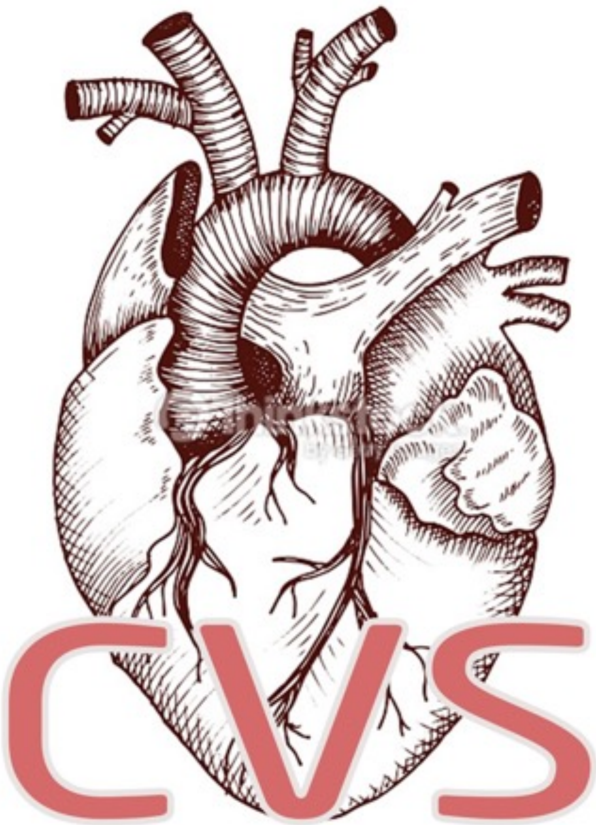

CVS

Physiology

♡ Slide   Sheet ♥

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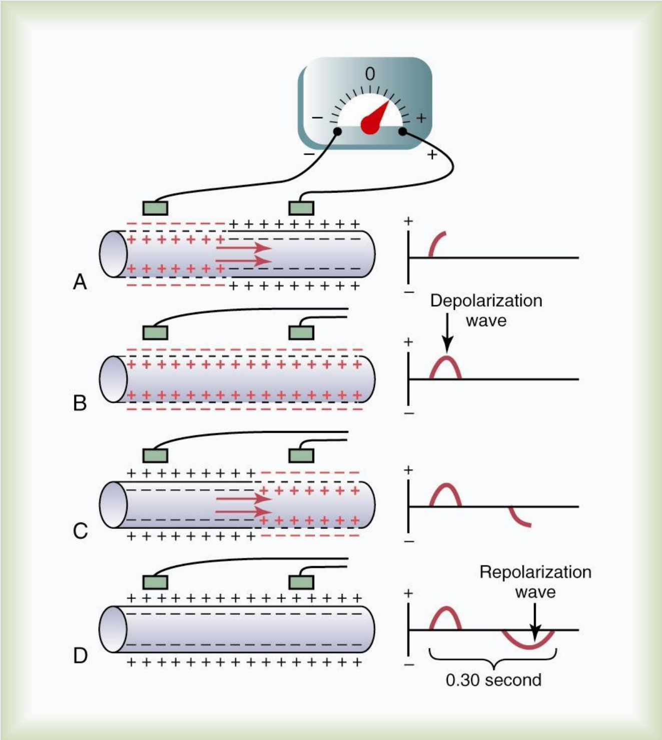
Electrocardiography

Remember:

An ECG is an *electro*cardiogram, so it has nothing to do with mechanical recording. In an ECG, we record depolarization and repolarization waves (electrical activity).

