Studies of the Spatial Vectorcardiogram in Normal Man

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The spatial vectorcardiograms of 75 normal subjects have been studied and some features of these records are described. The QRS sE and TsE-loops were found to have only two basic spatial configurations but with a variety of orientations thus giving widely different planar projections and in part accounting for the wide range of normal electrocardiograms. The significance of this and other findings is discussed and certain concepts pertinent to the study of the vectorcardiogram are presented.

The CONCEPT of vectorcardiography is not a new one. Increasing interest in this technic is evidenced by the number of papers and monographs recently published. This interest is stimulated particularly by the hope that spatial vectorcardiography will have clinical applications exceeding those of conventional electrocardiography. At present the many variations in methods of recording and analyzing vectorcardiograms create difficulties in comparing data from different laboratories. It is desirable that these procedures be standardized as early as possible to foster more general application of the vectorcardiogram.

Despite this lack of uniformity, it is considered that a report of our experience with the vectorcardiogram of normal adults and of certain concepts which have evolved during the past several years of study of the vectorcardiogram in this laboratory would be of some interest. It should be realized that, since vectorcardiography is still an experimental method with no standardized reference system or nomenclature and since this series of subjects is small, the results convey merely a general impression of the normal as recorded with the tetrahedral reference system of Wilson and associates and should by no means be construed as a complete description of all the possible variations that might be encountered in normal people under many different physiologic circumstances. This report is also intended to present certain aspects of the general problem of vectorcardiography, including a discussion of the reference system employed in these studies.

Materials and Methods

Studies were made on 71 male and four female medical students between the ages of 22 and 33 years who had no evidence of cardiovascular disease. A teleoroentgenogram of the chest was obtained for each subject, and careful fluoroscopic examination of selected subjects was performed to determine, insofar as possible, cardiac position.

Electrocardiograms, including the standard limb leads, unipolar limb leads, precordial leads V1 through V6, and a unipolar lead from an electrode placed 3 cm. to the left of the seventh dorsal vertebra (Vb), were obtained for each subject when the vectorcardiogram was recorded. For the purpose of evaluating the efficacy of vector analysis from electrocardiograms, leads I and V7 and leads Vb and Vv, representing the components of the frontal and sagittal projections of the vectorcardiogram, were recorded simultaneously at the conventional electrocardiographic film speed of 25 mm. per second and at a film speed of 50 mm. per second. Leads I and III, II and III, and Vb and Vv were also recorded simultaneously at conventional film speed.

Spatial vectorcardiograms (sVCG) were obtained with the use of the equilateral tetrahedron as a reference system. In this system the Einthoven triangle constitutes the frontal plane, and the remaining apex of the tetrahedron is represented by a point on the back 3 cm. to the left of the seventh
dorsal vertebra. Frontal and sagittal plane projections of the vectorcardiogram were photographed simultaneously from two single beam cathode-ray oscilloscopes. The frontal plane projection was obtained by connecting the right and left arm electrodes to the horizontal-deflecting plates of the cathode-ray tube and by connecting a Wilson central terminal and the left leg electrode to the vertical-deflecting plates. Connections were such that relative positivity of the left arm produced a deflection of the beam to the left (the observer's right), and relative positivity of the left leg produced a downward deflection.

In the sagittal plane, horizontal deflections were obtained from a Wilson central terminal and the back electrode, and vertical deflections from a central terminal and the left leg. Relative positivity of the back electrode resulted in movement of the electron beam to the right as viewed by the observer facing the sagittal plane from the left, and relative positivity of the foot resulted in a downward deflection.

