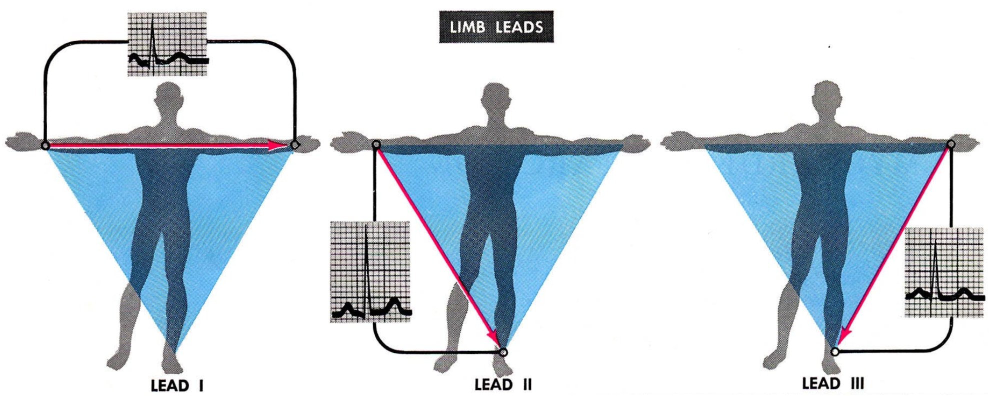
III. INTRODUCTION TO THE STANDARD ELECTROCARDIOGRAM (ECG)

Introduction to the Electrocardiogram

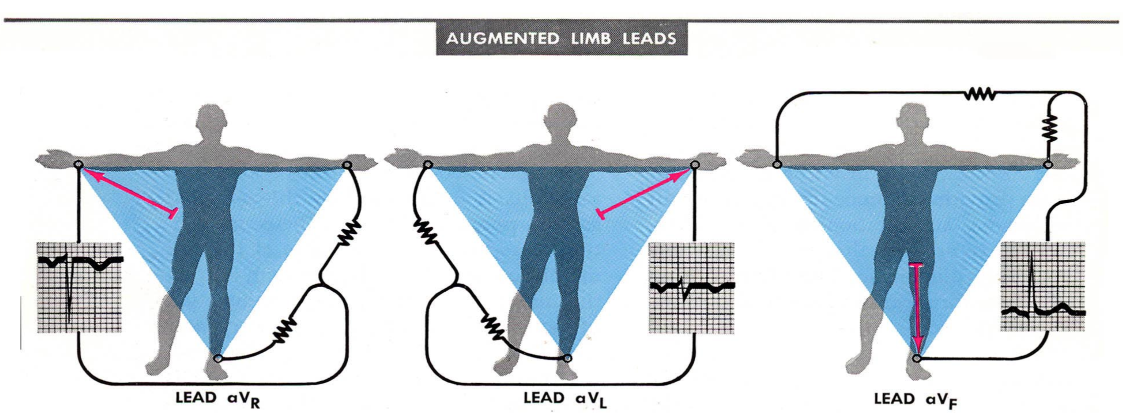
The electrocardiogram (ECG) represents the electrical activity of the heart graphically. The standard ECG uses 10 electrodes placed on the body surface in order to derive 12 leads. One electrode is placed on each arm and leg to derive the **limb leads**. Six limb leads are normally recorded.

[Figures III 1-3 are reproduced from: J. Harold Walton, M.D., Frank H. Netter, M.D. *The Electrocardiogram in Myocardial infarction.* Copyright 1968 by Ciba Corp. Reprinted from Clinical Symposia.   Vol 20, No 4.]

