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Biopac Student Lab® Lesson 6

ELECTROCARDIOGRAPHY (ECG) II
Introduction

Rev. 01152013

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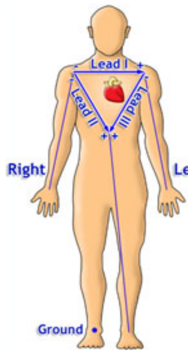

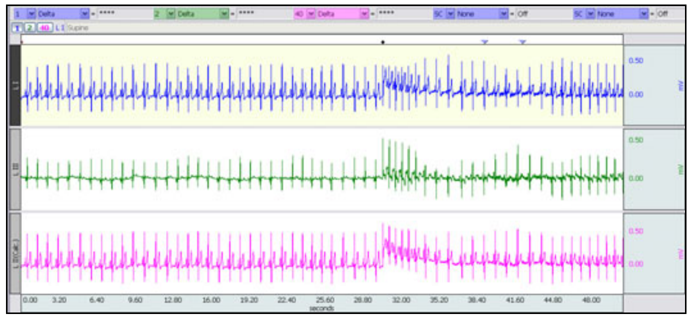

I. INTRODUCTION

Willem Einthoven developed a "string galvanometer" in 1901 that could record the electrical activity of the heart. Although it was not the first such recorder, it was a breakthrough in that it was accurate enough to duplicate the results on the same patient. Einthoven's work established a standard configuration for recording the ECG and won him the Nobel Prize in 1924. Since then, the ECG has become a powerful tool in diagnosing disorders of the heart. [It should be noted that the clinical interpretation of the ECG is quite empirical in practice, and has evolved from a long history of reference to and correlation with known cardiac disorders.]

> ***About Willem Einthoven:***
> 1860-1927
> Born in Semarang, Java
> Dutch physician
> Professor, University of Leiden, 1885-1927
> Nobel Prize: 1924

The electrical activity of each cardiac cycle begins with depolarization of the sinoatrial (SA) node, the primary pacemaker of the heart. The wave of depolarization spreads throughout the atria initiating contraction of atrial myocardium (see Lesson 5 ECG I for details.) Depolarization of the atria is recorded as the P wave of the ECG. Repolarization of the atria immediately follows the depolarization and occurs during the PR segment of the ECG. At the AV node, transmission of the electrical signal is slowed, allowing the atria sufficient time to complete their contraction, before the signal is conducted down the AV bundle, the left and right bundle branches, and the Purkinje fibers to ventricular myocardium. Depolarization of the ventricles is recorded as the QRS complex in the ECG, and repolarization of the ventricles is recorded as the T wave.

During the cardiac cycle, the current spreads along specialized pathways and depolarizes parts of the pathway in the specific sequence outlined above. Consequently, the electrical activity has directionality, that is, a spatial orientation represented by an electrical axis. The preponderant direction of current flow during the cardiac cycle is called the *mean electrical axis*. Typically, in an adult the mean electrical axis lies along a line extending from the base to the apex of the heart and to the left of the interventricular septum pointing toward the lower left rib cage.

The magnitude of the recorded voltage in the ECG is directly proportional to the amount of tissue being depolarized. Most of the mass of the heart is made up of ventricular myocardium. Therefore, the largest recorded waveform, the QRS complex, reflects the depolarization of the ventricles. Furthermore, since left ventricular mass is significantly greater than right ventricular mass, more of the QRS complex reflects the depolarization of the left ventricle, and orientation of the mean electrical axis is to the left of the interventricular septum.

The body contains fluids with ions that allow for electrical conduction. This makes it possible to measure electrical activity in and around the heart from the surface of the skin (assuming good electrical contact is made with the body fluids using electrodes.) This also allows the legs and arms to act as simple extensions of points in the torso. Measurements from the leg approximate those occurring in the groin, and measurements from the arms approximate those from the corresponding shoulder.

