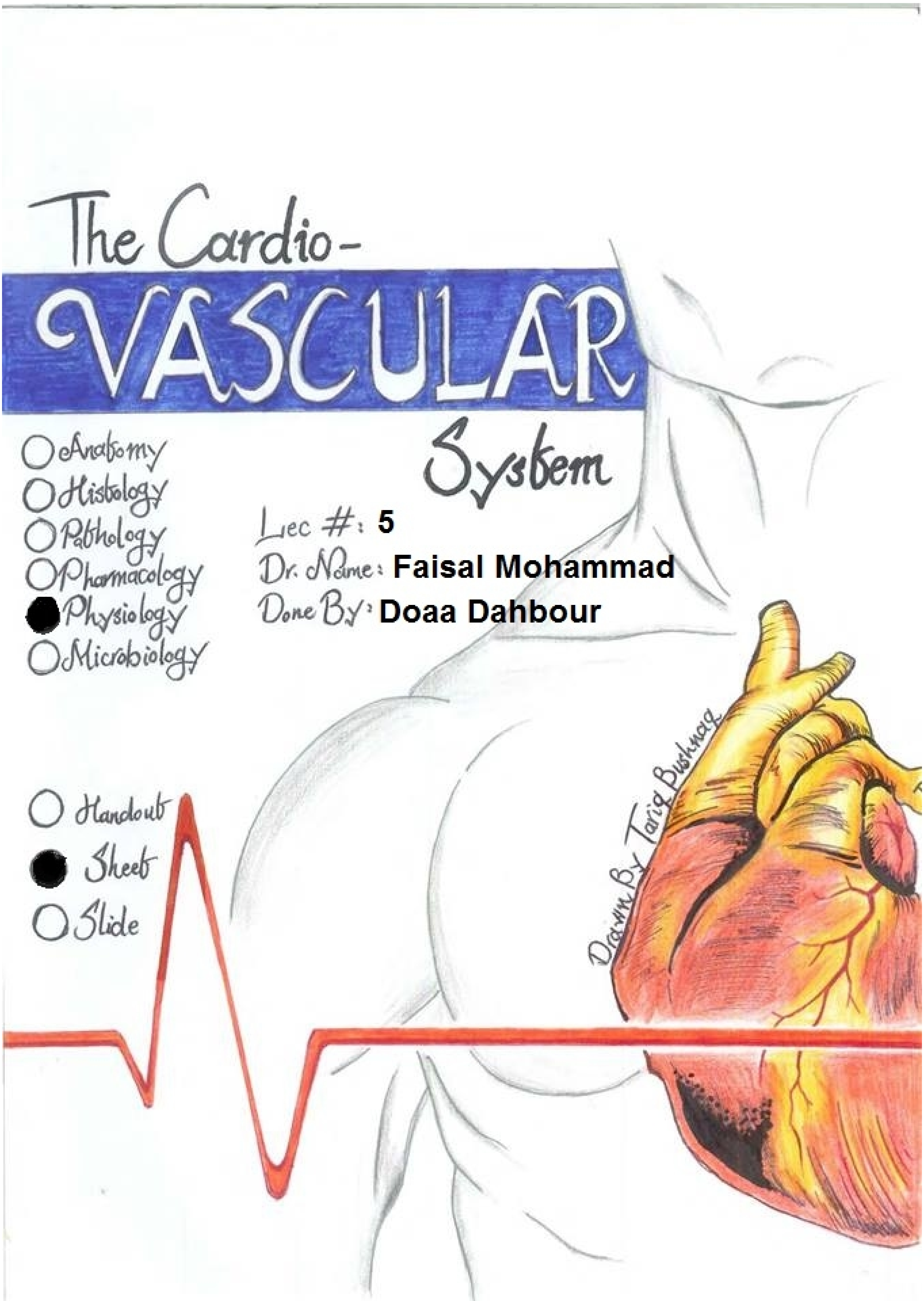

Lec #: 5

Dr. Name: Faisal Mohammad

Done By: Doaa Dahbour

(وَأَنْ لَيْسَ لِلْإِنْسَانِ إِلَّا مَا سَعَى * وَأَنَّ سَعْيَهُ سَوْفَ يُرَى)

ELECTROCARDIOGRAPHY

**** Notes :**

- Sheet references : Section two's recording , Guyton 12th edition (chapter 11) and doctor Faisal's slides .

- As the doctor explains , he comments on some slides . I'll put the contents of these slides in boxes with the extra notes added by the doctor (extra notes will be in a smaller font size or bold) . All the figures will be shown here also , so you need not refer to the slides .

- And lastly , this sheet is for physics lovers . Hope you'll find it an easy and enjoyable one . Ready ? Let's start ☺

- Recap :

In the previous lecture , we talked about the basic principle of electrocardiography . These are our objectives :

1) Describe the different "waves" in a normal electrocardiogram (P-QRS-T waves) and know what each one represents .
2) Recall the normal P-R and Q-T interval time of the QRS wave.
3) Distinguish the difference in depolarization and repolarization waves.
4) Recognize the voltage and time calibration of an electrocardiogram chart (Remember : The speed of the electrocardiograph is 25 mm/sec . Every small square is 1mm , so the speed of the electrocardiograph is 25 squares/sec . Time per one square = 1sec ÷ 25 squares = 0.04 sec/square . This is important to calculate cardiac cycle and heart rate .)

See next page →

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5) Point out the arrangement of electrodes in the bipolar limb leads, chest leads, and unipolar leads (Bipolar = we use two poles/electrodes of the galvanometer . We talked about limb leads in which the electrodes are connected to the limbs .)

