The Relationship of Unipolar Chest Leads to the Electrical Field of the Heart

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Using a method for measuring the electrical forces of the human heart in three dimensional space, studies of the precordial leads are reported which were designed to determine whether these deflections are principally measurements of the electrical field of the heart as a whole or are dominated by the forces from the region of the heart immediately beneath the electrode. It was found that the former was the case, which leads to a simpler and more rational method for interpreting the electrocardiogram than has been available heretofore.

The interpretation of the QRS and T deflections in the precordial electrocardiogram has been empiric and uncertain because it has not been known to what extent the precordial lead deflections are measurements of the potential variations of the portion of the ventricular myocardium directly beneath the electrode and to what extent they represent the potential variations of the ventricular muscle as a whole. This shortcoming does not exist in interpretation of the limb leads. The limb lead electrodes are so remote electrically from the heart that, in effect, they record the potential variations of the heart as a whole, that is, if there were single central dipoles for the excitation processes. Because of this, the limb lead deflections can be used to measure the resultant magnitude and direction in the frontal plane of the electrical forces of the heart. This has clarified and simplified interpretation of the limb leads and has led to the development of such useful tools in clinical electrocardiography as the mean electrical axis, instantaneous electrical axes, and the ventricular gradient.

Precordial lead deflections, on the other hand, are recorded from electrode positions so much nearer the center of the electrical field that it has seemed unlikely that the various surfaces of the ventricular myocardium could be electrically equidistant from each of these electrode positions. Therefore, most workers have felt that the mathematical methods so useful in interpretation of the limb leads could not be extended to interpretation of the precordial leads. However, since both limb and precordial leads are semidirect leads, and since there is only a relative difference between them in electrical remoteness from the heart, perhaps there are certain characteristics of the precordial deflections which represent measurements of the electrical forces of the heart as a whole. If these could be demonstrated, the precordial leads could be used to measure the electrical forces of the heart in the anteroposterior plane. By combining the measurements of the forces in this plane with those of the frontal plane made from the limb leads, the characteristics of the forces as they exist in three-dimensional space within the body could be determined. This would make it possible to base the clinical interpretation of the electrocardiogram on the relative magnitudes and directions of the QRS and T electrical forces in space. Such a method for interpreting the electrocardiogram would be much simpler, more rational and more accurate than methods based upon memorizing empirically established deflection sizes and contours on a number of arbitrarily selected leads.

Methods

The purpose of these experiments was to determine the extent to which the deflections recorded from precordial leads are measurements of the mean QRS and T electrical forces of the heart in the human subject. It is neces-
necessary to discuss certain theoretic principles underlying the method chosen for studying the problem before the method is described in detail.

Two principal assumptions were made in selecting the method. It was assumed that body surface deflections were measurements of an electrical field propagated in a volume conductor from central dipoles. This makes it possible to consider the electrical processes of the heart as resultant electrical vectors. A second assumption was that the electrical conductive properties of the human body are reasonably uniform. The uniformity of conductivity in the body has been a point of controversy among students of electrocardiography for many years. Recent theoretic and experimental studies in the human subject leave little doubt, however, that this assumption is reasonably valid.

These premises permit one to apply to the problem of the precordial leads the physical laws governing the distribution of an electrical field arising from a vector at the center of a homogeneous cylindrical volume conductor. In such a field, a plane of zero isopotentiality extends perpendicularly from the center of the vector to the surface of the cylinder, separating the surface into an area of positive potential on one side of this plane and negative potential on the other side. The line of zero isopotentiality defined on the surface of the cylinder where the plane intersects the surface is called the null contour. Its position is determined by the direction but not the magnitude of the vector at the center of the cylinder. It can be calculated for a cylinder, then, if the direction of the vector and the size of the cylinder are known. Or, this calculation can be reversed, and the direction of a vector at the center of a cylindrical volume conductor can be determined if the distribution of positive, negative, and null potentials on the surface of the cylinder are known.

