Doctor.021
no.5

CVS PHYSIOLOGY

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ELECTROCARDIOGRAPHY – NORMAL
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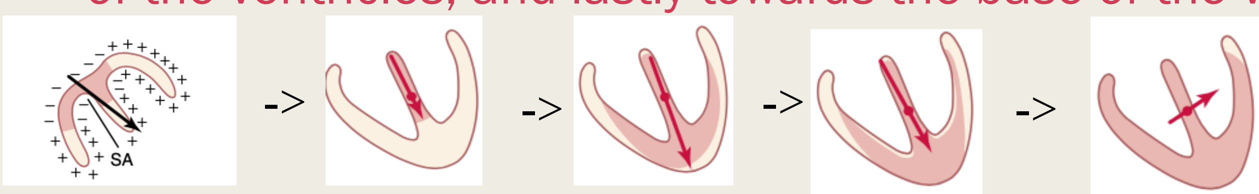
First and most importanlty, an ECG or EKG (electrocardiogram) is just a reflection of the electrical activity of the heart, this reflection is recorded from the skin of an individual, thus, the matter surrounding the heart (30-50ml of pericardial fluid, lungs, etc…) is actually conductive, and thus small portion of the electrical current spreads all the way to the surface of the body.

In order to understand what is being recorded on an ECG, we need to review the steps of the electrical cycle of the heart.

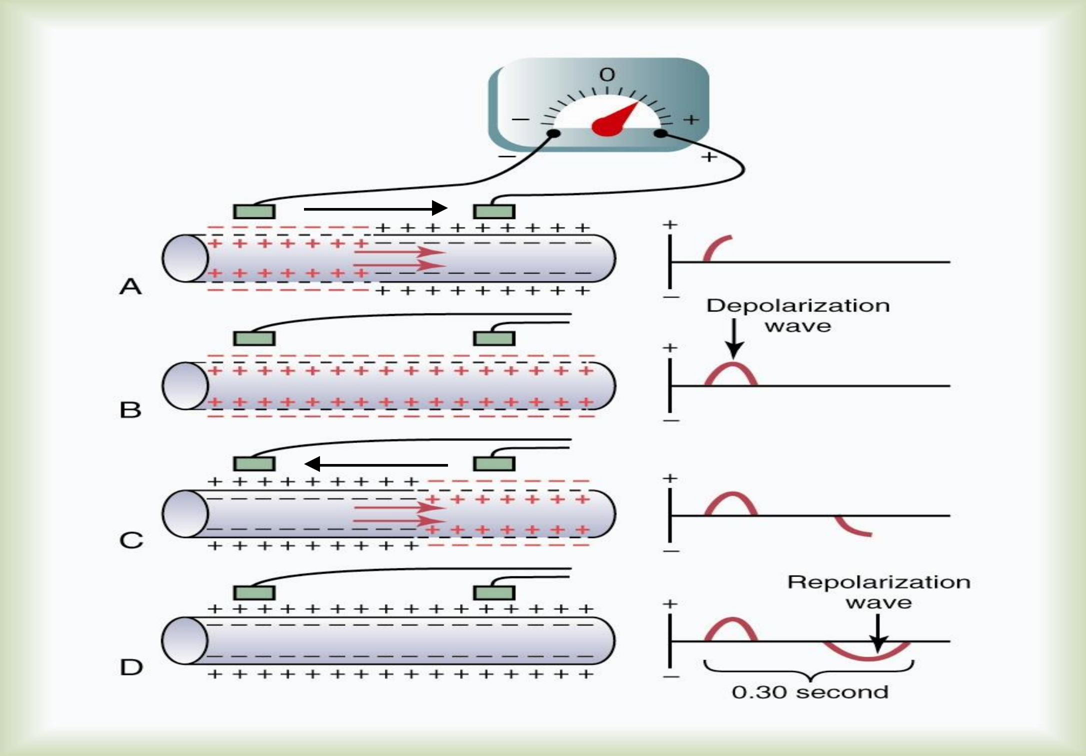
1. Depolarization spreads after firing of the SA nodes throughout the atrial syncytium, and through the internodal pathways to the AV node.
2. After a delay of 0.09 seconds, depolarization continues through the interventricular septum.
3. Depolarization spreads then towards the apex and the surrounding area of the ventricles, and lastly towards the base of the ventricles.



*The shaded area represents deploarization.

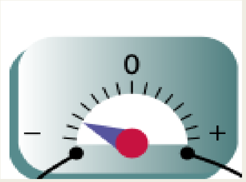
Depolarization and Repolarization Waves:

If we take a single cardiac muscle fiber and connect it through two electrodes to a galvanometer, and then measuer the differnce in voltage on two different points on the surface of the cell, we will see the following results:



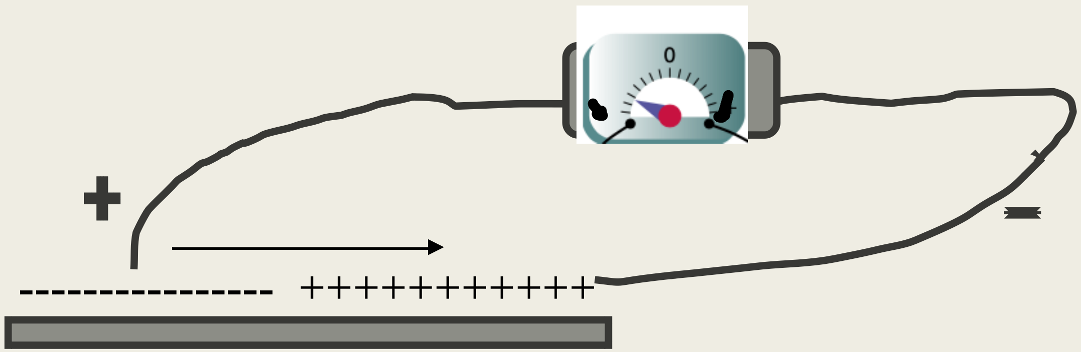
*This picture has a subtle mistake, in the fourth galvanometer reading, the repolarization wave is slightly lower in amplitude than the depolarization wave, which is wrong and they are actually equal since they occure on the same cardiac muscle fiber.

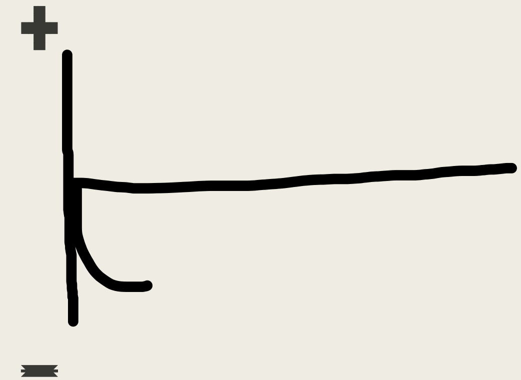
The galvanometer measures the difference of potenitial on the positive eleetrode from the potential on the negative electrode , and thus in part C in the galvanometer will look like this:



- Note that no potential is recorded when the ventricular muscle is either completely depolarized or repolarized.

- When the membrane depolarizes (Stage A), the surface becomes negative in charge, while the part that still didn't depolarize, is still positively charged on the surface, this generates a current on the membrane surface that moves from the negative portion to the positive portion of the membrane, as this current gets closer to the + electrode, we will see a positive reading on the galvanometer.
- This current is a vector (متجه) that has both a direction (left to right at stage A), and an amplitude, the amplitude is at MAXIMUM when half of the membrane is depolarized while the other half isn't, and thus we reach the top of the DEPOLARIZATION wave. As more of the membrane get depolarized, we will finally reach a point where the all the membrane is depolarized and - charged, thus there is no current, and the galvanometer recording gets back to zero (Stage B), this is called the ISOELECTRIC STATE.
- When repolarization starts, the first part of the membrane to depolarize is the first to repolarize (Stage C), the membrane charge of this part is now +, and the current now moves in the opposite direction (from right to left), that is, away from the positive electrode, so now the recording is negative, and a REPOLARIZATION waves appear, it is at maximum amplitude when the left half of the membrane is repolarized, while the right half is still depolarized, when all the membrane repolarizes, we again record zero.
- Very important: repolarization does not always firstly occur on the part that first depolarized, sometimes the last part to depolarize can be the first to repolarize, keep this in mind as it is essential to understand some aspect of the ECG.



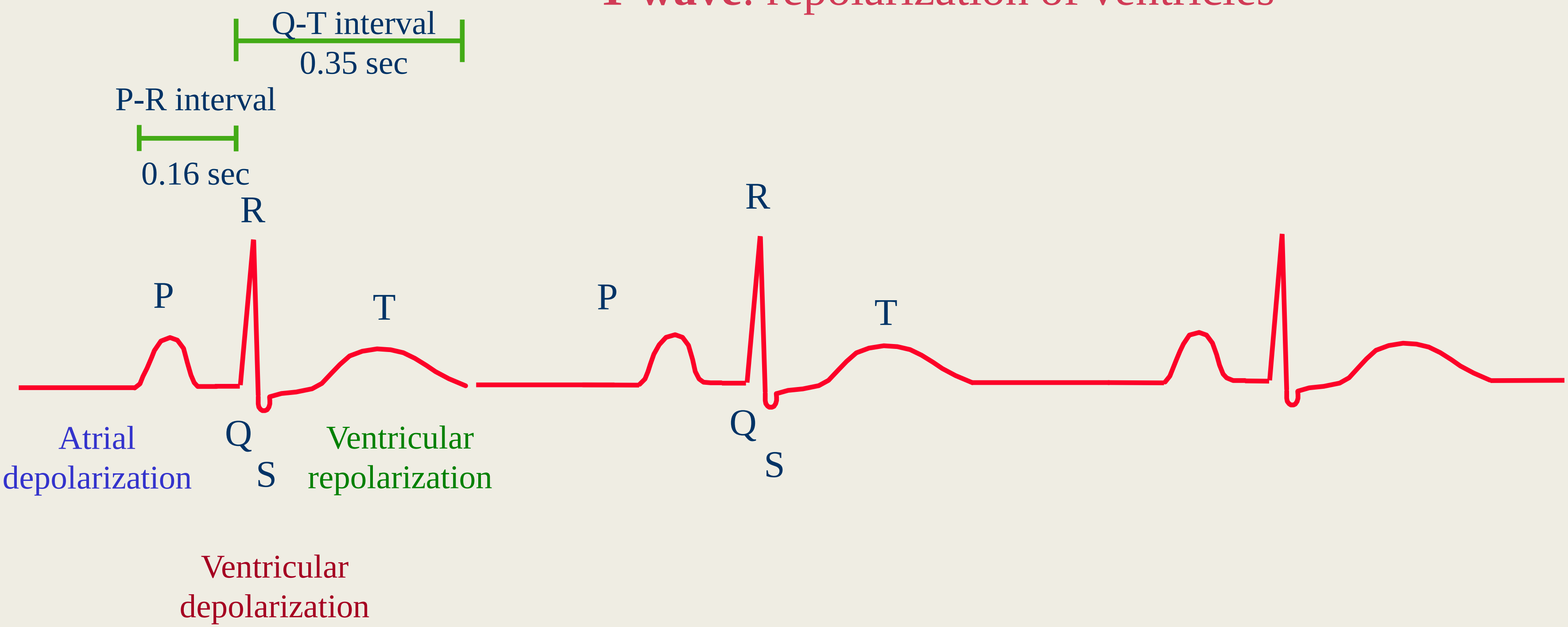


In this example the fiber is in stage A of the previous picture, however, look at the electrodes, they have switched places, and the positive electrode is one the depolarized membrane, while the negative electrode is on the still polarized (+) membrane side, the current moves from left to right, but away from the positive electrode, still this is a depolarization wave, however it is negative and downward on the graph.

Note: All these measurments have put both electrodes on the surface which shows a BIPHASIC action potential, if we put one electrode on the surface and one inside, we will get a result on the graph that is identical to what we see on the normal ventricular action potential, this is called a MONOPHASIC action potenital because it is composed of one continuous wave.