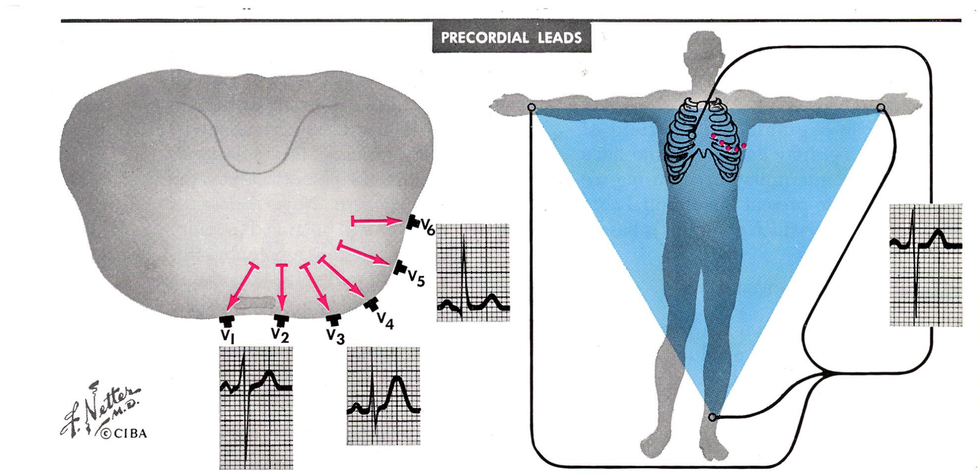
Fig.III-1 Leads I, II, and III are the bipolar limb leads:



Leads_aVR, aVL, and aVF, or the augmented limb leads are unipolar leads (Fig. III-2):



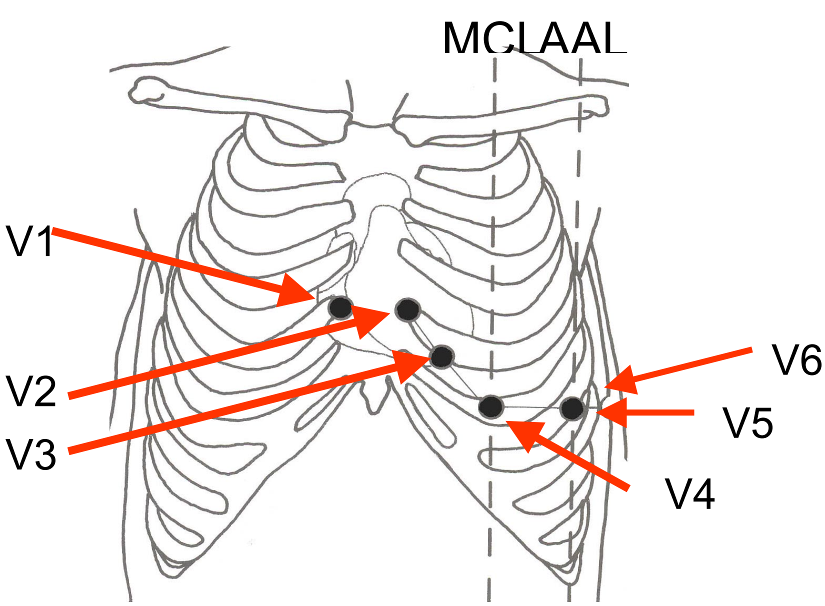
The other 6 electrodes are placed across the chest (Fig. III-3).



These are used to record another series of unipolar leads, the precordial leads. The limb leads provide a representation of electrical activity in the frontal plane of the body, while the precordial leads provide a representation of electrical vectors in the horizontal plane.

Correct placement of the precordial leads is critical in order to obtain an accurate representation of electrical activity in the horizontal plane (Fig. III-4). V1 is placed in the fourth intercostal space at the right sternal border, V2 is placed in the fourth intercostal space at the left sternal border, V4 is placed in the fifth intercostal space in the mid-axillary line, while V3 is placed midway between the electrodes for V2 and V4. The V5 electrode is placed in the fifth intercostal space in the anterior axillary line, while V6 is placed in the mid-axillary line in the fifth intercostal space. The patient should be supine when recording the standard ECG.