These two concepts, the null contour and the central vector, have counterparts in human electrocardiography and their calculation forms the basis for the present method of studying chest leads. Thus, the null contour of the cylinder is analogous to the pathway of transitional QRS and T complexes (deflections with as much upright as inverted component) around the chest. These transitional pathways can be determined by taking unipolar chest leads from all surfaces of the chest and noting the position on the chest of the electrodes which recorded transitional QRS and T complexes. For the counterpart of the vector at the center of the cylinder, a method is available for calculating the magnitudes and directions of the mean QRS and T electrical forces in three-dimensional space in the human subject with reasonable accuracy. These mean spatial vectors are the average of the vectors generated from the various surfaces of the heart during a single QRS or T cycle. Likewise, for the transitional complex, the chest lead deflections are examined for their resultant or average electrical sign—that is, whether the deflection is principally upright (positive), inverted (negative), or transitional (null) regardless of the overall size of the deflection.

The procedure in these studies, then, was to calculate the mean spatial QRS and T vectors for a given subject. Then, the null contours which these two vectors would project on the surface of a cylinder of the same dimensions as the subject's chest were calculated. These null contours were then compared with the pathways of transitional QRS and T complexes as determined by unipolar leads taken from all surfaces of the chest. If the null contours and transitional pathways coincided on the chest, the chest electrodes could be considered to be recording from the heart as a whole as far as the resultant or net characteristics of the deflection were concerned. In other words, the resultant electrical sign of the chest lead deflections could be considered to be established by single central QRS and T vectors. When the two determinations did not agree, the chest electrodes may have been dominated by the nearest surface of ventricular myocardium and were not recording from the heart as a whole.

To turn to the details of the method used in this study, the calculation of the mean spatial vectors is based on a method first suggested by Wilson, Johnston, and Kossmann which employs the three conventional positions of the limb lead electrodes with a fourth electrode placed on the back directly behind the
These four electrodes form a three-dimensional reference figure electrically. The Einthoven equilateral triangle is converted into an isosceles tetrahedron with the origin or zero-point of the figure at the mid-point of the frontal plane, and the four apices equidistant from this origin. The spatial vectors were calculated from this reference figure as follows: The resultant areas of the QRS and T deflections on the three limb leads were measured and these magnitudes were plotted on the triaxial reference system giving the frontal plane projections of the mean QRS and T vectors.

The components of these vectors on the 90-degree axis of the triaxial system were then added vectorially to the magnitudes on the back-to-left-leg lead on a 45-degree biaxial system, thus giving the sagittal plane projections of the mean vectors (fig. 1). From the projections of the vectors on these two planes the magnitude and directions of the mean spatial QRS and T vectors can be calculated as described elsewhere.

The QRS and T null contours for a cylinder resembling the subject’s chest were next calculated from these mean spatial vectors. The approximate position of a null contour on a subject’s chest can be easily visualized if the frontal and sagittal projections of the vector are known. For example, if the vector is found to be directed toward the left leg in the frontal plane, and has a slightly anterior direction in its sagittal projection, the plane perpendicular to this vector can be visualized as intersecting the chest along the upper right region of the chest anteriorly and the lower left region of the chest posteriorly, as shown in figure 2, A. If, on the other hand, a vector with this same frontal plane direction should in the sagittal plane prove to be directed somewhat posteriorly, the null contour now lies on the lower left side of the chest anteriorly, and the upper right side of the chest posteriorly, as shown in figure 2, B. (In the illustrations, the null contour is drawn as if formed by a plane perpendicular to the vector at its origin instead of at its center; this was done to make the constructions clearer, and is simply an example of vector translation.)