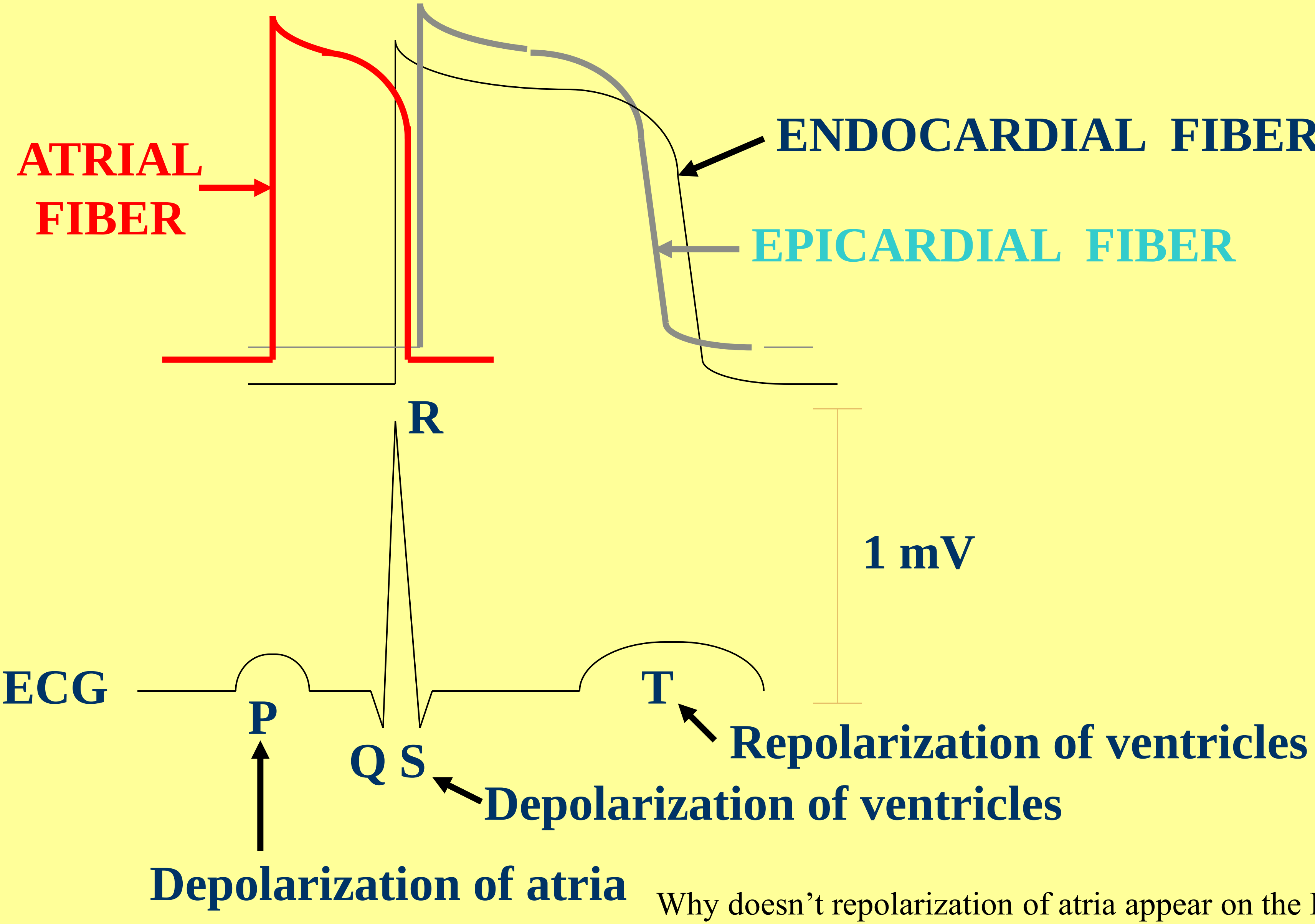
Normal EKG

P wave: depolarization of atrial myocardium.
Signals onset of atrial contraction
QRS complex: ventricular depolarization
Signals onset of ventricular contraction..
T wave: repolarization of ventricles

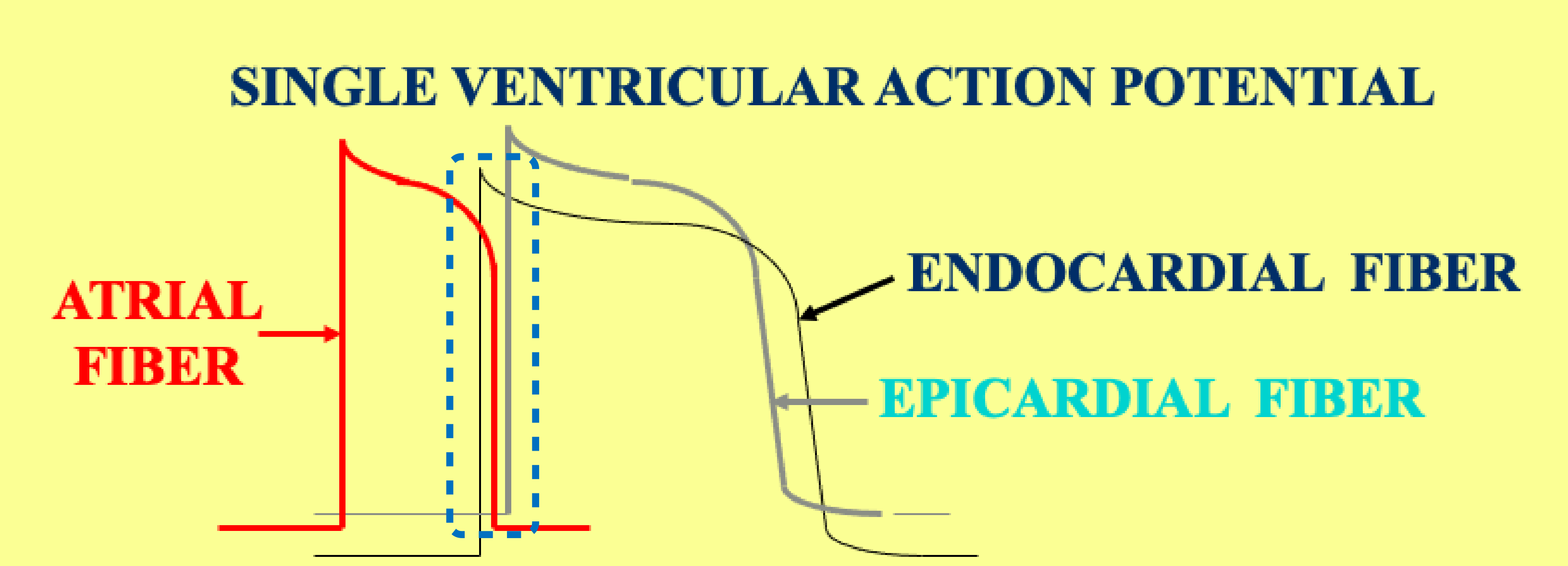


QRS complexes are either monophasic ("one wave QRS" if we have one R, "one wave QS" if we have only one negative deflection without R) or biphasic like the one above (two waves without Q) or triphasic (all 3 waves) .

SINGLE VENTRICULAR ACTION POTENTIAL



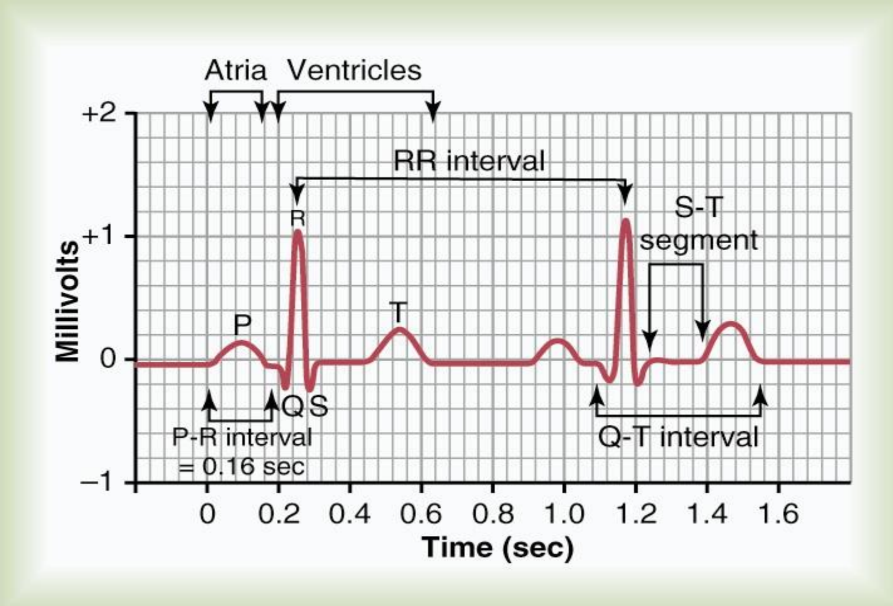
Why doesn't repolarization of atria appear on the ECG??



As you can see in these action potentials, the atria START to repolarize almost simultaneously with ventricular depolarization, thus the ATRIAL T WAVE (atrial repolarization wave) occurs at the same time as the ventricular depolarization wave happens (QRS complex), the QRS complex has a much greater amplitude, and so the ATRIAL T wave is MASKED and override by the QRS complex.

Note too that in the ventricles we have both a subendocardial layer that is close to the endocardium, and a subepicardial layer that's on the outside of the ventricular syncytium and beneath the epicardium, as you can see, the subepicardial (or epicardial) myocytes have shorter action potentials when compared with subendocardial (or endocardial) myocytes, keep this in mind too, because it happens during ventricular repolarization.

Standardized EKG's



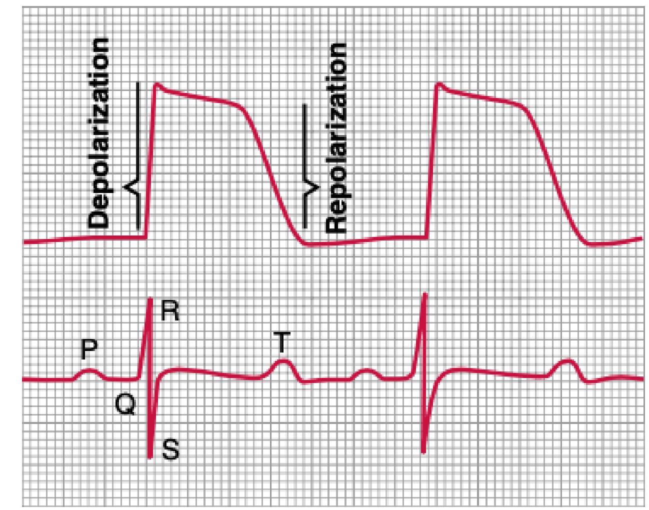


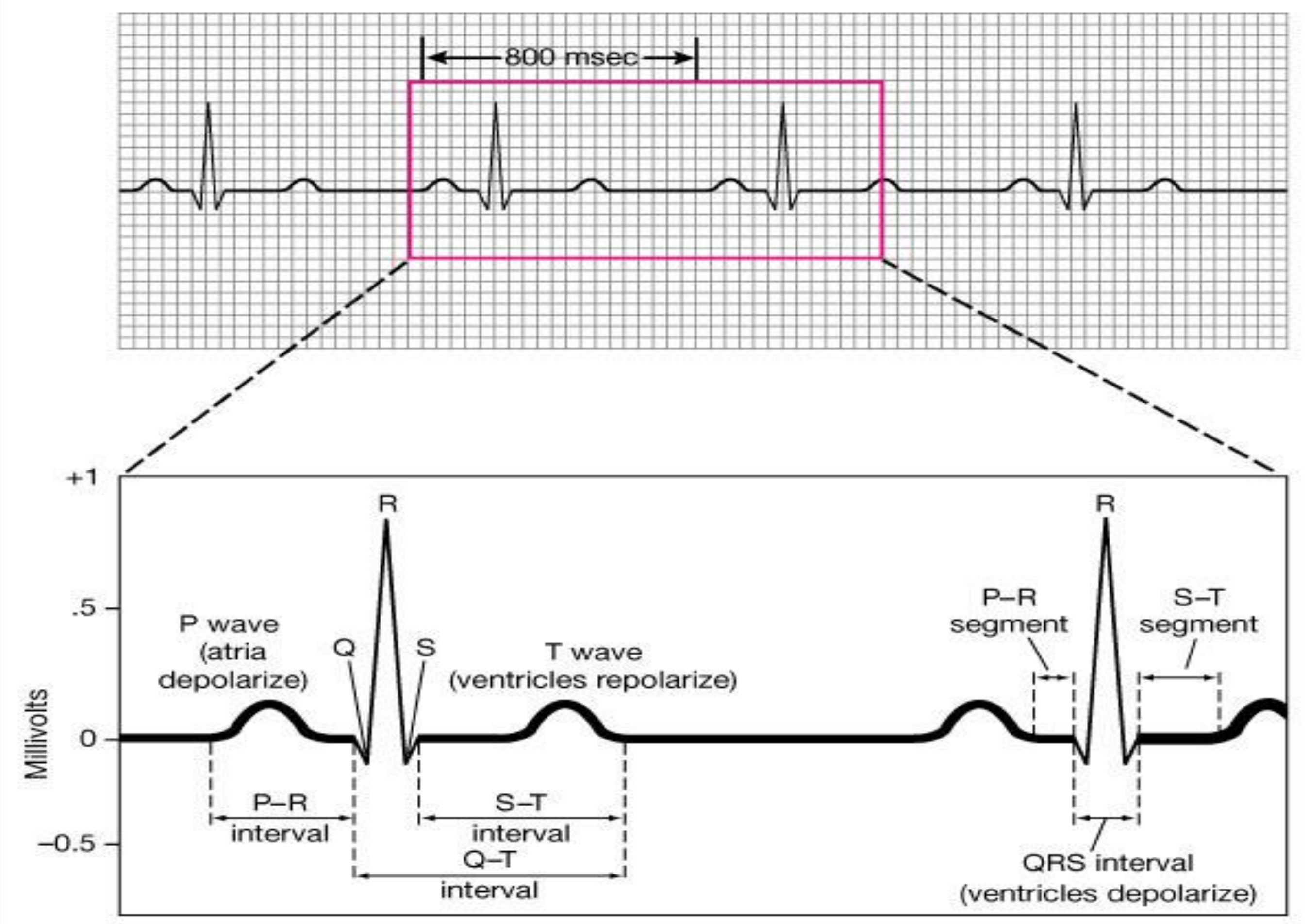
Figure 11-3. *Top,* Monophasic action potential from a ventricular muscle fiber during normal cardiac function showing rapid depolarization and then repolarization occurring slowly during the plateau stage but rapidly toward the end. *Bottom,* Electrocardiogram recorded simultaneously.

- Time and voltage calibrations are standardized: The vertical lines on the ECG are time calibration lines. A typical ECG is run at a speed of 25 millimeters per second, although faster speeds are sometimes used. Therefore, each 25 millimeters in the horizontal direction is 1 second, and each 5-millimeter segment, indicated by the dark vertical lines, represents 0.20 second. The 0.20-second intervals are then broken into five smaller intervals by thin lines, each of which represents 0.04 second.
- The horizontal calibration lines are arranged so that 10 of the small line divisions upward or downward in the standard ECG represent 1 millivolt, with positivity in the upward direction and negativity in the downward direction.

