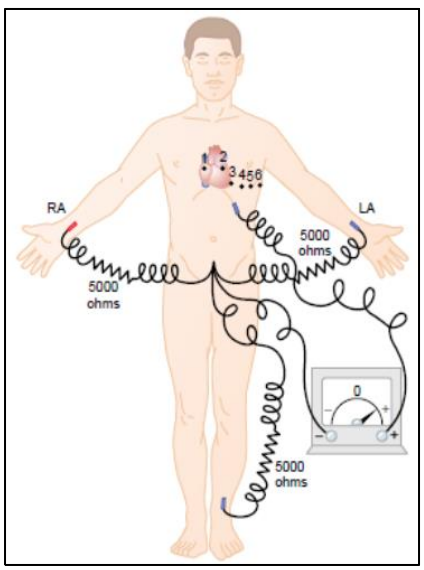
# Electrocardiography

In the previous lecture, we were talking about the unipolar limb leads. We said that to make the unipolar lead, you have to make the **negative** electrode as **zero** electrode, this is done by connecting all the 3 limbs to very high resistances (around 5000 Ω).Then the positive electrode is placed on the left arm (**LA/VL**), right arm (**RA/VR**), or left foot (**LL/VF**) & this is what we call sometimes **recording electrode**, or the **exploring electrode**.

The center of einthoven's triangle is the heart {the origin}, which is zero. We mentioned previously that **Wilson** found that the recording is amplified (is higher) if we remove the high resistance from the limb we are recording from.

For example, if we want to record from the **right arm** we remove the high resistance from the **right arm,** or if we want to record from the **left arm** we remove the high resistance from the **left arm**, and same goes for the left foot.

We do amplification to the electrode we want to measure by removing the high resistance from the limb we want to record from; that's why we call it **a**VL (when reading is from the left arm), **a**VR (right arm), **a**VF (left foot)(**A**ugmented).




The figure above shows the **Unipolar Leads** which are the Chest leads {V1-V6} + don't forget that the Augmented Limb Leads {aVR, aVF, aVL} are also unipolar. In unipolar, you connected the **high** resistance to the **negative** pole of the galvanometer, and the **positive** electrode is the **recording** electrode.

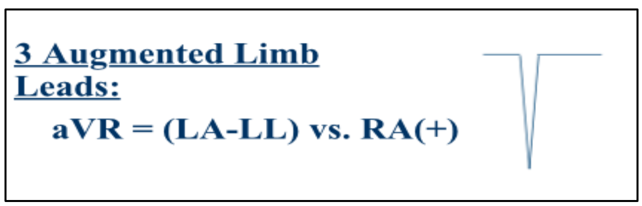
**The mean electrical axis (vector) of QRS**

Look to the aVR (in the situation of unipolar), the right arm is connected to the positive electrode, the other two limbs are connected to the negative electrode through high resistances; then the current is going to flow in the opposite direction, i.e. away from the right arm, that's why it's recording negative.