A more precise calculation of the null contour can be performed from the equation:

$$(X_{E_{cos}} + (Y_{E_{cos}}) - (Z_{E_{sin}}) = 0,$$}

where $E_r$ is the magnitude of the projection of the vector on the sagittal plane and $\theta$ the angle this projection makes with the anteroposterior axis of the plane, and $E_f$ is the magnitude of the projection of the vector in the frontal plane and $\phi$ the angle this projection makes with the +90-degree line of the triaxial system (fig. 2, C). By making the following substitutions in the equation, four points are located on a cylinder with the same diameters as the subject’s chest, and these points define the pathway of the null contour for the cylinder:

- Let $X = +a$, $Y = 0$, and solve for $Z$.
- Let $X = -a$, $Y = 0$, “ “ “ Z.
- Let $Y = +b$, $X = 0$, “ “ “ Z.
- Let $Y = -b$, $X = 0$, “ “ “ Z.

where $+a$ and $-a$ are the two radii which form the lateral diameter of the chest, $A$, and $+b$ and $-b$ are the radii of the anteroposterior diameter, $B$, of the chest. The lateral and anteroposterior diameters of the subject’s chest were measured with obstetric calipers, and the
chest was treated as an elliptic cylinder. The calculations indicate the units of distance which the four points, one at each end of the two diameters, lie above or below the equator of the cylinder as defined by a horizontal plane through the center of the electrical field. It was found empirically that this equator generally lies 2 to 4 cm. below the fourth intercostal space, somewhat below the region where V₁ and V₂ precordial leads are taken. The positions of the four points for each subject were plotted on a graph folded into a cylinder having the same diameters as the subject’s chest and a line was drawn connecting these points to resemble the pathway where a plane defined by these points would intersect the cylinder.

At the time the four bipolar leads were taken for calculating the spatial vectors, chest leads were also recorded using the Wilson central terminal with 5,000-ohm resistors and a 0.5-cm. exploring electrode. Leads were taken from the anterior and posterior surface of the chest at 1-inch intervals from above the level of the manubrium to below the umbilicus on the sternal and vertebral lines and, bilaterally, on the midclavicular, anterior axillary, mid-axillary, and midscapular lines. Care was taken that the electrode paste did not connect adjacent electrode positions. The deflections were mounted on paper the same size as had been used to plot the null contour. The transitional QRS and T complexes (the deflections with as much positive as negative area regardless of their total amplitude) were identified on each line and these deflections connected by a smooth curve. This indicated the pathway of transitional QRS and T complexes around the chest.

In a second part of the present study it was desirable to simplify this method of calculating the spatial vectors in order to study the mean spatial vectors as a part of routine clinical electrocardiographic interpretation. By this modified method, the direction but not the magnitude of the mean QRS and T vectors in the frontal plane can be accurately determined from simple inspection of the three limb leads: if on one of the three limb leads the deflection is conspicuously smallest, the vector must be directed relatively perpendicular to the axis of that lead. If on the other hand, the deflection is conspicuously largest on one of these leads, the vector must be directed parallel to the axis of that lead. This can be readily seen by plotting test vectors on the triaxial system, with due regard to the polarities of this reference figure. With a little practice, the direction of the mean QRS and T vectors in the frontal plane can be calculated within a 10-degree error by simple inspection of the tracing. By compar-

FIG. 2.—A, The vector has a slight anterior projection as seen in the sagittal plane calculations; accordingly, the null contour on the anterior aspect of the cylinder will lie superiorly to the equator of the cylinder. B, The vector is directed somewhat posteriorly, and therefore the null contour lies inferiorly to the equator of the cylinder. C, The projections of a mean spatial vector on three planes of the cylinder; $E_s$ is the component on the sagittal plane and $\theta$ its angle with the anteroposterior axis of the cylinder; $E_f$ is the component on the frontal plane, and $\phi$ its angle with the +90 degree axis in the frontal plane.
Fig. 3.—A (Left): V leads taken from the anterior and posterior chest of a normal young male subject (W. J., age 23, no cardiovascular disease); eight lines of tracings are presented. The absence of tracings from the upper ends of the axillary series is due to the attachment of the arms at these points. B (Right): The four spatial leads with the spatial QRS and T calculations. The projection on the frontal and sagittal planes, the chest dimensions, and the null contour calculations are presented.
ing the sizes of the QRS and T deflections of the limb leads and the back-to-left-leg lead, and by plotting these magnitudes on the biaxial system described earlier, the projection of the two vectors on the sagittal plane is determined.