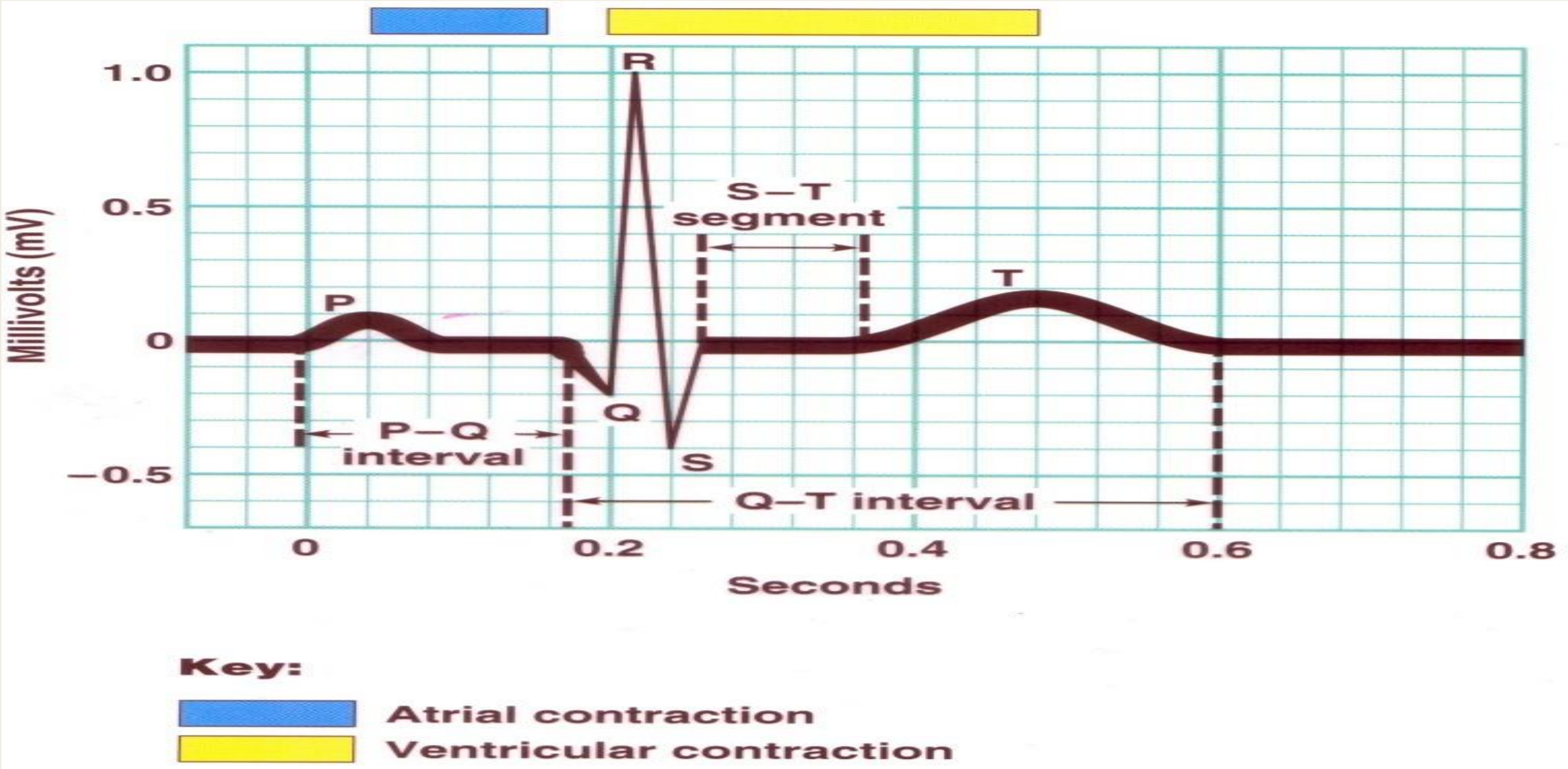
Electrocardiogram

- Record of electrical events in the myocardium that can be correlated with mechanical events
- **P wave**: depolarization of atrial myocardium.
  - *Signals onset of atrial contraction*
- **QRS complex**: ventricular depolarization
  - *Signals onset of ventricular contraction..*
- **T wave**: repolarization of ventricles
- **PR interval** or PQ interval: 0.16 sec
  - *Extends from start of atrial depolarization to start of ventricular depolarization (QRS complex) contract and begin to relax*
  - *Can indicate damage to conducting pathway or AV node if greater than 0.20 sec (200 msec) (AV block).*
- **Q-T interval**: time required for ventricles to undergo a single cycle of depolarization and repolarization
  - *Can be lengthened by electrolyte disturbances, conduction problems, coronary ischemia, myocardial damage*

Electrocardiogram



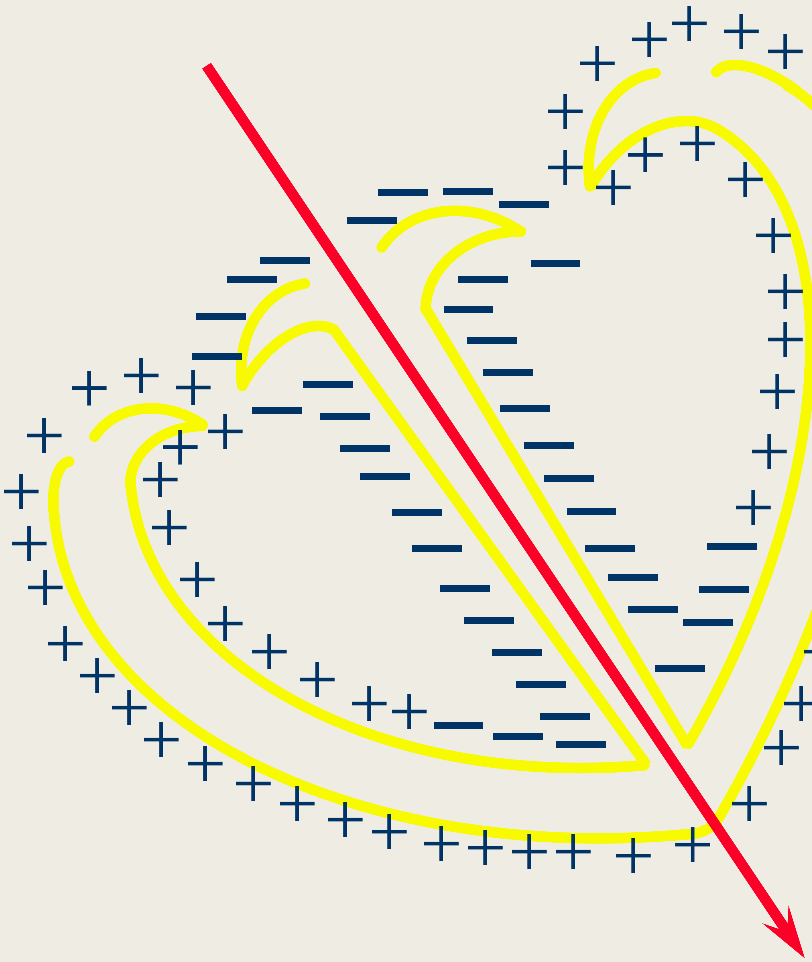
(b)



Depolarization of atria is with moderate velocity, that is why “P wave takes 100 msec”.
Depolarization of ventricles due to fast sodium channels, is fast, (QRS short duration 60 msec), repolarization is slow due to slow K+ channels. These channels are slow.
In the ventricles, because Depolarization occurs fast you can separate the three waves: septal= Q wave followed by major (apex of the ventricles and surrounding area) vector R wave finally by basal (base of the ventricles) small vector S wave. Repolarization is slow you don’t see three waves, you see only one wave T: slow and prolonged. The Three ventricular areas (septal, major and basal) repolarize in an overlapping and not separate fashion, so you see only one wave**.**

Flow of Electrical Currents in the Chest Around the Heart

Mean QRS Vector Through the Partially Depolarized Heart: if we algebraically sum and average all the electrical currents that move from – to + in the heart during each electrical cycle we get this vector, which represents how most electrical vectors in the heart are going to look like.



Flow of Electrical Currents in the Chest Around the Heart (cont'd)

- Ventricular depolarization starts at the ventricular septum (left side of the ventricular septum depolarizes first) and the endocardial surfaces of the heart.
- The average current flows positively from the base of the heart to the apex.
- At the very end of depolarization the current reverses for 1/100 second and flows toward the outer walls of the ventricles, (to spread depolarization to the bases, remember the 5 steps) near the base (S wave appears).

EKG Concepts

- The P wave immediately precedes atrial contraction.
- The QRS complex immediately precedes ventricular contraction.
- The ventricles remain contracted until a few milliseconds after the end of the T repolarization
wave.
- The atria remain contracted until the atria are repolarized, but an atrial repolarization wave cannot be seen on the electrocardiogram because it is masked by the QRS wave.

- The electrical activity of the AV node cannot be recorded on the ECG because the current that is initiated by it is very very small and because it is silenced by the SA node (the SA node firing is faster than it).

EKG Concepts (cont'd)

- The P-Q or P-R interval on the electrocardiogram has a normal value of 0.16 seconds and is the duration of time between the beginning of the P wave and the beginning of the QRS wave (beginning of the Q wave if it appears, if not, then the beginning of the R wave); this represents the time between the beginning of atrial contraction and the beginning of ventricular contraction.
- The word interval means that a wave (or more) is included in the time period, but the word segment just denotes the time between waves (no wave included in the time period)
- The terms PQ, PR interval can be used interchangeably, as the Q wave in many instances is absent and only an RS complex shows, if the Q wave appears it's called a PQ interval, if it doesn't then it's called a PR interval.
- The P-R interval shortens at faster heart rates due to increased sympathetic or decreased parasympathetic activity, which increase atrioventricular node conduction speed. Conversely, the P-R interval lengthens with slower heart rates as a consequence of slower atrioventricular nodal conduction caused by increased parasympathetic tone or withdrawal of sympathetic activity.

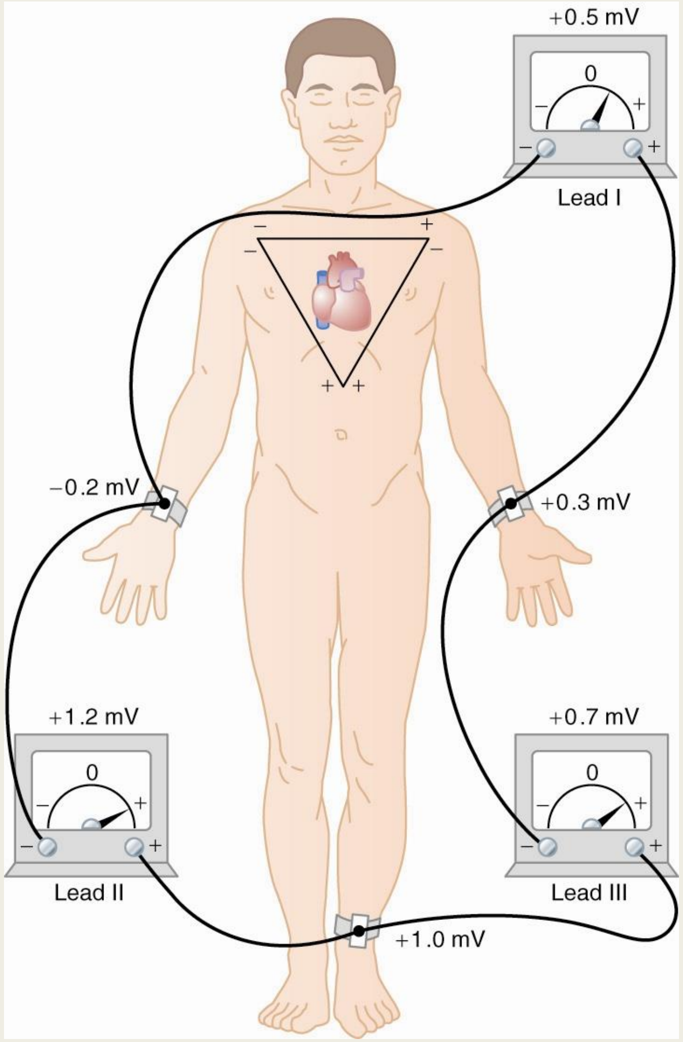
EKG Concepts (cont'd)

- The Q-T interval has a normal value of 0.35 seconds and is the duration of time from the beginning of the Q wave to the end of the T wave; this approximates the time of ventricular contraction.
- The heart rate can be determined with the reciprocal of the time interval between each heartbeat.
- For example if the time interval between two heartbeats is 0.8 seconds, then the heart rate = 60/0.8= 75 beats/min.

Bipolar Limb Leads

- Bipolar means that the EKG is recorded from two electrodes on the body.
- ***Leads make you see the heart from different angles…the three dimensions of the heart.***

A lead is a setup, a way you set the electrodes on the body surface in order to record the reflected electrical activity of the heart on the skin, different leads (setups) show different ECGs, different in terms of amplitudes, but usually not different in terms of the pattern on the ECG.