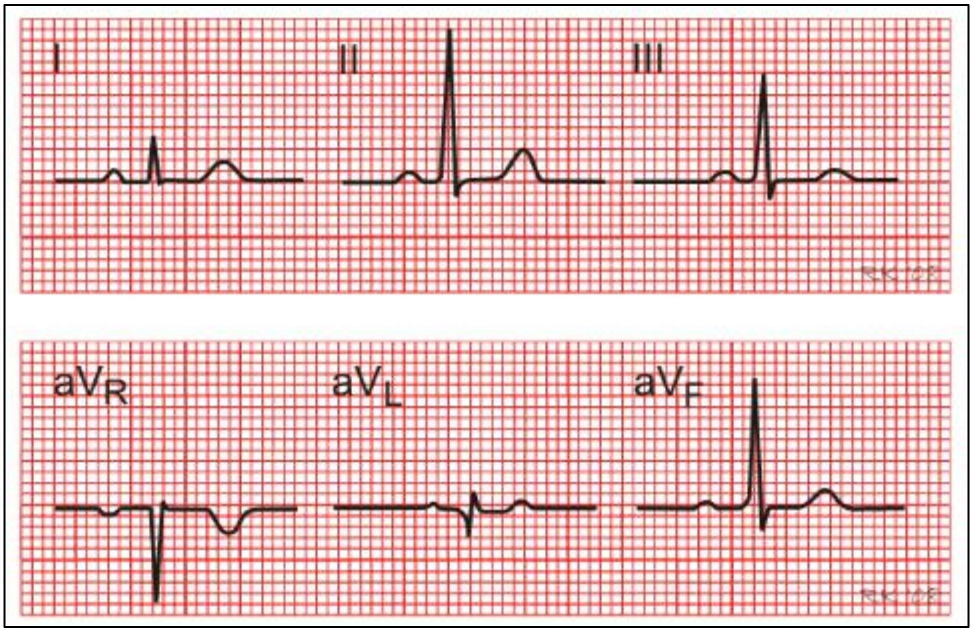
On the other hand, the other two {aVL & aVF} are going to record positive current; because they are in the direction of the QRS vector, but here, aVL will be positive but less than the positivity recorded from aVF; since aVF is situated more in the direction of QRS vector, i.e. closer to the direction of QRS vector.

However, if you want to record a positive QRS from the aVR lead, you can reverse the electrodes & in that case, QRS recorded from aVL & aVF will be negative {not conventional}.

**Remember**: the current flows from the **negative** to the **positive** direction.




These are the **unipolar** & **bipolar** limb leads:




These papers are divided into squares (we will see them in the lab).

The **X-Axis** is the **Time**

The **Y-Axis** is the **Voltage**

If the machine speed is 25mm/sec; and each small square has a width of 1 mm & a length of 1 mm,

( $\frac{1}{25}$ ) ->each small square resembles 0.04 seconds.

Remember that the mean vector of **QRS is never changed**

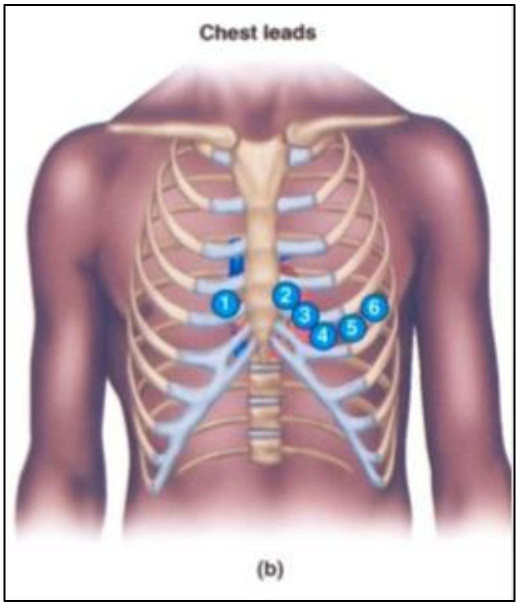
It is always pointing **leftward**, **inferiorly** and **anteriorly**.

Therefore we can analyze it into two planes:

1. The **horizontal** (transverse) plane (**chest leads**).
2. The **frontal** plane (**limb leads**).

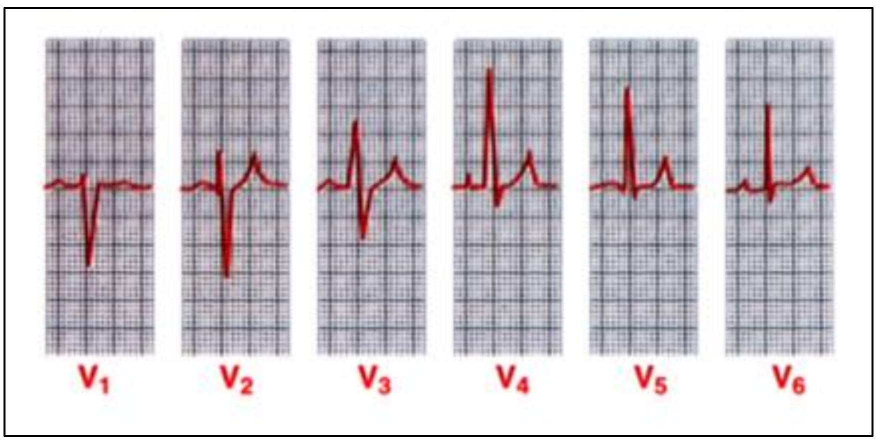
## 1. The Horizontal {transverse) Plane

The Precordial (Chest) Leads (Unipolar)




{V1-V6} **or** {C1-C6}; depends on the type of machine used.

