Differential Diagnosis of THE ELECTROCARDIOGRAM

ARBEIT
•
RUBIN
•
GROSS

ASIAN EDITION

F. A. DAVIS COMPANY, *Publishers*
PHILADELPHIA

HAKKO COMPANY LIMITED
TOKYO

Differential Diagnosis *of* THE ELECTROCARDIOGRAM

SIDNEY R. ARBEIT, M.D., F.A.C.C.

Associate Professor of Clinical Medicine, Seton Hall College of Medicine, Attending Physician, Jersey City Medical Center; Associate Attending Physician, Medical Division, Montefiore Hospital, New York City

IRA L. RUBIN, M.D., F.A.C.P., F.A.C.C.

Assistant Clinical Professor of Medicine, Columbia University
Attending Physician, Medical Division, Montefiore Hospital, New York City; Visiting Physician, Bronx Veterans Administration Hospital; Visiting Physician in Cardiovascular Disease, Morrisania City Hospital

HARRY GROSS, M.D., F.A.C.P.

Assistant Clinical Professor of Medicine, Columbia University, Attending Physician, Medical Division Montefiore Hospital, New York City; Director of Cardiology, City Hospital at Elmhurst, New York City

Illustrated

F. A. DAVIS COMPANY · *PUBLISHER* · PHILADELPHIA

ASIAN EDITION 1967

Hakko Company Limited Tokyo

書　　名 Differential Diagnosis of the ELCTROCARDIOGRAM

Original published in 1960
Asian reprinted in 1967

著　　者 SIDNEY R. ARBEIT, M.D., F.A.C.C.
IRA L. RUBIN, M.D., F.A.C.P., F.A.C.C.
HARRY GROSS, M.D., F.A.C.P.

原書出版者 F.A. DAVIS COMPANY Philadelphia, Pa., U.S.A.

版権所有出版者 HAKKO COMPANY LIMITED TOKYO JAPAN
八光株式会社
取締役社長 本司總一
東京都品川区西品川2丁目18番4号
電話 (492) 8 1 5 9
振替口座 東京 5 7 2 8 1番

Third Printing, March 1964

PRINTED IN THE UNITED STATES OF AMERICA
Library of Congress Catalog Card Number 60-7802

Reproduced in Japan by
Hakko Company Limited, Tokyo, Japan
under the contract with F. A. Davis Company,
Philadelphia, U.S.A.

PRINTED AND BOUND IN JAPAN

Preface

THIS BOOK is primarily a reference manual for the practicing physician. It is designed to enable the clinician who is not an expert in electrocardiography to establish a diagnosis from an unknown electrocardiogram or to confirm his previously made diagnosis.

This is accomplished by describing and illustrating easily detected deviations from the normal in the individual component parts of the electrocardiographic complex and presenting a comprehensive differential diagnosis based on these deviations. By this method we feel that the reader can reach a correct diagnosis in over ninety-five percent of the electrocardiograms encountered in clinical practice.

The book is divided into three parts. The first section deals with the normal and abnormal physiology of the origin and propagation of the electrical forces in the heart recorded in the electrocardiogram. A detailed description of the normal electrocardiogram is included.

The second section treats the differential diagnosis of the electrocardiogram. When an abnormality of any specific segment or segments of the electrocardiogram—the P, Q, QRS, ST, or T—is identified, the table of contents is consulted for the section and page where the differential diagnosis of this abnormality is presented. Changes occurring in serial electrocardiograms are also considered in the last part of this section.

The last section is devoted to descriptions of electrocardiographic patterns in specific disease states and to discussions of the clinical implications of various electrocardiographic abnormalities.

This book can, therefore, be used in several different ways:

Given an unknown electrocardiogram, a specific electrocardiographic diagnosis can be reached.

Given a correctly interpreted electrocardiogram, its clinical implications can be found.

Given a clinical diagnosis, the various electrocardiographic patterns associated with it can be ascertained.

We are happy to acknowledge our indebtedness to:

Felix Traugott, Director of the Department of Medical Illustrations, Jersey City Medical Center, who made all the illustrations in this book.

Miss Martha Margolin, for invaluable secretarial assistance.

Dr. Sidney P. Schwartz, Attending Cardiographer, Montefiore Hospital, for his stimulation and encouragement in the preparation of this book.

SIDNEY R. ARBEIT
IRA L. RUBIN
HARRY GROSS

Contents

PART I

PRINCIPLES OF ELECTROCARDIOGRAPHY

PART II

DIFFERENTIAL DIAGNOSIS BASED ON ABNORMALITIES OF THE ECG

PART III

CLINICAL CARDIOGRAPHY

Part I

PRINCIPLES OF ELECTROCARDIOGRAPHY

CHAPTER 1

Electrophysiology of the Normal Heart

IN THIS SECTION a brief description of the genesis of the electrical forces generated in the normal heart is presented. The alterations associated with disease states of the heart are then considered. Explanations of the electrophysiology of both the normal and the abnormal have been chosen for their simplicity and general acceptance. We feel it necessary to avoid controversial aspects of the subject. Detailed mathematical and laboratory background is beyond the scope of this book and may be readily found in other texts where the topic is treated in detail.

Only a few elementary basic electrical principles are presented in this chapter. A knowledge of these will aid materially in understanding the derivation of the electrocardiogram.

BASIC ELECTRIC THEORY

If a positive and negative pole (source and sink of current) are placed in a volume conductor in infinitely close proximity to each other, a dipole will be formed (Fig. 1). The pattern of current flow between these oppositely charged poles is dependent upon the conductivity of the medium. If the medium is highly conductive, current will flow from one pole to the other in a straight line as if through a copper wire and there will be no current flow or voltage disturbance in the surrounding medium. When the medium is resistive and homogeneous, the current cannot flow directly between the poles and must follow a longer and more complex pathway through the medium (Fig. 1). The voltage potential distribution associated with this current flow in the surrounding field and upon its surface is shown in Figure 2.