Bipolar Limb Leads (cont'd)

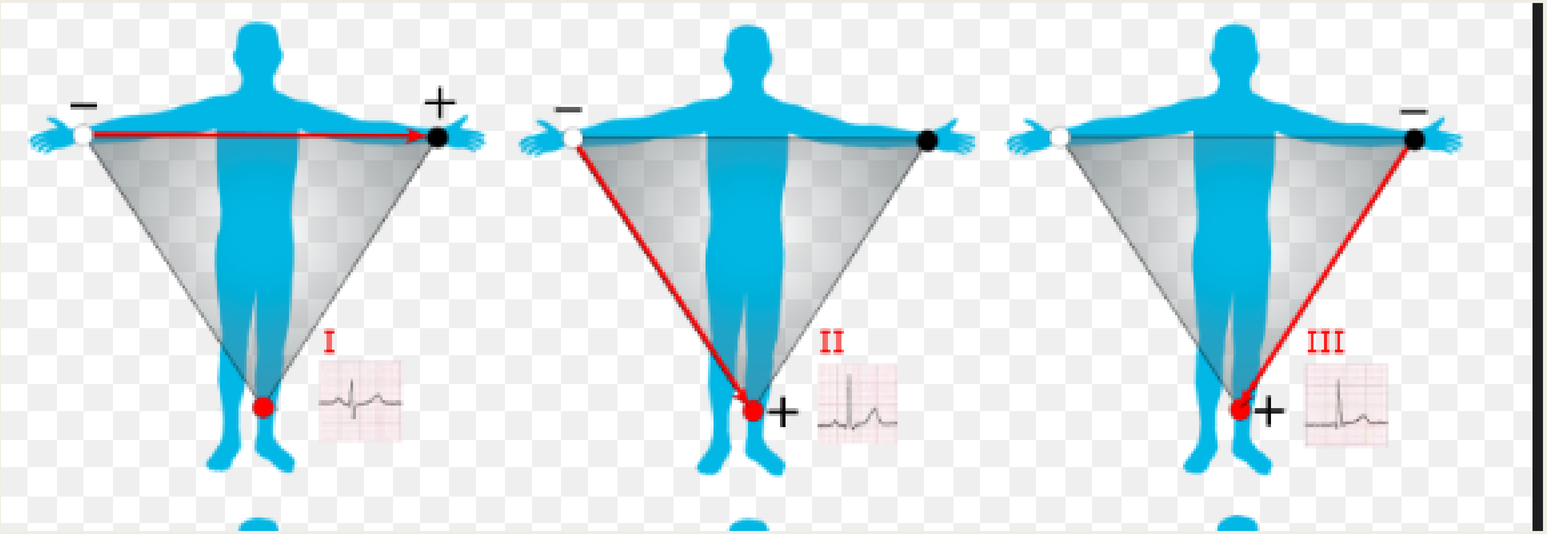
- Lead I - The negative terminal of the electrocardiogram is connected to the right arm, and the positive terminal is connected to the left arm.
- Lead II - The negative terminal of the electrocardiogram is connected to the right arm, and the positive terminal is connected to the left leg.
- Lead III - The negative terminal of the electrocardiogram is connected to the left arm, and the positive terminal is connected to the left leg.

- Who takes the + electrode? In descending order:

Left leg>left arm>right arm

Bipolar Limb Leads (cont'd)

- Einthoven's Law states that the electrical potential of any limb equals the sum of the other two (+ and - signs of leads must be kept unchanged). L II= L I + L III
- If lead I = 1.0 mV, Lead III = 0.5 mV, then Lead II = 1.0 + 0.5 = 1.5 mV:
- Funny ***I + III should equal IV not II :that is what Eindhoven did***



In the following slides we will see how the 5 sequential steps of the electrical cycle are reflected on the different leads (setups), keep in mind the principiles we learnt in our expirement on a single cardiac muscle fiber:

1. The current moves from the negative side of the membrane to the positive side.

2. As the current (vector) moves towards the + electrode (exploring or recording electrode), a positive deflection or wave is recorded.

3. As the current (vector) moves away from the + electrode (exploring or recording electrode), a negative deflection or wave is recorded.

4. The longer the vector (the higher it's amplitude) the larger the amplitude of the recorded wave or deflection (regardless of it's direction, whether a positive or negative deflection)
5. Depolarization is not always reflected with a positive upward wave or deflection.

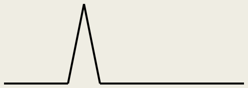
6. Repolarization is not always reflcted with a negative downward wave or deflection.

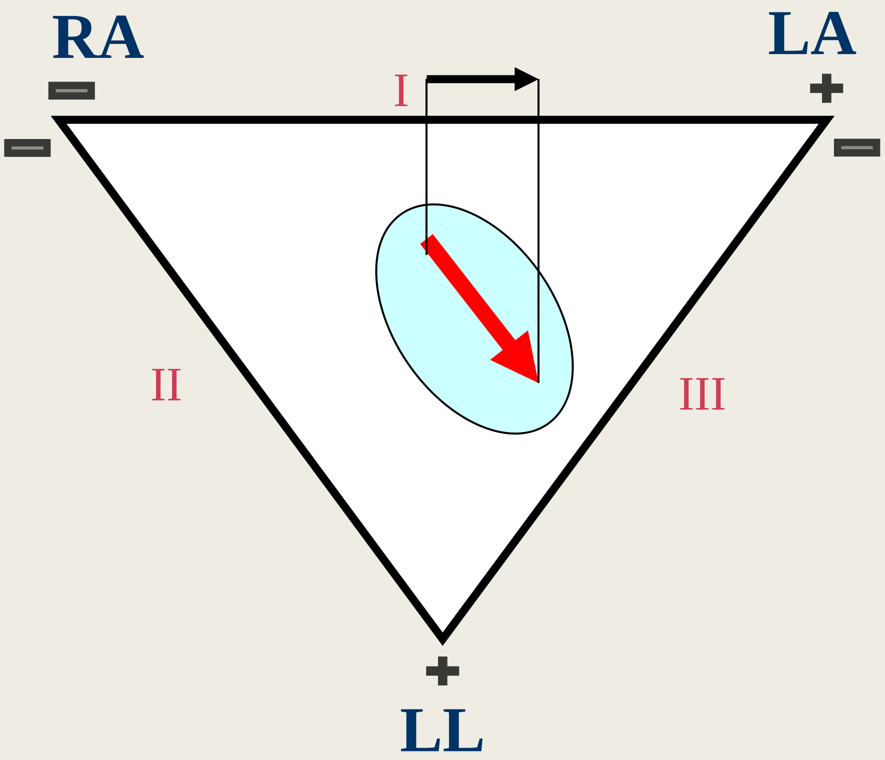
7. The red line(in the next slide) is the Mean QRS Vector Through the Partially Depolarized Heart: if we algebraically sum and average all the electrical currents that move from – to + in the heart during each electrical cycle we get this vector, which represents how most electrical vectors in the heart are going to look like and behave.

<u>ECG Recordings</u> (QRS Vector pointing leftward, inferiorly & anteriorly)

<u>3 Bipolar Limb Leads:</u>

I = RA vs. LA (+)



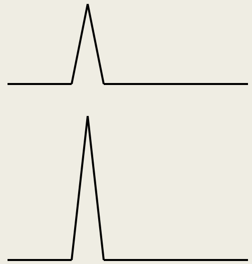


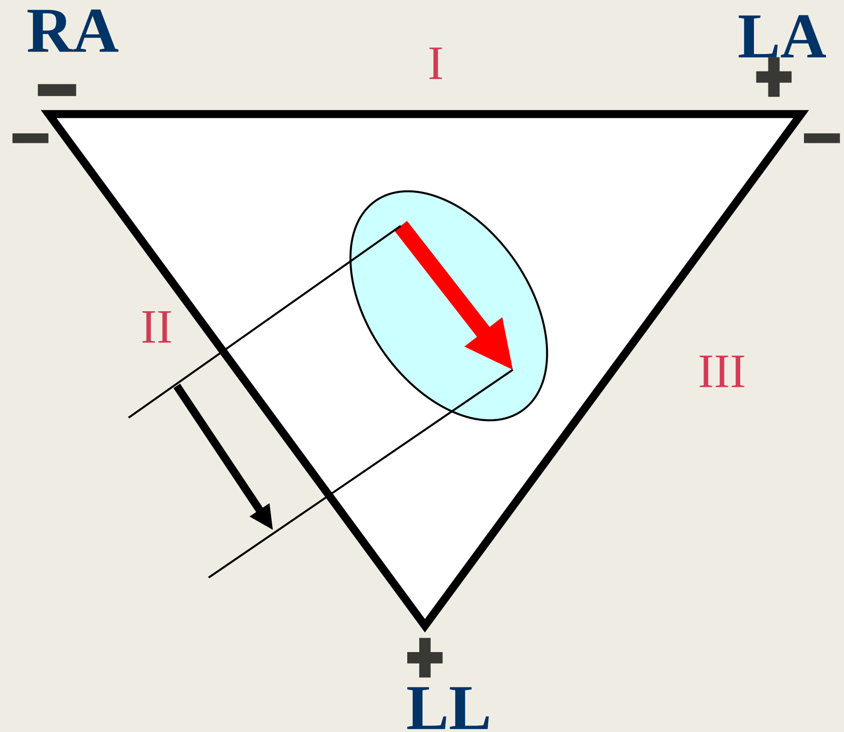
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)





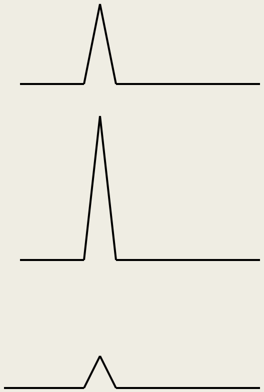
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

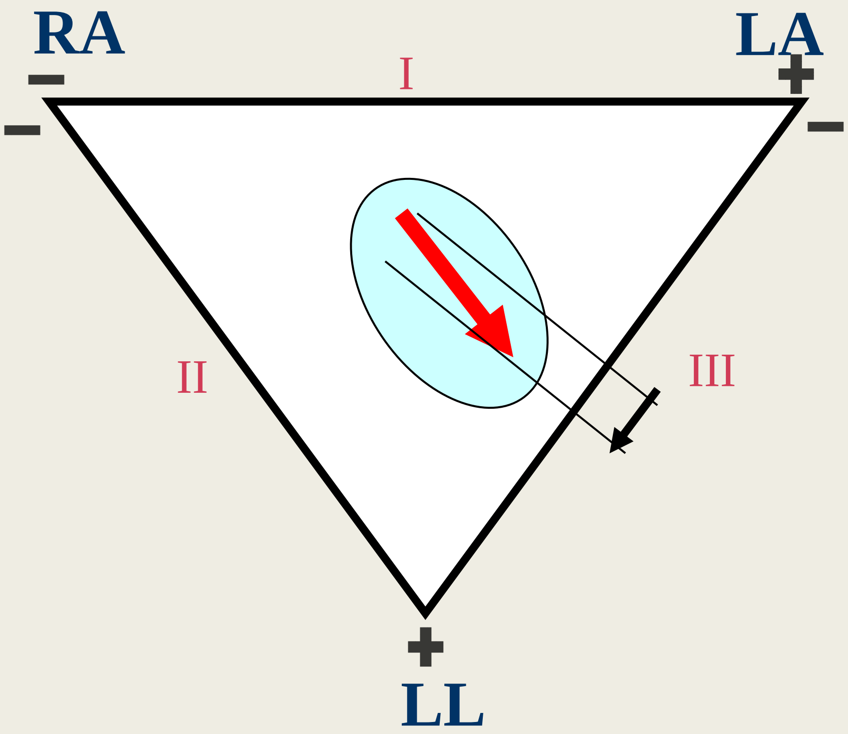
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

III = LA vs. LL (+)





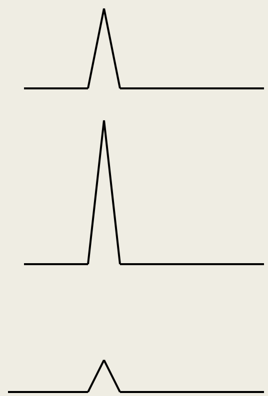
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

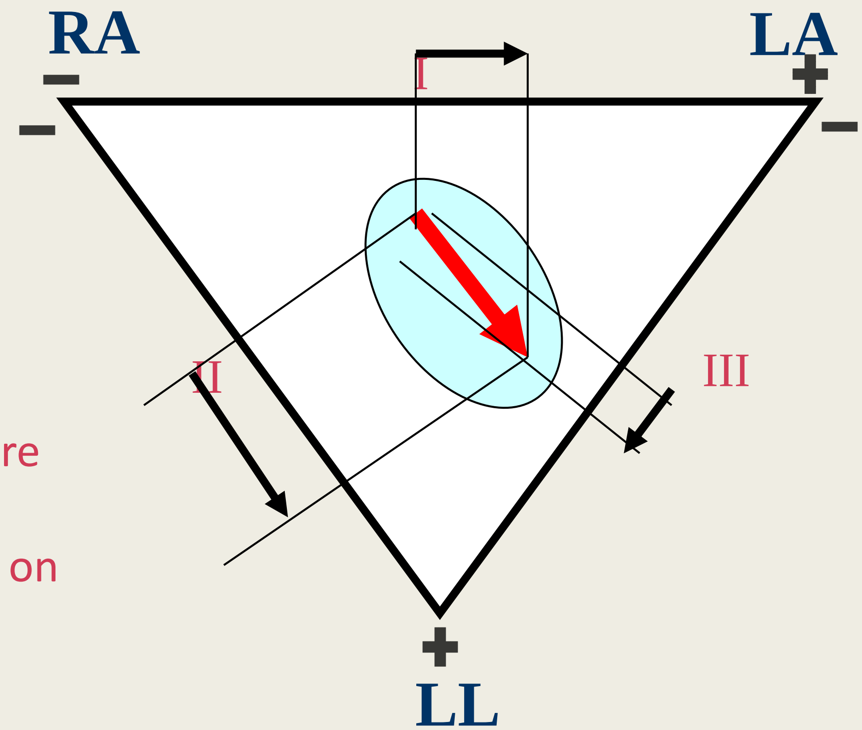
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

III = LA vs. LL (+)





It is obvious that the ECGs in these three leads are similar to one another because they all record a positive wave that reflects the mean QRS vector on the skin, however why do they record it with different amplitudes?