This is the unipolar chest leads recorded in the horizontal (transverse) plain




In lead **V1** and **V2** QRS recording of normal heart rate are mainly **negative**; because the chest electrode in these lead is nearer to the base of the heart than the apex –more to the right-. Conversely, the QRS in lead **V3**, **V4**, **V5**and **V6** are mainly **positive** because the chest electrode is nearer to the apex of the heart –more to the left-.

**Placement of electrodes**

You determine any point using two planes **vertical** and **horizontal** {surface anatomy}.

<table>
<tr><th>Position according to sternum</th><th colspan="3"></th><th>Recording (-/+)</th></tr>
<tr><td rowspan="2">On the right side</td><td rowspan="2">V1</td><td>Vertical</td><td>Parasternal line</td><td rowspan="2">Negative</td></tr>
<tr><td>Horizontal</td><td>$4^{th}$ Intercostal space</td></tr>
<tr><td rowspan="9">On the left side</td><td rowspan="2">V2</td><td>Vertical</td><td>Parasternal line</td><td rowspan="2">Negative</td></tr>
<tr><td>Horizontal</td><td>$4^{th}$ Intercostal space</td></tr>
<tr><td>V3</td><td colspan="2">Between leads V2 and V4</td><td>Positive</td></tr>
<tr><td rowspan="2">V4</td><td>Vertical</td><td>Mid-Clavicular line</td><td rowspan="2">Positive</td></tr>
<tr><td>Horizontal</td><td>$5^{th}$ Intercostal Space</td></tr>
<tr><td rowspan="2">V5</td><td>Vertical</td><td>Anterior Axillary line</td><td rowspan="2">Positive</td></tr>
<tr><td>Horizontal</td><td>$5^{th}$ Intercostal Space</td></tr>
<tr><td rowspan="2">V6</td><td>Vertical</td><td>Mid-Axillary line</td><td rowspan="2">Positive</td></tr>
<tr><td>Horizontal</td><td>$5^{th}$ Intercostal Space</td></tr>
</table>

Why do we need it?

- To take ideas about the electrical activity of the heart in all directions in order to find the abnormality {from the readings}

These are placed on the anterior surface of the heart, if you suspect that there is something abnormal in the posterior aspect of the heart; then you should place esophageal leads in the esophagus behind the heart directly, instead of placing it on the back, because many organs are going to intervene between the heart and the recording electrode {affects the accuracy of the readings}.

*Chest Leads (Precordial Leads) known as V1-V6 are very sensitive to electrical potential changes underneath the electrode*

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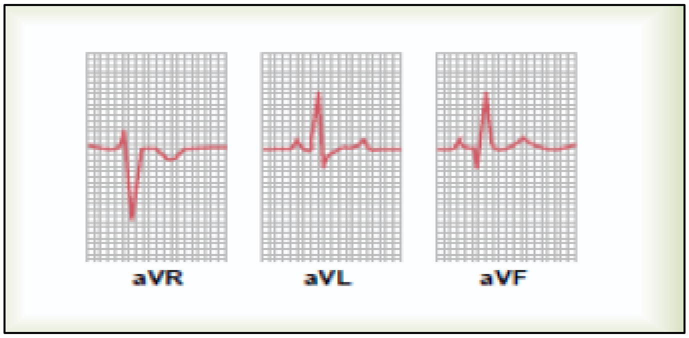
### 2. On The Frontal Plane