Standardizing factors, which are necessary because the potential differences are scalar quantities being treated as vectors, were such that 1 mv. introduced into the vertical-deflecting circuit of either oscilloscope produced a deflection of 1\(\frac{\text{150}}{\text{inches}}\) inches and, when introduced into the horizontal-deflecting circuits, produced a deflection of 1 inch on the oscilloscope used to record the frontal projection and 1\(\frac{\text{150}}{\text{inches}}\) inches on the oscilloscope used to record the sagittal projection.\(^{15}\)

The projections of the vectorcardiogram on the right, left and superior planes of the tetrahedron were obtained by selecting the proper electrode combinations and proper central terminal and employing appropriate standardizing factors. Each of these plane projections was recorded simultaneously with another plane projection sagittal to it and each pair of planes was treated as was the frontal plane and the plane sagittal to it. In addition, stereoscopic views of the spatial vectorcardiograms from the front, the right, the left and the superior planes of the tetrahedron were obtained by the use of a technic previously described.\(^{16-17}\) In all, eight plane projections and four stereoscopic views of the spatial vectorcardiogram were obtained for each subject. Frontal and left sagittal projections and frontal stereoscopic views were recorded, both with amplification sufficient to show all components of the vectorcardiogram and with higher amplification to show details of the P, QRS, and T \(\varepsilon\)-loops near the isoelectric point. Time was indicated in all records by interrupting the oscilloscopic trace 600 times per second. Finally, three-dimensional wire models representing each spatial vectorcardiogram were constructed to conform to all of the plane projections recorded.

Each of the plane projections, the stereoscopic photographs and the models was inspected, and the contour of the QRS and T \(\varepsilon\)-loops, their relation to each other, and the directions of rotation were noted. The "axis" or the "maximal vector" of the QRS and T \(\varepsilon\)-loops, which is indicated by a straight line drawn from the origin of the respective loop to its most distant point, was measured in millivolts in the frontal and sagittal projections. Their position in a triaxial reference frame applied to these planes was also noted. In the case of the left sagittal plane, the \(\pm 180\) degree axis of the triaxial reference system was placed anteriorly. In addition, the maximal extent of the left sagittal plane projection posterior to the isoelectric point was measured in millivolts.

Rotations of the QRS and T \(\varepsilon\)-loops about their maximal longitudinal axes were defined in the following manner. The equilateral tetrahedron is visualized with its frontal plane vertical. A line is drawn horizontally through the terminus of the maximal vector and perpendicular to it. Whenever the vector is vertical, the line must also be parallel with the lead I axis of the tetrahedron. This line is considered to be the zero axis of a triaxial reference system whose origin coincides with the terminus of the maximal vector. The triaxial reference system is perpendicular to the maximal vector, and its zero axis lies to the right of an observer viewing the vector from its terminus. In practice, the loop is visualized with the terminus of the maximal vector facing the observer, and the position of the ascending and descending limbs in the triaxial reference system is noted.

Because of reports indicating that spatial vectorcardiograms can be utilized to predict the form of the precordial leads,\(^{8,12}\) or that some characteristics of the spatial vectors can be inferred from the precordial leads,\(^{63}\) 63 of the records in which the superior projection was technically satisfactory were subjected to such analysis. This was carried out by marking the approximate anatomic position of the six conventional precordial electrode sites on a diagrammatic cross section of the human chest. Each of these points was connected by a straight line to a point at the center of the chest, as shown in figure 1A. Perpendiculars were then drawn to each of the lines, as shown for \(V_1\) in figure 1B. The isoelectric point of the superior projection of the vectorcardiograms was placed at the point of intersection of the lines shown in figure 1B. By this technic, the predicted polarity of the deflections in a given lead is indicated at any moment by the side of the line on which that portion of the vectorcardiogram lies. A similar analysis was carried out in 25 instances in which the horizontal plane projection of the spatial vectorcardiogram was recorded by means of the cuboidal system of electrode placement.\(^{13}\) It is realized that the superior plane and the horizontal plane of the cuboidal reference system do not coincide with each other or with the plane or planes defined by the precordial leads.
RESULTS

