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# PHYSIOLOGY

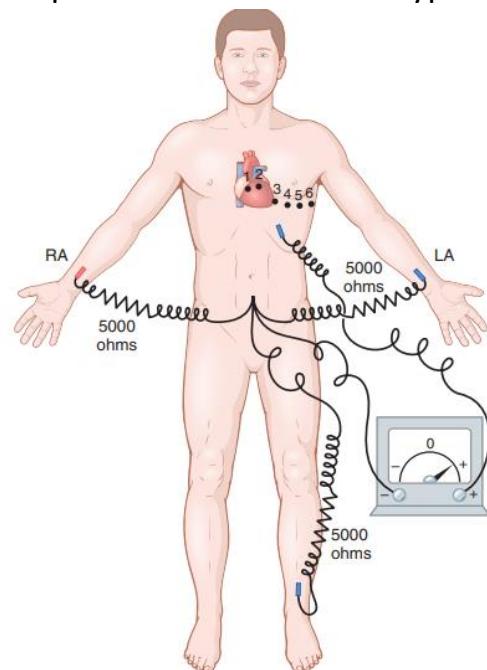
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## \* Augmented Unipolar Limb Leads

- Another system of leads in wide use is the augmented unipolar limb lead. In this type of recording we connect on the **negative** electrode three connections on the same exact positions where we put the Bipolar Limb Leads (right arm, left arm and left foot). These connections have Very High Resistance (=5000 Ohms) so that the net current in these three connections will be ZERO (called **indifferent** electrode).
- Note that all three connections are considered one negative electrode
- Then we place the positive electrode on a different position (Right Arm, Left Arm and Left Foot) each at a time calculating (VR, VL, and VF, respectively). The electrode is called **exploring** electrode.



- The problem with the above-mentioned experiment is that the recording was too small, so a scientist called Wilson removed the high resistance from the right arm and kept the high resistance in the other two limbs.
- After removing the high resistance connected to the right limb, he found that the recording was augmented (amplified) which was way better to calculate. He called the new recording aVR (augmented vector right arm).
- He did the same with the left arm and got an augmented record and called it (aVL), and the same with the left foot and got another augmented record and called it (aVF).

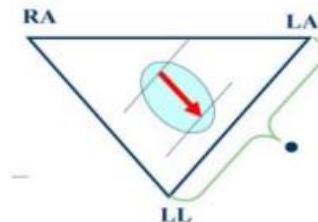
→ To summarize, in this type of recording, two of the limbs are connected through electrical resistances to the negative terminal of the electrocardiograph, and the third limb is connected to the positive terminal.

	Indifferent Electrode	Exploring Electrode
aVR	Connected to the left arm and left foot	Connected to the right arm
aVL	Connected to the right arm and left foot	Connected to the left arm
aVF	Connected to the right and left arms	Connected to the left foot

- It is called unipolar limb leads because we connect one pole to each of these limbs
- The mean electrical axis records positive if it's going towards the positive electrode, and negative if it is going away from the positive electrode

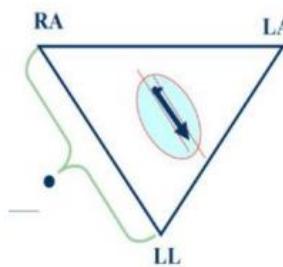
- **aVR:**

- $aVR = (LA - LL)$  vs. RA (+)
- The measured potential difference is between RA (+) and the center point between LA and LL (-)
- If we put the positive electrode in the right arm, aVR will move in opposite direction to the mean electrical axis so recording will be negative



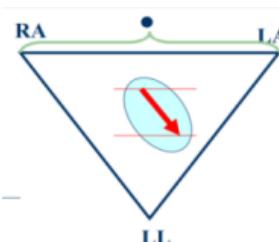
- **aVL:**

- $aVL = (RA - LL)$  vs. LA (+)
- The measured potential difference is between LA (+) and the center point between RA and LL (-)
- If we put the positive electrode in the left arm, aVL will move in the same direction to the mean electrical axis so recording will be positive (even though it's small, it records positively)

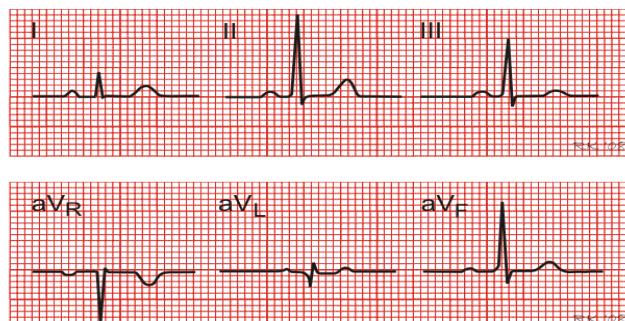


- **aVF:**

- $aVF = (RA - LA)$  vs. LL (+)
- The measured potential difference is between LL (+) and the center point between RA and LA (-).
- If we put the positive electrode in the left foot, aVF will move in the same direction to the mean electrical axis so the recording will be highly positive (most positive)



➔ Let's summarize using the following figure. aVR is negative because we are going away from the positive electrode, aVL is positive but in a small record and aVF is highly positive because its mean electrical axis is going towards the positive electrode in the left foot.