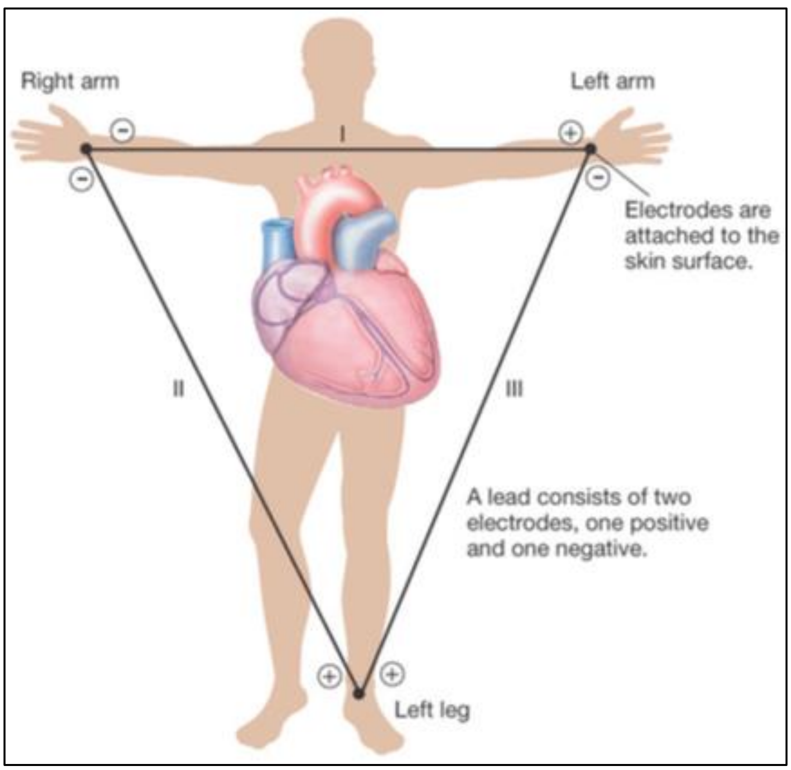
Bipolar: {Lead I, II, III} + Unipolar: {aVL, aVR, aVF}.

Unipolar limb leads




**Rule of the thumb:**

- **Right arm is always negative**
- **Left foot is always positive**



## Electrocardiography (ECG)


To record an ECG, **12 Galvanometers** are used to read recordings form **12 Leads** at the same time.

Notice that doing an ECG is a very easy thing, while reading it is the hardest thing to do.

**Reminder**

**P wave**: Atrial Depolarization.
**QRS Complex**: Ventricular Depolarization.
**T wave**: Ventricular Repolarization.

# Electrocardiography (ECG)

Our objective for this lecture

- Recognize the normal ECG tracing
- Calculate the heart rate

This is not the main objective; we don't calculate the ECG to know the heart rate! There are easier methods.

- Determine the rhythm

| Regular | Irregular | |
|---|---|---|
| | Regular irregularity | Irregular irregularity |
| If we measure one cardiac cycle and we trans-locate this to the 2nd and third cardiac cycle; and they are same. | Caused by 2nd degree AV block "Since it has regular pattern" | Caused by 3rd degree AV block |

- Calculate the length of intervals and determine the segments deflections
- Draw the Hexagonal axis of the ECG
- Find the mean electrical axis of QRS (Ventricular depolarization)
- Recognize the normal ECG tracing: We will do it in the lab!

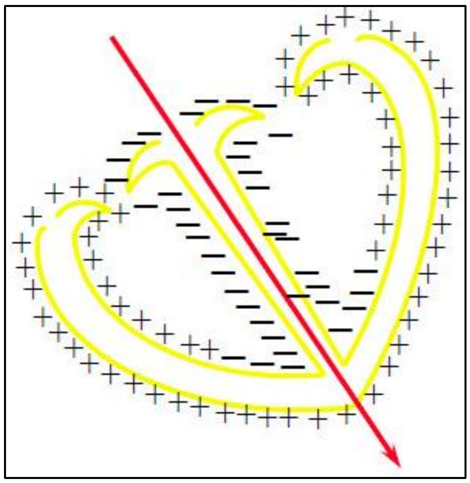
**Determine the mean electrical axis of QRS (Ventricular depolarization):**

The current goes from the **depolarized area (-)** to the still **polarized area (+)**. There is a vector with the arrowhead pointing in the **positive** direction –direction of the vector-. The length of the vector is the value of the vector, which is proportional to the voltage potential. The generated potential at any instance can be represented by an instantaneous mean vector.