If the 2 electrodes of the galvanometer are put on the surface of the muscle cell and the **potential difference** between these 2 points was recorded, we get the following results:

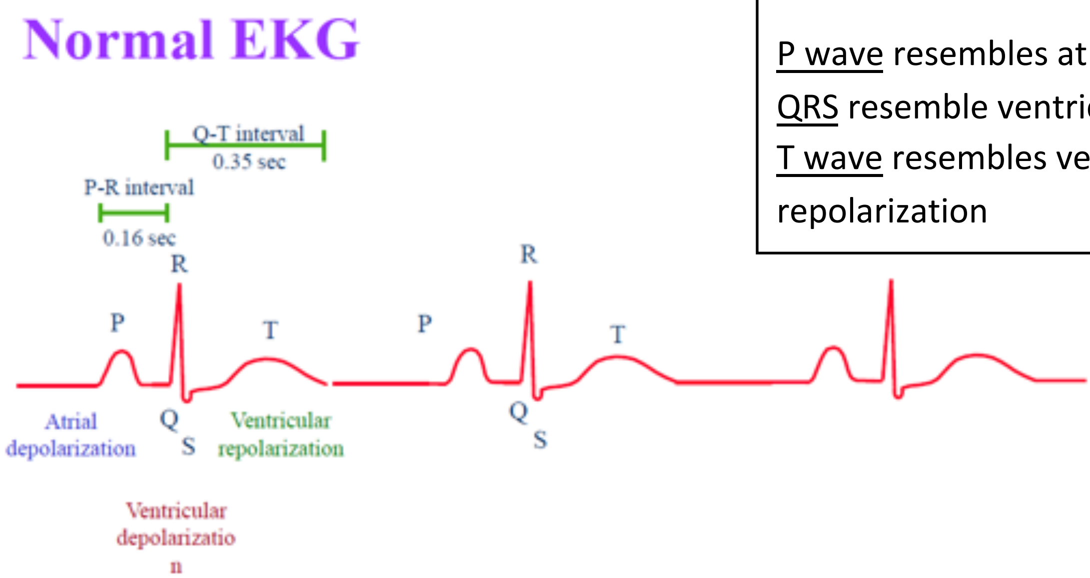
- First, when the whole muscle is still in the resting state the difference equals zero.
- After that (during depolarization), the potential difference increases until reaching a maximum when the muscle is halfway in depolarization (A in the figure).
- When the membrane is completely depolarized, the difference gets back to zero (B).
- Then repolarization starts and we get a difference in voltage but in the opposite direction (C).
- When the membrane is completely repolarized, the difference gets back to zero (D).



*__Note__ that no potential is recorded when the ventricular muscle is either completely depolarized or repolarized

The galvanometers in ECG are used with **amplifiers** because the potential difference that is in the heart during action potential is very small. In addition, when this potential reaches the skin (where we record it), it reaches 1-2 mV (even smaller).

An ECG machine has 12 leads, 12 galvanometers and each galvanometer is joined with an amplifier.



Remember:

<u>P wave</u> resembles atrial depolarization
<u>QRS</u> resemble ventricular depolarization
<u>T wave</u> resembles ventricular repolarization

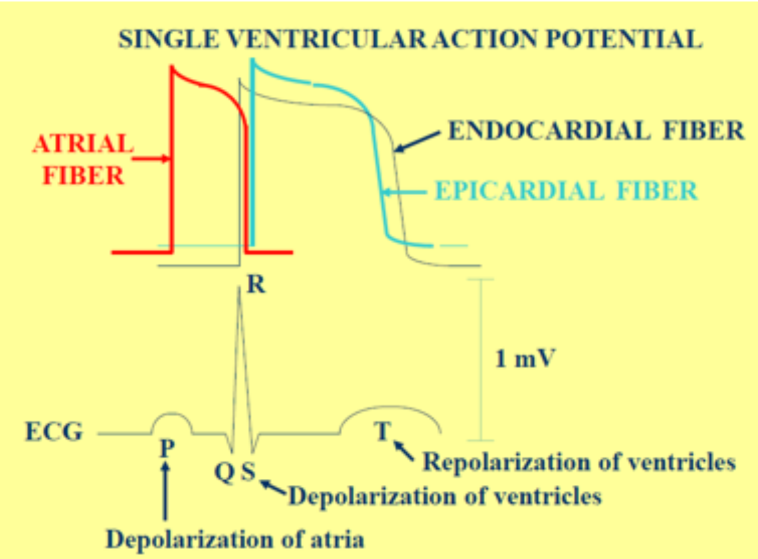
Two questions arise here:

1. **Why doesn't repolarization of the atria appear?**

   - It doesn't appear because it is being masked by the QRS wave.

