be the first part of systole).

At the **systolic phase** the first part low rapidly by pressure gradient and ventricular contraction, this is called ‘**rapid ejection**’ during which most of the blood will be pumped to the aorta and the pulmonary artery.

Then by the time, when the pressure in the arteries (aorta & pulmonary artery) increase, the blood flow will decrease and this is called ‘**late systole**’. (but here we **don't** say systasis only late systole).

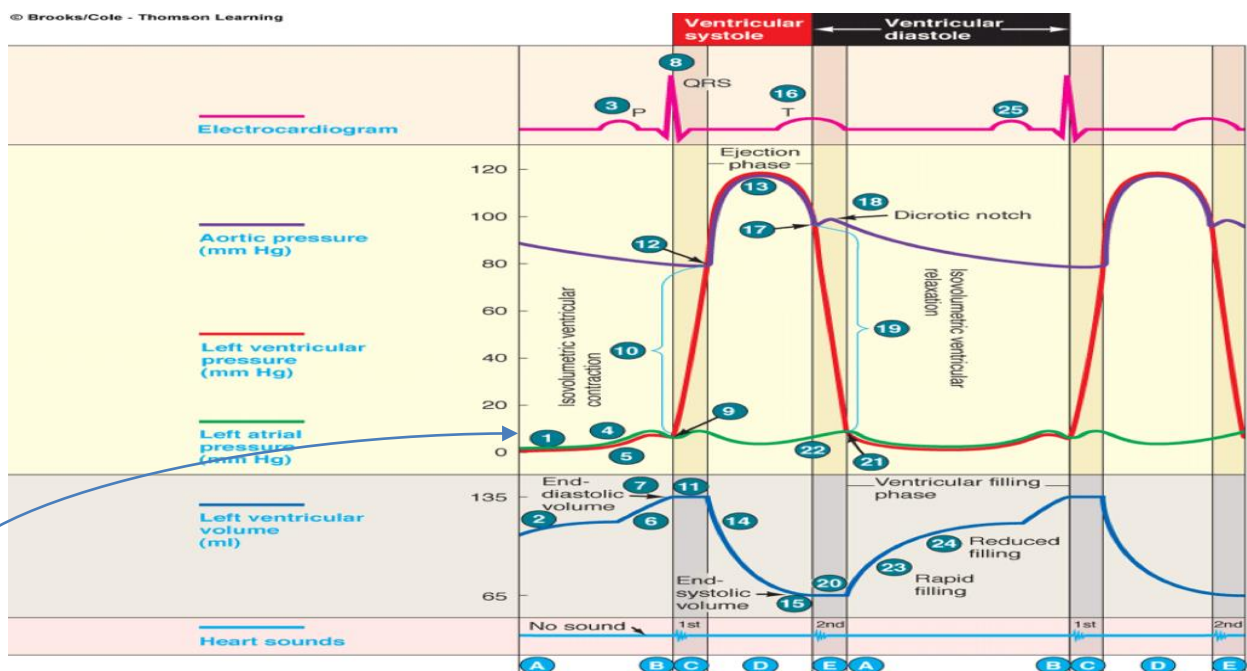
After late systole, the semilunar valves will close, the AV-valves will open, then the **isovolumic relaxation phase** starts (that will be the first part of diastole).

So we can divide diastole and the systole into 3 phases for each:

- Diastole⇒ isovolumic relaxation phase then rapid filling phase then diastasis (late diastole).
- systole⇒ isovolumic contraction then rapid ejection then late systole.

	isovolumic contraction	isovolumic relaxation
blood Volume in the ventricles	Constant (here the volume is very high but do not change)	Constant (here the volume is very low but do not change)
Ventricles	contraction	Relaxation
Valves	All of them are closed	All of them are closed

In this picture we can see the ECG in pink, aortic pressure in purple, left ventricular pressure in red and the left atrial pressure in green.



At point #1 ⇒ Atrial pressure is nearly around zero and when the blood accumulates in the atria the pressure inside the atria will rise to be around 2-3 mmHg.