** Lead 1 : between the right arm (-ve electrode) and the left arm (+ve electrode) .

** Lead 2 : between the right arm (-ve electrode) and the left foot (+ve electrode) .

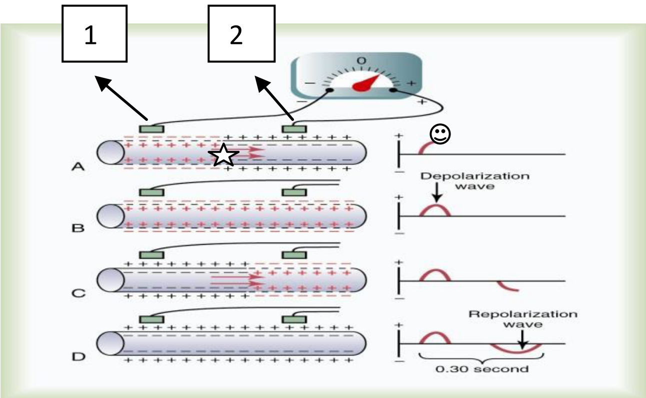
** Lead 3 : between the left arm (-ve electrode) and the left foot (+ve electrode) .

- The right arm is <u>always</u> connected to the –ve electrode and the left foot is <u>always</u> connected to the +ve electrode , why ? According to Einthoven (the scientist who invented the first electrocardiogram) , placing the electrodes this way gives us positive results after recording in all limb leads . If you reverse the electrodes , you'll get negative results . Scientists agreed on this internationally , so you can reverse the electrodes if you want but <u>you have to define them</u> before since you opposed the international agreement .

<u>المقصود :اصطُلح على ذلك عالميًا لتوحيد القياسات فقط و ليس بناءً على سبب علمي معيّن .</u>

The normal (standard) ECG is **12 lead ECG** (these 3 are only the <u>bipolar</u> limb leads , we also have 3 unipolar leads and 6 chest leads – discussed later) .

6) Describe Einthoven's law.



This figure shows us the principle of recording of depolarization and repolarization waves . Notice the two points numbered 1 & 2 , the stages (A-D) and the waves recorded beside each one . Let's start discussing these and add some notes that relate them to the heart .

Stage A : Depolarization starts from point 1 towards point 2 , a positive wave (upward deflected) is recorded . When the depolarization reaches the halfway (star in the figure) , the record has risen to a maximum positive value (the point that's marked by the smiley face ☺ on the curve) .

Stage B : Depolarization has extended over the entire fiber and the recording has returned to zero .

Stage C : Repolarization starts from point 1 towards point 2 (same direction as depolarization but the charges are opposite since we turned from depolarization to repolarization) thus the recorded wave will be in the opposite direction (negative , downward deflection) .

Stage D : Complete repolarization at the end , the potential returns to zero once again .

** Two IMPORTANT notes :

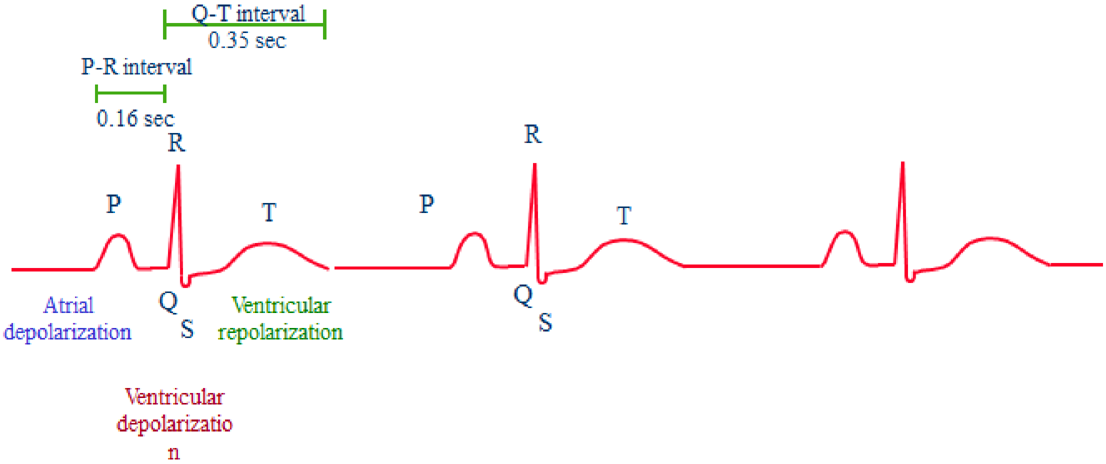
- When the ventricle is completely depolarized (at the end of stage B) or completely repolarized (at the end of stage D) , no potential difference is recorded between the 2 electrodes (galvanometer reading is ZERO) . In this case , **the isoelectric line** is recorded . When do complete depolarization and complete repolarization occur in the wall of the ventricle ?
  Complete depolarization : In plateau .
  Complete repolarization : In phase 4 .

- We noticed that depolarization and repolarization move in the same direction (from 1 to 2) and this resulted in two opposite waves (up and down) . This concept does NOT apply to the heart and that's why the two waves that represent ventricular depolarization (QRS) and repolarization(T) are BOTH upward deflected (+ve) – we'll discuss these waves in a minute . In the heart , depolarization starts from the endocardium towards the pericardium and from the base to the apex , whereas repolarization starts from the pericardium towards the endocardium and from the apex to the base (opposite to depolarization path) .