Fig. III-4

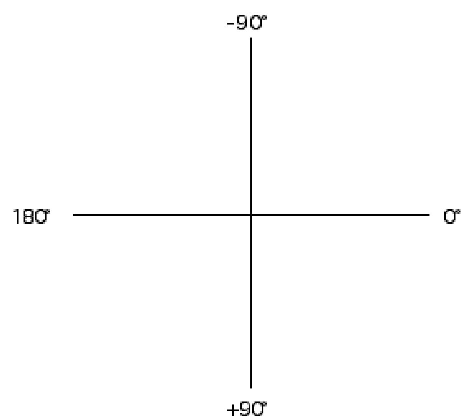


The vectorial representation of electrical activity in the frontal plane is in part characterized by the electrical axis in this plane. Derivation of the electrical access is based on Einthoven's triangle. Calculation of the frontal plane axis is illustrated in the following figures.

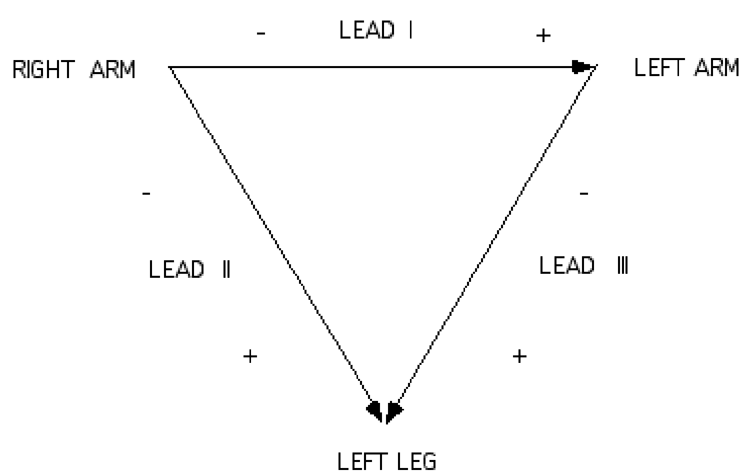
Calculation of the Frontal Plane QRS Axis

Only the limb leads (leads I, II, III, aVR, aVL, and aVF) are utilized to calculate the QRS axis. The V leads play no role in calculating the frontal plane QRS axis.

We use a planar reference system to describe the mean QRS axis. In this system angles are described in reference to an "x" (horizontal) axis, and a "y" (vertical) axis, as depicted below. (FIGURE III-5)



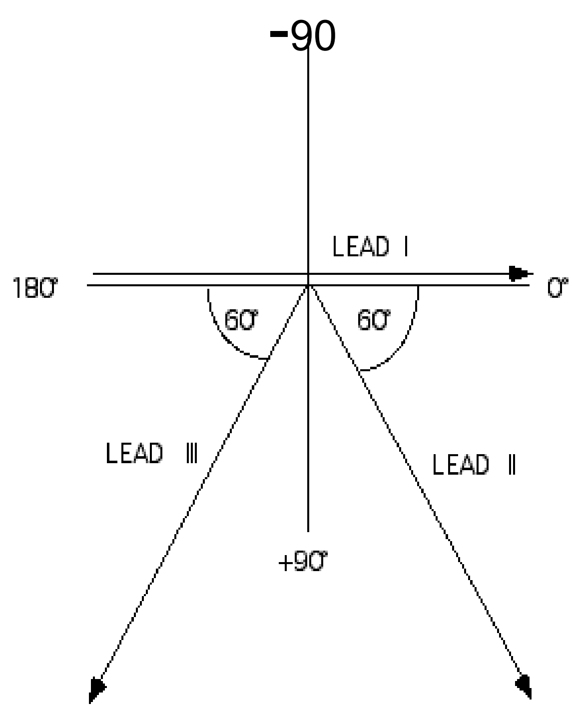
The next factor that you must realize is that lead I results from the electrical connections between the right arm and the left arm leads, and describes electrical activity in the X (horizontal) axis. When electrical forces are moving from right to left they describe a positive deflection in lead I on the electrocardiogram. If electrical forces are moving from left to right, they inscribe a negative deflection in lead I. (FIGURE III-6)