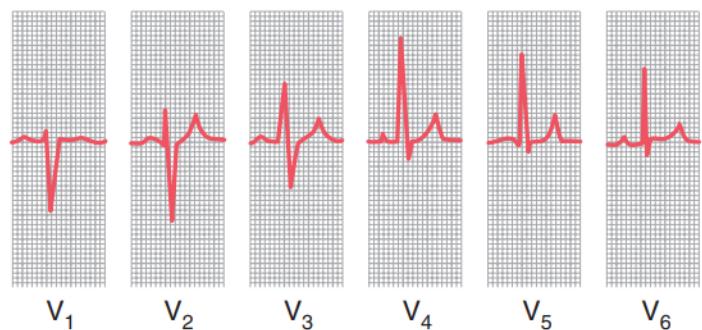


## \* Chest leads

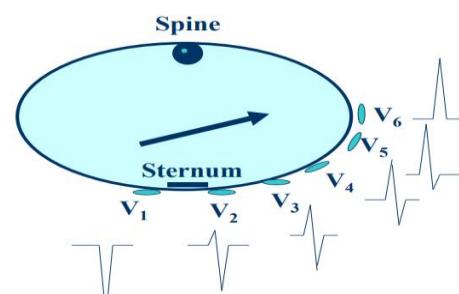
- In the limb leads we looked at the activity of the heart from the frontal plane, however using the Chest leads we will look at it from the horizontal plane.
- There are 6 unipolar chest leads (V1,V2,V3,V4,V5,V6) or we can call them (C1,C2,C3,C4,C5,C6).

Chest Lead	Location
V1	in the 4 <sup>th</sup> intercostal space (right side) just beside the sternum
V2	in the 4 <sup>th</sup> intercostal space (left side) around the sternum
V3	in the mid-way between V2 and V4
V4	in the 5 <sup>th</sup> intercostal space ( <b>left</b> side) in the mid-clavicular line
V5	in the 5 <sup>th</sup> intercostal space in the anterior axillary line
V6	in the 5 <sup>th</sup> intercostal space in the mid axillary line

- The following graph represents precordial (chest leads): indifferent electrode (RA-LA-LL) vs. chest lead moved from position V1 through position V6:



- The direction of the mean electrical axis is in V1 and V2 is away from the positive electrode so as we can see in this graph V1 and V2 are recorded negative
- V3 is recorded in the middle between positive and negative
- The direction of the mean electrical axis in V4 and V5 and V6 is toward the positive electrode so they're recorded positive
- Chest leads are very sensitive to electrical potential changes underneath the electrode
- Chest leads are considered unipolar leads



→ In conclusion, we have 12 leads, 9 of them are unipolar and 3 of them are bipolar

- The chest leads are from the transverse plane whereas the bipolar limb leads and the augmented unipolar leads are from the frontal plane.

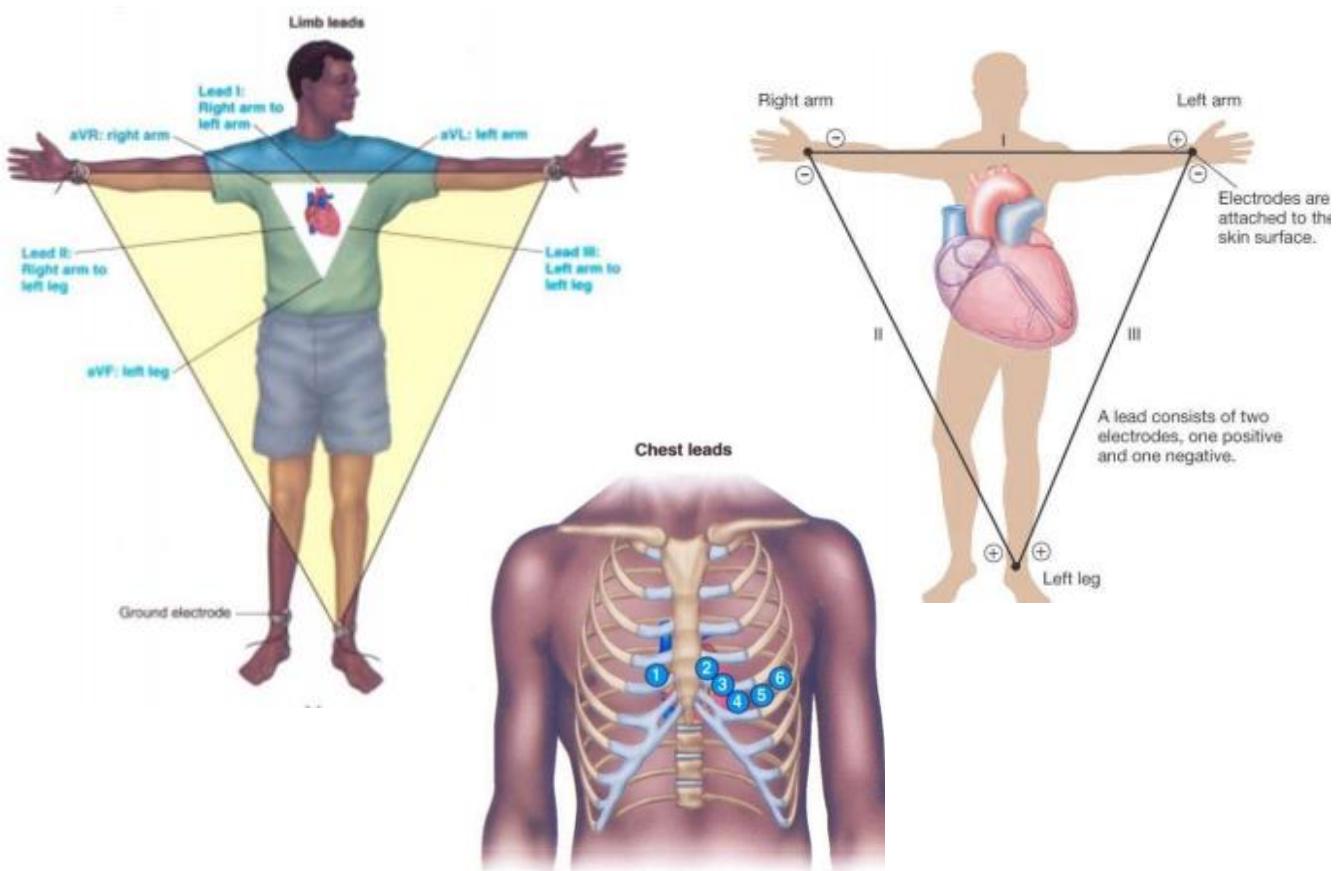
- The following figure presents a complete ECG (12 leads recording), as you can see:

- The QRS in lead II equals the QRS in both lead I and lead III
- aVR is negative whereas aVF and aVL are positive
- V1 and V2 are negative and V3 is starting to be positive (midline)
- V4, V5, V6 are positive



- Chest leads are placed anteriorly on the chest, they can tell you about what is happening in the anterior and inferior aspects of the heart, but they can't tell you about the changes in the posterior aspect of the heart. To inspect the posterior aspect of the heart, we use another type of electrode that's called esophageal electrode.
- You use esophageal lead if you have a suspicion that there might be something abnormal in the posterior surface of the heart. Esophageal lead is used by putting the exploring electrode in the esophagus through the larynx → throat → esophagus and you start recording when it becomes posterior to the heart.

- The following pictures are for further understanding:

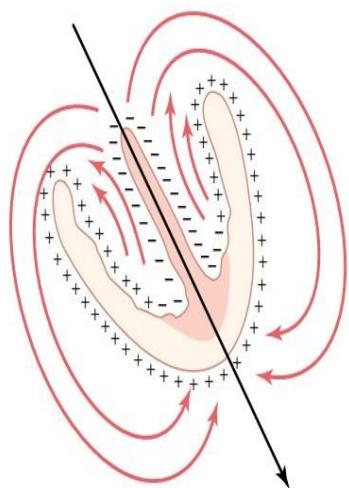


## ♥ Normal Electrocardiography:

↳ In this sheet we will continue talking about the normal ECG of the heart.

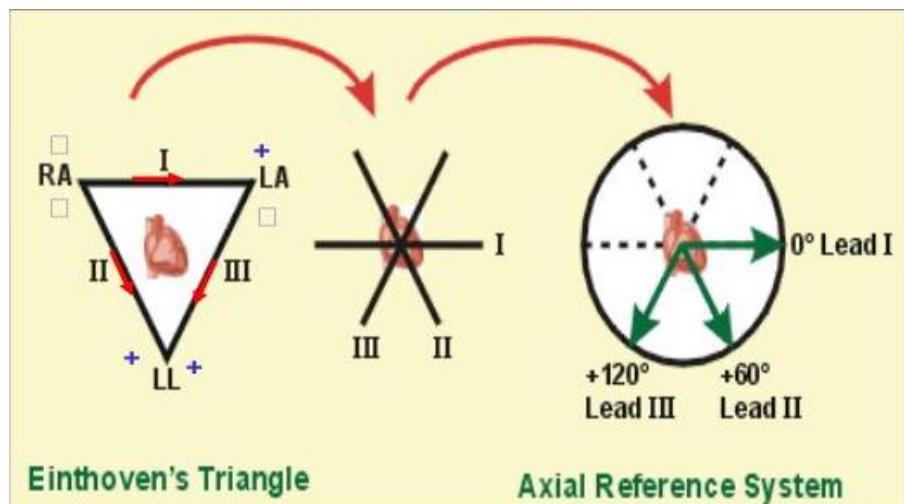
### ▪ Objectives:

1. Recognize the normal ECG tracing.
  2. Calculate the heart rate.
  3. Determine the rhythm (normal Vs abnormal).
  4. Calculate the length of intervals and determine the segments deflections (upward Vs downward).
  5. Draw the Hexagonal axis of the ECG (bipolar + unipolar leads, both at the frontal plane).
  6. Find the mean electrical axis of QRS (Ventricular depolarization).
- The current in the heart flows from the area of depolarization to the polarized areas, and the electrical potential generated can be represented by a vector, with the arrowhead pointing in the **positive direction**. By convection, the length of the vector is proportional to the voltage of the potential.
  - Direction of current flow is always from the negative point toward positive point. Current flows in all directions. **Mean direction** of flow of electrical potential at one instance is known as **instantaneous mean vector**.
  - In a normal heart, the average direction of the vector during spread of the depolarization wave through the ventricles, called the **mean QRS vector**, is  $60^\circ$  ( $-30^\circ$  -  $110^\circ$ ). **Clinically**, the normal mean QRS is between  $0^\circ$  and  $+90^\circ$ .
  - The figure shows, depolarization of the ventricular septum. At this instant of heart excitation, electrical current flows between the **depolarized areas inside the heart and the non-depolarized areas on the outside of the heart**. More current flows downward from the base of the ventricles toward the apex than in the upward direction. Therefore, the summated vector of the generated potential at this particular instant, **the instantaneous mean vector**, is represented by the long black arrow drawn through the center of the ventricles in a direction from **base toward apex**. Furthermore, because the potential is large, the vector is long.

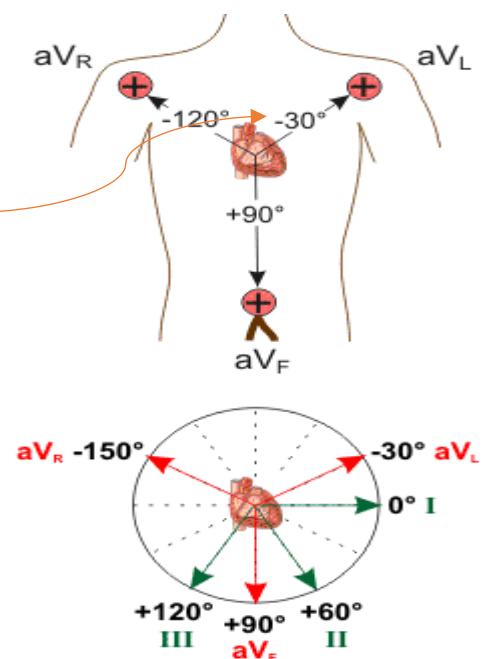


### ♥ Einthoven's triangle and law:

- The three standard limb leads (I, II, III) can be seen to form an equilateral triangle (each angle is  $60^\circ$ ), with the heart at the center. This is called the Einthoven's triangle. To facilitate the representation of electrical forces, the three limb leads of the triangle can be drawn in such a way that the three leads bisect each other and pass through a common central point. This produces a *triaxial reference* system with each axis separated from the next by  $60^\circ$ . with the lead polarity (positive and negative poles) and orientation (direction) remaining the same.

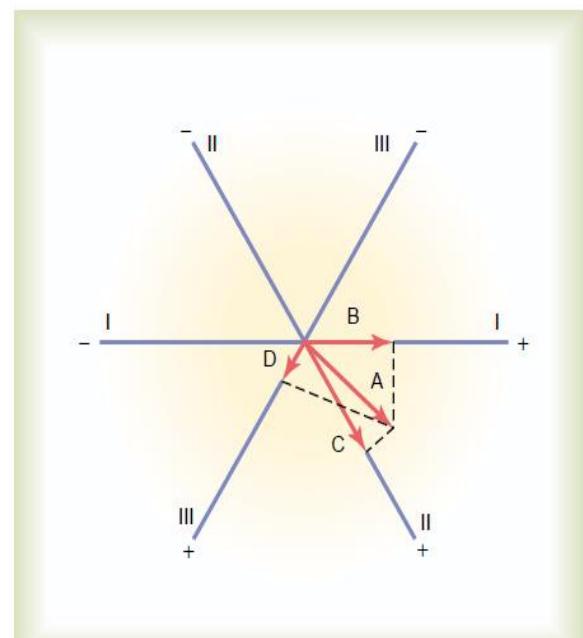
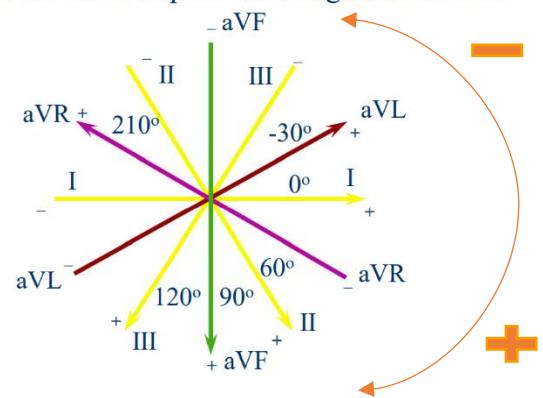


- Also, the augmented limb leads are recorded from one limb at a time (unipolar), the limb carrying the positive electrode, and the negative pole being represented by the central point. The three augmented limb leads ( $aV_R$ ,  $aV_L$ ,  $aV_F$ ) form another triaxial reference system, with each axis being separated from the next by  $60^\circ$ . When the triaxial system of the unipolar leads is superimposed on the triaxial system of the bipolar limb leads, we can derive a hexaxial reference system with each axis being separated from the next by  $30^\circ$ .