المقصود : باختصار (عكس العكس نفس) ، في القلب تسير الموجتان باتجاهين متعاكسين ، و الشحنات أيضًا متعاكسة مما يجعل اتجاه المنحنى بالنهاية نفسه لكلا الموجتين .
موجتان يعني :
إزالة الاستقطاب - Depolarization
AND
إعادة الاستقطاب - Repolarization

Simple enough ? Let's carry on ☺

- Normal ECG :



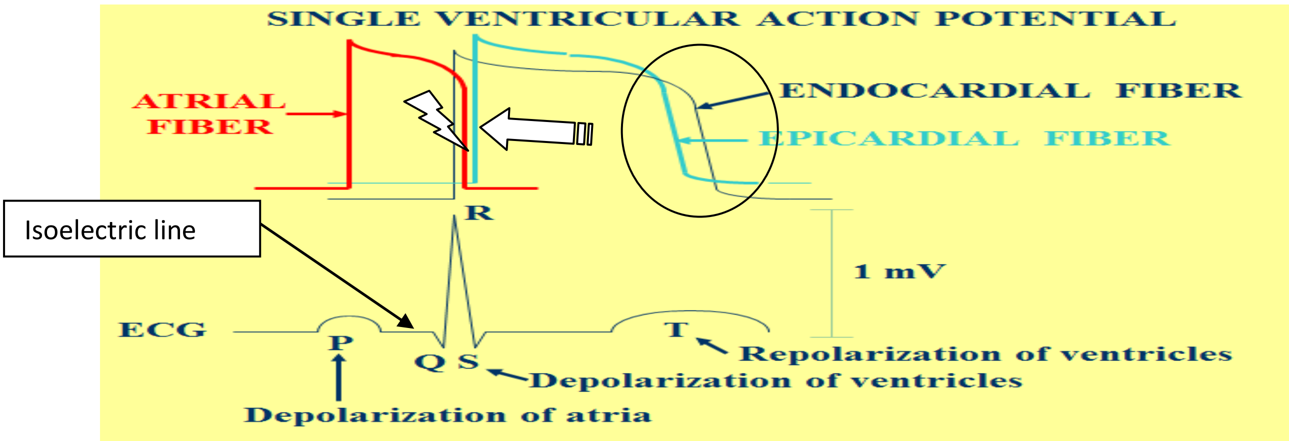
** P = Depolarization of the atria ,

QRS complex = Depolarization of the ventricles ,

T = Repolarization of the ventricles .

** Atrial repolarization is not shown , why ? Because atrial repolarization and ventricular depolarization occur at the same time . Ventricular depolarization masks atrial repolarization .

** T wave is a positive wave (upward deflected) because depolarization and repolarization don't start from the same point (go in opposite directions as we explained previously) .



Notice the depolarization of the atria (P wave) .

The isoelectric line between the end of P and the beginning of Q represents a state of complete depolarization .

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Notice the line indicated by ⚡ (red) ; this line represents atrial repolarization .

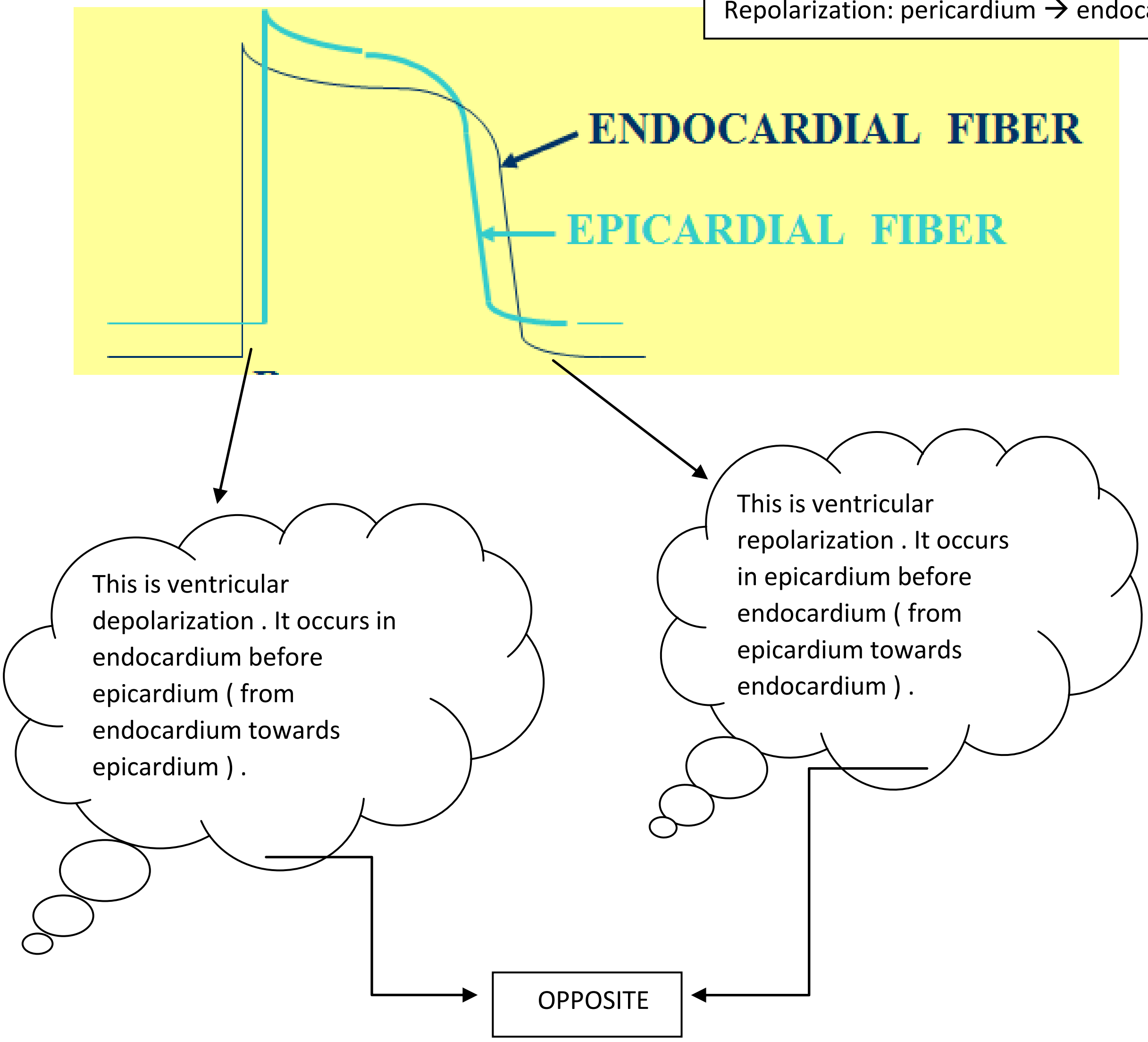
The line indicated by ⇦ (blue) represents ventricular depolarization .