As the pressure in the atria “green line” is higher than the pressure in the ventricles “red line” there will be a pressure gradient and the blood will flow to the ventricles.

At point #4 \Rightarrow the pressure in the atria will increase, because of atrial contraction after filling of the ventricles. If you compare it with ECG it will represent PR_{segment}. So The atria will be depolarization during the p_{wave} but it will contract at PR_{segment}.

In addition to contraction of the atria 'to increase the pressure inside it' the blood that is in the ventricles will try to go back to the atria so it will push the AV-valve toward the atria, so the volume of the atria will be decreased and that will increase the atrial pressure a little bit (this happens during isovolumic contraction).

"The mitral and tricuspid valves have structure like umbrella, the blood will push the valve to the atria then the papillary muscle and the chordae tendineae will bring it back to the normal level"

Also during ejection of the ventricles there will be accumulation of the blood in the atria (from vena cava), that will increase the pressure in atria to be ready for the next filling of ventricles.

So to sum up the information: -There are 3 mechanisms to increase the pressure in the atria:

- 1) atrial contraction.
- 2) isovolumic contraction of the ventricles (pushing of the valve).
- 3) accumulation of the blood in the atria during the ejection of the ventricles.

After atrial contraction, the AV-valves will close (**that will give us the first heart sound**) and the semilunar valves are still closed (the **red line** is higher than the **green line**). so what will happen is the contraction of the ventricles, so the pressure will increase, but the volume is constant "isovolumic contraction" that is at point # 10.

By the time, the pressure in the ventricle "**red**" is higher than the pressure in the aorta "**purple**" the semilunar valves will open (point #12) and the ejection will start (point # 13)

#12 \Rightarrow The pressure in the aorta **before** opening of the valve is 80 mmHg (diastolic pressure)

#13 \Rightarrow The pressure in the aorta **after** opening of the valves is 120 mmHg (systolic pressure)

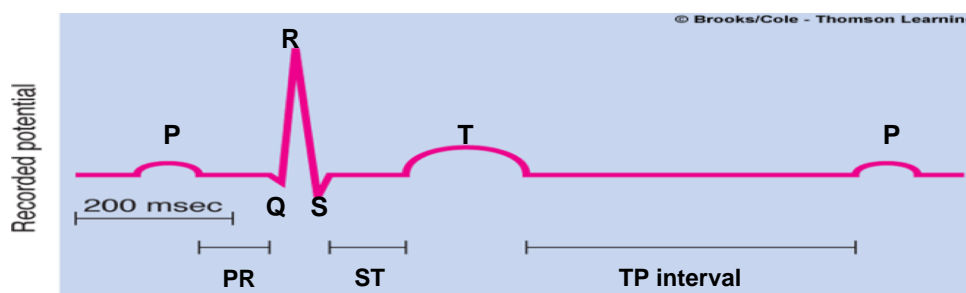
At point #17 \Rightarrow most of blood is in the aorta. So there will be closure of semilunar valves (**so that will give the second heart sound**) and the relaxation of ventricles will start "isovolumic relaxation" (note: AV-valves are still closed).

At point #18 \Rightarrow there will be a little bit increase in the pressure after closure of the aortic valve, because the blood will try to go back to the ventricles, so it will push the

valve little bit down, then the valve will come back again to its normal position, so the valve will push the blood back to aorta and cause this increase in the pressure that is called **dicrotic notch or Incisura**.

At point #21⇒ the pressure in the ventricles will decrease (due to ejection of the blood) and the pressure in the atria will be higher than the pressure in the ventricles (due to accumulation of the blood in the atria) so AV-valves will open again.

If we compare this to ECG again:



- **P wave** ⇒ depolarization of the *atria* only (the atria will not contract here).
- **PR segment** ⇒ atrial contraction.
- **QRS** ⇒ isovolumic contraction (beginning of systole so the pressure will increase without ejection), end of diastole (opening of aortic valve, closure of AV-valve “that will give the first heart sound”, open of sodium channels in the ventricles and opening of potassium channels in the atria)
- **ST segment** ⇒ the ejection will start (ventricular contraction).
- **T wave** ⇒ isovolumic relaxation.
- By the end of **T wave** ⇒ end of systole, beginning of diastole (opening of AV-valves, closure of aortic valve “that will give the second heart sound”).

where is the *end* of the systolic period on ECG? It is at the end of **T wave**. And the *beginning* of the systole is in **QRS**.