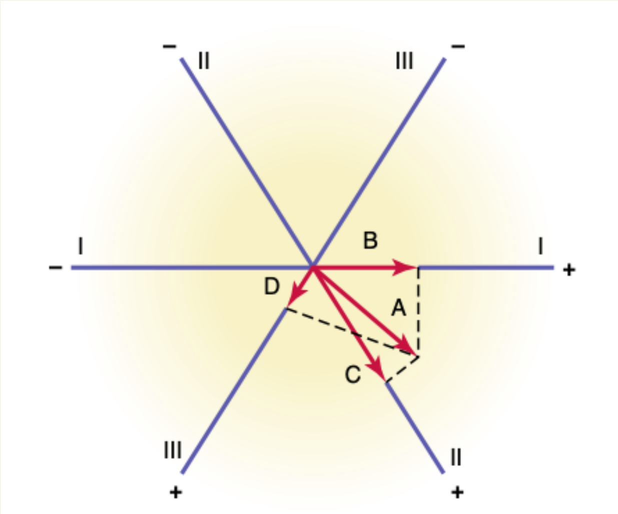
Remember

1. As the current (vector) moves towards the + electrode (exploring or recording electrode), a positive deflection or wave is recorded.

The QRS mean vector (red arrow) above, is moving most closely towards the positive electrode of LEAD II, thus lead II records the positive wave with the highest amplitude.
The red arrow moves least closely towards the LEAD III positive electrode, thus lead III shows the positive wave with least amplitude.
Lead I in intermediate, and thus it records the second largest positive wave.

You will learn more about this in the topic of vector analysis, but here's an illustration to further understand what's happening in the previous slide:

The red arrow A is the same QRS mean vector we saw in the previous slide, as you can see if you extend a line (the dashed black line) from the head of the red arrow until it meets the axis of a lead, and then draw a line that moves on the lead axis towards this black line, if the drawn line moves from - to + ends of the lead, then the lead records a positive deflection, and the longer this drawn line is, the larger the amplitude recorded.

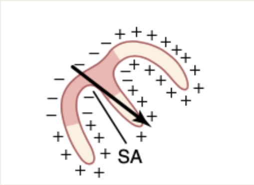


As shown, vector C is moving from the - to + ends of lead II, and is the longest vector when compared to B and D, thus lead II records the largest positive wave.

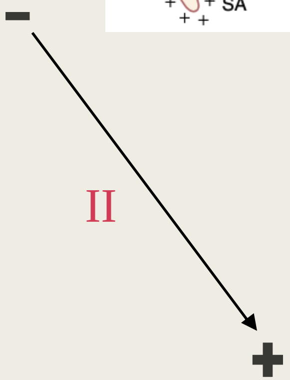
Check vectors B and D in the same way, and you conclude with the same results on the previous slide.
Lead II > leadI > LeadIII

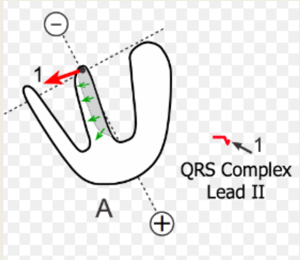
If it's still not clear don't worry, more is gonna come on this topic later.

Now lets apply this to all 5 steps of the electric cycle, not just the mean QRS vector, we will stick with lead II, since all three leads show similar patterns but just different amplitudes:

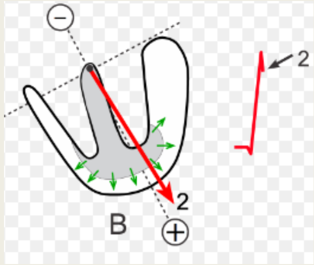


1-Atrial depolarization: the atrial depolarization current moves towards the + electrode, a positive P wave is recorded!

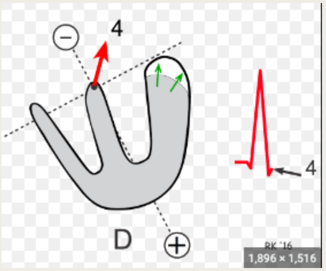




2-Septal depolarization, starts on the left side first, this creates a current that moves from left to right, the moves AWAY from the + electrode, a Q wave is recorded!



3- depolarization of the apex, current towards the + electrode, almost idetical to the mean QRS vector, the large R wave is recorded!.

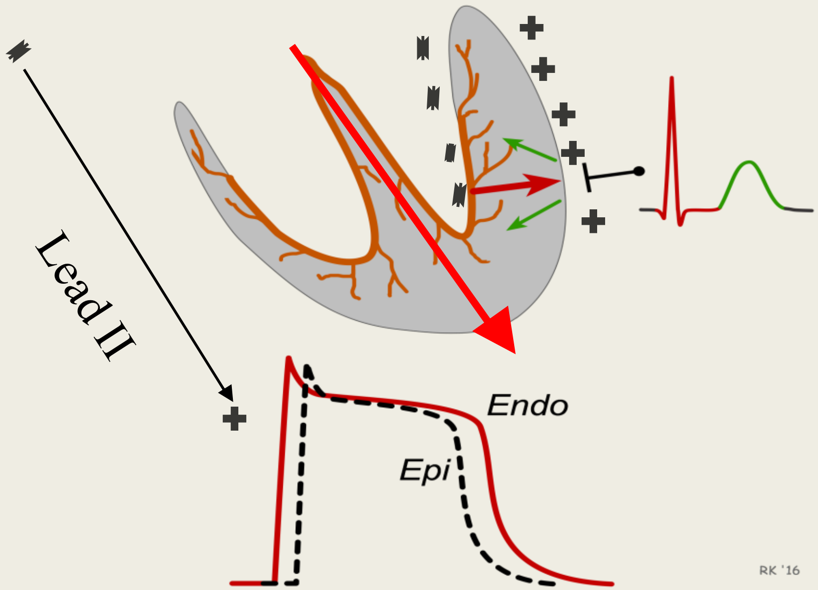


4- depolarization of the bases, the current moves AWAY from the + electrode, the S wave is recorded!

The last step, the step that is responsible for the appearance of the T wave, is special and deserves a slide for itself:
After full ventricular depolarization, it makes since that the subendocardial (or endocardial) layrer of muscle is going to be the first on to repolarize and gain back a positive surface charge, but this does not happen in THE VENTRICLES, because of the high intraventricular pressure during systole, the endocardial layer of muscle finds it harder to repolarize, and the subepicardial (or epicardial) layer of muscle repolarizes first!

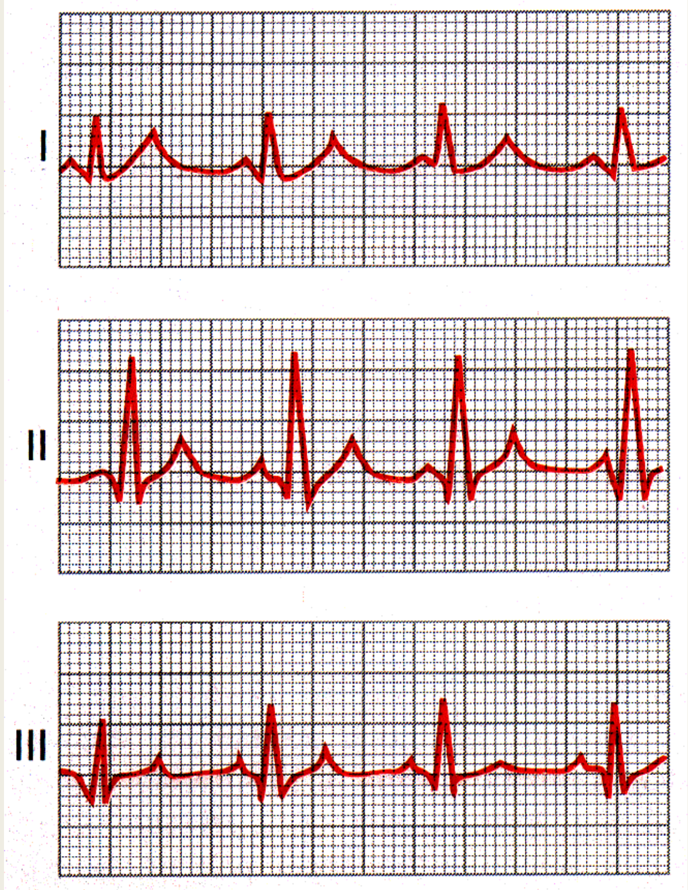
So the last ventricular muscle cells to depolarize, are the first to repolarize, they get back their + surface charge, and thus the current during ventricular repolarization is very similar to the one in stage 3 of the previous slide!(positive wave)

For this very reason, the T wave appears on the ECG as an UPWARD POSITIVE wave and not a negative downward wave, ponder this illustration:



As you can see, during this last stage of ventricular repolarization, repolarization occurs outside to the inside, thus the surface becomes + first, and the current moves towards the apex just like the current in stage 3 of the previous slide, current moves towrds the + electrode of lead II, the POSITIVE T WAVE appears!!.

Bipolar Limb Leads (cont’d)

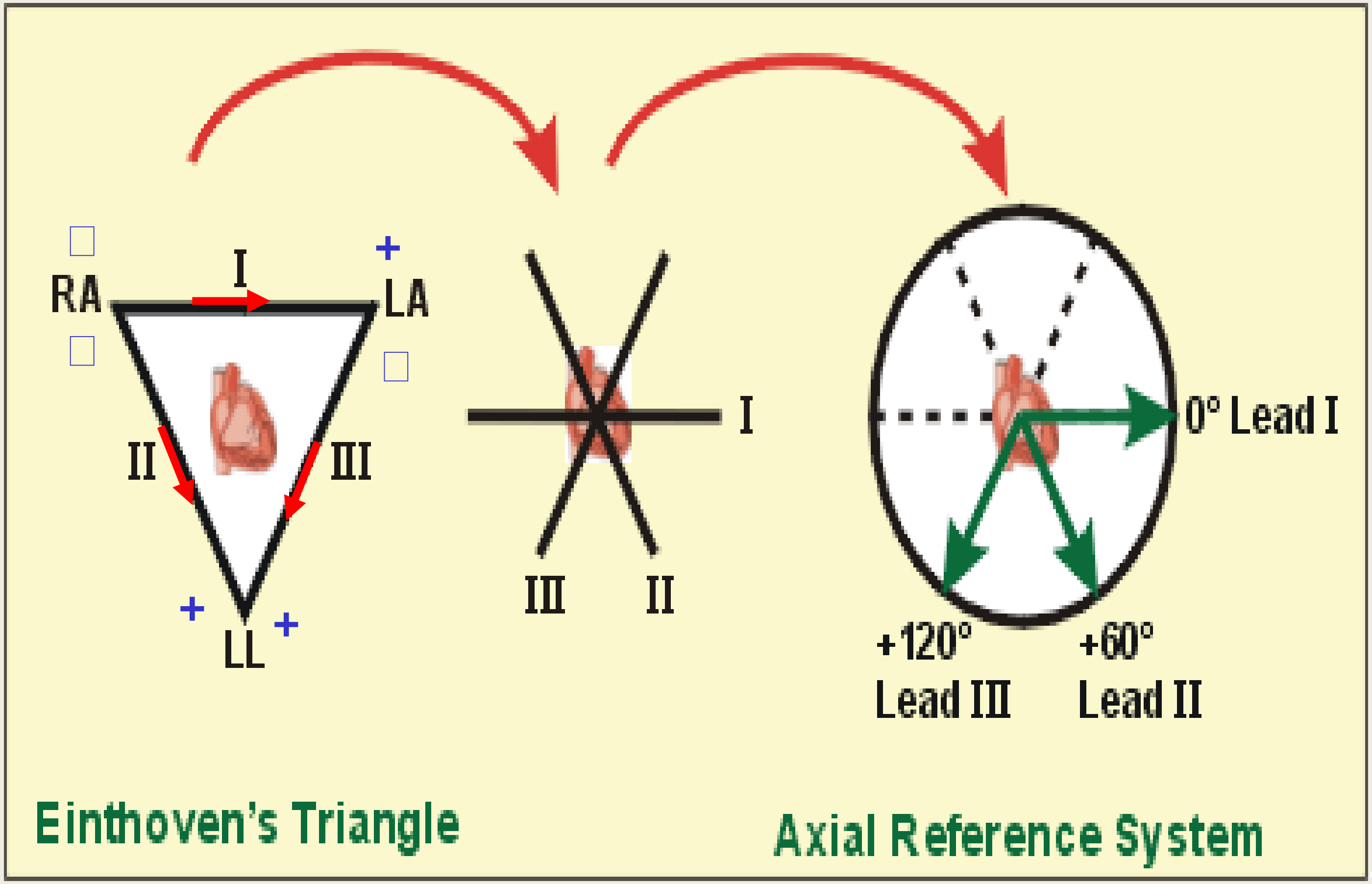


0.5 mV

1.2 mV

0.7 mV

Einthoven's triangle and law: *How these three limb leads are oriented to each other?*



Augmented limb leads:

A scientist named Wilson tried to connect one limb to the + electrode, and then connected all three limbs to the – electrode and adding resistance of 5000 ohm to each limb connection to the – electrode, this makes the potential on the - electrode near zero, so you record approximately only potential of the limb connected to the + electrode.
The problem with this method was that the ECG waves were too small, another scientist named Goldman removed the resistance and the connection of the negative electrode to the limb connected to the + electrode, and this made the ECG signal much more larger and AUGMENTED, giving rise to the augmented unipolar limb leads.