These voltage changes can be recorded at the boundary of the finite, homogeneous conducting medium by a voltmeter. The maximum voltage is recorded at the points where a line through the two poles of the dipole is projected to the boundary. A plane perpendicular to this line and between the two poles is at zero potential. On the positive side of the plane, progressively increasing positive voltages are recorded until the maximum is reached on the line of the dipole. On the negative side of this plane, progressively increasing negative voltage is recorded in a like manner.

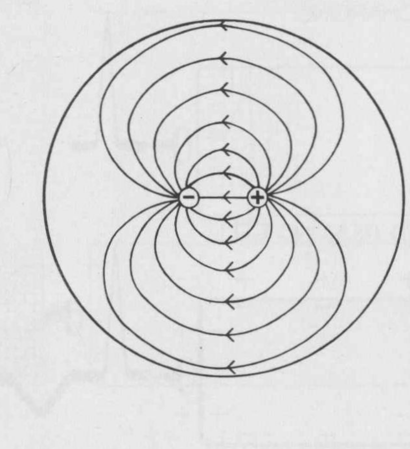

FIGURE 1. Current flow between the poles of a dipole in a homogeneous, finite conductive medium.

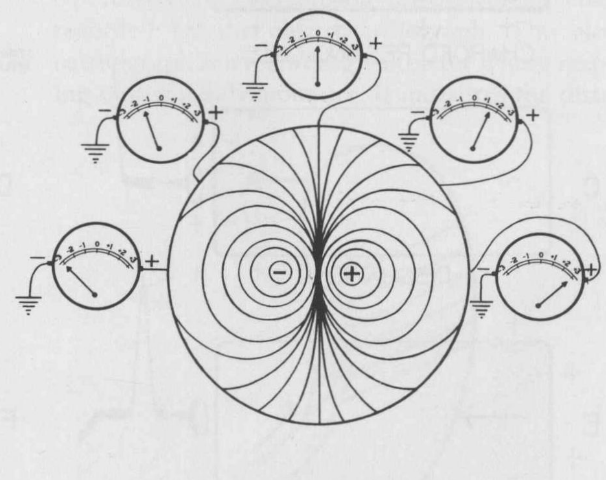

FIGURE 2. Voltage distribution at the boundaries of the medium associated with the current flow pattern of Figure 1.

The intensity of the voltage measured at the boundary of the medium falls at a rate proportional to the square (or some higher power) of the distance from the source. Despite the lower voltage recorded, the distribution of positive and negative voltages remains the same.

From the electrical point of view, the heart may be viewed as a source of electromotive force lying near the center of the body. The body is a three-dimensional figure which may be considered as a uniform, finite, homogeneous volume conductor. The flow of current within the body which results from activation of myocardial cells is associated with changes in voltage which may be measured at the boundaries of the body—the skin.

THE CELL AS A SOURCE OF ELECTRICAL POTENTIALS

The source of the electrical activity of the heart is the myocardial cell. In the resting state this cell is at zero potential and there is no electrical activity or field. The cell is actually charged, but the positive charges on the outside of the cell and the negative charges on the inside are insulated from each other by the high resistance of the cell membrane (Fig. 3A). If the cell is not disturbed, there is no flow of current and no measurable voltage in the surrounding field.

When a stimulus is applied to this resting cell, it causes the cell membranes to become permeable to the flow of ions. The opposing positive and negative charges promptly neutralize each other at the point of the applied stimulus, causing this point to become negative with respect to the as yet unaffected portion of the cell (Fig. 3B). In the field surrounding the cell, there will now be a measurable flow of current secondary to this voltage differential. The loss of electrical resistance and the resultant electrical permeability of the cell membranes spread in a wavelike fashion from the point of stimulation to the far end of the cell, the depolarization or excitation wave (Fig. 3C).

When the dipole has moved the entire length of the cell, the cell becomes devoid of all electrical charge and, therefore, as in the resting state, the measured potential in the surrounding field is zero (Fig. 3D). The cell is now described as depolarized. Mechanical contraction follows immediately.

Following depolarization, the cell by its metabolic activity restores itself to its previous resting charged state and the membrane resumes its function of separating the external positive charges from the internal negative charges. In the isolated cell this process also spreads in a wavelike fashion through the length of the cell, starting from the point initially stimulated and following the path of the wave of depolarization. This is the repolarization wave (Fig. 3E).

Electrically, the repolarization wave acts as if it too were a dipole with its positive pole at the first point depolarized and the negative facing the remainder of the cell, the reverse of the depolarization process. As this reversed dipole moves down the length of the isolated myocardial cell, it produces an electrical field opposite in sign to the excitation wave. The recorded voltages are, therefore, opposite in direction to those of the depolarization wave. When the entire cell is repolarized there is no further electrical activity and the cell resumes its charged resting state (Fig. 3F).