The pathways of the null contours for QRS and T were compared with the pathways of transitional QRS and T complexes in three groups of subjects: (1) In 8 subjects the mathematically calculated null contours were compared with transitional pathways determined by the extensive anterior and posterior exploration described above. Two of these are illustrated; one of the subjects (figs. 3, 4, and 5) was a normal young man, the other (figs. 6 and 7) a 50 year old woman with a recent high lateral myocardial infarction. (2) In 20 subjects the visually calculated null contour was compared with extensive explorations of the anterior portion of the chest alone, in the manner outlined. (3) In over 1,000 consecutive subjects the visually calculated null contour (the back-to-left leg lead has been taken routinely in the Grady Memorial Hospital for the past year) was compared with the position of the transitional QRS and T deflections as they were encountered in routine V₁ to V₆ precordial leads.

A discussion of the validity of treating deflections from all surfaces of the body as due to the same electrical forces is appropriate before the results of this study are presented.

It has been shown by other workers that in a volume conductor the amplitude of a deflection varies inversely with the square of the distance from the dipole at the center of the conductor to the recording electrode. This means that beyond a certain distance from the center of the field further displacement of the electrodes will result in negligible further change in amplitude of the deflection. In the human subject, this distance has been found to be 10 to 12 cm. from the heart. Electrodes more remote from the heart than this are, in effect, electrically equidistant from the heart, no matter what their differences in anatomic remoteness. Reversely, at such an electrode position all parts of the heart are electrically equidistant from the electrode.

In the present studies, however, electrode positions considerably less than 10 cm. from the heart are treated as electrically equidistant from all parts of the heart. The reason for this was that these experiments were concerned with the resultant electrical sign of the deflection and not the amplitude of the deflection. Adequate electrode remoteness will occur at points less distant from the heart in studies concerned with the distribution of electrical positivity and negativity than in studies concerned with the amplitude of the deflections. This can be explained in terms of current electrocardiographic theory by considering the properties of direct- and semidirect-lead QRS deflections.

A direct lead is taken by placing the recording electrode directly on the myocardium; in a semidirect lead the electrode is separated from the heart by electrically inactive but conducting tissue. In direct leads the QRS complex has been shown to consist of two parts: (1) an “intrinsic deflection,” which is the descending limb of the R wave and is written when the portion of the myocardial surface immediately beneath the electrode undergoes activation, and (2) the “extrinsic components,” which are the portions of the complex preceding and following the intrinsic deflection and represent the activation of the remaining surfaces of the ventricular muscle.

Thus, in a direct lead the characteristics of the extrinsic components come nearer to reflecting the characteristics of the electrical field of the heart as a whole than does the amplitude of the deflection, for the amplitude is written by the intrinsic deflection, representing the very small subjacent portion of the myocardium. Because the amplitude-distance relationship for the various regions of the heart is an exponential one, nearly all but the subjacent portion of the heart are brought into electrical equidistance at electrode distances considerably less than 12 cm. from the heart. This can be seen in the tracings published in connection with amplitude-distance studies of the deflection as a whole, for the general contours of the deflections have become constant at electrode positions much less than 12 cm. from the heart. The contour of a deflection and its resultant electrical sign are principally functions of the
Fig. 4.—The tracings are from the same subject as those of figure 3. A and B: The null points on the anterior and posterior aspects of the cylinder are plotted and connected by a line which describes the pathway of intersection on the surface of the cylinder of a plane defined by these four null points for the QRS and T mean spatial vectors; these are lines of zero isopotentiality for the electrical field of each vector. C and D: QRS and T complexes from the V leads are copied onto paper the same size as was used for the null contour plotting; the transitional complexes are connected by a smooth curve which indicates the QRS and T transitional pathways for that subject.
extrinsic components of the deflection. Therefore, at electrode positions less than 12 cm. from the heart, under most circumstances, the resultant electrical sign of a deflection (whether it is a principally positive or negative deflection) reflects the mean electrical activity of the heart as a whole.