The difficulty of describing three-dimensional records of variable form is obvious. Some previous publications from this laboratory have partially avoided this difficulty by including two or more plane projections of each of the vectorcardiograms being described.\textsuperscript{19,20} Since due to slight movement of the cathode-ray beam during electrical diastole or is distorted by muscle tremor or by electrical interference. Such distortion is of greater significance in the case of the small P $s\sigma$-loop than in the case of the larger QRS and T $s\sigma$-loops. For these reasons, a detailed study of the normal P

![Figure 1](image1.png)

**FIG. 1.** Relation of precordial leads to the superior plane projection of the vectorcardiogram. (A) The approximate anatomic location of the precordial leads in a transverse plane of the body. (B) Relation of $V_1$ to the superior or horizontal plane projection of the spatial vectorcardiogram. Portions of the vectorcardiogram located anteriorly to the perpendicular (interrupted line) to $V_1$ indicate a positive deflection and portions located posteriorly to this perpendicular a negative deflection in lead $V_1$ of the electrocardiogram.

![Figure 2](image2.png)

**FIG. 2.** Stereoscopic frontal view of a representative normal P $s\sigma$-loop. The T $s\sigma$-loop and a portion of the QRS $s\sigma$-loop are also shown.

the larger number of records forming the basis of the present report makes it impractical to illustrate each, stereoscopic records have been selected to demonstrate the more common variations in form and orientation of the normal vectorcardiogram. These records, when viewed from a distance of 5 to 10 inches with a card placed between the two projections, give the observer a single stereoscopic image.

*The P $s\sigma$-Loop*

With present methods of recording, the P $s\sigma$-Loop is sometimes obscured by a halo $s\sigma$-loop was not attempted at this time. Certain general features of the normal P $s\sigma$-loop were apparent, however.

The most commonly encountered form and orientation of the P $s\sigma$-loop is illustrated by the stereoscopic photograph in figure 2. As demonstrated in this figure, the axis of the P $s\sigma$-loop was usually directed downward, forward and to the left. Characteristically, one or more relatively large serrations were present in the contour of the loop. In most of the spatial vectorcardiograms, the P $s\sigma$-loop was located posterior to the QRS $s\sigma$- and T $s\sigma$-loops.

*The QRS $s\sigma$-Loop*

At the beginning of these observations inspection of the plane projections seemed to indicate considerable intrinsic variation in contour among the QRS $s\sigma$-loops of this group of normal subjects. The extensive variations were comparable to those of the QRS complex of normal electrocardiograms. However, continued study of the stereoscopic views and the three-dimensional models modified this view. From these records it
appeared that, aside from detailed variations, all QRS sE-loops in this series could be described as variants in spatial position of two basic patterns. This prompted the description of these QRS sE-loops and the T sE-loops under the headings of types 1 and 2.

Type 1

Sixty-six of the 75 records studied could be described as spatial positional variants of a pattern which is illustrated by the vectorcardiogram shown in figure 3. The eight plane and four stereoscopic views, such as were
obtained for each subject, are shown in this figure for a representative subject. The spatial orientation of the vectorcardiogram can be most easily appreciated by inspecting the frontal stereoscopic view according to the directions previously given. The impression obtained of the three-dimensional form and orientation of the record may then be compared with the actual projection in planes other than the frontal. For example, the impression gained from the stereoscopic view concerning the extent of displacement of the various portions of the vectorcardiogram, anterior and posterior to the isoelectric spot, may be checked in the left sagittal projection.

(a) General Characteristics. In general, the QRS sE-loops of type 1 were elliptoid figures whose widths were approximately one-third of their respective lengths. For the most part the contours were smooth, with no sudden changes in direction. The loop was traced on the screen of the oscilloscope relatively slowly for a short distance near the origin, which represented up to about one-third of the QRS interval, faster through the major portion of the record containing the vectors of greatest magnitude, and slowly again near the terminus, which again represented up to about one-third of the QRS interval. The direction and magnitude of the maximal QRS vectors in the frontal and left sagittal projections and the maximal extent of the QRS posterior to the isoelectric point are summarized in Table 1.