   Note from the figure:

   - Phase 0 of the atria (depolarization) → P wave
   - Phase 3 of the atria (repolarization) happens in the same time as phase 0 (depolarization) of the ventricles. That's why repolarization of the atria doesn't appear.



2. **T wave is a repolarization wave but it is an upward deflection (just like the depolarization wave and not the opposite). Why?**

- Because depolarization and repolarization don't start from the same area. Depolarization starts from the endocardium to the epicardium and from the base to the apex of the heart. While repolarization starts from the epicardium to the endocardium and from the apex to the base of the heart.
  If you go back to the first figure you can see that depolarization and repolarization both started from left to right, and their corresponding waves was in opposite directions. If they started from opposite sides (like what happens in the heart), both waves will be in the same direction.

But why depolarization and repolarization don't start from the same area in the heart?

- It could be a due to an intrinsic property of endocardial and epicardial and muscles. It takes the endocardial muscles a little bit longer to repolarize than the epicardial muscles.
- A more acceptable theory states the following: depolarization is always followed by systole (contraction) and repolarization is followed by diastole (relaxation). So, when there is depolarization of the ventricles, it is followed by contraction. And because the cells of the ventricle are intermingled with each other, there is an increase in the force in the center. This increased force in the center will affect mostly the endocardium. And because this force presses too much on the endocardium, it ***delays*** repolarization; it changes the permeability of endocardial cells to the extent that it delays repolarization.

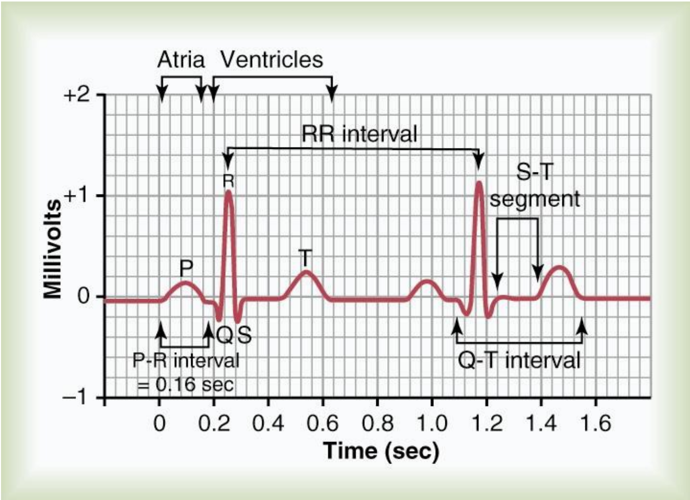
When can atrial repolarization appear? And if it appeared, will it be an upward or a downward deflection?

- In AV block (heart block), the time between depolarization of atria and ventricles will be more. In this case, atrial repolarization might appear (we said might not must, because atrial repolarization is slow, so even in AV block, sometimes it appears and sometimes it doesn't). When it shows up, it will appear as a downward deflection because pressure in the atria is much less than that of the ventricles. This pressure will not be enough to cause a delay in the repolarization of the endocardium of the atria. That's why it will appear as a downward deflection. We call this wave the T wave of the atria. Normally, it wont show up.

Standardized EKG's

We usually record ECG waves on paper that has horizontal and vertical lines. The *standard* speed of the machine is **25 mm/sec**. In some cases, this speed is changed (increased or decreased). Every small square represents 1mm.
The X axis represents time. So, every small square in the X axis represents **0.04 sec** (1/25). The Y axis represents voltage. In this axis, every 10mm (10 small squares) equal 1 mV.

The **cardiac cycle** is between one R and the next (or between 2 successive P or T waves). You start with one point and end at the same point. Usually R is used because it is more obvious (more sharp).



A cardiac cycle represents one heartbeat. So we can calculate the heart rate by knowing the time for one cycle in an ECG. How?