The resultant electrical sign of a deflection is a gross property of the deflection. To use such a property for the study of the electrical field of the heart might seem to be lacking in precision. Actually, however, the distribution of transitional complexes, those with a resultant electrical sign which is zero or null, is a quite precise property of a mean spatial vector, for the electrode writing such a deflection lies on a plane perpendicular to the vector. From this distribution of transitional complexes it is possible to determine the direction in space of the mean QRS and T electrical forces of the heart with reasonable accuracy, as these experiments demonstrate. The calculation gives no information as to the magnitudes of QRS and T forces. To determine their magnitudes from electrode positions less than 12 cm. from the heart would require more information about the electrical field of the heart than is at present available.

It must be recognized that body surface leads give at best only crude and general notions of the electrical processes of the heart. These limitations are often overlooked when theories or instruments of considerable intrinsic precision are adapted to the human electrocardiogram. However, the reverse has often been true, and sound principles governing the propagation of electrical forces have been delayed in their acceptance by an awareness of these limitations—even to the extent that some investigators have regarded the properties of the electrical field of the heart in the human subject as unique and not subject to recognized principles of physics.

There may also appear to be an oversimplification in comparing precordial deflections in the human subject to potential variations taking place on the surface of an idealized cylindrical volume conductor. After all, the

![Fig. 5.—The recordings are from the same subject as those of figures 3 and 4. Comparison of null contours and transitional complex pathways on the anterior chest, A, and the posterior chest, B.](image-url)
Fig. 6.—A (Left): Precordial leads taken from eight longitudinal lines on the anterior and posterior chest of a 53 year old woman (C. B.) with a recent high lateral myocardial infarction (note Q wave, elevated RS-T segment, and inverted T wave in the leads taken in the region of the left axilla). B (Right): The calculation of the null contour from the four spatial leads.
human chest is only crudely cylindrical, it is variable in its contour, the heart is anatomically eccentrically placed in the chest, and the intervening tissues are remarkably different in gross structure. Nevertheless, as others have indicated, the distribution of an electrical field in space is expressed by laws which are different from those governing anatomic distance and structure. In an electrical sense, the chest proves to be remarkably similar to a cylinder with the heart at its center, as these studies demonstrate.

FIG. 7.—The recordings are from the same subject as those of figure 6. Comparison of the pathway of the QRS and T null contours with the pathways of transitional QRS and T complexes on the anterior chest, A (left), and the posterior chest, B (right).

RESULTS

In all instances the distribution on the chest of transitional QRS and transitional T complexes closely followed the lines of zero isopotentiality, or null contours, calculated for the same subject’s chest from his mean spatial QRS and T vectors. Figures 5 and 7 illustrate the similarity between the transitional pathways and the null contour in 2 cases taken from Group 1. In the thousand-odd cases studied, then, unipolar leads from the chest recorded deflections which in resultant direction resembled projections from single central QRS and T spatial vectors. The forces from the ventricular surface nearest the electrode did not significantly dominate the deflections in this regard. Because this study has been concerned with the resultant sign of the entire complex, no conclusions can be drawn regarding the extent to which individual portions of the QRS complex in precordial leads were written as if by single central instantaneous vectors.

In Group 3 subjects, there was often a discrepancy of one or two, rarely three, V-lead positions between the electrode position where the transitional complex was recorded and the electrode position through which the null contour was calculated to pass. In some instances this discrepancy was found to be due to inaccurately placed back or precordial electrodes. In other subjects, the simplifications and schematizations of the electrical field necessary for this type of study may have been the source of error. For example, the null contours were calculated for this group of subjects as if they all had chests of the same size, because chest
measurements were not available for this group of subjects. This must have introduced error in the calculations because, with other things equal, the size of the chest, especially its width, plays an important part in determining which precordial lead will write the transitional complex.