In this type of recording, two of the limbs are connected through electrical resistances to the negative terminal of the electrocardiograph, and the third limb is connected to the positive terminal. When the positive terminal is on the right arm, the lead is known as the aVR lead; when on the left arm, it is known as the aVL lead; and when on the left leg, it is known as the aVF lead (F for foot).

These leads are similar to the bipolar limb leads in their recordings, however there's a very unique thing about aVR.
In aVR lead, the positive electrode is on the right arm, this puts the + electrode closer to the base of the heart, the mean QRS vector moves from the base towards the apex, so in aVR lead, the mean QRS vector is moving AWAY from the + electrode!! Remember:
its like what happens when we switch the 2 electrodes (remember the start of the lecture)

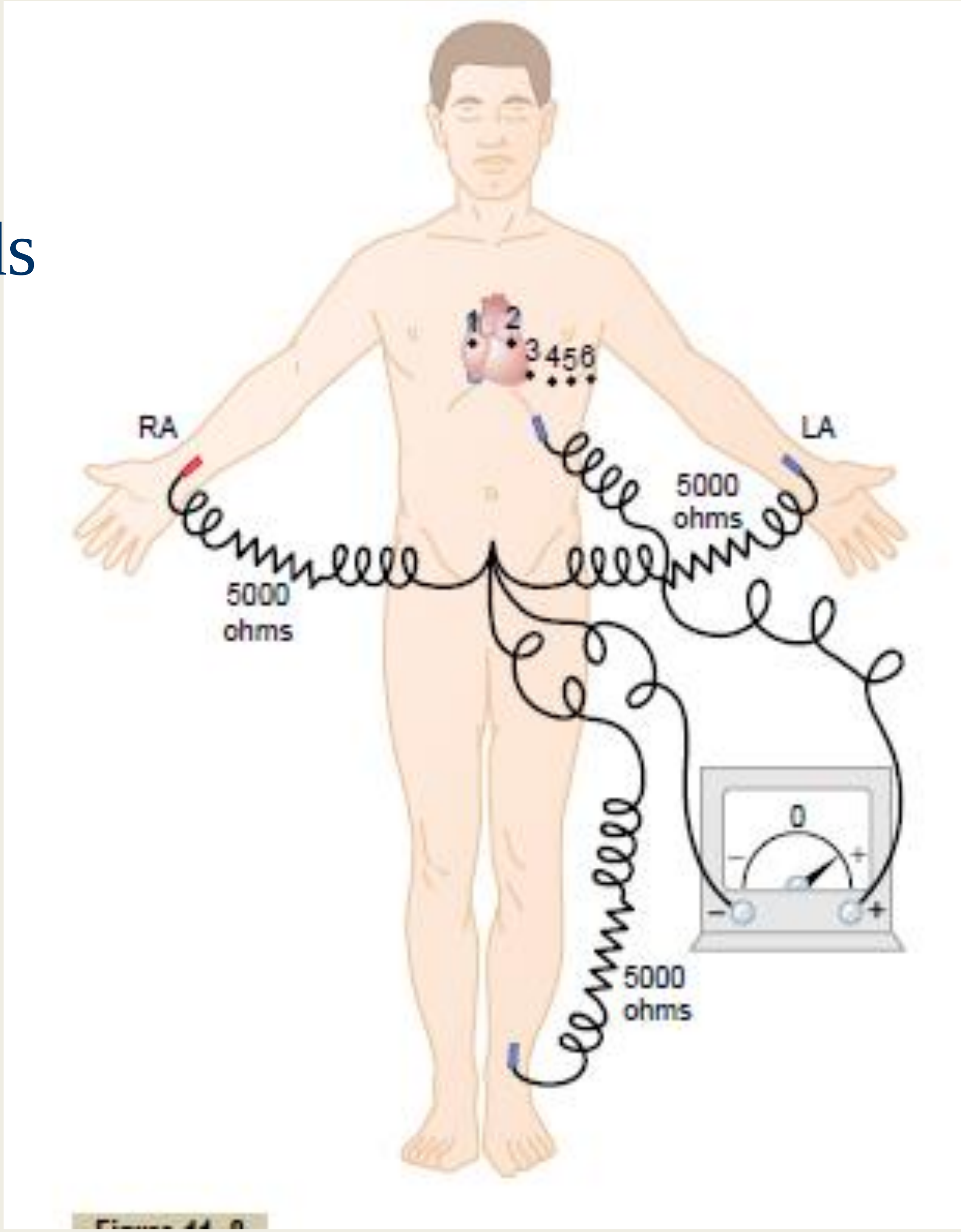
This results in aVR lead being a reverse of other other leads, the R wave is downward, the Q and S waves face upward!

As the current (vector) moves away from the + electrode (exploring or recording electrode), a negative deflection or wave is recorded

Other EKG Leads (cont'd)

- In augmented Unipolar Limb Leads: aVR, aVL, and aVF are also in use. For aVR the +ve electrode is the right arm, and the - electrode is on the left arm + left leg; in aVL the +ve electrode is left arm; in aVF the +ve electrode is left foot and the negative electrode is the other two limbs. ***The voltage of the augmented lead is 50% more than the nonaugmented leads.***

Unipolar Limb Leads



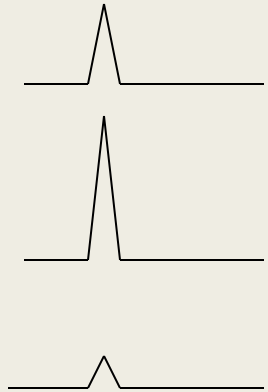
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

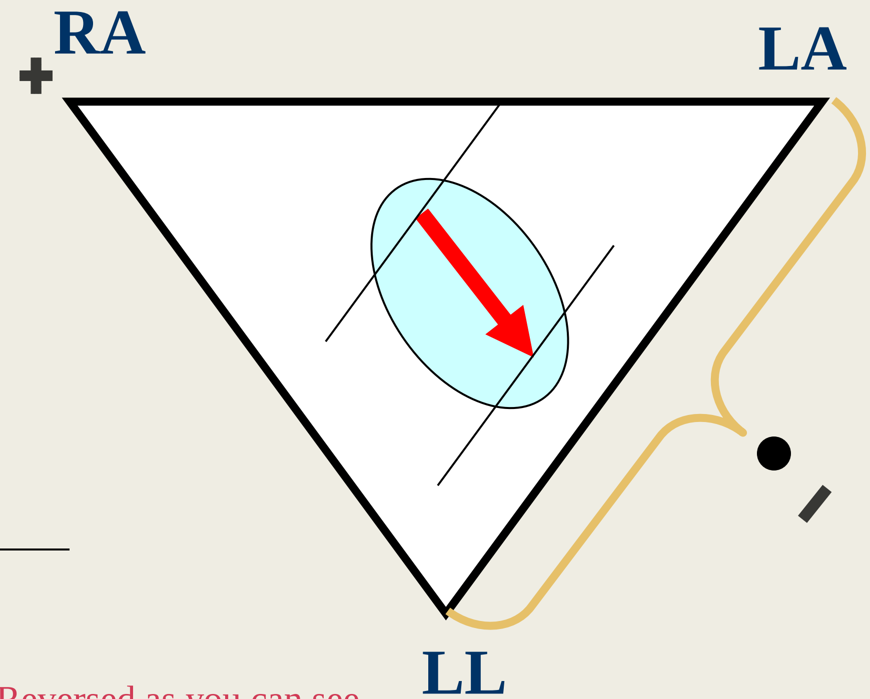
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

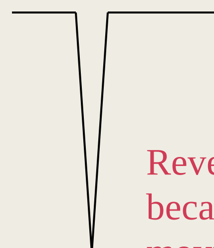
III = LA vs. LL (+)





3 Augmented Limb Leads:

aVR = (LA-LL) vs. RA(+)

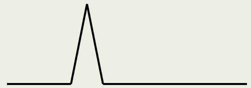


Reversed as you can see because the QRS vector is moving away from the + aVR electrode.

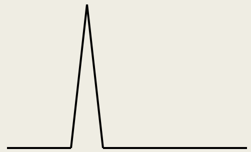
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

3 Bipolar Limb Leads:

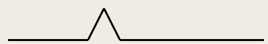
I = RA vs. LA (+)

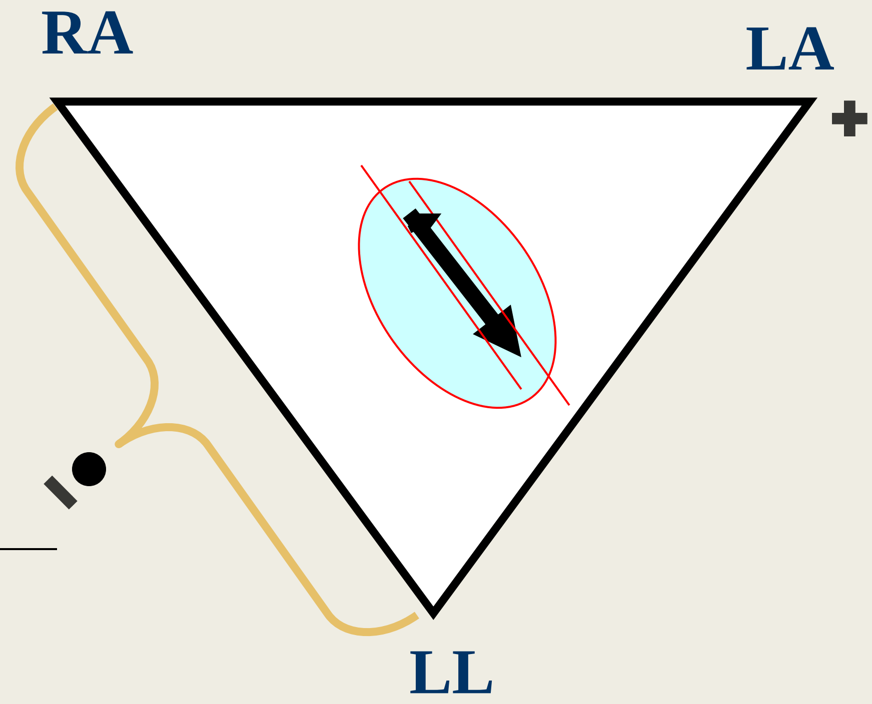


II = RA vs. LL (+)

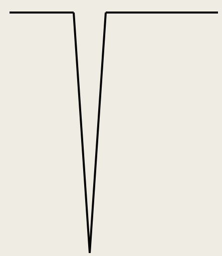


III = LA vs. LL (+)





3 Augmented Limb Leads:



aVR = (LA-LL) vs. RA(+)

aVL = (RA-LL) vs. LA(+)

Similar to lead III

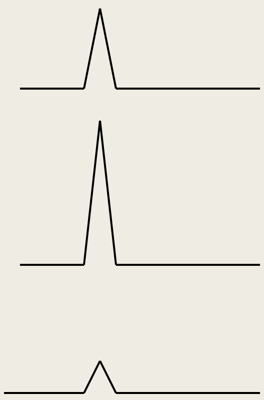
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

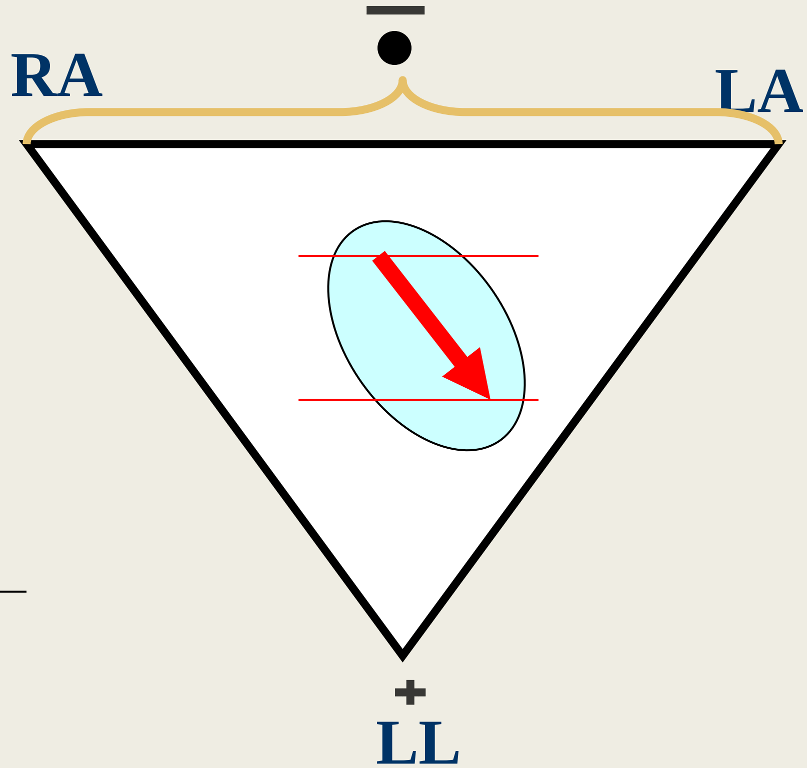
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

III = LA vs. LL (+)



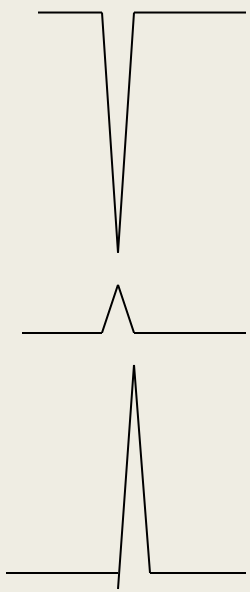


3 Augmented Limb Leads:

aVR = (LA-LL) vs. RA(+)