You can conclude that these two events occur at the same time and that's why atrial repolarization is masked by ventricular depolarization (masked by QRS wave) thus not shown .

** Atrial repolarization might be seen if the ventricular depolarization is delayed and comes later than normal for any reason (AV block is an example) .

Now notice the circle . It represents repolarization of the ventricles . It's clear that repolarization in epicardium (pericardium) occurs BEFORE repolarization in the endocardium (thus repolarization starts from epicardium and moves toward the endocardium which is opposite to depolarization as you can see in the figure below , therefore repolarization wave is upward deflected) .

Depolarization: endocardium → pericardium
Repolarization: pericardium → endocardium



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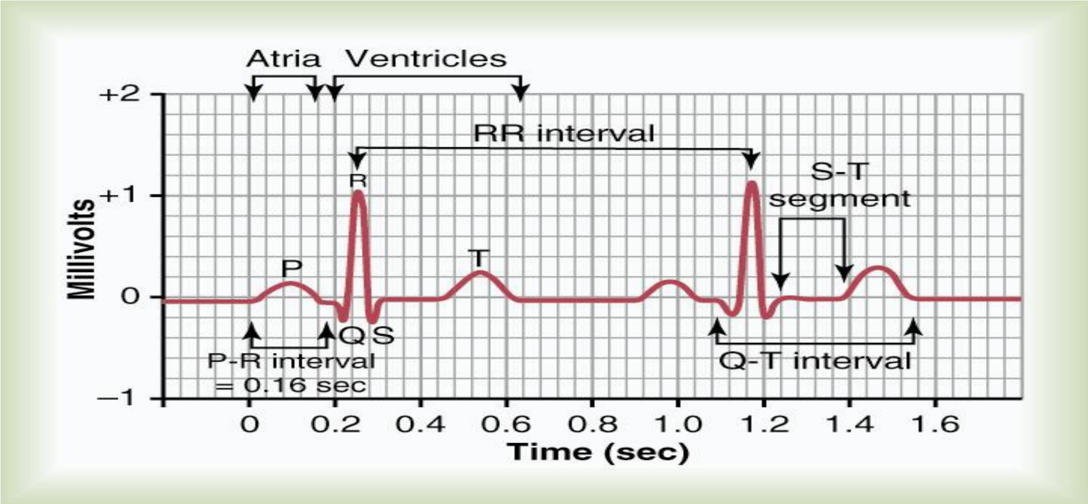
- **Standardized ECG :**



* * X-axis : Time (sec)

Y-axis : Voltage

* * 10 mm (10 squares) ⟶ 1 millivolt

25 mm ⟶ 1 sec (this is the speed of the electrocardiogram , so for each small square it's 0.04 sec) .

* * Cardiac cycle : The duration between a wave and the same wave that's next to it (ex. from R to R is a cardiac cycle , from P to P is a cardiac cycle, and so on .). **The cardiac cycle represents a complete heart beat ,** accordingly , The cardiac cycle is important to calculate the heart rate , before discussing this let's define the interval and the segment .

Interval : Must include a wave . Indeed , the best interval to be taken as a cardiac cycle is the R-R interval (R interval) , this interval includes waves such as the T wave and the P wave following the T .

Segment : Isoelectric line (No waves) . Notice the S-T segment in the figure above .

So when we say P-R interval ⟶ from the beginning of P to the beginning of Q or R (includes the P wave) , however ; when we say P-R segment ⟶ From the end of P to the beginning of Q (P wave is not included , no waves , an isoelectric line) .

* * **Heart rate :** Any cardiac cycle can be used to calculate the heart rate but the best one is the R-R interval . Let's illustrate this by an example :

If the **R-R** interval is 1 second (25 squares) , then the time for a cardiac cycle which represents one heart beat is 1 second , so :

One beat	1 second
X = ???	60 seconds(1 minute)

X = heart rate (how many beats you have in one minute), you can calculate it : 60÷1 = 60 beats / minute .

Similarly , if the **R-R** interval is 0.6 , the heart rate will be 60÷0.6 = 100 beat / min .

If the **R-R** interval is 0.8 then the heart rate equals 60÷0.8 = 75 beat / min.

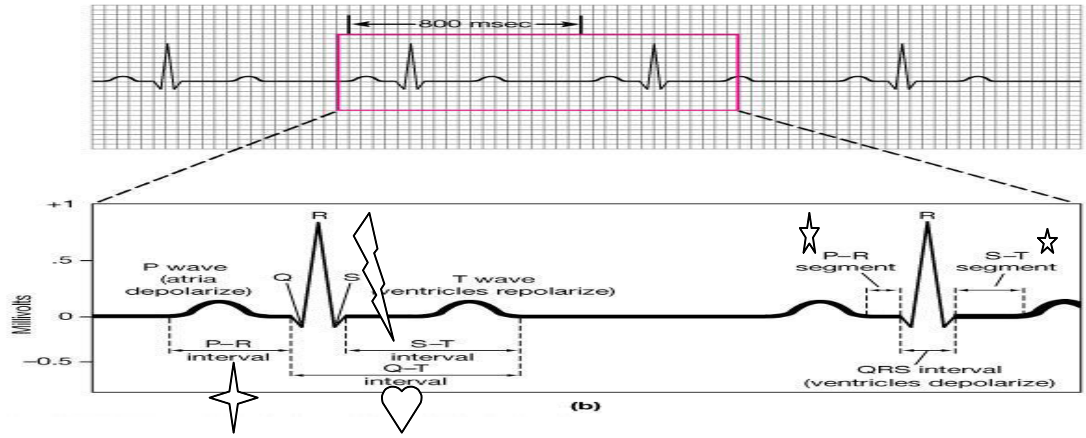
Notice the inverse relation between the cardiac cycle and the heart rate .