Also, in calculating the null contours, the zero point or origin of the spatial vector was considered to lie at the center of the chest. For most electrode positions on the chest this may have been valid, considering the electrical remoteness of these electrodes. In many instances, however, the precordial group of chest leads was undoubtedly sufficiently near the heart to record the resultant potentials as projections from a center point significantly to the left of the mid-line. If corrections had been made for these anatomic shortcomings, the results might have been improved, but this would have made the method more cumbersome and would not have increased its usefulness.

In certain of these subjects it is possible that the position of the null contour on the chest did not perfectly coincide with the position of the V lead with the transitional complex because there was significant domination of the V-lead deflections by the underlying myocardial surface—not enough to reverse the direction of the V-lead complexes, but enough to weight them for or against the occurrence of the transitional complex at the predicted precordial lead position. At areas of the chest where the myocardium is particularly close to the chest wall, for example V4 position, this may have been true. Precise calculation of the degree of resultant positivity or negativity of the deflections at each electrode position might have disclosed more discrepancies. However, such calculations were not considered justified in view of the variables and sources of error they would involve.

Two subjects were encountered in this series of over 1000 cases in whom the underlying ventricular surface appeared to dominate the resultant direction of the deflection at a small area of the chest immediately overlying the apex of the heart. In both cases, positive T waves were predicted for the precordial leads V1 to V6 from the mean spatial T vector. However, the precordial tracings proved to have erect T waves at all positions except V4 where a small isolated area of T negativity was found. The QRS complexes fitted well with the null contour established by the spatial QRS vector in these cases. Both subjects were young men with normal body builds and no clinical evidence of heart disease, and therefore this type of isolated T-wave inversion in the precordial leads must be considered to be normal. Further studies of the mechanism of this unusual type of T-wave disturbance will be reported elsewhere.

**DISCUSSION**

This demonstration that the resultant electrical signs of the chest lead deflections reflect the direction in space of the mean QRS and T vectors sheds light on several theoretic aspects of human electrocardiography. For example, these findings affirm the hypothesis that the body is a relatively homogeneous volume conductor. In the experiments, unipolar leads were taken from many different sites on all surfaces of the chest. Since the characteristics of these deflections so closely agreed with the characteristics of the electrical field projected from spatial vectors, the body cannot have significantly distorted the distribution of the electrical forces. This uniformity of conductivity, first suggested by Einthoven, has been challenged by many workers in the past, but has received more and more support in recent years. It is a fundamental assumption in most current methods for electrocardiographic interpretation, and there is now little room to doubt that it is satisfactorily valid for clinical electrocardiographic methods. For the same reason, the experiments lend support to the assumptions upon which spatial or three-dimensional electrocardiography is based.4-5

The validity and usefulness of the Wilson central terminal is demonstrated by these studies. Under the circumstances of these experiments, the central terminal was found to establish a reference point which was satisfactorily near the zero point in the sagittal as well as the frontal plane of the body. Ashman11 studied the relationship of the central terminal
to the precordial leads by a different method and also concluded that it establishes a reference point reasonably near the center of the electrical field in three-dimensional space.

The present study assumes the heart's electrical field to have a spatial distribution in the body such that the four spatial electrodes can be considered to form an isosceles tetrahedron electrically. In this figure, the zero point of the field lies at the mid-point of the frontal plane and equidistant electrically from the four electrodes. The error is evidently not great when the precordial lead deflections are treated as reflecting the mean direction of QRS and T forces arising from this point.

These studies also demonstrate that conventional precordial leads can be used to measure certain spatial characteristics of the QRS and T forces of the heart. Einthoven introduced his three limb leads thirty years ago as a method for studying the characteristics of these forces as they are projected on the frontal plane of the body. However, the clinical correlation of abnormalities in these leads with various types of cardiac disorders rapidly outstripped the growth of knowledge of the mechanisms producing these electrical abnormalities. Accordingly, the three leads have not been widely used to measure the electrical forces involved; instead, clinical electrocardiography has come to be based upon recognizing wave forms in the complexes of these and other often randomly selected leads for the interpretation. Ultimately, of course, clinical electrocardiography must be based upon an analysis of the changes in the electrical forces of the heart if it is to become a rational and objective clinical procedure. Principally owing to the work of Wilson and his colleagues, this method of interpretation is coming nearer to realization, and the present article is a step in this direction.