Table 1.—Summary of Measurements in Type I, QRS sE-Loops

<table>
<thead>
<tr>
<th></th>
<th>Maximal Vector in Frontal Plane</th>
<th>Maximal Vector in Sagittal Plane</th>
<th>Posterior Extent (MV.)</th>
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<tbody>
<tr>
<td></td>
<td>Angle</td>
<td>Length</td>
<td>Angle</td>
</tr>
<tr>
<td>Minimal</td>
<td>+20</td>
<td>0.31</td>
<td>0</td>
</tr>
<tr>
<td>Maximal</td>
<td>+89</td>
<td>1.73</td>
<td>+84</td>
</tr>
<tr>
<td>Average</td>
<td>+66</td>
<td>0.99</td>
<td>+46</td>
</tr>
</tbody>
</table>

Fig. 4. Magnitude and direction of maximal QRS vectors in the frontal plane.

(b) Variable Characteristics. The records of type 1 differed chiefly as regards orientation about their anteroposterior, transverse and longitudinal axes. These axes may be defined as follows: (1) The anteroposterior axis is normal to the frontal plane and passes through the isoelectric point. (2) The transverse axis is normal to the anteroposterior axis and transverse to the body and passes through the isoelectric point. (3) The longitudinal axis of the respective sE-loops is represented by the maximal instantaneous mean electrical axis of the loop.

1. Orientation about Anteroposterior Axis: The variations in position about the anteroposterior axis are illustrated by figure 4, in which the magnitude and direction of the maximal QRS vectors in the frontal plane are shown for all 66 type 1 QRS sE-loops which were analyzed. It should be recognized that, although the magnitude and direction of a single vector have only limited meaning, they...
can be used to indicate the approximate orientation of records of essentially similar form. In the frontal plane the direction of the maximal vector varied between +20 and +89 degrees.

![Fig. 5. Frontal stereoscopic view of a spatial vectorcardiogram with a “type 1” QRS sE-loop oriented horizontally about its anteroposterior axis.](image)

Figure 5 shows a frontal stereoscopic view of a vectorcardiogram in which the QRS sE-loop is essentially similar in contour to that shown in figure 3 but which differs by being oriented more horizontally about the anteroposterior axis.

2. Orientation about the Transverse Axis: Variations in position about the transverse axis are illustrated by figure 6, which shows the

![Fig. 6. Magnitude and direction of maximal QRS vectors in the sagittal plane.](image)

![Fig. 7. Frontal stereoscopic view of a spatial vectorcardiogram with a “type 1” QRS sE-loop rotated posteriorly about its transverse axis.](image)

![Fig. 8. Diagrammatic representation of the main types of orientation of the QRS sE- and T sE-loops about their longitudinal axes encountered in the spatial vectorcardiograms of 75 normal subjects. The number of spatial vectorcardiograms encountered with each of the orientations shown was as follows: (A) 13 “type 1” QRS sE-loops, 10 T sE-loops associated with “type 1” QRS sE-loops. (B) 33 “type 1” QRS sE-loops, 36 T sE-loops associated with “type 1” QRS sE-loops, and four T sE-loops associated with “type 2” QRS sE-loops. (C) Three “type 1” QRS sE-loops, seven T sE-loops associated with “type 1” QRS sE-loops and two T sE-loops associated with “type 2” QRS sE-loops. (D) Two “type 1” QRS sE-loops. (E) 15 “type 1” QRS sE-loops, one T sE-loop associated with a “type 1” QRS sE-loop, and one T sE-loop associated with a “type 2” QRS sE-loop.](image)
magnitude and direction of the maximal QRS vectors in the left sagittal plane for all 66 QRS sE-loops. The extremes were +66 and +129 degrees. Figure 7 shows a frontal stereoscopic view of a vectorcardiogram whose QRS sE-component is again similar in contour to that shown in figure 3 but which is oriented differently about the transverse axis, being rotated posteriorly with respect to the usual normal record.