- Note that each of the six leads retains its polarity and orientation. The hexaxial reference system is important in determining the major direction of the heart's electrical forces (the electrical axis of the QRS complex).
- Perpendicular leads:
  1. I and aVF
  2. II and aVL
  3. III and aVR
- Lead I is recorded from two electrodes placed respectively on the two arms. Because the electrodes lie exactly in the horizontal direction, with the positive electrode to the left, the axis of lead I is 0 degrees.
- In recording lead II, electrodes are placed on the right arm and left leg. The right arm connects to the torso in the upper right-hand corner and the left leg connects in the lower left-hand corner. Therefore, the direction of this lead is about +60 degrees.
- By similar analysis, it can be seen that lead III has an axis of about +120 degrees; lead aVR, +210° or -150°; aVF, +90 degrees; and aVL -30 degrees.
- Let's revise the basics of vectorial analysis by this example (extra example to clarify things before digging deeper in the analysis):
  - Vector A is the instantaneous electrical potential of a partially depolarized heart. To determine the potential recorded at this instant in the ECG for each one of the three standard bipolar limb leads, perpendicular lines (the dashed lines) are drawn from the tip of vector A to the three lines representing the axes of the three different standard leads, as shown in the figure. The projected vector B represents the potential recorded at that instant in lead I, projected vector C represents the potential in lead II, and projected vector D represents the

Axes of the Three Bipolar and Augmented Leads



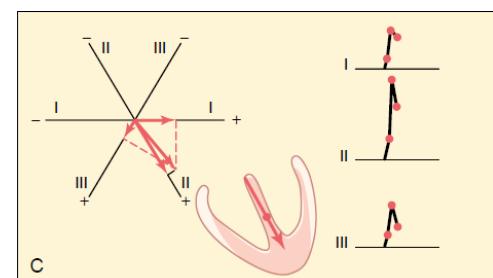
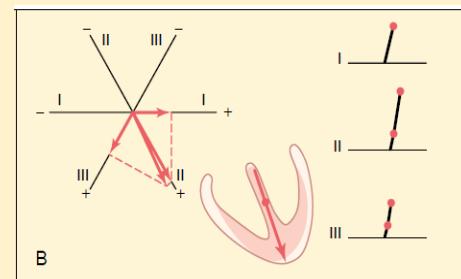
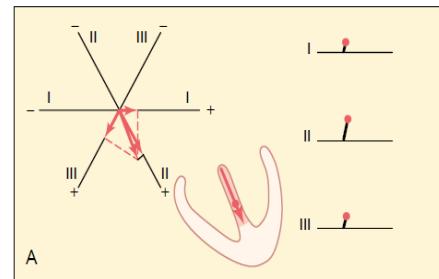
potential in lead III. In each of these, the record in the electrocardiogram is positive that is, above the zero line because the projected vectors point in the positive directions along the axes of all the leads. The potential in lead I (vector B) is about one half that of the actual potential in the heart (vector A); in lead II (vector C), it is almost equal to that in the heart (because almost all of the electrical activity is coming toward the lead in that instant); and in lead III (vector D), it is about one third that in the heart (electrical activity is not heading directly toward this lead, but still detected by the lead).

the ventricular muscle has just begun to be depolarized. At this time, the vector is short because only a small portion of the ventricles—the septum—is depolarized. Therefore, all ECG voltages are low, as recorded. The voltage in lead II is greater than the voltages in leads I and III because the heart vector extends mainly in the same direction as the axis of lead II.

- Q wave is present if the left side of the septum depolarizes first.

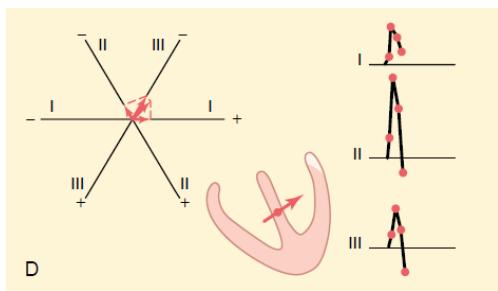
The heart vector is long because much of the ventricular muscle mass has become depolarized. Therefore, the voltages in all electrocardiographic leads have increased (especially lead II). The depolarization vector is large because half of the ventricle is depolarized. Lead II should be largest voltage when compared to I and III when the mean vector is  $60^\circ$ .

the heart vector is becoming shorter and the recorded electrocardiographic voltages are lower. Also, the axis of the vector is beginning to shift toward the left side of the chest because the left ventricle is slightly slower to depolarize than the right.



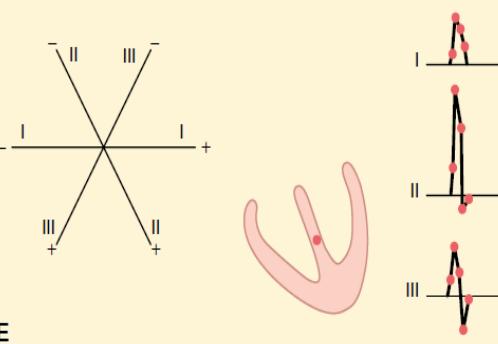
the heart vector points toward the base of the left ventricle, and it is short because only a minute portion of the ventricular muscle is still polarized positive. Because of the direction of the vector at this time, the voltages recorded in leads II and III are both negative that is, below the line (S wave) whereas the voltage of lead I is still positive (sometimes it is also negative).