The usefulness of studying the electrocardiogram in terms of the spatial vectors is illustrated by the following example. The QRS complex in a particular precordial lead, V₁ for example, may resemble the QRS complex of one of the unipolar limb leads, V₉_R for example. This has been adduced to mean that, in this instance, the right side of the electrical field faces the right arm. This interpretation has been found useful in defining the position and rotation of the heart*; however, it has never been clear why the leads with similar QRS complexes often have dissimilar T waves. Thus, the QRS may be inverted in both V₁ and V₉_R but the T wave may be upright in V₁ and inverted in V₉_R in the same subject. The explanation for this nonconcordance between QRS and T complexes in the two leads becomes apparent when the positions of the V₁ and V₉_R electrodes on the chest are considered in the light of the direction of the mean spatial vectors. Since the mean QRS and T vectors do not necessarily have the same direction in a given subject, the distribution of positive and negative fields for each on the surface of the chest will be different. Thus, in a normal subject the QRS vector is often directed to the left and somewhat posteriorly. Therefore, the null contour, defining where transitional QRS complexes will be recorded, runs longitudinally down the left side of the chest. The area of the chest to the right of this line is electrically negative, and electrodes placed here will therefore write deflections which are inverted in their resultant direction. The area to the left is positive and deflections on this surface will be resultant upright in direction. Since the electrodes for V₁ and V₉_R are placed to the right of this line, both leads will write downward deflections, and these QRS deflections will "resemble" one another to this extent. The spatial T vector on the other hand may be directed vertically and slightly anteriorly. The pathway of transitional T waves will, in such a case, lie transversely across the upper chest. V₁ and V₉_R electrode positions lie on opposite sides of this transitional zone, and the T wave of V₁ will therefore be erect, while the T wave of V₉_R will be negative or inverted.

Using vector principles, much of empirical electrocardiography can be reduced to vector generalizations which greatly simplify clinical interpretation. For example, to make the electrocardiographic diagnosis of ventricular hypertrophy, it need only be remembered that the spatial QRS vector tends to be directed toward the ventricle with the larger relative muscle mass. Accordingly, in right ventricular hyper-
trophy the mean spatial QRS vector should drift to the right and anteriorly. Under these circumstances the limb leads will record right axis deviation. In the precordial leads, the pathway where transitional QRS complexes will be recorded for a vector with this direction runs obliquely across the upper left side of the chest. The pathway will cross the precordium near the V4 precordial electrode position. V leads taken to the right of this pathway will write QRS deflections which are upright in resultant direction because their electrode positions lie in the area of electrical positivity for this spatial vector direction. The QRS complexes in V leads taken to the left of this line will be inverted in resultant direction because this is the area of electrical negativity. This is the same distribution of QRS complexes that has been associated with right ventricular hypertrophy in all empiric studies of the electrocardiogram in this disorder.

The many variations from this pattern of distribution of upright and inverted precordial QRS complexes can be easily evaluated by determining the direction of the mean spatial QRS vector in the given case. The T vector, normally relatively parallel with the QRS vector in space, tends to become directed away from regions of ischemia and of hypertrophy. Accordingly, by studying the distribution of positive and negative T waves in the various leads, the direction of the spatial T vector can be determined, and from this the location of the area of disturbed electrical activity can in general be identified.

The ventricular gradient is a concept which Wilson and co-workers introduced to define a fundamental relationship between the QRS and T vectors in the frontal plane of the body. This concept is the basis for a more rational and accurate method for interpreting the limb lead electrocardiogram. The results of the experiments reported here indicate that the precordial leads can also be interpreted in terms of the ventricular gradient. The mean directions of the spatial QRS and T vectors can be readily determined from the three limb leads and the six precordial leads. It is thus possible to determine the angle between the two vectors (the QRS-T angle) in space, and this angle is an expression of the ventricular gradient.