Since active metabolism of the cell is required for repolarization, the process takes more time and the

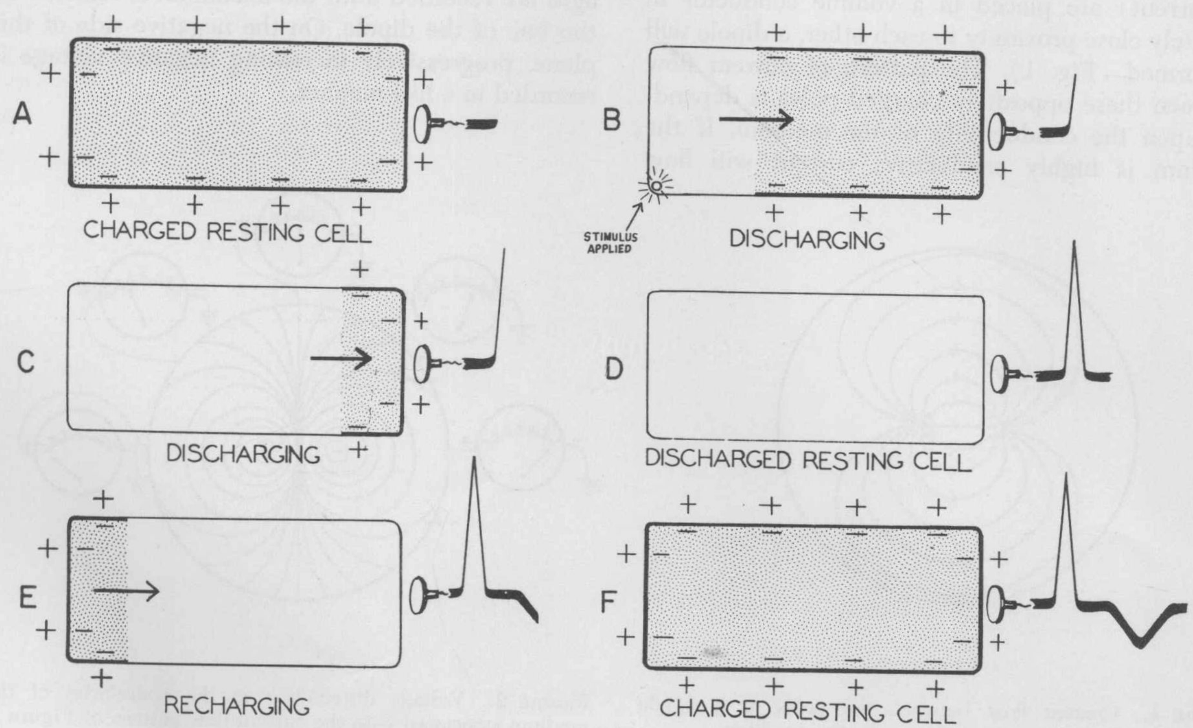

FIGURE 3. See text.

voltage measured is of lower amplitude, though of longer duration, than that of depolarization. However, the total current that flows in depolarization and repolarization is equal. The voltages measured during each process are also equal, although opposite in direction.

Accompanying reorientation of charges on the cell, there are shifts of potassium and sodium into and out of the cell. The mechanism for this shift, its significance and its relation to the electrical activity are not clearly established at this time. Depolarization, or the wave of excitation, may, according to Wilson, be thought of as the crest of a wave, preceded by a positive pole and followed by a negative pole. It may also be conceived of as a dipole whose positive pole is the source of electric current and whose negative is the point to which this current flows, the sink. In electric theory these are infinitely close to each other. The dipole moves in the direction of the wave of excitation. A positive voltage is recorded on the side toward which the positive pole of the dipole is moving. A negative voltage is recorded from the side facing the negative pole of the dipole (Fig. 4). If the dipole passes under a measuring electrode, a diphasic curve is recorded, one that rises as the dipole approaches it, falls to zero as the dipole passes under it, and becomes negative as the dipole moves away from it.

THE HEART AS A SOURCE OF ELECTRICAL POTENTIALS

The human heart behaves electrically as if it consisted of a mass of such single cells, all parallel to each other, oriented with one end at the endocardial and the other at the epicardial surface (Fig. 5). The wave of depolarization starts at the endocardial surface and spreads to the epicardial surface. The depolarization process causes the QRS wave and the repolarization process, the T wave. During the interval between them (the S-T segment), there is no dipole and no voltage is recorded. The sequence of events occurring in the isolated cell (repolarization opposite in polarity to depolarization) would result in a T wave opposite in sign to the QRS. However, in the intact heart, which is a syncytium of myocardial cells, the resultant electrical voltages measured make it appear that the repolarization proceeds in the direction opposite to depolarization. The last part depolarized (the epicardium) is also the first repolarized. Contrary to the findings in the isolated cell, the repolarization wave, the T wave of the human heart, lies in approximately the same direction as the depolarization wave, the QRS.

In the intact human heart there are innumerable dipoles moving in many directions at the same time. The voltages from those moving in opposite directions tend to cancel each other. Those moving in the same direction are added. Those moving in divergent directions are added geometrically. The vectorial sum of all of these voltages at each successive instant during the cardiac cycle (the over-all dipole) may be considered as the single electromotive force (emf) responsible for the voltage changes recorded by the electrocardiograph. The electrocardiograph is a recording voltmeter whose responding unit is a galvanometer. It measures the distribu-