So the *systolic period* is from **Q wave** “or sometime **R wave**” to the end of **T wave** which is called **QT interval**. This represent the ventricular action potential (depolarization, plateau and repolarization of the ventricles).

-we shouldn't say QRS because the Q wave is not always there but the R wave is always there so if we said Q wave **or** R wave **or** QRS they give the same meaning-

The *diastolic period* is from the end of **T wave** to the **R wave** (because **p wave** and **PR segment** are within the filling so they are part of diastole).

Now, where is the **atrial systolic period**? From the beginning of the **P wave** “actin potential” to the **Q wave** (or **QRS** or sometime **R wave**).

Why T_{wave} is positive? Because the direction of repolarization is exactly opposite to the direction of depolarization.

What does Q_{wave} represent? It represents the depolarization of the base of the septum.

Why S_{wave} is negative? This is because direction of the current is away from the electrode. So it depends on the position of the electrode.

At systole when the blood flow to aorta the aorta will be dilated. Then the semilunar valve will close so the pressure in the aorta will decrease as well. It will continually go down until the second systole comes, but the pressure will not approach zero, because the aorta will recoil. This recoiling phenomenon is called **hemodynamic**.

In some **diseases** (*aortic regurgitation*) the aortic valve will not close and some of the blood will flow back to the ventricles so the diastolic pressure in aorta will decrease to very low magnitude in the aorta (it may reach 20 – zero mmHg)

The **systolic pressure** is present in the ventricles, aorta and large arteries.

The **diastolic pressure** is present in the aorta and large arteries, but **NOT** in the ventricles (because the ventricles are relaxed).

So again there is **NO** pressure in the ventricles during diastole. (The pressure in the *ventricles* during filling 'diastole' may be 1,2,3 mmHg **but it's not that pressure to be measured**). In the *atria* the pressure could be 1-5 mmHg but not more than that.

Two things to remember in your life:

1. Pace maker of the heart is SA node.
2. Diastolic pressure in the aorta **NOT** in the ventricles. (there might be a question in the exam about this)

When we talk about the cardiac output we use these terms:

During filling phase when the ventricles are filled with blood, this blood "**volume**" is called **end diastolic volume** or **preload**.

Then the ejection will start and the blood will be pumped out of the ventricles at the end of systole there will be blood in the ventricles, that blood "**volume**" is called **end systolic volume** but we do **NOT** call it afterload.

Afterload is the blood that's present in the **arteries** which will cause the **peripheral resistant**.

Notes:

- The only difference between the right and the left heart is the pressure, the maximum pressure in the right ventricle is 26-28 mmHg.
- The pressure in the systole is related to the excitement of the heart (it could be 120 or 140 mmHg). And the best time to measure it is at the morning when the person wakes up after resting (any time after that the emotion will affect the measurement).
- During sleeping the pressure will decrease, so after waking up the pressure will increase because the activity is increase as well.
- During isovolumic contraction/relaxation as we said there is a contraction/relaxation, the shape of the heart will change due to contraction/relaxation, but there is no change in volume.
- When we say that this person has a high or low blood pressure we mean by that the systolic and diastolic pressure.

A student asked: Is the volume of blood that enters the right ventricle is equal to the volume that enters the left ventricle?

what is coming to the right ventricle suppose to be coming to the left ventricle but when the contraction of the 'atria' start it will not be 100% precise (for example there will not be 50 ml in right side and 50 ml in the left side but it could be 50 ,51, 52). But at the end of the day the volume must be equal if it were not there will be a problem.

So in the first beat there may be 50 ml in the second beat 51 in the other beat in will be 49 so the overall at the end of the day the volume will be equal in the both sides.

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شركة فريكو