- the last part to depolarize is near the left base of the heart which gives a negative vector (S wave).



the entire ventricular muscle mass is depolarized, so that no current flows around the heart and no electrical potential is generated. The vector becomes zero, and the voltages in all leads become zero.

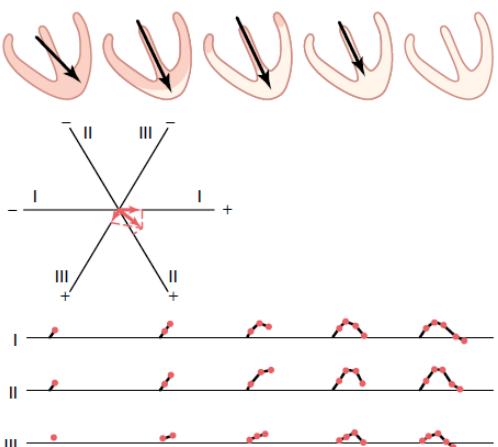
**EXTRA:** The recording represents comparison in voltage detected by the electrodes at two different points not the actual potential. ECG does not record a potential at all when the ventricular muscle is completely depolarized or completely repolarized, because both electrodes are “viewing” the same potential, so no difference in potential between the two electrodes is recorded.



After the ventricular muscle has become depolarized, repolarization begins and proceeds. This repolarization causes the T wave in the electrocardiogram.

Because the septum and endocardial areas of the ventricular muscle depolarize first, it seems logical that these areas should repolarize first as well.

However, this is not the usual case. The greatest portion of ventricular muscle mass to repolarize first is the entire outer surface of the ventricles. The endocardial areas, conversely, normally repolarize last. Because the outer surfaces of the ventricles repolarize before the inner surfaces, the positive end of the overall ventricular vector during repolarization is toward the apex of the heart. As a result, the normal T



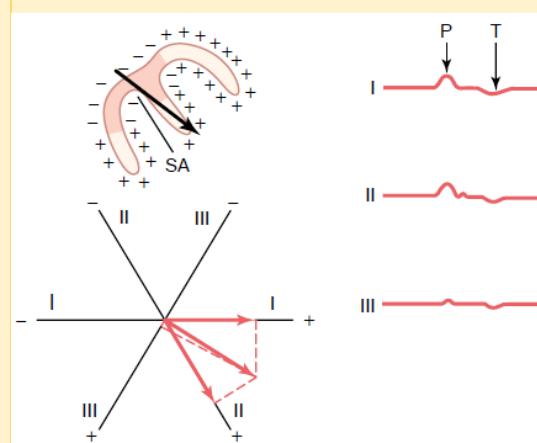
wave in all three bipolar limb leads is positive (upward deflection), which is also the polarity of most of the normal QRS complex.

### Repolarization:

Apex → base

Outer-surface → inner-surface

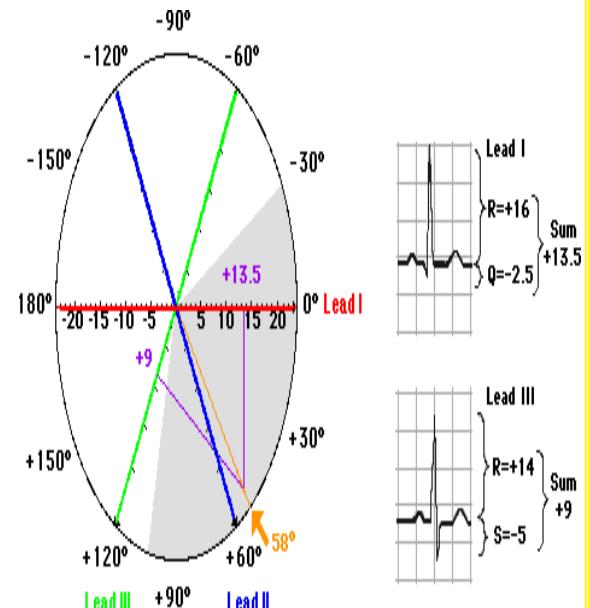
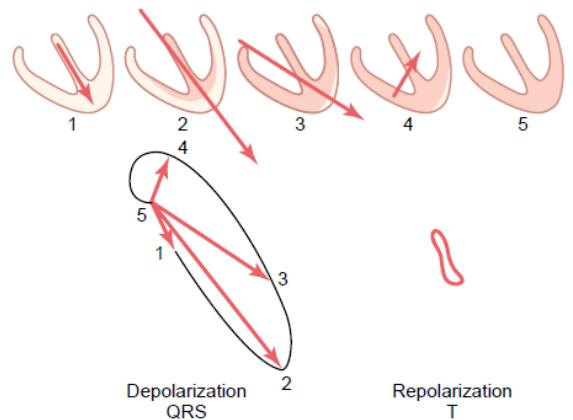
- Depolarization of the atria begins in the sinus node and spreads in all directions over the atria. The direction of initial depolarization is denoted by the black vector. The vector remains generally in this direction throughout the process of normal atrial depolarization. Because this direction is generally in the positive directions of the axes of the three standard bipolar limb leads I, II, and III, the ECGs recorded from the atria during depolarization are also usually positive in all three of these leads, this record of atrial depolarization is known as the atrial P wave.
- The area in the atria that becomes repolarized first is the area that had originally become depolarized first. Thus, when repolarization begins, the region around the sinus node becomes positive with respect to the rest of the atria. Therefore, the atrial repolarization vector is backward to the vector of depolarization. (**Note that this is opposite to the effect that occurs in the ventricles**). atrial T wave follows the atrial P wave, but this T wave is on the opposite side of the zero-reference line from the P wave; that is, it is normally negative rather than positive in the three standard bipolar limb leads.
- In the normal electrocardiogram, the atrial T wave appears at about the same time that the QRS complex of the ventricles appears. Therefore, it is almost always totally masked by the large ventricular QRS complex, although in some very abnormal states, it does appear in the recorded electrocardiogram.