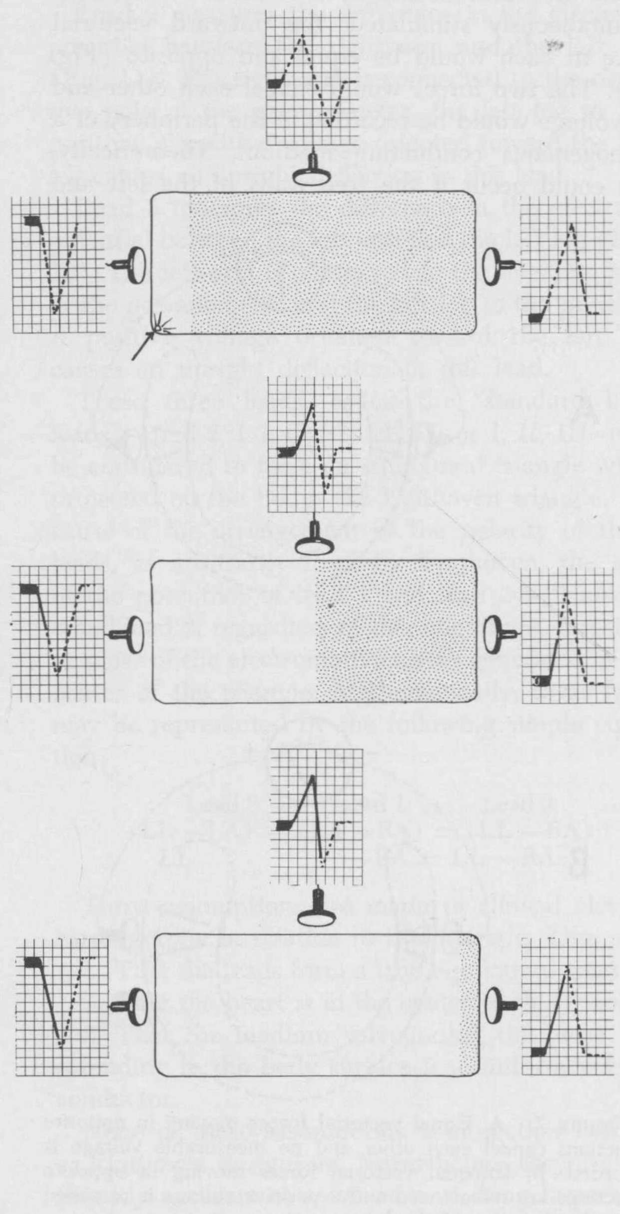

FIGURE 4. See text.

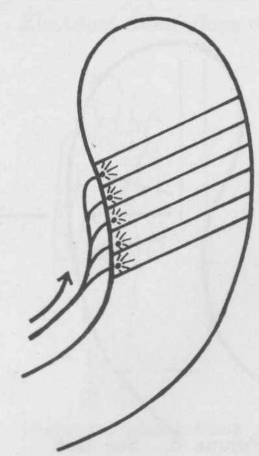

FIGURE 5. See text.

tion of these voltages at the periphery (boundary) of the body—the skin.

In clinical electrocardiography it is assumed that the heart lies in the center of the body and that the surrounding structures are homogeneous conductors of electricity.

Various lead points on different parts of the body record different views of this over-all dipole which is constantly moving in space during the entire period of electrical activity in the heart. However, they are all recording the only one electromotive force from the heart that is available to us in clinical electrocardiography.

VECTORIAL PRESENTATION OF THE ELECTROMOTIVE FORCE OF THE HEART

In electrocardiography the geometric sum of all of the electromotive forces at any instant is represented by a vector. All vectors are characterized by three qualities: magnitude, the total measured force; direction, or pathway; and sense, or orientation in space.

This concept is better visualized if we consider an isolated block of the left ventricle. In this block, multi-directional, simultaneous dipoles may be represented at each instant by a single vector—the geometric sum of all these dipole forces (Fig. 6).

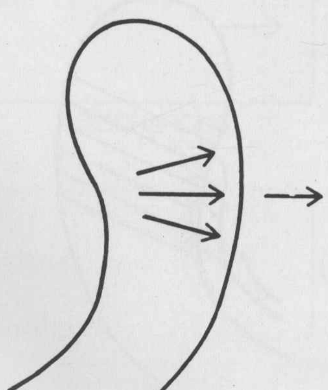

FIGURE 6. See text.

If this isolated block of the myocardium were opposed by an equal and oppositely placed block of the myocardium and both of these blocks were simultaneously stimulated, the outward vectorial force in each would be equal and opposite (Fig. 7A). The two forces would cancel each other and no voltage would be recorded at the periphery of a homogeneous conducting medium. Theoretically, this could occur if the free walls of the left and right ventricles were of equal thickness and were the only two portions of the myocardium being depolarized at that instant.

If one of these forces were larger than the other, we would measure the resultant imbalanced voltage (Fig. 7B). Since the left ventricle is thicker and contains more cells than the right, it is a source of greater electromotive force than the right and, therefore, dominates the electrical field of the heart and contributes the greatest voltage to the electrocardiogram.

At each successive instant, different portions of the myocardium are undergoing depolarization. The instantaneous vector representing the vectorial sum of these forces is continuously changing in magnitude and direction during the entire cardiac cycle. If a vector is drawn for each successive instant during the entire cycle and the tips connected by a curved line, this curved line is the vectorcardiogram (Fig. 8). The electrocardiograph records this same electrical activity as a scalar quantity plotted against time.