3. Orientation about the Longitudinal Axis: Figure 8 diagrammatically summarizes the variations in orientation about the longitudinal axis which were encountered in this series of records. In this figure a paper strip is intended to represent the QRS sE- or the T sE-loops. Thirteen QRS sE-loops were oriented as shown in A, 33 of the QRS sE-loops had varying degrees of rotation of the type shown in B, and three were oriented as shown in C. Two records showed different degrees of rotation of the ascending and descending limbs of the QRS sE-loop as shown in D. In 15 records, two or more portions of the QRS sE-loops were oriented differently about the longitudinal axis, as is illustrated in E. When viewed from the terminus of the maximal QRS vector, the position of the efferent limbs in a triaxial
reference system, placed as described under "Methods," varied between -135 and +105 degrees. The position of the afferent limbs, similarly viewed, varied between +180 and -135 degrees. The range in orientation of the efferent and afferent limbs is shown diagrammatically in figure 9. Figure 10 depicts a QRS sE-loop again similar in form to that shown in figure 3 but rotated counterclockwise about its longitudinal axis in contrast to the usual normal record.

**Direction of Inscription.** In 63 subjects the QRS sE-loop was inscribed in a clockwise direction in the frontal and in a counterclockwise direction in the left sagittal projection. In one subject the orientation of the QRS sE-loop was such that it was inscribed in a counterclockwise direction in both frontal and left sagittal projections, and in two subjects the QRS sE-loop was traced in a counterclockwise direction in the frontal and a clockwise direction in the left sagittal projection. The direction in which the QRS sE-loops were inscribed in the plane projections was influenced by orientation of the sE-loop about the anteroposterior, transverse, and longitudinal axes and not by differences in the general form of the loops. This is illustrated in figure 11, which shows three models constructed to conform to the plane projections of three different QRS sE-loops. In A, the models are shown in frontal view as they appeared on the screen of the oscilloscope as frontal projections of the sE-loops. When viewed from the front, the QRS sE-loops appear to be extremely different. Model 2 possesses the most common orientation of the QRS sE-loop and differs from model 1 mainly in its orientation about the anteroposterior axis. Model 3, which is traced counterclockwise in its frontal projection, is oriented differently in space, in this case mainly about the longitudinal and transverse axes. In figure B the same models are oriented differently to show that they are grossly similar in form. The apparent differences shown in figure 11A were due mainly to differences in position of the QRS sE-loops.

**Table 2.—Summary of Measurements in Type II, QRS sE-Loops**

<table>
<thead>
<tr>
<th>Maximal Vector in Frontal Plane</th>
<th>Maximal Vector in Sagittal Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QRS</strong></td>
<td><strong>T</strong></td>
</tr>
<tr>
<td>Angle (mv.) Length (mv.) Angle (mv.) Length (mv.) Angle (mv.) Length (mv.)</td>
<td></td>
</tr>
<tr>
<td>Minimal</td>
<td>+37 0.36 +30 0.12</td>
</tr>
<tr>
<td>Maximal</td>
<td>+116 0.84 +65 0.47</td>
</tr>
<tr>
<td>Average</td>
<td>+53 0.63 +45 0.28</td>
</tr>
</tbody>
</table>

![Fig. 12. Frontal, left sagittal, and frontal stereoscopic views of a representative normal "type 2" QRS sE-loop.](image-url)
Type 2

Contour. Nine QRS sE-loops could not be conveniently considered with the 66 just described. These records were essentially similar in form and were characterized by having a greater area enclosed by the portion of the QRS sE-loop behind the isoelectric point than did the records of the type 1 pattern. In some subjects this resulted in a maximal QRS vector directed into the first or second sextants of the triaxial reference system and directed posteriorly in the left sagittal projection. A summary of the measurements of length and direction of the maximal QRS vectors in frontal and left sagittal projections and of the extent of the QRS loop behind the isoelectric point is presented in table 2.