For teaching purposes , the value 0.8 is considered the normal for the cardiac cycle . However , in medicine , you always have ranges . It's not either black or white **! The normal range for the heart rate is between 60 and 100 beats / minute .**

Below 60 ⟶ bradycardia

Above 100 ⟶ tachycardia .

- The doctor read this slide , I marked the additional notes he said by **bold** .
- 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 **(Contraction starts after depolarization , we don't record the contraction as a wave , but it's a fact that the P wave is followed by atrial contraction i.e. atrial systole)**
- **QRS complex**: ventricular depolarization
  - Signals onset of ventricular contraction **(QRS wave is followed by ventricular systole) .**
- **T wave**: repolarization of ventricles **(T wave is followed by ventricular diastole)**
- **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) – **most of the time the Q is not shown so we measure the interval from beginning of P to the beginning of R and we call it PR interval . If Q is shown we measure the interval from P to Q and we call it PQ interval .**
- **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 .



PR interval (or PQ interval) represents conduction of the waves when we have atrial depolarization from the SA node till reaching the ventricles (remember that QRS represents ventricular depolarization) , so PR interval includes the AV delay (atrioventricular conduction) . **It is maximally 0.2 sec** (5 small squares since each square = 0.04 sec) . **If the PR interval exceeds 0.2 seconds , then there's heart block (AV damage , delayed conduction) .** Since the conduction to the ventricles is delayed (i.e. ventricular depolarization is delayed), atrial repolarization can be seen in this case .

* * Degrees of heart block :

1st degree : PR > 0.2 but each P is followed by QRS (number of P waves = number of QRS waves) – incomplete heart block . here you might see the repolarization of atria because ventricular depolarization is late here.

2nd degree : PR > 0.2 but not every P is followed by QRS , some P waves are followed by QRS whereas other P waves are not . **Still there's a pattern!** For example , there might be 2 P waves then 1 QRS or 3 P then 1 QRS and so on ... In our example , we call this heart block(2 ; 1 heart block) , 2 is the number of P waves and 1 is the number of QRS waves (mostly P waves are more than QRS waves) – secondary heart block (incomplete heart block)

3rd degree : This is the complete heart block . There is **no association between P and QRS ,** they're completely dissociated thus no pattern is noticed . In this case , the AV node fails to do its job in conduction completely thus the ventricles will contract by the rate of Purkinje fibers which is 15-40 beats / min .

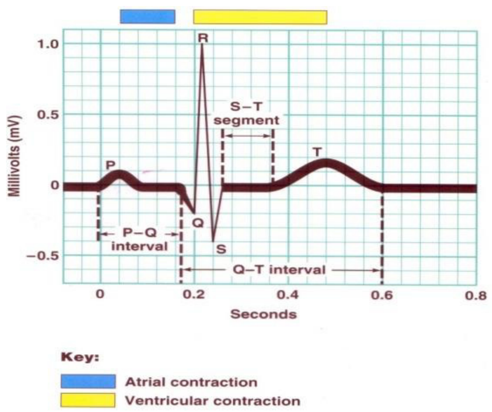
QT interval ♡**:** Between the beginning of Q till the end of T . It denotes ventricular systole . Normal value is around 0.35 – 0.45 seconds (Ordinary value according to Guyton is about 0.35 seconds) .

ST interval includes a T wave since it is an INTERVAL .

** The doctor reminds you that the normal cardiac cycle lasts for 0.8 seconds (800 milliseconds) .

ST and PR segments ☆ : include no waves as we said (no intervals), they represent isoelectric lines (state of complete depolarization or repolarization) . ST segment is very important for cardiologists ; we don't care about its length . What we are concerned with is its arrangement relative to the standard isoelectric line . The ST segment might be higher that the isoelectric line (elevated) or lower than it (depressed) . Elevated or depressed ST segment is the first indication of ischemia (Remember : ischemia is decreased blood flow , infarction is cessation (complete stop) of blood flow , ischemia might progress to infarction) . So both elevated and depressed ST segments indicate ischemia and if these are noticed when doing ECG , the patient must be put under observation in the hospital .

A student asked if this applies to the PR segment , the doctor said yes but the PR segment is usually small and may not be shown in this case so we mainly depend on the level of ST segment to detect ischemia (ST segment is much more important than the PR segment) .

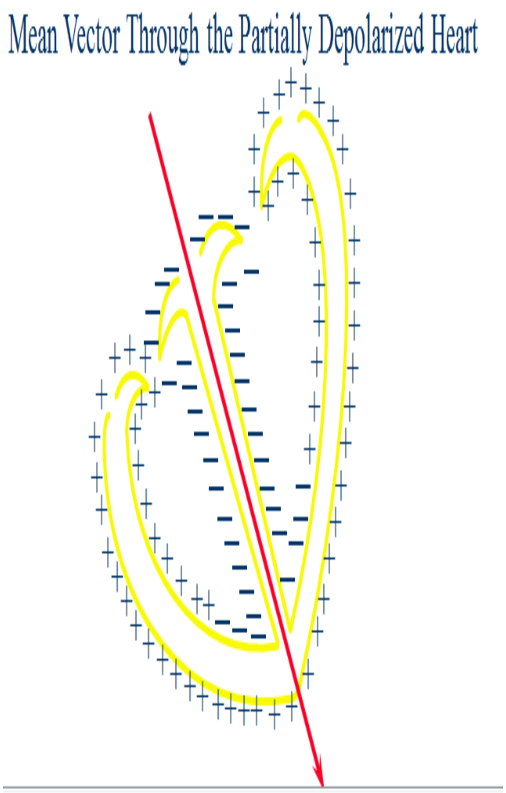


Notice the key that tells you when each action occurs . Remember that we don't record systole and diastole of atria and ventricles as waves . However , we explained their relations with the recorded P-QRS-T curve .