Lead II results from the electrical activity recorded between the right arm and the left leg lead. Lead II registers a positive deflection when electrical activity is moving from the right arm towards the left leg (electrical forces moving downward). It registers a negative deflection when electrical forces are moving from the leg towards the right arm (upward).

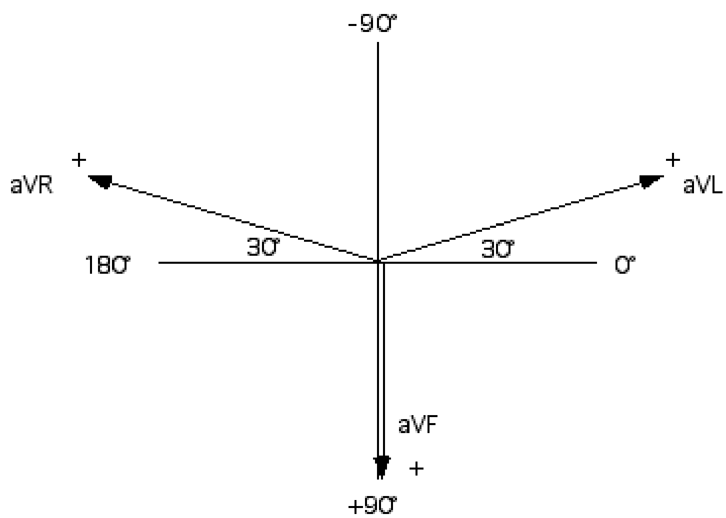
Lead III represents the electrical activity recorded between the left arm and the left leg lead. It registers a positive (upward) deflection when electrical activity is traveling towards the left leg from the left arm, and a negative deflection when forces are moving from the leg towards the arm (upward moving forces).

The accompanying diagram depicts in the frontal plane (the plane parallel to the anterior chest wall) the electrical angles described by the deflections on each of the standard limb leads I, II, III. (FIGURE III-7)



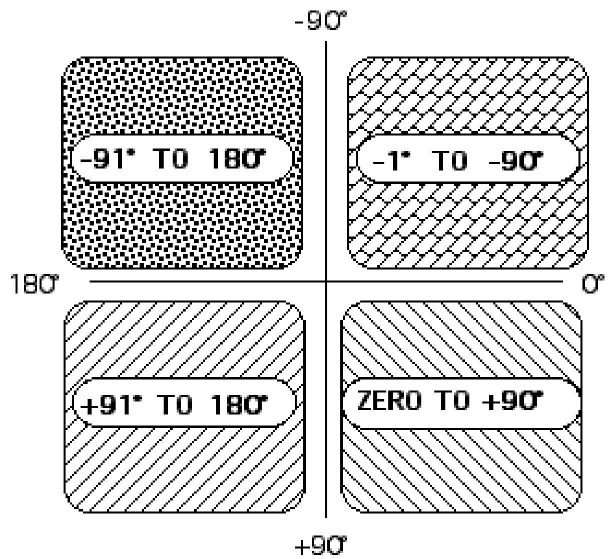
The unipolar, or augmented, limb leads, aVR, L, F, also portray electrical activity in the frontal plane, but electrically result from different connections of the limb lead electrodes.