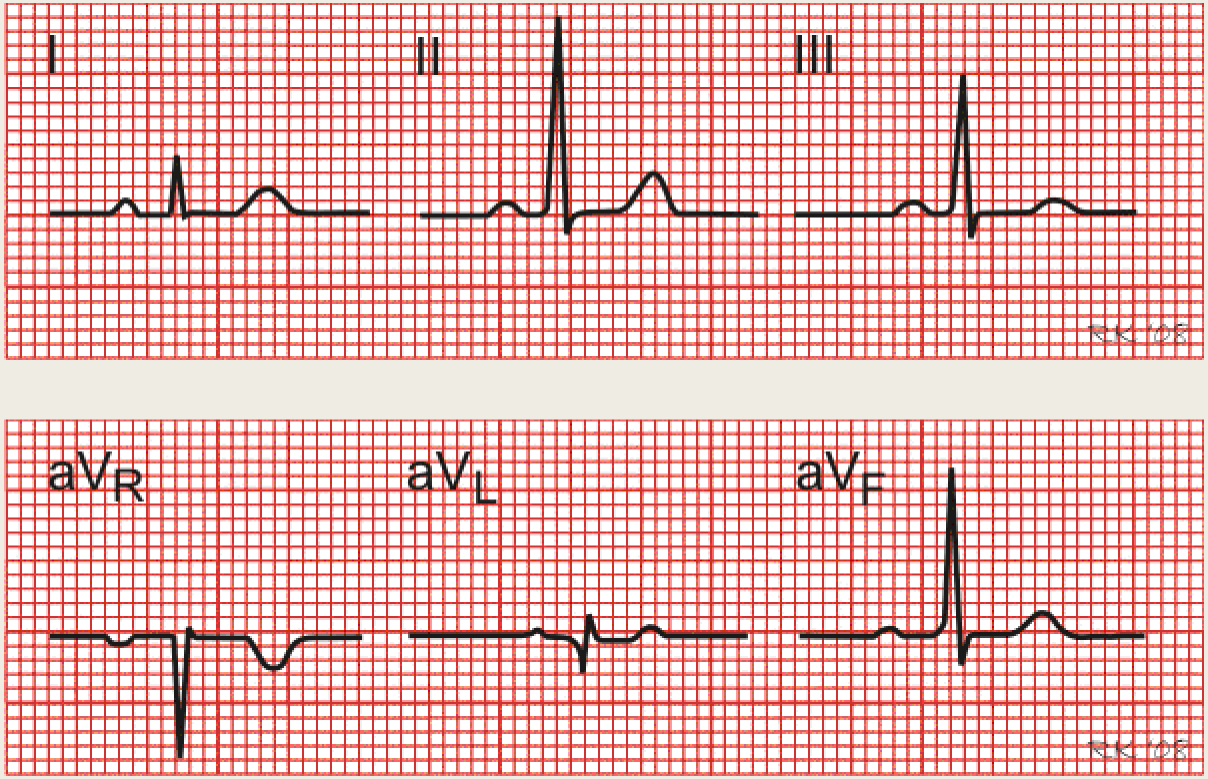
aVL = (RA-LL) vs. LA(+)

aVF = (RA-LA) vs. LL(+)



Bipolar and Unipolar Limb Leads

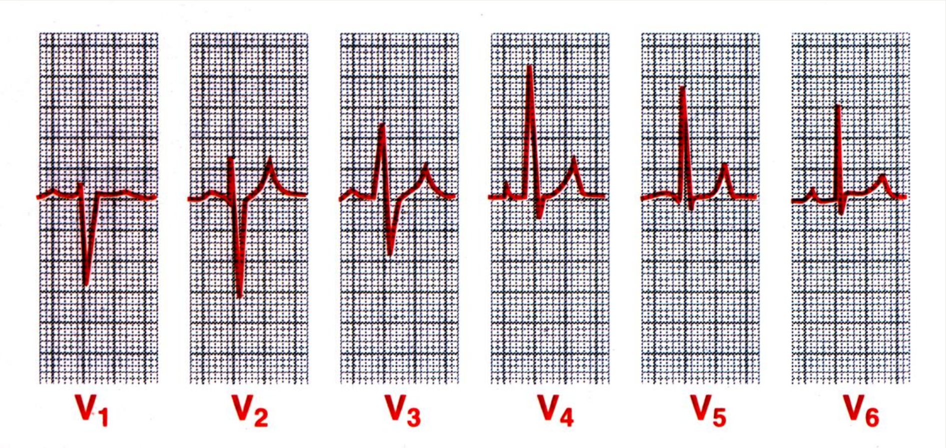
There is a mistake in the picture ,Lead I and Lead III are swapped.



Other EKG Leads

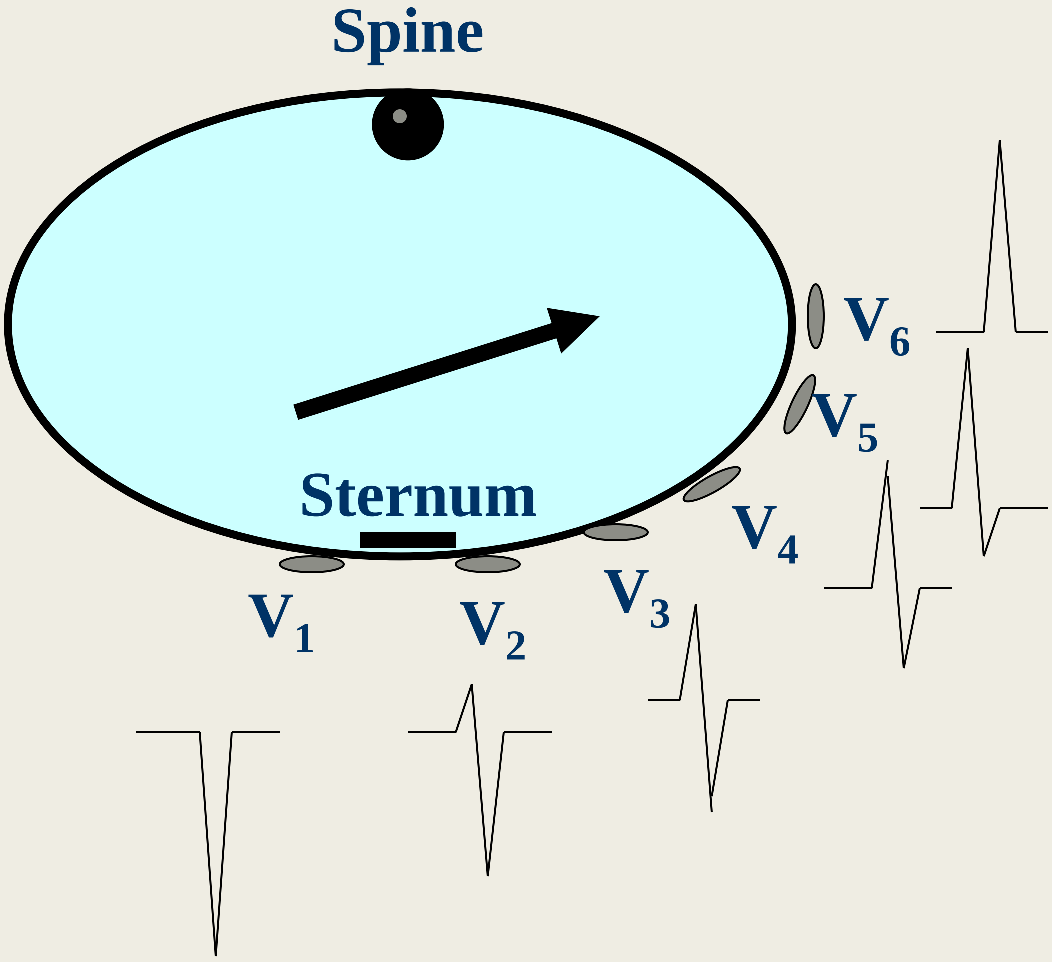
- Chest Leads (Precordial Leads) known as V_1-V_6 are very sensitive to electrical potential changes underneath the electrode.
- These leads are done by connecting the negative electrode to all three limbs on high resistances, so now this electrode is indifferent and it's potential is almost zero, the + electrode is placed on point V1-V6 on the chest, because the + electrode is directly above the heart and records high voltage we don't have the problem of augmentation here that was faced in nonaugmented unipolar limb leads.
- in leads V1 and V2, the QRS recordings of the normal heart are mainly negative because the chest electrode in these leads is closer to the base of the heart than to the apex, and the base of the heart is the where negativity begins.(again , like when we switch the electrodes,(remember the start of the lecture))

V4-V6 have mainly + QRS recordings because the + electrode is placed close to the apex of the heart where the positive charge mainly remains during depolarization of the ventricles.

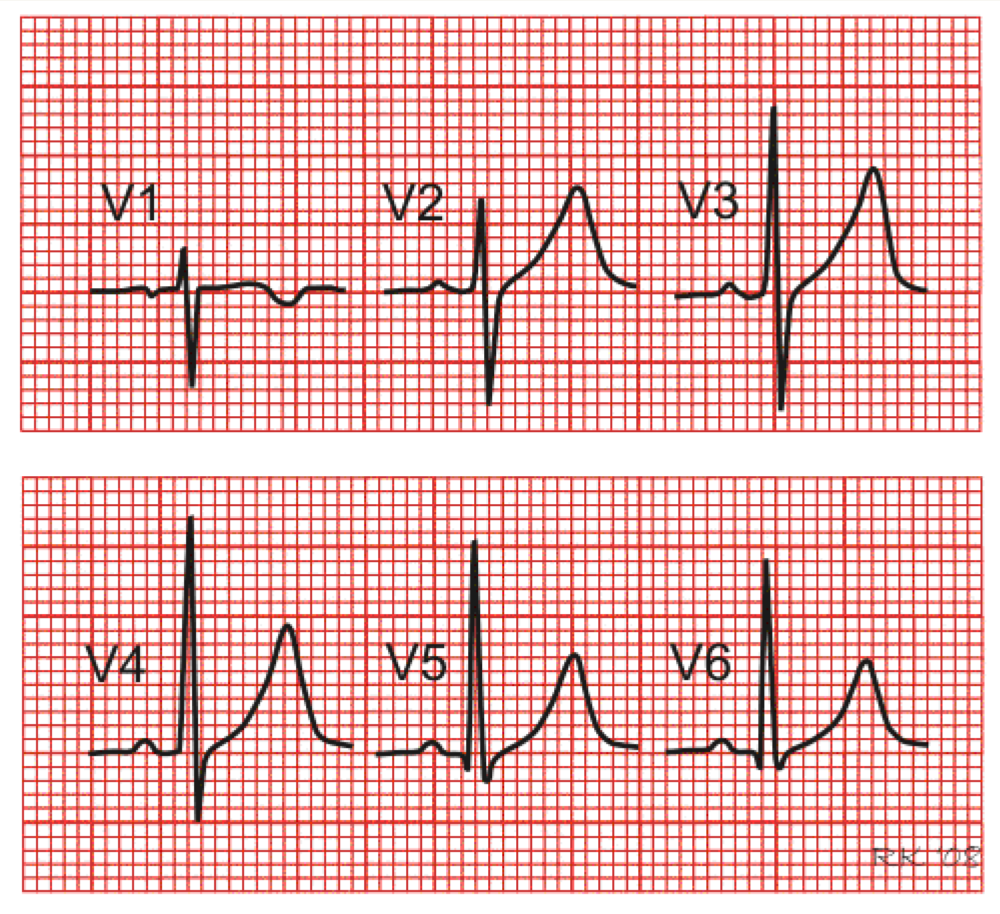


6 PRECORDIAL (CHEST) LEADS

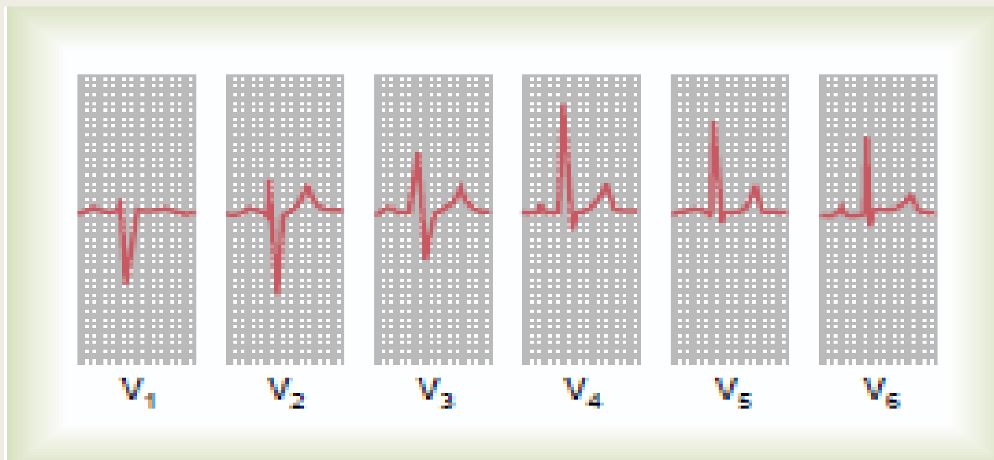
Precordial leads: Horizontal plane: antero-posteriorly or transverse plane .
The + electrode on the chest (not breast in females) and the - electrode (indifferent, null) is connected with the three LA, RA, LL each with high resistance 5000 Ω ohm each of them to give near (almost) zero voltage.