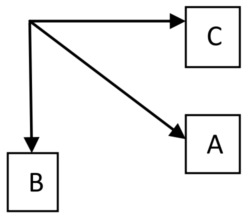
- Flow of electrical current :

Depolarization starts in the interventricular septum . Think of the heart as a 3D structure (it has a volume through which electricity is conducted) . when depolarization starts in the interventricular septum, electrical current that represents spread of depolarization goes from the depolarized area to the still polarized areas , so we have too many currents spreading everywhere toward the still polarized areas at the same time . Each current represents a vector متجه , since we have too many currents (vectors) , a resultant vector with one direction can be calculated المحصلة . Indeed , as depolarization spreads through the heart , the electrical currents change continuously and accordingly , the net (resultant) vector changes as well because it's the sum of them . جمع متجهي للقيمة والاتجاه

At the end , after complete depolarization , there'll be no vectors moving to the still polarized areas because all areas became depolarized , and thus the resultant vector equals zero .



The arrow indicates the resultant vector at a certain point . You can figure out its contribution on the X axis , Y axis and Z axis by analysis



A is the resultant vector .

B is the contribution of the resultant vector on the Y axis .

C is the contribution of the resultant vector on the X axis .

Similarly you can find its contribution on the Z axis .

- Ventricular depolarization starts at the ventricular septum 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 from 1/100 second and flows toward the outer walls of the ventricles near the base (S wave).

  (The last area that gets depolarized is the posterior aspect of the left ventricle . At the very end stage of depolarization , the whole heart is depolarized and this area is the only one that's still polarized i.e. the resultant vector will be directed towards it (the posterior aspect of the left ventricle). Depolarization of this area results in recoding of the S wave) .

Now let's revise the ECG concepts from the slides .

Additional notes are in bold .

** 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 **(During T wave the ventricle is mostly in systole . AFTER the T wave is recorded , ventricular diastole occurs) .**

** 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.

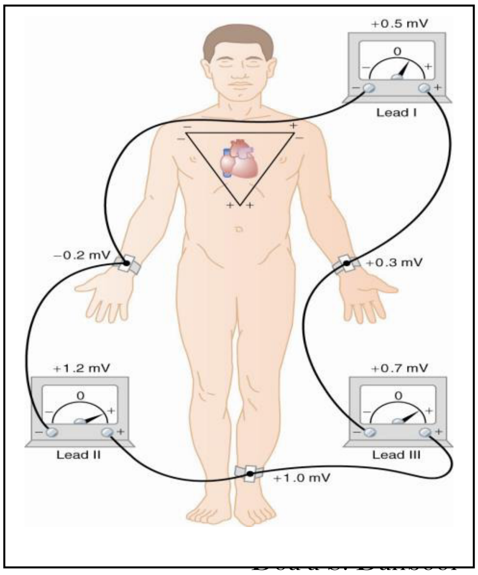
** The P-Q or P-R interval on the electrocardiogram has a normal value of 0.16 seconds **(maximum = 0.2 sec)** and is the duration of time between the beginning of the P wave and the beginning of the QRS wave; this represents the time between the beginning of atrial contraction and the beginning of ventricular contraction.

** 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 (systole) .

** The heart rate can be determined with the reciprocal of the time interval between each heartbeat **(The shorter the cardiac cycle , the faster the heart rate . The longer the cardiac cycle , the slower the heart rate – inverse relation) .**

- **Bipolar limb leads :**

  We talked about them at the beginning of the sheet . Bipolar means the ECG is recorded from two electrodes in the body . This figure show you the 3 bipolar limb leads .



** Lead 1 : between the right arm (-ve electrode) and the left arm (+ve electrode) .

** Lead 2 : between the right arm (-ve electrode) and the left foot (+ve electrode) .

** Lead 3 : between the left arm (-ve electrode) and the left foot (+ve electrode) .

The right arm is <u>always</u> connected to the –ve electrode and the left foot is <u>always</u> connected to the +ve electrode ,

** Note : The right foot is for earthing (discharge) – لتفريغ الشحنة

Einthoven had an idea! The idea was making a triangle from these 3 limb leads . Triangle heads are the right arm , the left arm and the left foot .The heart is placed in the center of this triangle since it is the source of electricity . The triangle is an equilateral triangle مثلث متساوي الأضلاع و الزوايا Each of its three angles equals 60 degrees . This triangle was called Einthoven's triangle .

**** Einthoven's law :**

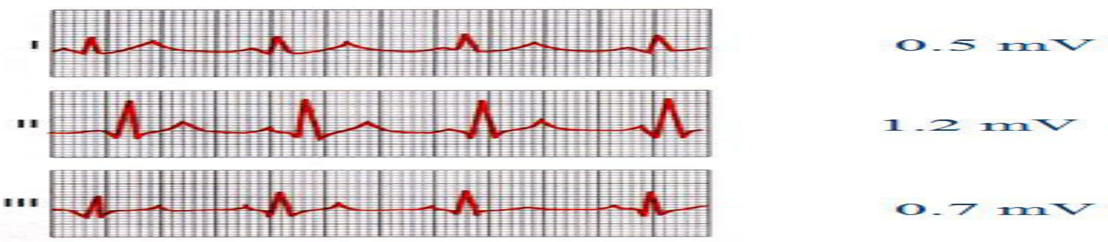
The algebraic summation of QRS waves for lead 1 and lead 3 equals the sum of QRS waves in lead 2 .

L II= L I + L III

(Algebraic summation means that signs must be taken into consideration ; remember: upward deflection is positive, downward deflection is negative , in a typical QRS wave : Q is –ve , R is +ve , S is –ve) .