Lead aVR is derived from the right arm lead versus all the other three limb leads connected together. Lead aVL results from the electrical forces between the left arm lead and the other three limb leads connected together, while aVF results from the left leg lead compared with the other three limb leads connected together. In each case, a positive (or upward) deflection on the electrocardiogram is produced when electrical activity is moving towards the appropriate limb (right arm, left arm, or left leg) in the case of aVR, aVL, and aVF, respectively. (FIGURE III-8)



It is important to realize that two components are important in determining the appearance of the QRS complex in any given lead: the direction of electrical forces relative to the lead, and the magnitude of forces. A large positive deflection will be produced in any lead when the electrical forces are moving in parallel with the lead, while minimal deflections will be formed when the electrical forces are moving perpendicular to the lead. The direction of deflection, positive or negative (upward or downward) in any lead is determined by the direction in which the electrical forces are moving in relation to the lead. That is, forces moving downward and leftward (approximately 60° below the horizontal axis) will produce a maximal positive deflection in lead II, while forces moving upward and rightward, towards the right arm, would produce a maximal negative deflection in lead II. Likewise, forces moving exactly from right to left, parallel to lead I (the two arms) would produce a maximal positive deflection, while forces moving from left to right will produce a maximal negative deflection. Conversely, forces moving straight up and down would produce minimal deflection in lead I.

By convention, we describe the mean frontal plan QRS axis as belonging in one of four quadrants, as depicted in the diagram (Fig. III-9) below: zero to +90°, +91 to +180°, -1° to -90°, or -91 to 180°. For clinical purposes, it is often not necessary to specify the exact QRS axis. Rather, it is necessary only to describe the quadrant in which the QRS axis falls, as shown here.



Here is one way to describe the QRS axis: (1) look for a limb lead with the minimal net positive or minimal negative deflection. This could be either a lead with very little recognizable deflection in either direction, or equally large positive and negative deflections, such that the sum of positive and negative deflections is close to zero. The mean electrical axis will then be perpendicular to this lead. For example, if lead I has close to zero net amplitude, the axis would be either +90° or -90°.   Then, look at any of the inferior leads: II, III, or aVF. If these leads register a predominantly positive deflection, the QRS axis will be closer to +90°. If the inferior leads (II, III, aVF) are predominantly negative, the axis is closer to -90°. (Fig. 6 below)

Here is a second example. If lead aVF has the smallest net deflection, the QRS axis would either be zero or 180°. In order to determine which of the two directions the axis truly lies, one must then look at other leads. Look at lead I. If the major deflection in lead I is positive, then the QRS axis is approximately 0°. If lead I is predominantly negative, the QRS axis is closer to 180°. (Fig. 7 below)

Sometimes, no ECG lead can be identified which appears to have zero net amplitude. In this case, decide which lead(s) have the largest positive or negative deflections. The QRS axis will

be close to the direction of this lead. In the example, lead II is very positive. The axis will be approximately +60°. Since lead I is positive, the axis is about +60°. (Fig. 8A below)
In the next example although lead II is positive, lead I is negative. Therefore, the axis is approximately +110°. (Fig. 8B below)
In the next example, lead II is negative, and lead I is positive. Therefore, the QRS axis is approximately -60°. (Fig. 9A below)
In the final example, lead II is negative, and lead I is also negative. Therefore, in this case, the QRS is approximately -110°. (Fig. 9B below)