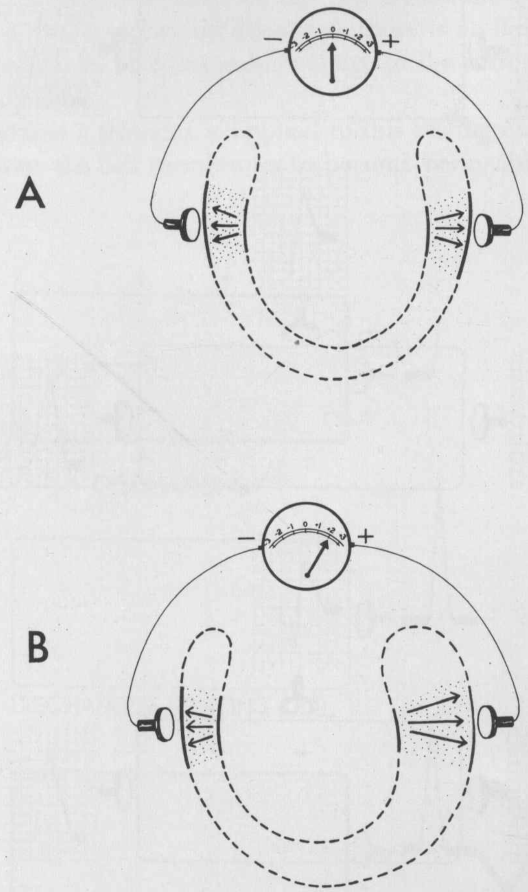

FIGURE 7. A, Equal vectorial forces moving in opposite directions cancel each other and no measurable voltage is recorded. B, Unequal vectorial forces moving in opposite directions are unbalanced and a positive voltage is recorded from the direction of the larger vector.

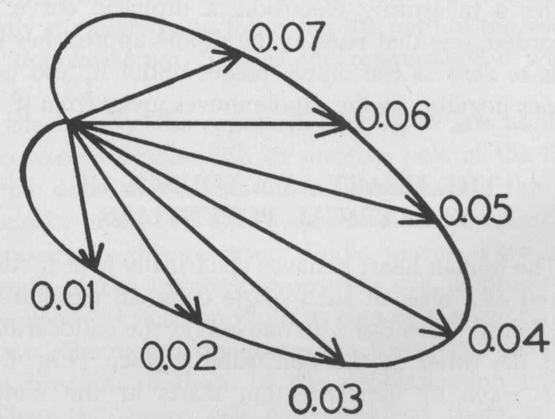

FIGURE 8. The vectorcardiogram constructed from a series of instantaneous vectors of the depolarization process, 0.01 second apart.

CLINICAL RECORDING OF THE ELECTROMOTIVE FORCE OF THE HEART IN THE FRONTAL PLANE

The body may be viewed as a cylinder from which information about the electrical changes taking place within it are derived by leads properly oriented in any of its three planes (Fig. 9). By convention, the electrocardiogram is derived from two of these three planes, the frontal and the horizontal. Leads 1, 2 and 3 and the unipolar limb leads constitute the frontal plane leads. The precordial chest leads, the V leads, constitute the horizontal plane leads.

Standard Leads (L1, L2, L3). The frontal plane leads are connected to the extremities, the right arm, the left arm and the left leg. The right leg lead is used to ground the body to the direct writing electrocardiograph and does not contribute any voltage to the electrocardiogram. Lead 1 measures the difference in the electrical potential between the right arm and the left arm (Fig. 10). The right arm is connected to the negative pole of the galvanometer, the left to the positive pole. A positive voltage oriented toward the left arm causes an upright deflection in the electrocardiogram.

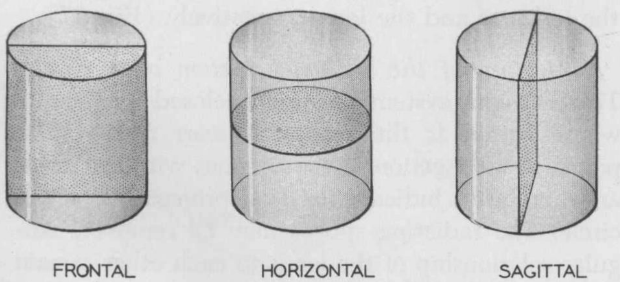

FIGURE 9. Diagrammatic illustration of the three planes of a cylinder representing the human torso.

Lead 2 measures the difference in the electrical potential between the right arm and the left leg (Fig. 11). The right arm is connected to the negative pole of the galvanometer, the left leg to the positive. A positive voltage oriented toward the left leg causes an upright deflection in this lead.

Lead 3 measures the difference in the electrical potential between the left arm and the left leg (Fig. 12). The left arm is connected to the negative pole of the galvanometer and the left leg to the positive. A positive voltage oriented toward the left leg causes an upright deflection in this lead.

These three leads, called the "standard limb leads"–L1, L2, L3; or S1, S2, S3; or I, II, III–may be considered to form an equilateral triangle when projected on the body–the Einthoven triangle. Because of the arrangement of the polarity of these leads, as arbitrarily fixed by Einthoven, the sum of the potentials of lead 1 and lead 3 will always equal lead 2, regardless of the magnitude, direction or sense of the electromotive forces generated at the center of the triangle. Mathematically, these facts may be represented by the following simple equation:

$$\text{Lead 3} + \text{Lead 1} = \text{Lead 2}$$
$$(LL - LA) + (LA - RA) = (LL - RA)$$
$$LL - RA = LL - RA$$

Three assumptions are made in clinical electrocardiography in relation to this triangle. They are:

1. That the leads form a true equilateral triangle;
2. That the heart is in the center of this triangle;
3. That the medium surrounding the heart and extending to the body surface is a uniform volume conductor.

None of these assumptions is altogether correct, as Einthoven recognized. Nevertheless, they are sufficiently accurate to serve as a working hypothesis in electrocardiography.

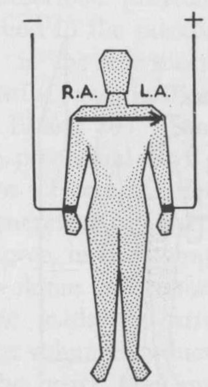

FIGURE 10. Electrical connections of standard lead 1.