The accurate calculation of the magnitude and direction of the ventricular gradient is too time-consuming and exacting for routine clinical use. With a little practice, however, the spatial QRS-T angle can be determined from simple inspection of the conventional limb and precordial leads. This is done by first determining the direction of the QRS and T vectors in the frontal plane, using the triaxial reference system with due regard to its polarity. The limb lead on which the QRS is conspicuously largest or smallest as a resultant deflection is identified. The QRS vector will have a direction parallel with the axis of the lead with the largest deflection, or perpendicular to the axis of the lead with the smallest deflection. The same procedure is followed for the T vector, and with experience the directions of the two vectors in the frontal plane can be determined by inspection within a 10-degree error.

In order to determine how far anteriorly or posteriorly from its frontal plane projection a spatial vector is directed, the precordial lead with the transitional deflection is identified. As has been shown in the above experiments, the electrode position where this complex occurs tends to lie on a plane which is perpendicular to the spatial vector at its origin. One can easily visualize, then, how far anteriorly or posteriorly from the frontal projection the spatial vector must be tilted to have its plane pass through this particular V-lead position. To visualize the vector in space, it is helpful to draw the frontal outline of the chest (or, simply a cylinder) with the frontal plane vector drawn at the center of the figure in the direction determined for it from the three limb leads (fig. 2). The position of the precordial V-lead which contained the transitional complex is marked on the figure. The spatial vector will, of course, perfectly superimpose on the frontal plane projection in this view. The line where the plane intersects the surface of the cylinder can then be drawn on the figure to pass through the point identifying the precordial electrode position with the transitional complex. Once the method is understood, the QRS-T angle in
space can usually be evaluated without using the diagram, the entire procedure taking no more time than conventional methods for reading tracings. The QRS-T angle rarely exceeds 45 degrees in the frontal plane or 50 degrees in space in the normal subject, and such criteria as these can form the basis for the clinical interpretation of the electrocardiogram.

This modification of existing methods for electrocardiographic analysis makes clinical interpretation of the electrocardiogram more rational and objective, for the vectorial method tends to be a quantitative study of the electrical forces of the heart instead of a description of the deflections on arbitrarily selected leads. Furthermore it greatly simplifies learning to read the electrocardiogram, for all possible variations and combinations in resultant direction of the QRS and T waves on all possible leads anywhere on the body are implicit in the directions of these two mean vectors. The memorizing of deflection sizes and combinations on the various unipolar and bipolar limb leads and precordial leads, and the taking of additional unusual leads become largely superfluous. The accuracy of the interpretation is enhanced because variations in the deflections due to altered position of the heart are quickly identified, and because the precision of the ventricular gradient concept is incorporated into the method. A more detailed description of the vector method and its usefulness for electrocardiographic interpretation will be presented elsewhere.

**Conclusions**

1. The relationship of the QRS and T deflections of the precordial leads to the mean spatial QRS and T vectors has been studied.

2. A method is presented for determining the distribution of QRS and T positivity and negativity on the surface of a cylindrical volume conductor the shape of the subject’s chest from the mean spatial QRS and T vectors. In a large number of subjects this distribution closely resembles the distribution of resultant positive and negative QRS and T deflections on the chest as determined by conventional V-lead methods.

3. This similarity in distribution indicates that when precordial V leads are studied for their resultant electrical sign, that is, whether they are principally positive or negative deflections, they reflect the mean direction in space of the electrical forces of the heart as a whole; the portion of the myocardium directly beneath the electrode does not appear to dominate significantly the precordial deflection as far as its resultant direction is concerned under most circumstances.

4. Precordial leads can therefore be interpreted by the same vector technique already demonstrated to be of such value in interpreting limb leads. This method reduces interpretation to an analysis of the angle between the mean QRS and T vectors in space, which proves greatly to simplify the reading of precordial and limb leads, enhances their accuracy, and provides a more rational basis of electrocardiographic interpretation.

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