Ideally, electrodes are placed on the ankles and wrists for convenience to the subject undergoing the ECG evaluation. In order for the ECG recorder to work properly, a ground reference point on the body is required. This ground is obtained from an electrode placed on the right leg above the ankle. To represent the body in three dimensions, three planes are defined for electrocardiography (Fig. 6.1.) The bipolar limb leads record electrical activity of the cardiac cycle in the frontal plane and will be used in this lesson to introduce principles of vectorcardiography.

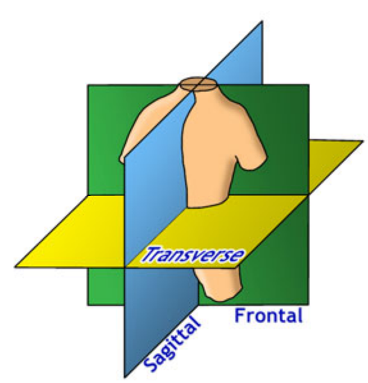

Fig. 6.1 ECG planes

A *bipolar lead* is composed of two discrete electrodes of opposite polarity, one positive and the other negative. A hypothetical line joining the poles of a lead is called the *lead axis*. The electrode placement defines the recording direction of the lead, when going *from the negative to the positive electrode*. The ECG recorder computes the difference (magnitude) between the positive and negative electrodes and displays the changes in voltage difference with time. A standard clinical electrocardiograph records 12 leads, three of which are called standard (bipolar) limb leads.

The standard bipolar limb leads, their polarity and axes are as follows:

Lead	Polarity	Lead Axis
Lead I	right arm (-) to left arm (+)	± 180° - 0°
Lead II	right arm (-) to left leg (+)	-120° - +60°
Lead III	left arm (-) to left leg (+)	-60° - + 120°

The relationships of the bipolar limb leads are such that the sum of the electrical currents recorded in leads I and III equal the sum of the electric current recorded in lead II. This relationship is called *Einthoven's law,* and is expressed mathematically as:

$$\text{Lead I} + \text{Lead III} = \text{Lead II}$$

It follows that if the values for any two of the leads are known, the value for the third lead can be calculated.

A good mathematical tool for representing the measurement of a lead is the vector. A *vector* is an entity that has both magnitude and direction, such as velocity. At any given moment during the cardiac cycle, a vector may represent the net electrical activity seen by a lead. An electrical vector has magnitude, direction, and polarity, and is commonly visualized graphically as an arrow:

- The length of the shaft represents the magnitude of the electrical current.
- The orientation of the arrow represents the direction of current flow.
- The tip of the arrow represents the positive pole of the electrical current.
- The tail of the arrow represents the negative pole of the electrical current.

The electric current of the cardiac cycle flowing toward the positive pole of a lead axis produces a positive deflection on the ECG record of that lead. An electric current flowing toward the negative pole produces a negative deflection. The amplitude of the deflection, negative or positive, is directly proportional to the magnitude of the current. If the current flow is perpendicular to the lead axis, no deflection is produced in the record of that lead. It follows that for as given magnitude of electrical current, the largest positive deflection will be produced by current flowing along the lead axis toward the positive pole, and the largest negative deflection produced by current flowing along the lead axis toward the negative pole (Fig.6.2) When the direction of current flow is between the lead axis and its perpendicular, the deflection is smaller. This is true for current flowing away from as well as toward the positive pole.

Due to the anatomy of the heart and its conduction system, current flow during the electrical cardiac cycle is partly toward and partly away from the positive pole of the bipolar limb leads. This may produce a biphasic (partially +, partially -) deflection on ECG lead record. A good example is the coupled Q-R or R-S deflections of the QRS complex typically seen in Lead II. At any given moment, the bidirectional electric current can be represented by a single mean vector that is the average of all the negative and positive electrical vectors at that moment (Fig. 6.3.)