Now depolarization starts from septum, at this instant there are too many vectors going everywhere. You have to think of the heart as a three dimensional structure, which means the current is going everywhere. And they have a resultant, which is called the **instantaneous resultant**. المحصلة اللحظية

If you want to see its value (value of instantaneous resultant) on lead I, II or III, you should analyze it on the plane of lead I, II or III. Every moment there is another resultant, other values. In the end, when there is complete depolarization; the resultant is **zero** {no more depolarization}.

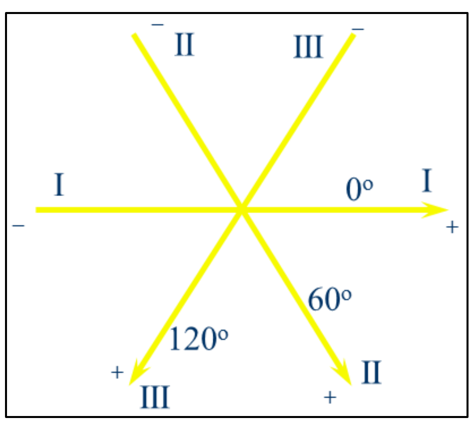
The mean for all instantaneous resultants is the **mean electrical axis of QRS**, which is supposed to be 60°(59°according to Guyton), but we say from -30° to +110° to include all normal situations. Clinically, we have a range (from 0° to +90°); because it is easier to deal with than (-30° to 110°).



This is a mean instantaneous vector when depolarization starts in the septum, it has a direction and value, and we analyze it.

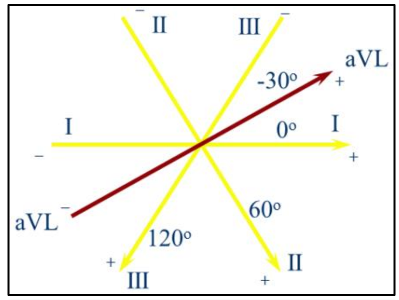
**Drawing the Hexagonal axes of the ECG**

We draw the trigonal axes of the 3 bipolar limb leads that we talked about previously

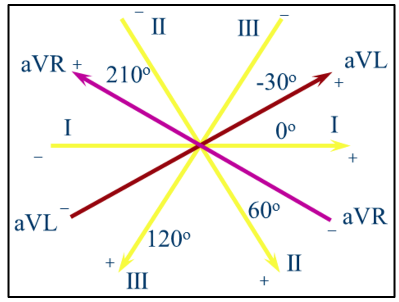



But this time we also include the **Unipolar Augmented Limb Leads: aVR, aVL and aVF.**

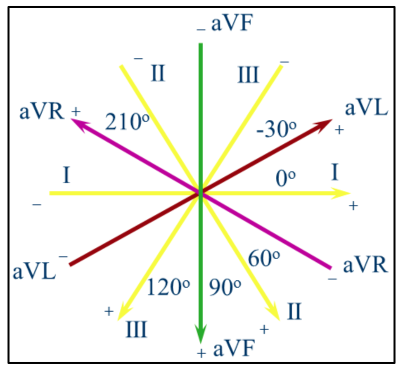
aVL: From the heart to the left arm intersects (bisects) the angle between lead I and III
0-30= -30°




aVR: From the heart to the right arm
Bisects the angle Between lead I and II
180+30= 210° or -150°




aVF: From the heart to the left foot
Bisects the angle Between lead II and III
60+30= 90°




**How to draw the Mean Electrical Axis**

Since all limb leads' vectors are on the same plane & there are angles between them, we can use any **two** of them to draw the mean electrical axis.