Heart rate (beat/min) =

$$\frac{\textbf{60 (sec/min)}}{\textbf{RR interval (sec/beat)}}$$

- If there were 25 small squares between successive R waves (RR interval), the cardiac cycle then takes 1 second. To calculate the heart rate (beats/min) we divide 60sec over the cardiac cycle: 60/1=60 beats /sec.
- If the RR interval was 15 small squares → cardiac cycle =0.04 * 15 =0.6 seconds → the heart rate = 60/0.6 =100 beats/min
- If the RR interval was 20 small squares → cardiac cycle =0.04 * 20 =0.8 seconds → the heart rate = 60/0.8 =75 beats/min

Note: for teaching purposes, we usually take the cardiac cycle time as 0.8 seconds. Normally, however, it could be any other value depending on the heart rate.

Normally, the heart rate is between **60-100 beats/min**. If it is below 60 we call it **bradycardia**, and it is caused by the parasympathetic system. If it is above 100 we call it **tachycardia**, and it is caused by the sympathetic system.

Another way of calculation: we divide 1500 / no. of small squares between the 2 Rs. It is basically the same.

$$\frac{60}{0.04 * \text{no. of small squares}} = \frac{1500}{\text{no. of small squares}}$$

1500

We don't make an ECG to know the heart rate! We can easily palplate it. But if we are making an ECG for a certain cause, we can use it to calculate the heart rate. It should be the same.

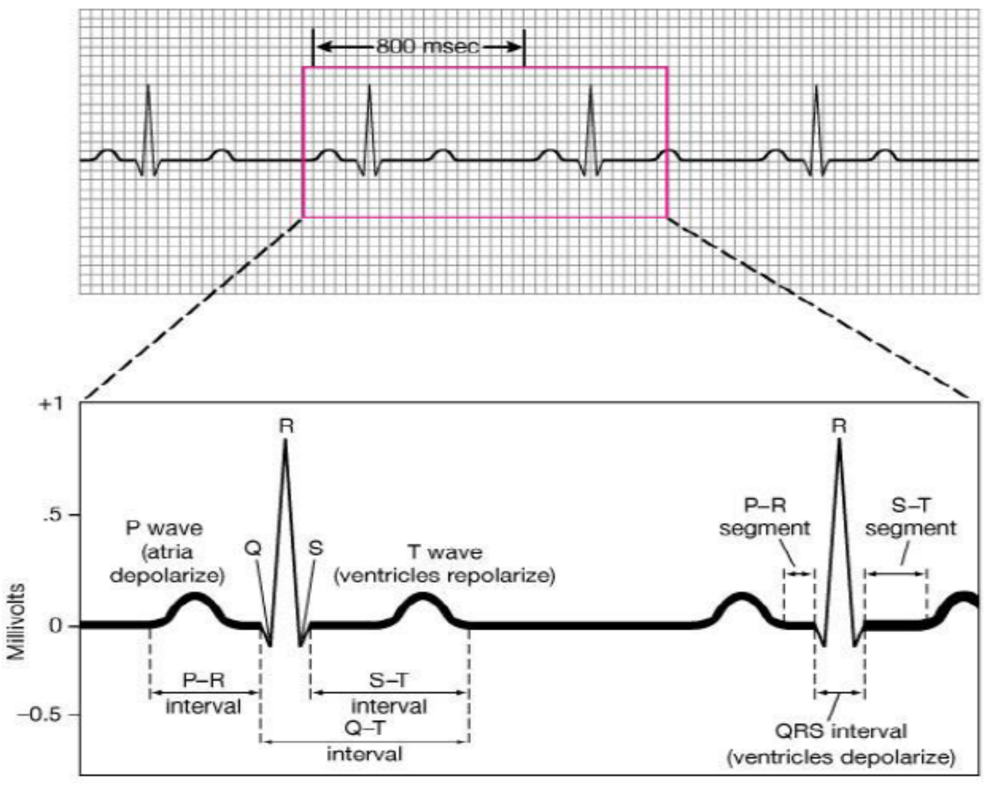
For your info.

The first people who invented the electrocardiogram where German, and in Deutsch cardio is written with a K (kardio), that's why sometimes you find it written as EKG. British stick to ECG while Americans are open; they use both ECG and EKG and EKG is more common.

When we say that the heart is rhythmic, we mean that it is regular. **Arrhythmia**, on the other hand, means irregularity of the heart.