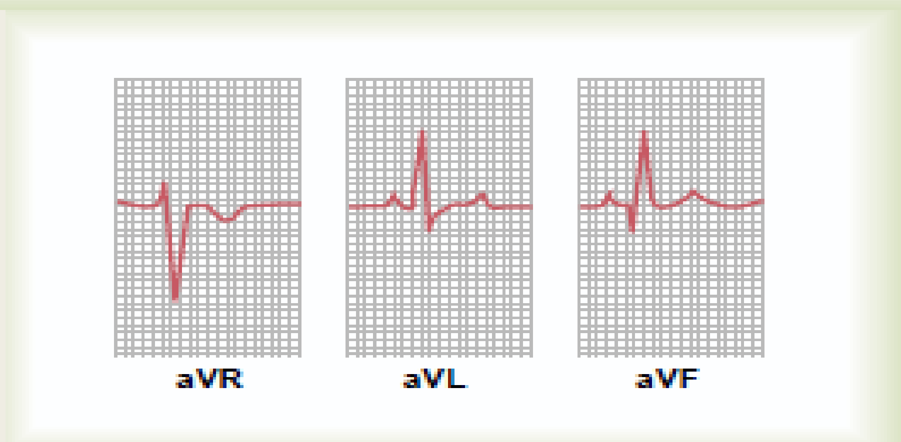


Chest leads (Unipolar)



Unipolar Leads






I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6

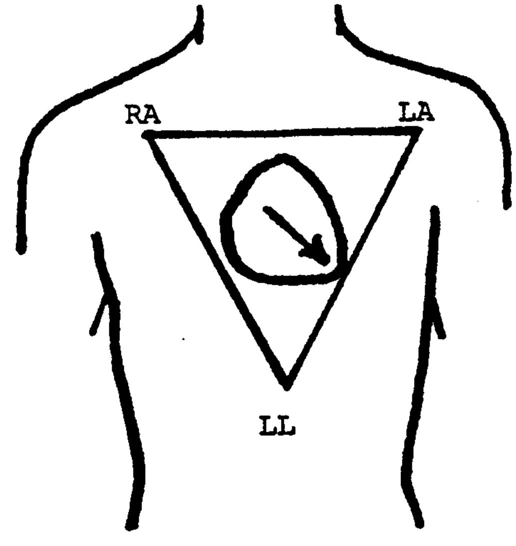
<u>ECG Recordings:</u> (QRS vector---leftward, inferiorly and anteriorly

3 Bipolar Limb Leads

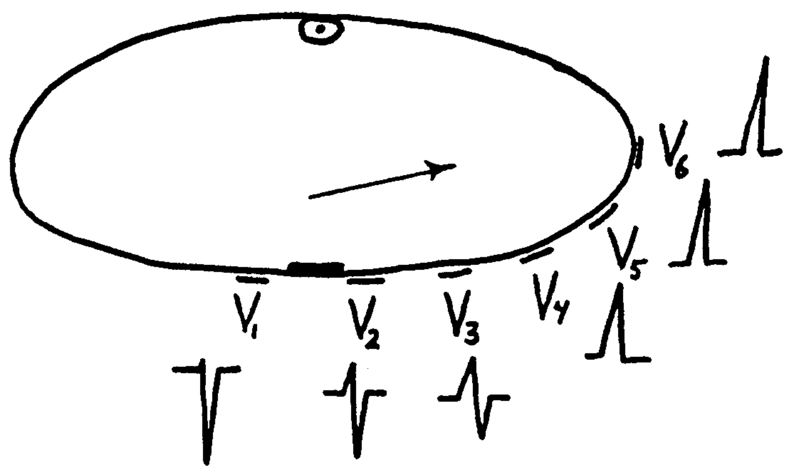
- I = RA vs. LA(+)
- II = RA vs. LL(+)
- III = LA vs. LL(+)

3 Augmented Limb Leads

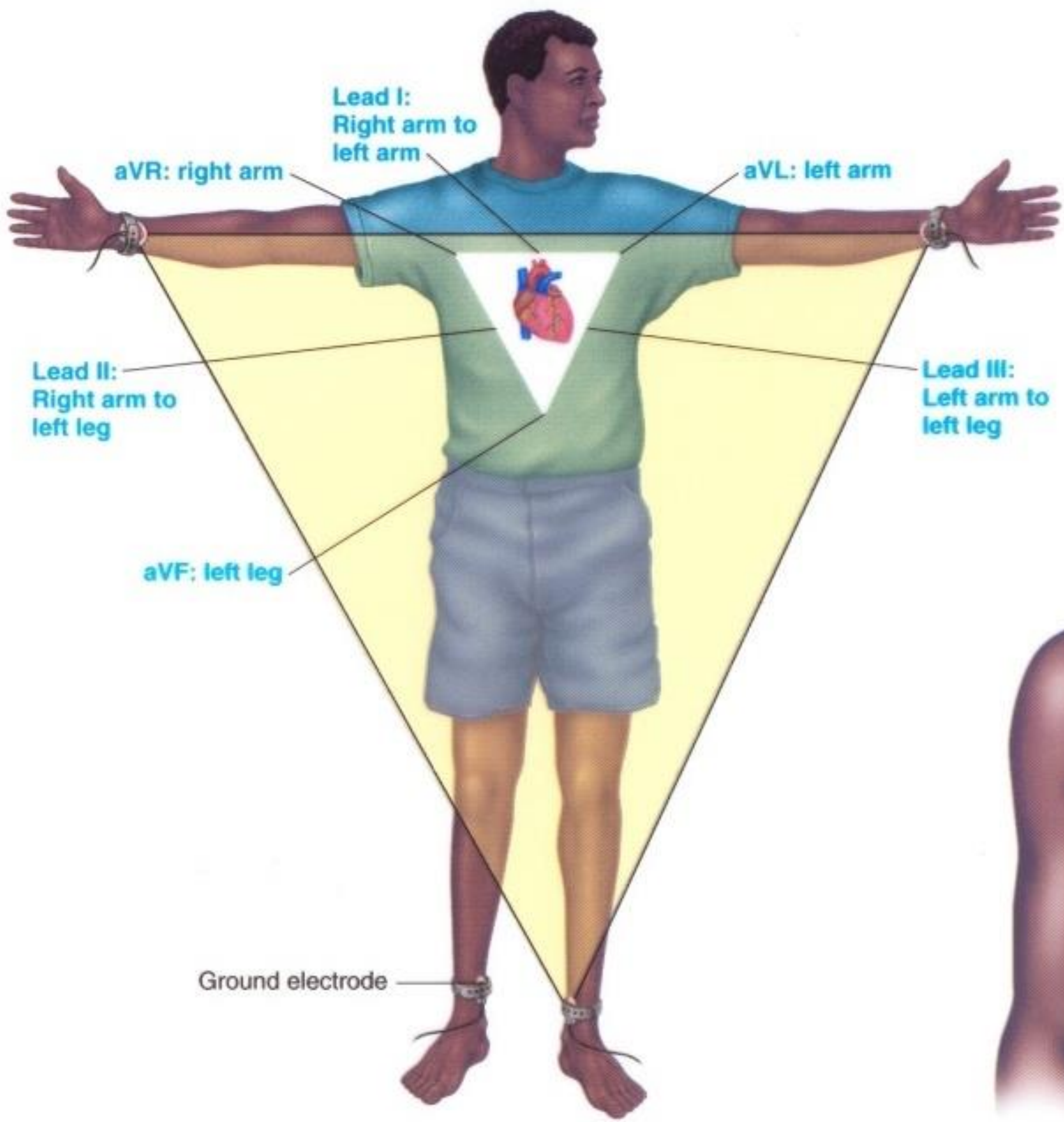
- aVR = (LA-LL) vs. RA(+)
- aVL = (RA-LL) vs. LA(+)
- aVF = (RA-LA) vs. LL(+)



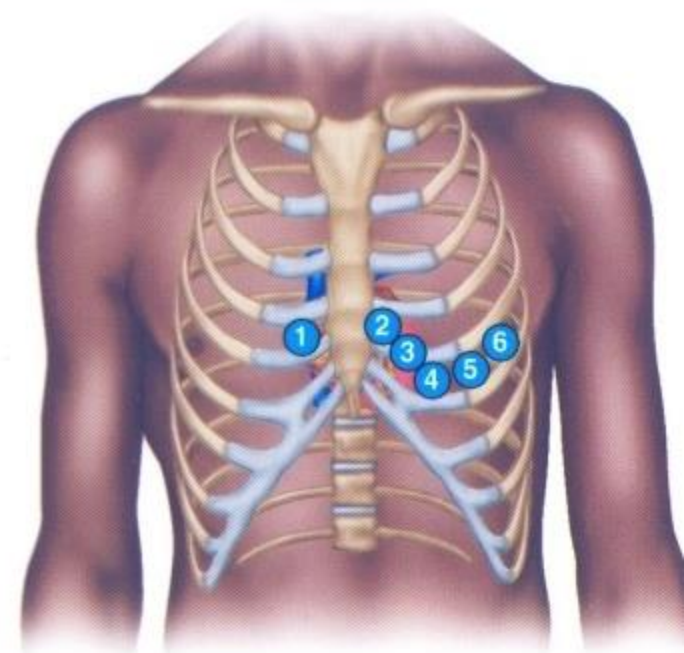
6 Precordial (Chest) Leads: Indifferent electrode (RA-LA-LL) vs. chest lead moved from position V_1 through position V_6.



Electrocardiogram leads



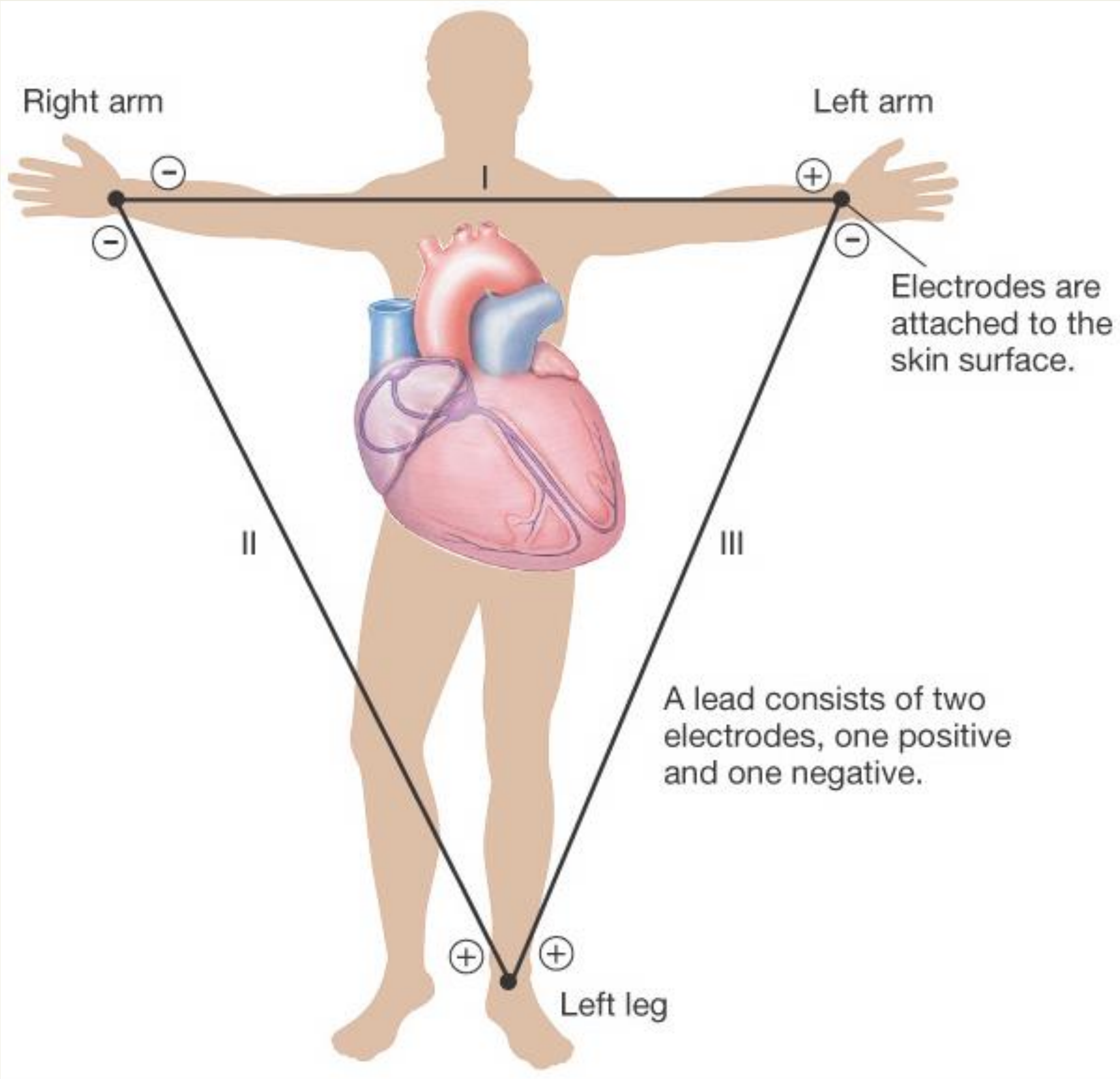
(a)



(b)

Electrocardiogram (ECG):Electrical Activity of the Heart

- Einthoven's triangle
- P-Wave – atria
- QRS- wave – ventricles
- T-wave – repolarization



اللهم يا رب العالمين، يا أرحم الراحمين، يا
رب السماوات والأرض، يا من بيده مقاليد
الأمور، نسألك أن تنصر أهل غزة على
أعدائهم الذين ظلموهم وضيقوا عليهم

Thank You

V2: fixed the mistake in the picture in slide 38 , the unipolar and bipolar limb leads.