- point 5 is the zero-reference point. While the heart muscle is polarized between heartbeats, the positive end of the vector remains at the zero point because there is no vectorial electrical potential. However, as soon as current begins to flow through the ventricles at the beginning of ventricular depolarization, the positive end of the vector leaves the zero-reference point.
- When half of the ventricle is depolarized, vector-2 has the largest potential difference.
- Vector-4 represents depolarizing of the posterior aspect of the left ventricle (S-wave).
- The recording of the QRS complex is the same on all the leads, even on the unipolar leads and the horizontal chest leads (V1-6).

### ◆ Determining Mean Electrical Axis:

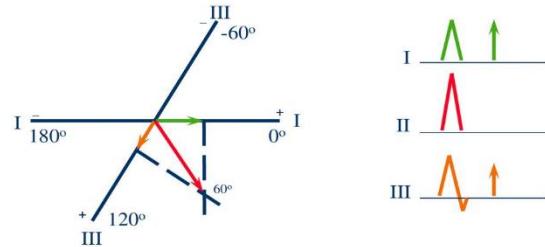
- To calculate the mean electrical axis of the QRS complex in this example, standard leads I and III were used but any combination of two of the six could have been used (we don't use chest leads). The vectorial sum of the deflections of the QRS complex for each lead is calculated in millimeters.
- In this example, the Q wave is -2.5 mm deep and the R wave is +16 mm high to give a sum of +13.5 mm for lead I
  - The point corresponding to this sum is then located on lead I (the positive direction being towards the arrow of each lead) and a perpendicular is dropped from lead I
  - The same is done for lead III.
  - A line is then drawn from the center of the grid through the point of intersection of the two perpendicular lines to obtain the mean electrical axis. In this case, the mean



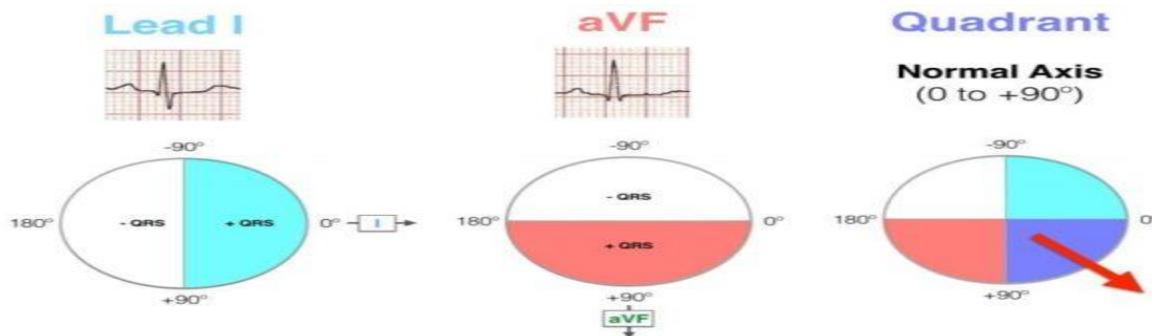
electrical axis of the QRS complex is 58 degrees, which is within the normal range.

- ♥ In this example, the obtained mean electrical axis of the QRS complex is  $60^\circ$ , which is basically the axis of lead II.

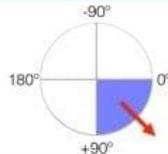
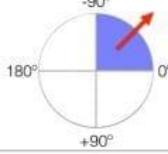
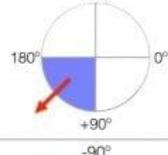
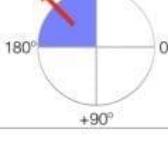
**Plot of the Mean Electrical Axis of the Heart from Two Electrocardiographic Leads**



- ♥ The most efficient way to estimate axis is to look at **LEAD I and LEAD aVF**.
- A positive QRS in Lead I puts the axis in roughly the same direction as lead I.
- A positive QRS in Lead aVF similarly aligns the axis with lead aVF.
- Combining both coloured areas, the quadrant of overlap determines the axis. So, If Lead I and aVF are both positive, the axis is between  $0^\circ$  and  $+90^\circ$  (i.e. normal axis).