Intervals and segments:

An **interval** should include at least one wave. What we care about in an interval is its time.
A **segment** doesn't include a wave. In a segment we look at the isoelectric line. The line in a segment might be above (elevated) or below (depressed) the isoelectric line, and we call it an upward or a downward deflection, relatively. Both cases denote ***ischemia*** (emergency). In ischemia, some ischemic areas are already depolarized when electricity reaches them, so this causes a downward deflection. On the other hand, some ischemic areas are hyperpolarized. So when electricity reaches these areas it will cause an upward deflection. So, ischemic areas can be depolarized or hyperpolarized.



✓ **P-R interval (or P-Q)**: from the beginning of the P wave to the beginning of the R wave (or the Q-T interval). It includes the P wave. We usually call it P-R interval rather than P-Q because the Q wave doesn't show up most of the time.
It resembles the conduction of depolarization between the atria and ventricles. Normally, this interval should not exceed **0.2 seconds** (=5 small squares =1 big square). When it is greater than 0.2sec, this can indicate damage to conducting pathway or AV node (AV block).

AV block has **3 degrees**: (in all degrees → P-R intervals > 0.2 seconds)

- **1st degree heart block**: AV is not conducting the impulse fast enough. There is some damage in the AV but it still conducts every beat; every P is followed by QRS.

- **2nd degree heart block**: AV is a little bit damaged so it sometimes passes the impulses and sometimes not. But there is a rhythm. Sometimes, for every 2 P waves there is 1 Q (and we call it 2:1). It can also be 3:2 or 4:2, etc. There is a regularity of this abnormality. (**the first no. is always bigger than the second as it represents P waves and they are always more than Q waves).

- **3rd degree heart block**: AV is damaged completely. There is NO association between P and QRS; P and QRS waves are completely dissociated. P waves have a rate and QRS waves have another rate, meaning that the rates of atria and ventricles are different (they should be the same). The rate of the ventricles will be lower than 40 (the rate of Purkinje fibers). So, when you see that the rate of QRS is lower than 40, it is definitely 3rd degree (complete) heart block. We call this **ventricular escape beat** (the ventricles escape the rate of SA node and start to contract on their own) and this happens to prevent cardiac arrest.

  These patients need **Artificial Pacemaker**, and we implant it in the right ventricle (not the right atrium! AV node is blocked!)

1st and 2nd degree heart block are called ***incomplete heart block***. 3rd degree is called ***complete heart block***.

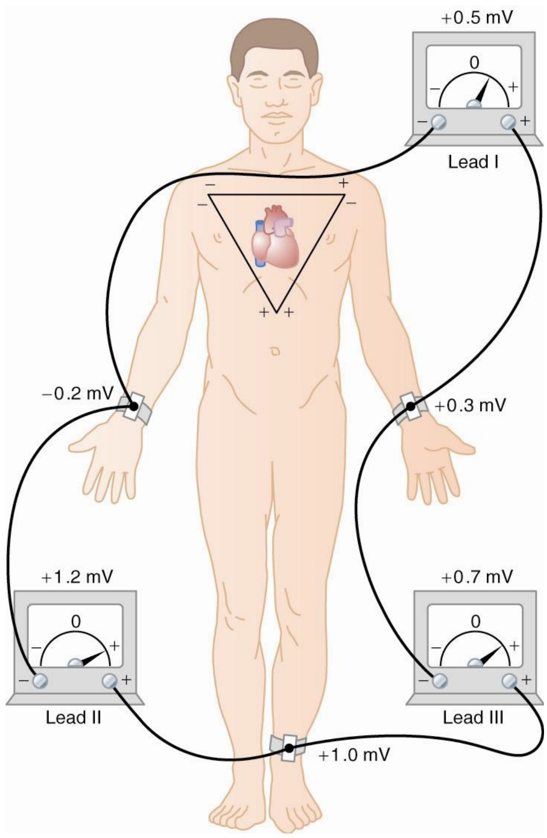
- ✓ **QRS interval**: it resembles ventricular depolarization and it should be fast. Maximally, it is **0.12 seconds** (=3 small squares). If it is prolonged, it means that the ventricles is depolarizing slower than normal (The QRS will be wide). This could be **caused by**:
  - Hypertrophy of ventricular muscles: because of hypertension for example.
  - Bundle branch block: here, the impulses reach the ventricles through ventricular muscles whose conduction rate is moderate (0.5m/sec).
- ✓ **Q-T interval**: from the beginning of the Q wave to the end of the T wave. Usually, it is half the RR interval (normally, it is half RR or less, equal to or less than 0.4 sec).
- ✓ **P-R segment**: from the end of the P wave to the beginning of the R or Q wave. It resembles atrial plateau (completely depolarized).
- ✓ **S-T segment**: from the end of the S wave to the beginning of the T wave. It resembles ventricular plateau (completely depolarized). Remember, what is important about this segment is to see if it is elevated above or depressed below the isoelectric line, which denote ischemia that may be caused by coronary artery obstruction. This might happen in case of stress (physical activity, drugs, etc). This also might happen in the other segments.
- ✓ **T-P segment**: resembles completely repolarized ventricles.