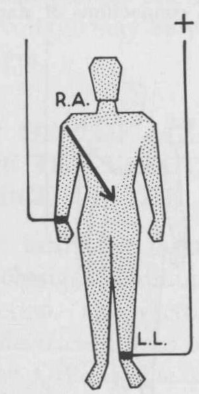

FIGURE 11. Electrical connections of standard lead 2.

FIGURE 12. Electrical connections of standard lead 3.

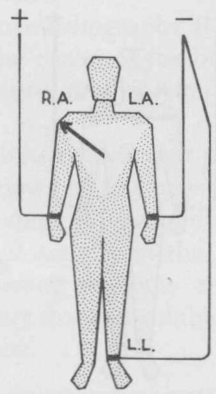

FIGURE 13. Electrical connections of standard lead aV_R.

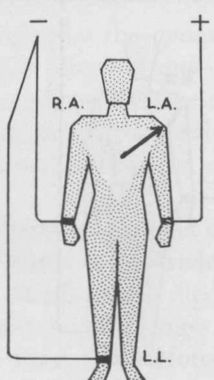

FIGURE 14. Electrical connections of standard lead aV_L.

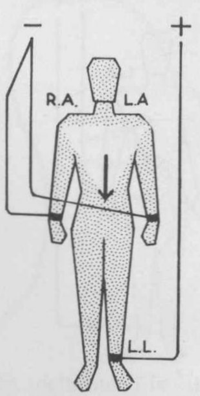

FIGURE 15. Electrical connections of standard lead aV_F.

Unipolar Extremity Leads (aV_R, aV_L, aV_F). Wilson devised a method for recording additional information from the frontal plane leads. By connecting the wires attached to the right arm, left arm and left leg through resistors, a new terminal, the Wilson Central Terminal, was formed. This terminal was connected to the negative pole of the electrocardiograph. At this terminal the voltage fluctuation throughout the entire cardiac cycle was theoretically zero and actually negligible. The positive electrode of the electrocardiograph is placed on any of the three extremities. The negative is connected to the Wilson Central Terminal. By this means a new electrocardiographic lead, the unipolar limb lead, is obtained. Since the Wilson Central Terminal is theoretically always at zero potential, the exploring or positive electrode will record only the potential changes from the extremity to which it is attached. The leads derived by placing the exploring electrode on the right arm, left arm and left leg, are called, respectively, "V_R," "V_L" and "V_F." If the electrical connection between the central terminal and the limb being explored is removed, the recorded voltage is increased, yielding a larger, more easily read complex. Leads recorded in this manner are called "Goldberger leads" or "augmented unipolar limb leads"—aV_R, aV_L and aV_F (Figs. 13-15).

In spite of the fact that the removal of one connection to the central terminal invalidates the concept of the zero potential central terminal, the resultant complexes are practically identical with those derived from the "true" unipolar leads and are generally accepted in practice today.

Angular Relationships between the Frontal Plane Leads. The relationship between the limb leads and the unipolar leads is a precise mathematical one. However, we shall avoid the mathematics and present rather their visual or pictorial relationship.

Triaxial System. The triaxial reference system of Bayley is a convenient method for presentation of the internal electromotive forces in the frontal plane as recorded by the standard limb leads 1, 2 and 3.

The horizontal top line of the Einthoven triangle, representing lead 1, connecting the right arm to the left arm, may without loss of accuracy be displaced downward until it passes through the center of the electrical field of the heart (Fig. 16).

Lead 2, the left diagonal of the Einthoven triangle, may be displaced to the right without change in its angular relation to lead 1.

In similar fashion, lead 3, the right leg of the triangle, may be moved to the left.

All three lines cross at one point, the electrical center of the heart.

Hexaxial System. The unipolar limb leads can conveniently be added to the triaxial reference system to form a hexaxial reference system. These three leads—aV_R (the augmented unipolar right arm lead), aV_L (the augmented unipolar left arm lead), and aV_F (the augmented unipolar left leg lead)—may be thought of as direct lines from the center of the heart (zero potential point) to the right arm, the left arm and the legs, respectively (Fig. 17).

Projection of the Hexaxial System on a Circle. This hexaxial system may be enclosed in a circle whose center is the electrical heart center. The points of intersection of the six lines with the circle are marked to indicate the lead projections on the circle. The radiating spokes may be removed. Angular relationship of the leads to each other remain the same (Fig. 18). Lead 1 is at zero degrees; aV_L, 30 degrees to the left of it, at minus 30; lead 2, at plus 60 degrees. The mirror image of aV_R, minus aV_R, lies midway between leads 1 and 2, at plus 30 degrees; aV_F at plus 90; and lead 3 at plus 120.

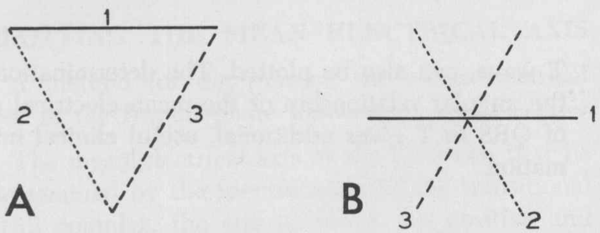

FIGURE 16. A, Einthoven triangle formed by standard leads 1, 2 and 3. B, Triaxial reference system of Bayley formed by the displacement of the three sides of the Einthoven triangle so that they cross at a single, central point.