Like the records of type 1, these QRS sE-loops were essentially smooth in contour. Unlike the QRS sE-loops of type 1, they did not enclose narrow ellipse-like areas but wider areas which in some records approached a circular form. In all records in this group the width of the QRS sE-loop was one-half or more of the length.

Orientation. Because of the tendency of these QRS sE-loops to enclose roughly circular areas, the position of the maximal QRS vector is of less value in indicating orientation. The initial portion of all records, however, enclosed an area in the sixth or in the fifth and sixth sextants of the triaxial reference system in the frontal plane and in front of the isoelectric point in the sagittal plane. The terminus of all records enclosed an area in the first and second sextants of the triaxial reference system and located behind the isoelectric point.

All of these loops tended to enclose single plane areas, the upper surface of which in six records was directed toward the left shoulder of the Einthoven triangle, in two records was directed toward the right shoulder, and in one record was essentially perpendicular to the frontal plane. A frontal stereoscopic view of a record typical of those of type 2 is shown in figure 12.

The T sE-loop

Because of the known influence of ventricular depolarization on the order of repolariza-
tion, the respective T sE-loops of the records divided into types 1 and 2 on the basis of similarity of the QRS sE-loops will be described separately.

The T sE-Loops Associated with Type 1 QRS sE-Loops

The most common form of the T sE-loop is a narrow elliptoid figure which is traced more slowly in its effenter than in its afferent portion. A frontal stereoscopic view of a representative normal T sE-loop is shown in figure 3. A summary of the measurements obtained is included in table 1.

Orientation about the Anteroposterior Axis. The direction of the maximal T vector varied between 0 and +84 degrees in the triaxial reference system of the frontal plane. Figure 13 shows the magnitude and direction of the maximal T vectors in the frontal plane.

Orientation about the Transverse Axis. Variations in position about the transverse axis are indicated in figure 14. Here the magnitude and direction of the maximal T vectors are shown in a triaxial reference system applied to the left sagittal plane. The direction varied between +77 and +144 degrees.

Orientation about the Longitudinal Axis. This will be described by reference to figure 8. Ten of the T sE-loops were oriented as shown in figure 8A, 36 as shown in B, seven as shown in C, and one as shown in E. Twelve records were not considered technically satisfactory for this part of the study.

The T sE-Loops Associated with Type 2 QRS sE-Loops

A summary of the magnitude and direction of the maximal T vectors in the frontal and sagittal projections is included in table 2. In form, the T sE-loops of six of the nine subjects included in this group were narrow elliptoid figures similar to those found in type 1. In four subjects the T sE-loops presented a different appearance, enclosing as did the QRS sE-loops almost circular areas. Whereas the T sE-loops of all subjects included in type 1 had widths of less than one-third of their length, the widths of the T sE-loops of these subjects were one-half or more of their length.

Orientation. Although the spatial orientation of the T sE-loops of type 2 was largely within the limits defined for type 1, the variations were not as extreme. In the frontal plane, axes lay between +30 and +65 degrees and in the left sagittal plane between +113 and +150 degrees. Orientation about the longitudinal axis was likewise within the limits found for type 1. Two T sE-loops were oriented as shown in figure 8A, four as shown in B, two as shown in C, and one as shown in E.

The Junction

In 11 records the junction between the QRS sE-loop and the T sE-loop was displaced with reference to the isopotential point. A stereoscopic view of a record with this characteristic is shown in figure 15. A quantitative study of the position and magnitude of displacement of the junction was not attempted for the same reasons that a detailed study of the P sE-loop was not carried out. However, it should be mentioned that, when discernible, displacements varied in space and were not confined to one plane projection.