When you do an ECG, you have 12 recordings. We take different recordings (leads) to have different "views" of the heart and have a better understanding.

Bipolar Limb Leads

Lead I: We put one electrode on the right arm and the other on the left arm.
Lead II: We put one electrode on the right arm and the other on the left foot.
Lead III: We put one electrode on the left arm and the other on the left foot.

The galvanometer has 2 electrodes, one is positive and the other is negative. Here's a tip to remember where we put each in these leads: ***The left foot is always positive and the right arm is always negative***.



This means that:

- In LI: right arm → (-) , left arm → (+)
- In LII: right arm → (-) , left foot → (+)
- In LIII: left arm → (-) , left foot → (+)

But why do we put them like this? Einthoven, the man who invented this, put the electrodes in these directions to have positive recordings in all 3 leads. If we reversed the – and + electrodes, we only get the opposite recordings.

We call these 3 leads **bipolar limb leads** because we connect both electrodes on the body.

When you see the ECG machine, you also see them connecting an electrode to the right foot (this is an earth). They connect it to discharge the electrostatic energy .

The 3 bipolar limb leads make a triangle called **Einthoven's triangle**.

Einthoven's triangle is an equilateral triangle. What are the benefits of that?

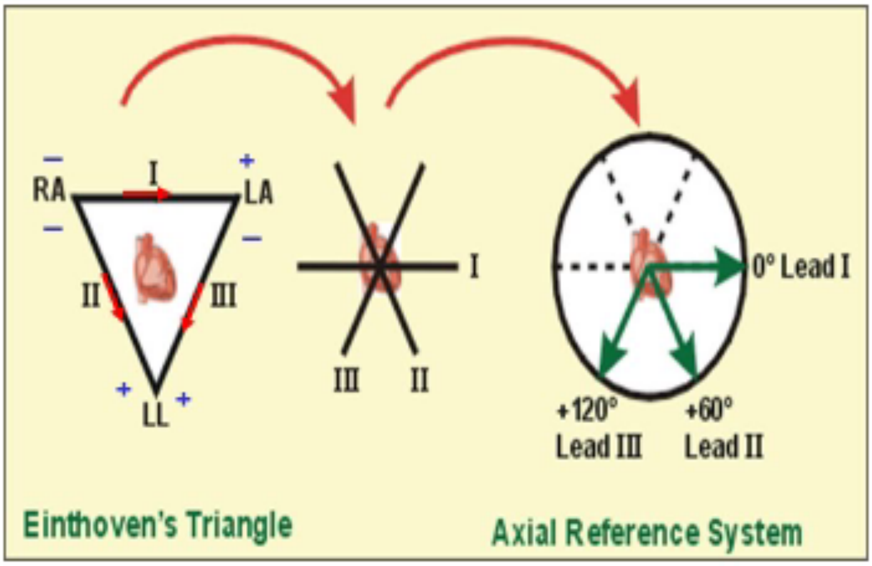
Remember that the angel between any two sides of an equilateral triangle is 60. Also the center of this triangle is the center of a circle that can be drawn around it. In addition, if we draw perpendicular lines from the center toward the sides they will halve them. Also these perpendicular lines have the same length.

Einthoven's Law states that the voltage of QRS in lead I plus the voltage of QRS in lead III equals the voltage of QRS in lead II (*L II= L I + L III*). We find the *algebraic summation* of the voltage of QRS. How? By counting the small squares in the positive and the negative directions (remember: every 10 small squares equal 1 mV).