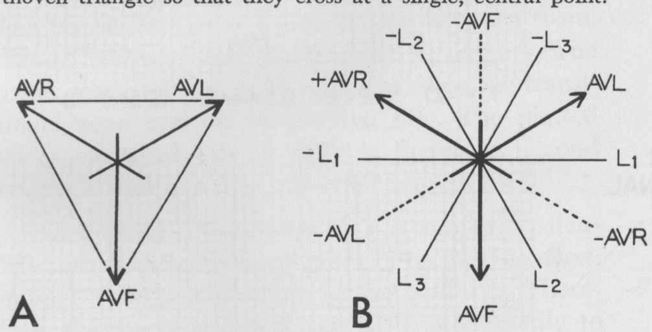

FIGURE 17. A, The unipolar limb leads are shown arising from a single point in the center of the Einthoven triangle. B, The unipolar limb leads are superimposed on the Bayley triaxial system to form a hexaxial reference system.

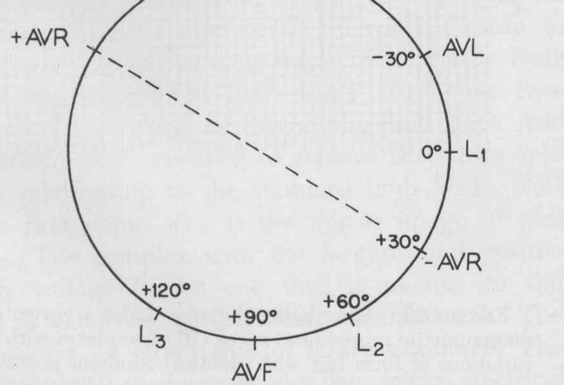

FIGURE 18. The projection of the hexaxial reference system onto a circle. The radiating spokes are removed. The angular relationship between the various frontal plane leads is indicated in the diagram. The dotted line indicates the relationship of +AVR to —AVR, its mirror image.

CLINICAL RECORDING OF THE ELECTROMOTIVE FORCE OF THE HEART IN THE HORIZONTAL PLANE (PRECORDIAL LEADS V_1 TO V_6)

Additional information may be derived as to the nature of the internal electromotive forces in the heart by taking the precordial or V leads. These record information in a horizontal plane through the body at about the level of the fourth or fifth intercostal space.

These leads are constructed as follows: The indifferent or negative electrode is the Wilson Central

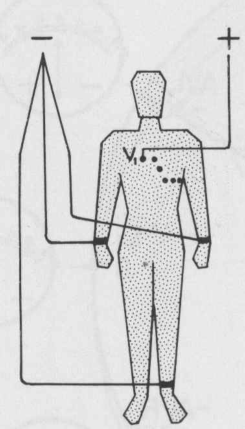

FIGURE 19. Electrical connections for taking the precordial V leads.

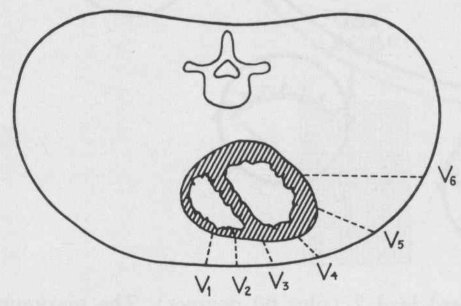

FIGURE 20. Diagrammatic relationship of the V leads to the heart.

Terminal, as described previously. The exploring electrode attached to the positive pole of the electrocardiograph is moved successively through a series of arbitrarily fixed positions on the chest, the V leads (Figs. 19 and 20). (See p. 17 for the exact location of the precordial lead positions.)

We now have a frame of reference for recording the voltage generated by the heart, a source of electromotive force, in the living body, a presumed homogeneous volume conductor. The clinical electrocardiographic leads are arranged around the periphery of the volume conductor. As voltages are generated in the heart, they may be measured at these various lead points. The form and amplitude of the internal voltage may be visualized from these measured voltages.

DERIVATION OF THE MEAN ELECTRICAL AXIS OF THE ELECTROMOTIVE FORCE OF THE HEART

In the intact heart the instantaneous vector of depolarization changes continuously in both amplitude and direction. The vectorial sum of all the instantaneous electrical forces occurring during depolarization, the QRS, is the mean electrical axis (MEA) of QRS.

The electrode toward which the vector points will record the maximum positive voltage, while that away from which the vector points will record the maximum negative voltage. A plane at right angles to the mean vector defines the zone of zero voltage, the null point or transitional zone of that instantaneous vector (Fig. 21). At this point the positive and negative voltages are equal. The resultant complex can be either a straight line or a diphasic curve whose total positive and negative voltages equal each other.

For investigational purposes the exact measurement of the area under the wave is indispensable. For clinical purposes, however, simple inspection of the diphasic curve is usually sufficient to determine net positivity or negativity (Fig. 22).

The measurement of the mean electrical axis of the QRS, particularly in the frontal plane, is a useful clinical tool. It can be calculated relatively easily and frequently aids in the differentiation of a normal from an abnormal electrocardiogram. Similarly, the mean electrical axis of the repolarization wave, the T wave, can also be plotted. The determination of the angular relationship of the mean electrical axis of QRS to T gives additional, useful clinical information.