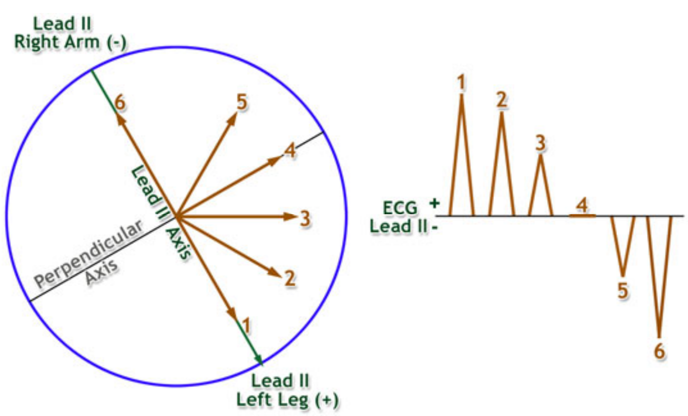

Fig. 6.2

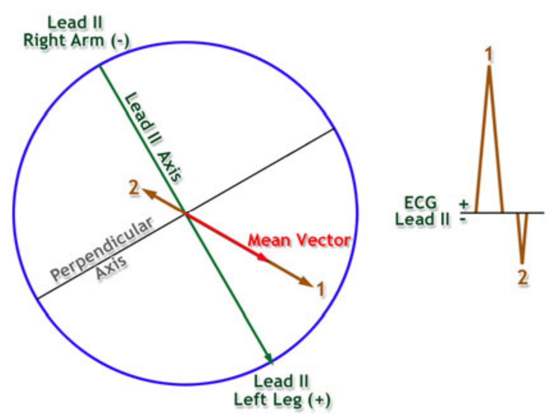

Fig. 6.3

The bipolar limb lead axes may be used to construct an equilateral triangle, called Einthoven's triangle, at the center of which lies the heart (Fig. 6.4.) Each side of the triangle represents one of the bipolar limb leads. The positive electrodes of the three bipolar limb leads are electrically about the same distance from the zero reference point in the center of the heart. Thus, the three sides of the equilateral triangle can be shifted to the right, left, and down without changing the angle of their orientation until their midpoints intersect at the center of the heart (Fig. 6.4.) This creates a standard limb lead vectorgraph with each of the lead axes forming a 60-degree angle with its neighbors. The vectorgraph can be used to plot the vector representing the mean electrical axis of the heart in the frontal plane.

A vector can represent the electrical activity of the heart at any instant in time. The mean electrical axis of the heart is the summation of all the vectors occurring in a cardiac cycle.

Since the QRS interval caused by ventricular depolarization represents the majority of the electrical activity of the heart, you can approximate the mean electrical axis by looking only in this interval, first at the R wave amplitude, and then at the combined amplitudes of the Q, R, and S waves. The resultant vector, called the QRS axis, approximates the mean electrical axis of the heart.

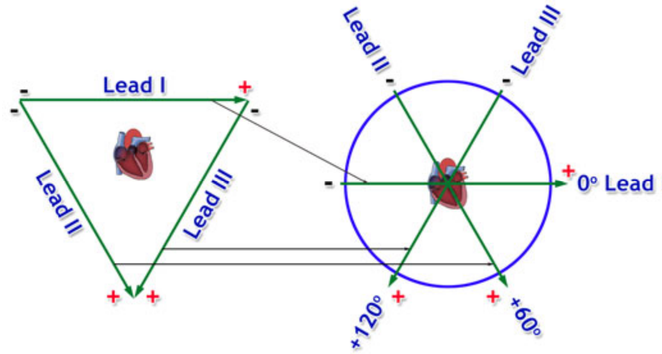

Fig. 6.4

An initial approximation of the mean electrical axis in the frontal plane can be made by plotting the magnitude of the R wave from Lead I and Lead III (Fig. 6.5.) To plot R wave magnitude:

1. Draw a perpendicular line from the ends of the vectors (right angles to the axis of the Lead.)
2. Determine the point of intersection of these two perpendicular lines.
3. Draw a new vector from point 0,0 to the point of intersection.

The direction of the resulting vector approximates the mean electrical axis of the heart. The length of the vector approximates the mean potential of the heart.