The current is a vector (we define it by a magnitude and a direction).

Electricity (current) goes from negative to positive (from the depolarized area to the polarized area). (see the left part of the figure below).

So for example, the current in L1 goes from the right arm (-ve) to the left arm (+ve).



If the current was going in a circle, its resultant will be zero. But in Einthoven's triangle this is NOT the case.

Every lead has a vector (going from negative to positive), and the resultant of these 3 vectors is in between and is parallel to lead two; it is not zero (look at the right part of the figure). How did we find the resultant? We moved the 3 vectors in a parallel manner (without changing direction or value), and put them in a way so they meet at the center point.

Also, to find the resultant of lead 1 and lead 3, we can extent a line from lead 1 (from the head of L1 in the triangle, which will not change its direction or value) and then the resultant will be between them and parallel to lead 2.

If lead II had the opposite direction, the resultant will be zero (vectors will be in a circle). This is **Kirchhoff's second law of electrical circuits**. Kirchhoff's law states that if electrical vector were going in a circle, their resultant will be zero (LI+LII+LIII=0). To avoid this, Einthoven reversed the direction of lead II → LI+ (**-LII**) +LIII=0 → **LI+LIII=LII** (Einthoven's Law). Einthoven's Law is done on bipolar limb leads and not other leads.

Normally, Lead 2 has the highest QRS value (the more obvious value), so in ECG paper, we find under all leads a long stripe of lead 2, and doctors use it in some calculations.

Depolarization of ventricles starts at the septum, and then it spreads to the right and the left ventricles. At any time, we will have many currents (vectors) in all directions, so we can calculate the resultant vector for them. As depolarization moves on, these vectors will change so we will have another resultant vector.

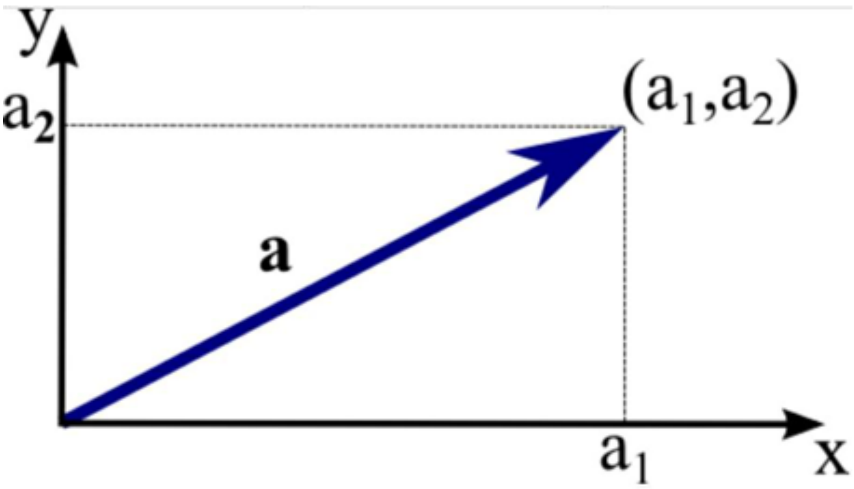
The last part to be depolarized is the posterior aspect of the left ventricle.

Q: How do I know the value of a vector on the X axis? (Or Y axis)

By drawing a perpendicular line form the head of this vector on x axis (same thing for y axis). In the figure below, we can find the value of vector A on x axis by drawing a perpendicular line from its head on x axis → the value is a1

Q: But if we have its values on X axis and on Y axis, how can we find the resultant?

By drawing perpendicular lines form X axis and Y axis and at the point of intersection (a1,a2) we draw a line from the center to it, and this line is the resultant.



So what is the importance of all this ? This is important in calculating the resultant of the leads (mean electrical axis of the heart, discussed later)

But in order to do this we need to make the leads meet at one point (the center of the triangle), so in order to do this, we move them in a parallel manner, and by that we get trigonal axis and the angel between any two of them (the leads) is 60. (See Einthoven's triangle figure in the previous page for better understating).

More details in the next lecture