FIGURE 6

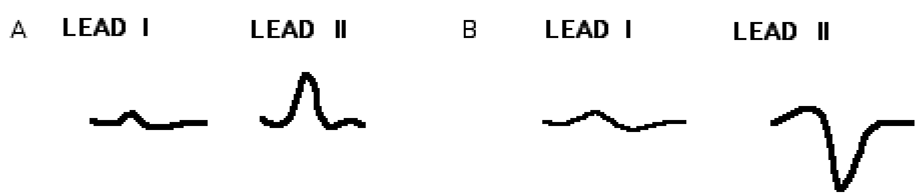


FIGURE 7

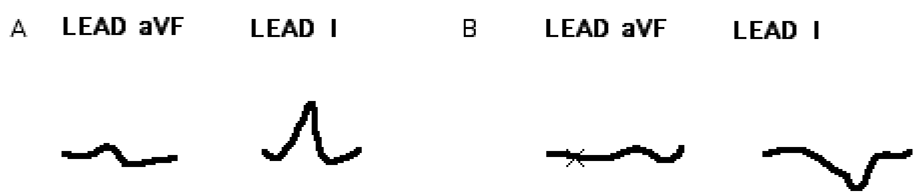


FIGURE 8

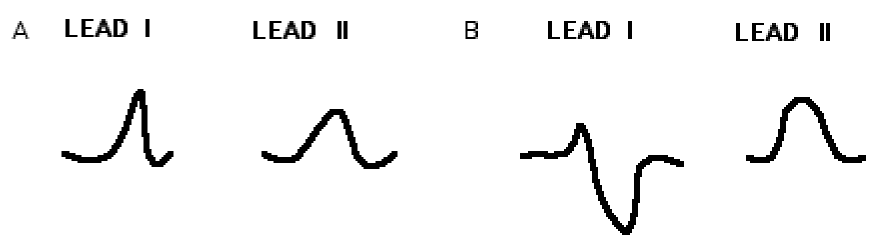
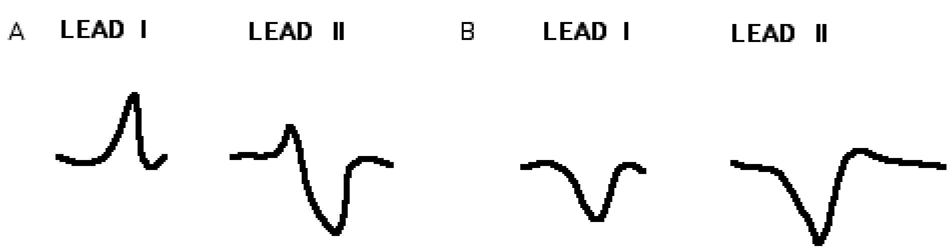
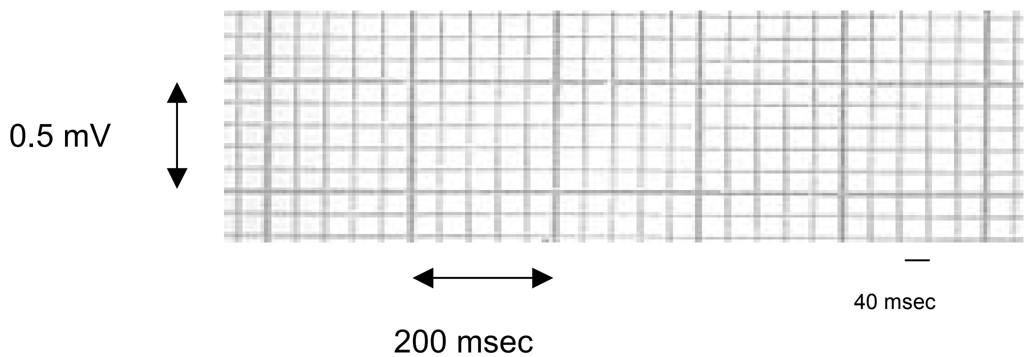