10

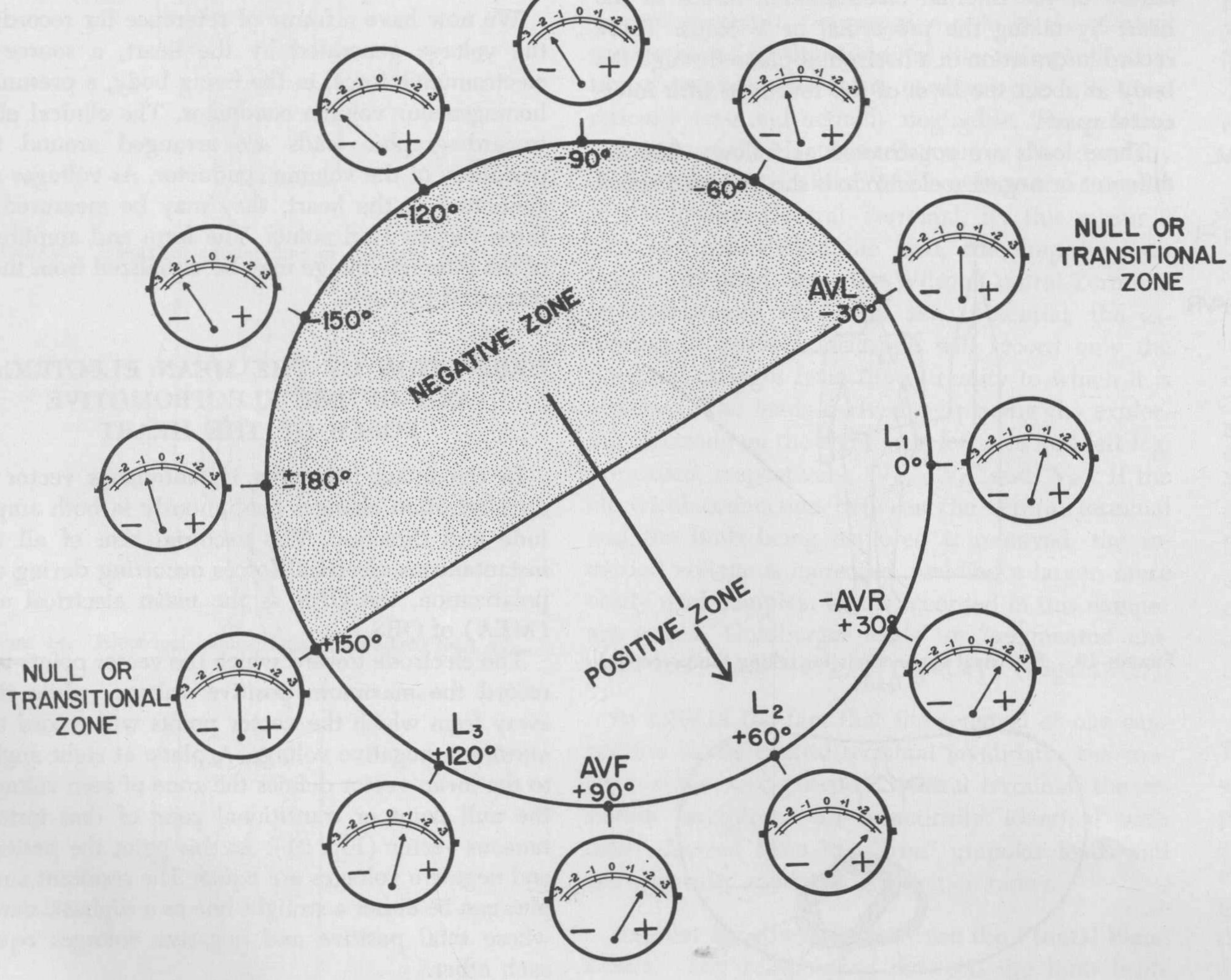

FIGURE 21. The mean vector of depolarization is directed toward lead 2 (plus 60 degrees). The maximum voltage is recorded at this lead position. The maximum negative voltage is recorded 180 degrees away, at minus 120 degrees. At right angles to the axis of the vector there is a null or transitional zone where the sum of the recorded voltages is zero. In this illustration it is located at minus 30 degrees, aV$_L$, and at plus 150 degrees. All voltages recorded in front of the null zone are resultantly positive. All behind it are negative.

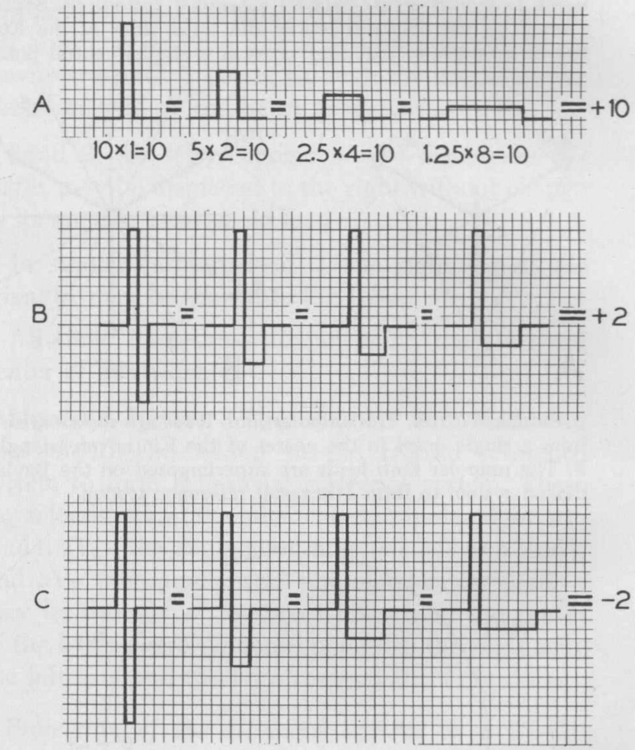

FIGURE 22. Calculating the area under a curve. A, Four diagrammatic representations of QRS complexes with marked variations of form but with identical resultant positivity. All enclose ten boxes. B, Four diagrammatic QRS complexes, in all of which the R waves are constant in form and amplitude and enclose ten boxes. The S waves vary in form and amplitude but all enclose the same total area—eight boxes. The QRS, therefore, is resultantly positive by two boxes. C, Similar to "B" except that the area under the S is now twelve boxes and the QRS complex is, therefore, resultantly negative.