For example: let's use **lead I** and **aVF lead** –the easiest-.

Please note that the following 6 steps of drawing the mean electrical axis apply on any 2 leads you choose not only lead 1 & aVF lead.

**Note:** In order to draw & then calculate the mean vector of QRS –mean electrical axis-, we need at least two leads. The easiest thing to take is aVF with lead I, because they are perpendicular to each other.

1. You look at the ECG, and algebraically summate the QRS complex on lead I. For example it turned out to be 5.
   Note: algebraic summation means that you take the value along with its sign (+ve above the zero baseline & - below it).
2. You count 5 mm, and draw a perpendicular line on lead I {this –the line extending 5 mm from the center towards the positive axis of lead I-is the value of the mean electrical axis of QRS on lead I}.
3. Now do algebraic summation of QRS on aVF.
4. Draw another perpendicular line on aVF; they will intersect at one point.
5. Draw a line between the center and the point of intersection.
6. And you measure the angle Ø between **lead I** and the **new line**:

$$\emptyset = \tan^{-1}\frac{\text{aVF}}{\text{Lead I}}$$

> **Note**: We consider the value of the angle from this equation directly to be the angle of the mean electrical axis if we were dealing with **lead I** and **aVF, however,** we can use the equation if we're using any other 2 perpendicular leads' axes, with paying attention to use the right values instead of aVF & lead I, but we'll have to do some editing on the resulting value of the angle like subtraction or summation & after that, we'll get the angle of the mean electrical axis. Otherwise, you have to deal with trigonometry {more complicated}.

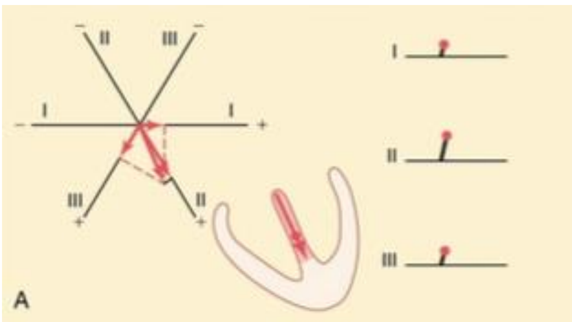
This is the mean vector of QRS. If it happens to be between 0° (lead I) and 90° (aVF), this is normal situation. It is clinically known by looking directly to lead I and aVF on the ECG. If they are both positive, then the angle is definitely going to be between 0-90° {no need to draw}.

| **Left Axis Deviation of QRS**<br>**If aVF is (-ve) and lead I is (+ve)**<br>**Angle Between 0° and -90°** | **Right Axis Deviation of QRS**<br>**If aVF is (+ve) and lead I is (-ve)**<br>**Angle Between 90° and 180°** |
|---|---|
| The heart is deviated to the left<br><br>**Causes**<br><br>• Normally, **short** and **obese** people. The heart is pushed to the left, so here; it's not a pathologic condition.<br><br>That's why we increase the range up to -30°.<br><br>• **Left ventricular hypertrophy:**<br><br>Too much electricity, depolarization takes longer time.<br>And so the right side is depolarized before the left side.<br>Therefore, the current moves from the depolarized (-) site (Right) to the still polarized (+) site (left).<br><br>• **Left bundle branch block:**<br><br>Late contraction of the left ventricle; since depolarization is transferred through ventricular muscles instead of Purkinje fibers which takes more time (slower depolarization). | The heart is deviated to the right<br><br>**Causes**<br><br>• Normally, **tall** and **thin** people. The heart is pushed to the right, also here, it's not a pathological condition.<br><br>That's why we increase the range up to +110°.<br><br>• **Right ventricular hypertrophy**<br><br>Too much electricity, depolarization takes longer time.<br>And so the left side is depolarized before the right side.<br>Therefore, the current moves from the depolarized (-) site (left) to the still polarized (+) site (right).<br><br>• **Right bundle branch block**<br><br>Late contraction of the right ventricle; since depolarization is transferred through ventricular muscles instead of Purkinje fibers which takes more time (slower depolarization).<br><br>Sometimes, right axis deviation is caused by some lung diseases either acute or chronic.<br>Also, dextrocardia is sometimes detected accidentally upon ECG examination & appears as a right axis deviation; also it can be detected through auscultation when the heart sounds aren't as clear on the left side as on the right side. |