FIGURE 9



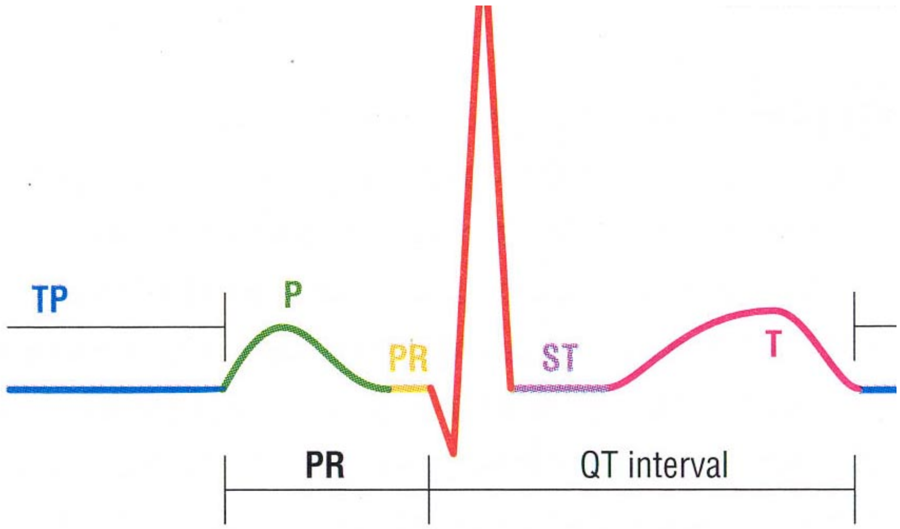
The electrocardiogram is recorded on graph paper. During a standard recording the x axis represents time, and the y axis denotes amplitude in terms of voltage. The standard recording speed for the electrocardiogram is 25 mm per second. The standard ECG is recorded on a grid of 1mm squares. Every fifth square is highlighted by a bold line. At the standard recording speed of 25mm per second, 1mm on the horizontal axis represents 40 milliseconds. Therefore, one large box (5 little squares) represents 200 milliseconds, or 1/5 of a second. With this knowledge, the heart rate can be calculated easily by measuring the number of squares between successive heartbeats. The time between successive heartbeats represents the cycle length of the rhythm. The cycle length of the rhythm is the inverse of the heart rate. Heart rate may be converted into cycle length, and vice versa, by dividing either value into 60,000 (the number of milliseconds in one minute).

At standard amplification, the y axis on the ECG paper represents voltage, with each small box representing .1 mV. Therefore, two large boxes represent 1.0 mV.