Look at the figure above :

QRS of lead 1 = 0.5 , QRS of lead 3 = 0.7 , the sum of these equals QRS of lead 2 (0.5 +0.7 = 1.2) .



<u>** Physical base of Einthoven's law :</u>

Do you remember Kirchhoff's second law ? Well , Kirchhoff's second law states that *The directed sum of the electrical potential differences (voltage) around any closed network is zero* .

(RA= right arm , LA = left arm , LL = left leg (foot)) .

The directions of the arrows (in figure 1) indicate the flow of electricity in a closed loop . According to Kirchhoff's second law , the sum of electrical potentials equals zero so we don't get a value for the resultant vector . Einthoven solved this problem by switching the electrodes in lead 2 (see figure 2) thus you can get a value for the resultant vector .

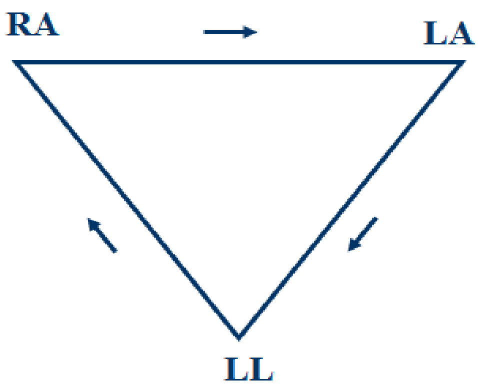


Figure 1 : According to Kirchhoff :

Lead 1 + lead 2 + lead 3 = zero .

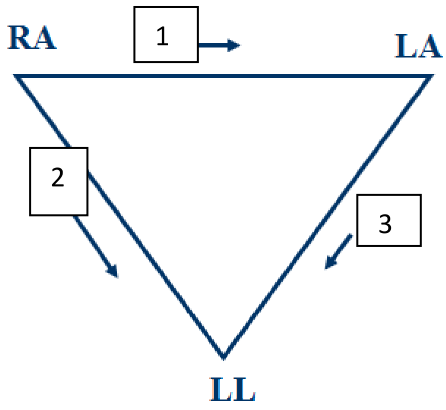


Figure 2

So ..

Arrow 1 indicates mean vector of lead 1 (from – RA to + LA) .

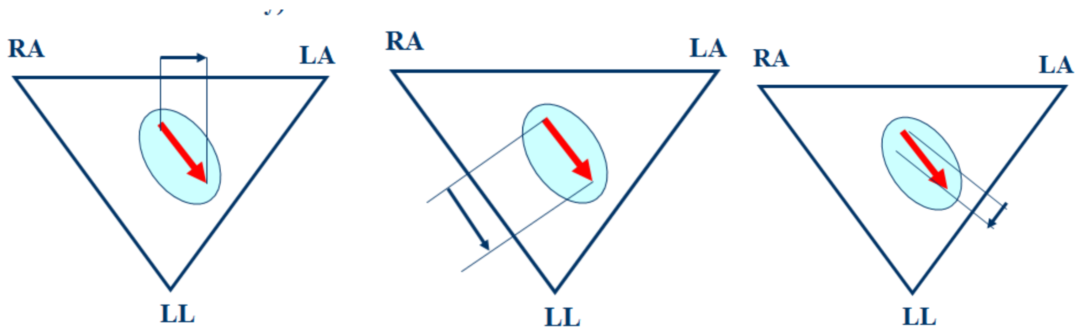
Arrow 2 indicates mean vector of lead 2 (from – RA to + LL) .

Arrow 3 indicates mean vector of lead 3 (from - LA to + LL) .

Now the rule is : Lead 1 + lead 3 + (- lead 2) = zero i.e. lead 1 + lead 3 = lead 2 (Einthoven's law ☺)

(- lead 2 because Einthoven reversed lead 2) .

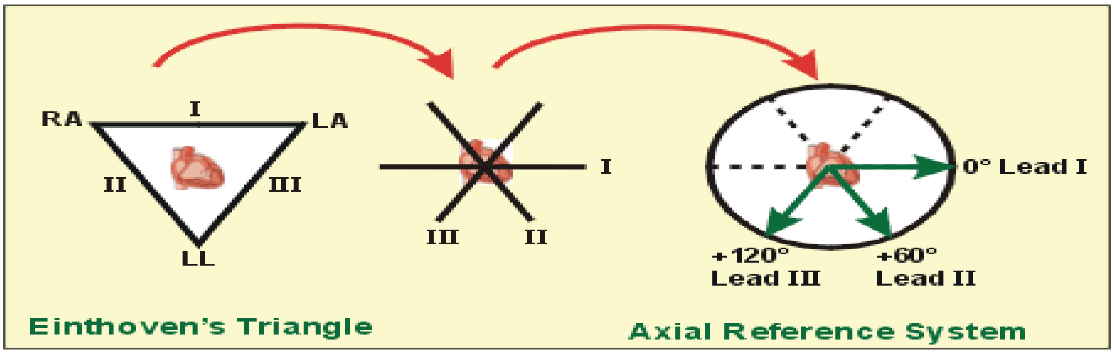
Now the doctor shows three figures that represent the analysis of the resultant vector :



What I want you to understand is that the vector inside the triangle is the resultant QRS vector . **The resultant QRS vector is directed anteriorly , inferiorly and to the left .** Remember that the heart is a 3D structure .

As shown in the 3 previous figures , we can analyze the resultant vector to figure out the contribution of each lead by extending a column from the head of the resultant vector and another column from the tail of it .

Keep in mind that this is an equilateral triangle and each angle equals 60 degrees .