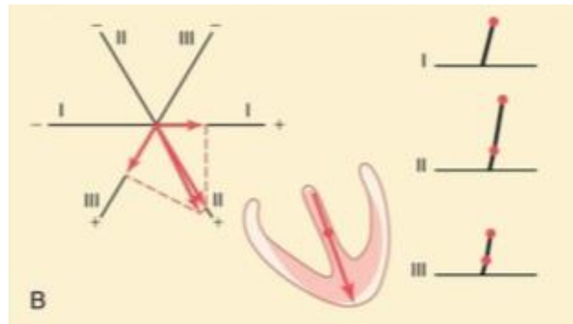
**Why QRS complex is composed of three waves?**

This is a recording of the value of the electrical axis on the plane of lead I, II and III.

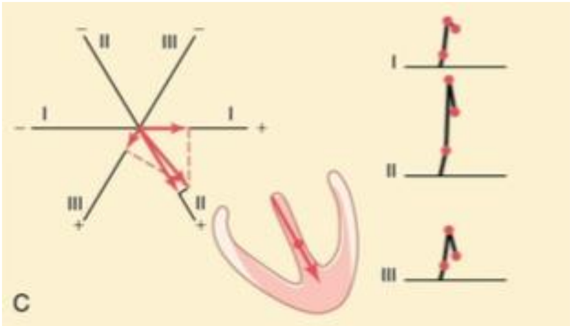
We recorded 5 instances only {although we record everything; every instant has a vector}




- The first vector represents the depolarization of the septum, which is the resultant/ mean instantaneous vector. If you analyze it on the plain of lead I, II and III, you will get values for each one.

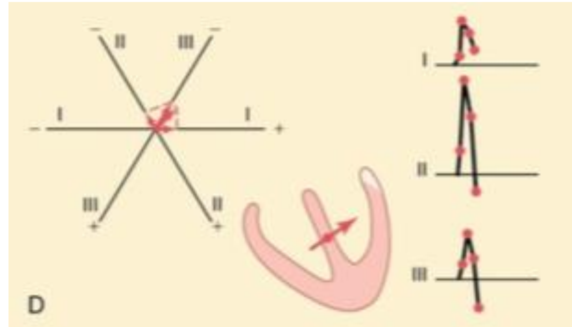



- The depolarization wave spreads. There is another resultant/ another instantaneous vector. You analyze it again on the 3 leads
- All leads' values are increasing
- The depolarization vector is large because half of the ventricle is depolarized (much of the ventricular mass has become depolarized)

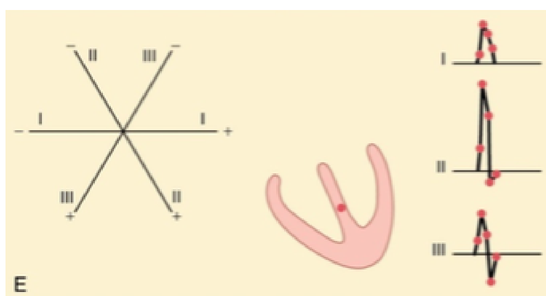



- ❖ By analyzing the resultant instantaneous vector on the third instance, we notice that the values of lead I, II and III are decreasing; because the outside of the heart apex is now electronegative; neutralizing much of the electro-positivity on other epicardial surfaces of the heart.

- ❖ The mean vector is shifting toward the left side of the chest because the left ventricle is slightly slower to depolarize than the right ventricle.




- ❖ Here, the last part of the heart that depolarizes is the posterior aspect of the left ventricle.
- ❖ The vector went from the depolarized to the polarized area.
- ❖ Note that on lead I, the reading became less positive, however, on lead II & lead III the readings became negative with more negativity on lead III.
- ❖ This is the cause of the **S wave**.