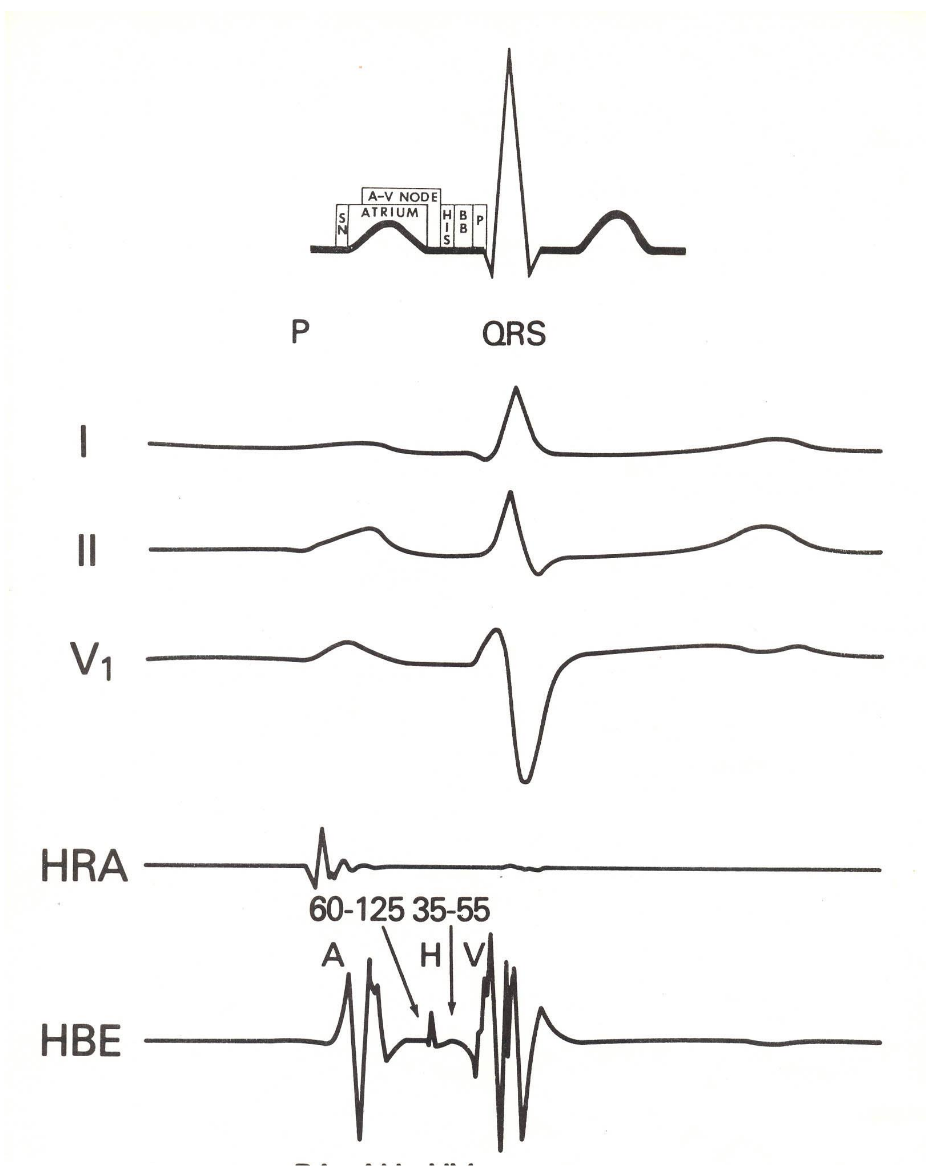


Activation (depolarization) and repolarization of the cardiac chambers is represented by deflections on the standard electrocardiogram. The P wave results from depolarization of the atria. It has a characteristic morphology during normal sinus rhythm. The normal P wave has a duration of 80 to 100 msec. Following the P wave, there is normally an isoelectric interval during which the normal wave front progresses through the AV node, His bundle, bundle branches, and Purkinje network. Because these components of the cardiac conducting system are composed of very small masses of tissue, they do not produce a recognizable deflection on the standard electrocardiogram. Thus, the electrocardiogram is isoelectric during this time. With the onset of activation of the ventricles by the Purkinje network, recognizable deflections again are produced, the QRS complex. The QRS complex results from activation (depolarization) of the ventricles. Following depolarization of the ventricles, there is again typically an isoelectric interval (the ST segment) followed by the T wave, which represents depolarization of the ventricles. You may observe that there is no named waveform representing atrial repolarization. Atrial repolarization occurs at the same time that ventricular depolarization is taking place. Because the ventricular muscle mass is so much greater than the atrial muscle mass, depolarization of the ventricles (represented by the QRS complex) dwarfs any wave produced by the relatively small atrial muscle mass. The normal duration of the QRS complex is 60 to 100msec. The normal PR interval is 120 to 200 msec in duration.

Components of the ECG:



Correlation between intracardiac electrical events and the standard ECG:



The electrocardiogram may be altered by a number of factors. Metabolic abnormalities affecting activation or repolarization of the atria and ventricles may produce changes. Abnormalities producing characteristic changes in the electrocardiogram include alterations in potassium and calcium concentrations, and events such as myocardial ischemia or infarction. Enlargement of cardiac chambers might also be expected to reduce abnormalities of the appropriate cardiac chamber. However, because the ECG is an electrical event, anatomic abnormalities, such as chamber hypertrophy or dilation may not always produce the expected changes in the electrocardiogram. It may be hazardous to attempt to infer too much anatomic information from the electrogram.

Changes in the P wave and QRS complex also result when conditions alter the normal sequence of activation of the respective chambers. Characteristic abnormalities are described when the sequence of atrial activation is disturbed, or when inter-atrial conduction is prolonged. Likewise, the QRS complex assumes characteristic abnormalities when the normal sequence of ventricular activation is perturbed.