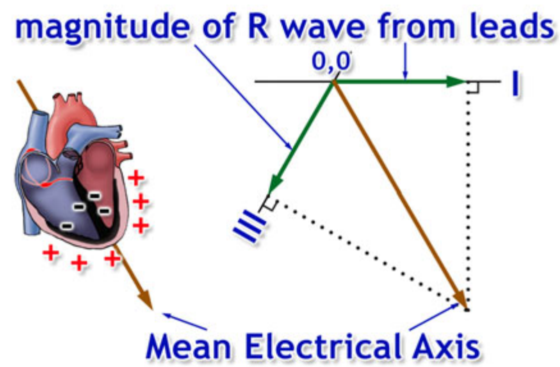

Fig. 6.5

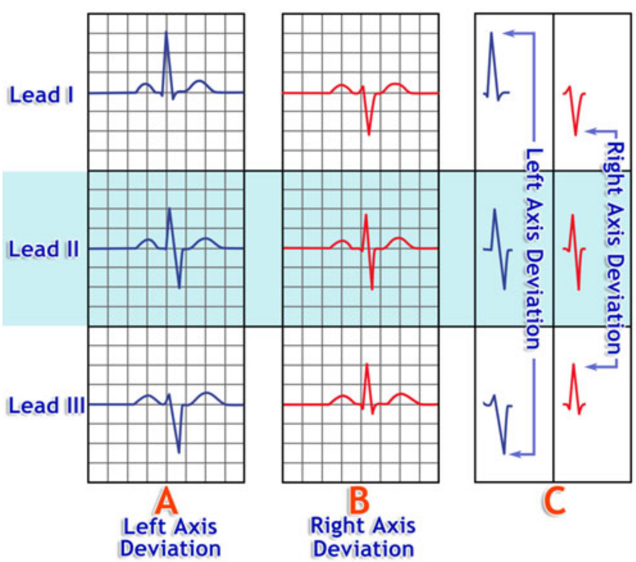

Fig. 6.6

A more accurate method of approximating the mean electrical axis is to algebraically add the Q, R, and S potentials for one lead, instead of using just the magnitude of the R wave. The rest of the procedure would be the same as outlined above.

The normal range of the mean electrical axis of the ventricles is approximately -30° to +90°. The axis may shift slightly with a change in body position (e.g., standing versus supine) and variation among individuals within the normal range occur as a result of individual differences in heart mass, orientation of the heart in the thorax, body mass index, and the anatomic distribution of the cardiac conduction system.

A shift in the direction of the QRS axis from normal to one between -30° and -90° is called left axis deviation (LAD.) Left axis deviation is abnormal and results from conditions that cause the left ventricle to take longer than normal to depolarize. One example is hypertrophy (enlargement, and hence a longer conduction pathway)) of the left ventricle associated with systemic hypertension or stenosis (narrowing) of the aortic valve.

Left axis deviation may also occur when the conduction pathway or the left ventricular myocardium is damaged, creating blockage and slowing of the depolarization signal. Common causes of this include coronary occlusion (spasm, thrombosis, etc.) and injuries resulting from drug usage. Fig. 6.6A shows typical ECG patterns of Leads I, II, and III associated with LAD.

A shift in the direction of the QRS axis from normal to one between +90° and +180° is called right axis deviation (RAD.) In some cases right axis deviation may be normal, such as in young adults with long narrow chests and vertical hearts, but in the majority of adults, right axis deviation generally is associated with hypertrophy of the right ventricle or damage to the conduction system in the right ventricle. In both conditions, the right axis deviation results from a slowing or blockage of the depolarization signal for the right ventricle. Fig. 6.6B shows typical ECG patterns of Leads I, II, and III associated with RAD. A convenient method of differentiating LAD and RAD is to examine the QRS patterns of Leads I and III. A pattern where the apices of the QRS complexes go away from each other is left axis deviation (Fig. 6.6C.) A pattern where the apices approach one another is right axis deviation.