Completely depolarized {no mean instantaneous vector} … reading is zero… now we have a complete S wave & thus a complete QRS complex.

**Q wave** can be recorded, some people might have the Q wave apparent on their ECG, but recording the Q wave depends on the first instantaneous vector of ventricular depolarization, which is the vector of septum depolarization, i.e. Q is due to depolarization of the septum.

“” Q wave is a slight negative depression that appears sometimes at the beginning of the QRS complex in one or more of the leads, which if occurs, is caused by initial depolarization of the left side of the septum before the right side, which creates a weak vector from left to right for a fraction of a second, before the usual base-to-apex vector occurs”” Guyton; P132.

Note that everybody has his/her own electrocardiogram (ECG), depending on the heart and its electricity.

## T wave {Repolarization of the Ventricle}

- Repolarization takes longer than Depolarization.
- Atrial depolarization begins at sinus node and spreads toward A-V node. This should give a + vector in leads I, II, and III.
- Atrial repolarization can’t be seen because it is masked by QRS complex.
- Atrial depolarization is slower than in ventricles, so **first area to depolarize is also the first to repolarize.** So, ***if atrial T wave is apparent in the ECG***, then it’s going to be a negative atrial repolarization wave in leads I, II, and III.
- Ventricular repolarization has a positive value in ECG because **the last area to depolarize is the first area to repolarize** (the reason for that is the high blood pressure inside the ventricles during contraction, which greatly reduces the coronary blood flow to the endocardium, thereby slowing the repolarization in the endocardium area) & because of that, the mean vector during repolarization is directed towards the apex of the heart & that explains the positive value of the T wave in the 3 leads I, II & III.

**When can we see atrial repolarization wave on ECG?**

In cases of AV block {**not** bundle branch block}; which leads to slower heart rate (15 -40 beats/min).

**What if QRS complex was downward deflected –below the zero baseline- in both lead I & aVF lead on ECG? & what does it mean?**

In this case, the mean electrical axis will be drawn between 180° & 270° (-90°) & it means that there is severe either right or left axis deviation of QRS.

**How to know whether we have severe right or severe left axis deviation of QRS?**

We ask the patient, and we know from the signs & symptoms; if the patient has right heart disease; then he suffers from right axis deviation of QRS, and vice versa.

**Calculations**

**Cardiac Cycle** = Number of Squares {between R-R for example} * 0.04 (time for one square)

Let's say R-R interval = 0.83sec which is the time for one cardiac cycle,

∴Heart rate = (60 sec)/ (0.83 sec) = 72 beats/min

General calculation: heart rate = (60)/ time for one cardiac cycle

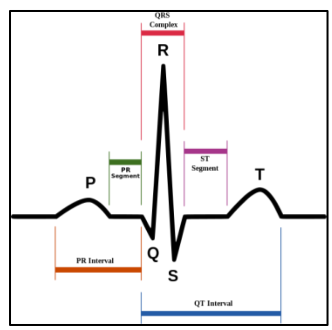
Keeping in mind this is used if the heart is regular, if not:

- Take too many cycles and find the average.
- Take a longer strip and count how many cycles there are in a minute.

| Intervals | |
|---|---|
| **P-Q/P-R Interval** | **QRS Complex** |
| From beginning of P till beginning of Q<br>= Number of Squares * 0.04<br>Should be less than **0.2** | From beginning of Q till end of S<br>= Number of Squares * 0.04<br>Should be less than **0.12** |

How to determine if the rhythm is regular or not?

By using a caliber, determine the R-R distance, and apply this distance on the next R-R interval & the interval after it & so on, if the distances are the same, then it's a regular rhythm, otherwise, it's irregular which could be regular irregular or irregular irregular.




الشمس أجمل في بلادي من سواها، والظلام، – حتى الظلام – هناك أجمل، فهو يحتضن {العراق}.

Done By: Faisal Al Noua'aimi & Mustafa Alkaraghouli