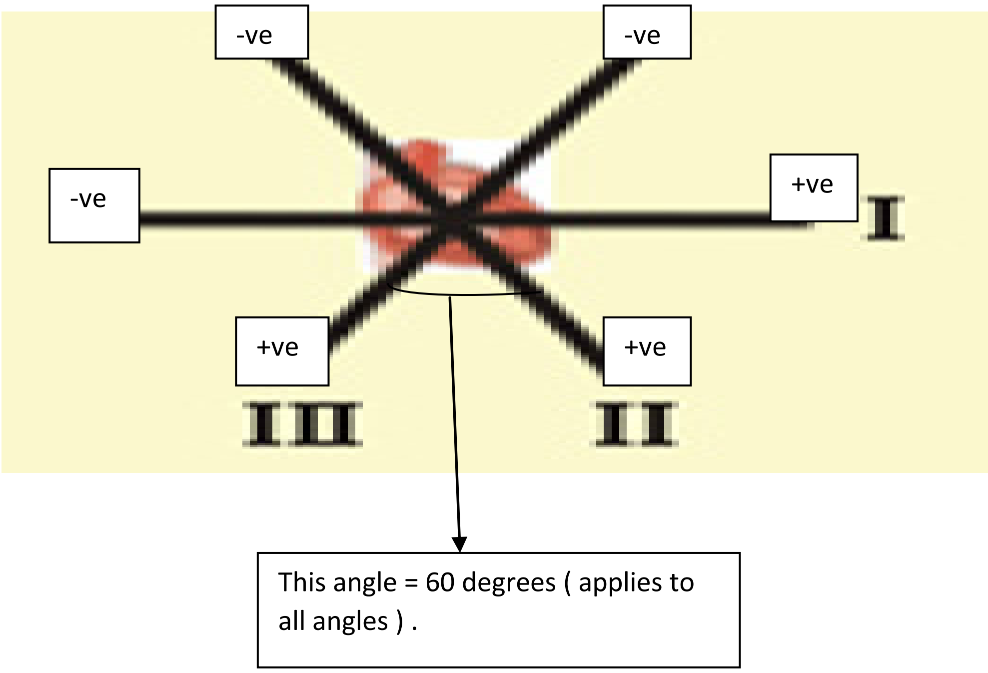
Why did Einthoven choose an equilateral triangle ?

You can draw a circle that touches the heads of an equilateral triangle and the center of this circle will be the center of the triangle. The center in our case represents the heart .

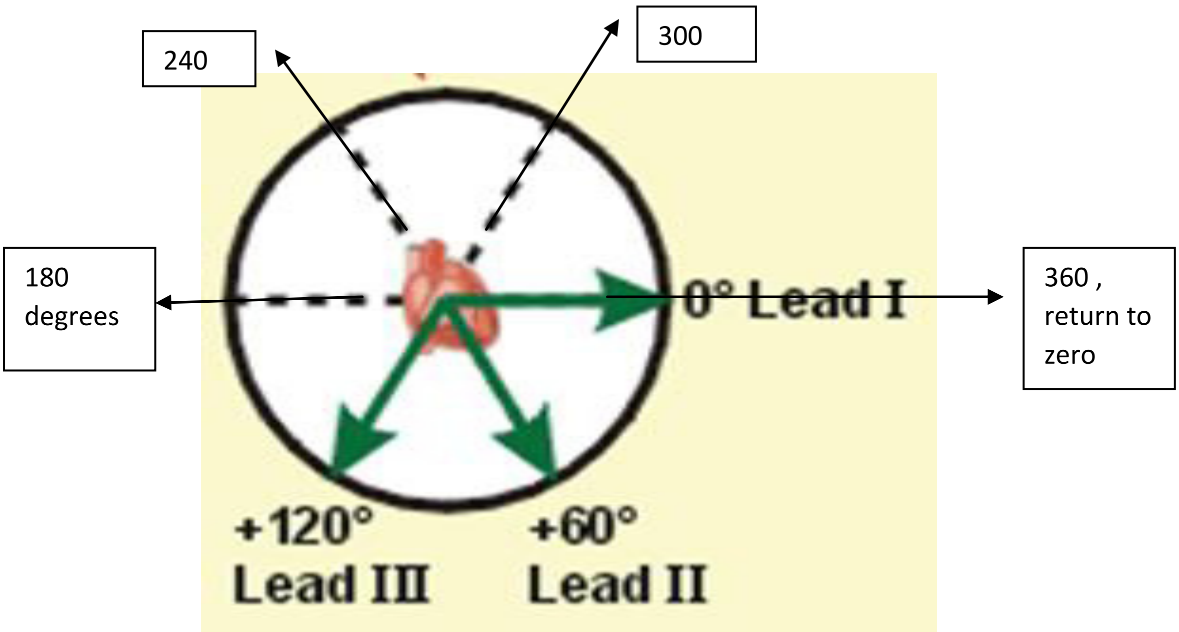
المثلث متساوي الأضلاع له خصائص مميزة و لهذا تم اختياره ، مثلًا لو أنزلنا عمود من المركز على كل ضلع فإنّ هذا العمود سوف ينصّف الضلع .

As you can see , we are dealing with a <u>triangular axis</u> .

In the triangle above , you can transform the vectors that represent the three limb leads so they meet at the center of the triangle (Transformation of the vectors means we move them in a parallel way , we don't change the direction neither the value, the vector passes through the center) . The angle between each of them is still 60 degrees . This is what we get :



Now , a circle can be drawn around the three vectors after transformation . Lead 1 is the point we start measuring the angels from (zero value in the figure below is related to lead 1) .



What's the benefit we get from doing all this ?

After doing the ECG , the mean axis of the QRS must be between (zero degree and +110 degree (normal range)) . This is the normal range , if it is beyond 110 degrees or less than zero then it's abnormal .

This will be clarified in the next lecture inshallah .

And finally the lecture is done !!!

Feel free to give me your feedback ☺

Good luck ☺

Dedication :
إلى الصديقة و الأخت براءة السيوف ♡

Written by : Doa'a Dahboor .