- The following table summarizes all the possible cases:
  - Normal Axis = QRS axis between  $0^\circ$  and  $+90^\circ$ .
  - Left Axis Deviation-**LAD** = QRS axis between  $0^\circ$  and  $-90^\circ$ .
  - Right Axis Deviation-**RAD** = QRS axis between  $+90^\circ$  to  $+180^\circ$ .
  - Extreme Axis Deviation = QRS axis between  $-90^\circ$  ( $+270^\circ$ ) and  $+180^\circ$ , to determine whether it is left or right you should trace the patient's history for any clues that suggest right or left deviation, because ECG is not the only tool to reach a diagnosis.

Lead 1	Lead aVF	Quadrant	Axis
<b>POSITIVE</b>	<b>POSITIVE</b>		<b>Normal Axis</b> (0 to +90°)
<b>POSITIVE</b>	<b>NEGATIVE</b>		<b>**Possible LAD</b> (0 to -90°)
<b>NEGATIVE</b>	<b>POSITIVE</b>		<b>RAD</b> (+90° to 180°)
<b>NEGATIVE</b>	<b>NEGATIVE</b>		<b>Extreme Axis</b> (-90° to 180°)

### Heart Rate Calculation:

Measure the distance between two successive ECG complexes (as the number of small squares). The number of ECG complexes by 1 min (beats/min) is equal to:

$$60 / \text{number of small square} \times 0.04$$

Or basically **1500/No. of small squares**

**Mostly used interval is the R-R interval**

**R-R interval = 0.83 sec or 20.75 small squares**

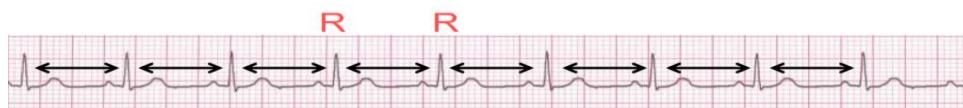
**Heart rate (beat/min) =  $60/0.83$**

$$= 72 \text{ beats/min}$$

- Keep in mind that the R-R interval (period) is the same in every cycle, because the heart rate should be regular. In irregular heart rate, the intervals are not identical.
- P-R interval is measured from the onset of the P wave to the beginning of the QRS complex, it should be less than or equal to 0.2 sec, if it is more than 0.2 it denotes that something is abnormal.
- QRS complex, starts from the beginning of Q to the end of S, and should be less than 0.12 sec.
- Q-T interval is usually about 0.35-0.4 sec
- S-T segment should be isoelectric, you look for deflection, either upward or downward. The same applies for the P-R segment.
- The reference point for the isoelectric line is the T-P segment.

### ♥ Determine regularity:

- ☞ The distance between R-R intervals and QRS complexes should be the same, if the distance differs the rhythm is irregular. Several methods can be used to determine rhythm regularity, these include using calipers, marking a paper with a pen. By counting the small squares between the R-R interval (each large square = 5 small squares) and comparing this distance each time (should be the same).
- Patterned irregularity (regular irregularity) is when the irregularity repeats in a cyclic fashion.

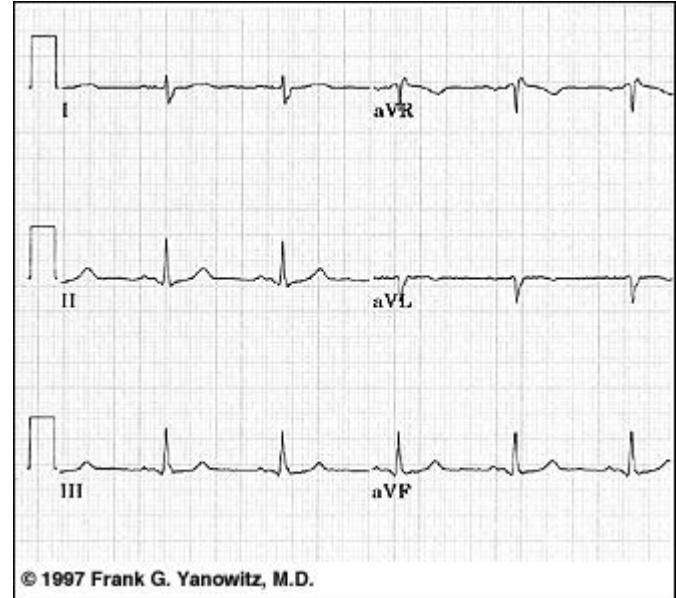


### Quiz:

1. If there were 3 large squares in an R-R interval what would the heart rate be?
  - 100 bpm
  - 90 bpm
  - 80 bpm
  - 70 bpm

**1. Determine the QRS axis for this ECG:**

- a. -100 degrees
- b. -30 degrees
- c. +15 degrees
- d. +90 degrees
- e. Indeterminate



**2. P wave represents:**

- a. Depolarization of right ventricle
- b. Depolarization of both atria
- c. Depolarization of left ventricle
- d. Atria to ventricular conduction time

**3. In normal ECG one of the following waves is not represented, which one is that?**

- a. Depolarization of atria
- b. Repolarization of atria
- c. Depolarization of ventricles
- d. Repolarization of ventricles

♥ **Answers:**

1. A
2. D (Lead I is isoelectric and since aVF is positive, you know the axis is +90 degrees).
3. B
4. B