Relation of the Spatial Vectorcardiogram to Precordial Leads

Sixty-three of the records were utilized as outlined under “Methods” to predict the form of the precordial electrocardiogram. Figure 16 shows the superior plane projection of a vectorcardiogram superimposed on the reference system used to indicate the precordial leads, the precordial leads predicted from this projection, and the precordial leads actually recorded from the same subject. Note that R' waves are present in leads V1 through V4, which
were derived from the vectorcardiogram, but not in the precordial leads which were actually recorded. Detailed characteristics of form and magnitude were not successfully predicted in any of the records analyzed. In 19 subjects large S waves were predicted in the left-sided chest leads, whereas no such waves were present in the precordial leads actually recorded. In 10 subjects, large R' waves were predicted in the precordial leads to the right of the transition zone, whereas no R' waves were present in the recorded leads. Since this pattern is considered abnormal by conventional electrocardiographic criteria, the spatial vectorcardiogram as used in this analysis must be considered inadequate to predict the form of the precordial leads.

**DISCUSSION**

The spatial vectorcardiogram obtained with the equilateral tetrahedron as the reference system of Wilson and associates offered many advantages over the others and no disadvantage not inherent in all of them.

Among the advantages of the equilateral tetrahedral reference frame are: (1) Only one more electrode position needs to be added to the three already employed for recording the three standard leads. (2) All electrode positions are accurately and readily duplicated in serial recordings. (3) The electrodes are simple to apply and are easily retained in position. (4) Existing experience and knowledge obtained for the generally accepted equilateral triangle...
of Einthoven can be readily applied to any or all the plane surfaces of the equilateral tetrahedron because these too are equilateral triangles.

The disadvantages common to all reference frames, including the equilateral tetrahedron, are due to the fact that: (1) The electrode positions are not truly remote. (2) The conducting medium of the body is not electrically homogeneous. (3) The electric dipole of the heart is not a single point source. (4) The electrode positions are not equidistant from the potential source.

Without entering into detailed analysis of the advantages and disadvantages of the various spatial reference frames, we are of the opinion that, although the equilateral tetrahedron is not ideal, it is superior to any others considered to date. It appears to us that it is advantageous to exploit as much knowledge as possible from electrocardiography, at least during the developmental phase of vectorcardiography, and the equilateral tetrahedron offers definite advantages in that regard.

During the early phases of these experimental studies, considerable difficulty was encountered in identification and interpretation of normal spatial vectorcardiograms. The normal plane projections were so variable that it was impossible to recognize with certainty a normal record and to differentiate a normal record from an abnormal one under study at the same time. This difficulty was overcome to a large extent when it was found that the normal spatial vectorcardiograms could be divided into two fundamental types and that the variations in configurations of the plane projections were merely the result of variations in spatial orientation of these two types of patterns. It then became a practice first to identify the fundamental type and then to proceed with the more detailed analyses and interpretations. It is of interest that Ashman\textsuperscript{13} several years ago indicated that the normal spatial vectorcardiogram could be reduced to a mean pattern and that this pattern was useful in the application of the spatial vectorcardiogram to electrocardiography and to analyses of the spatial gradient, $sG$.

It is not likely that only two normal patterns exist. More recent observations indicate a transitional pattern. Many more normal records under the influence of many physiologic states must be studied before the normal spatial vectorcardiogram can be adequately defined. It is also important to realize that we have divided the spatial vectorcardiogram into two types entirely for convenience and that we use them in our analyses for the same reason. Eventually, and as soon as possible, such a division should be discarded, for obviously it will tend to restrict analyses.

Certain characteristics of the configurations and spatial orientations of the spatial vectorcardiogram are presented in the tables and configurations. Unfortunately, the recordings were not satisfactory for a study of the P and T $aE$-loops of all subjects. The limited number of records suitable for P and T $aE$-loop analyses were only sufficient to define the patterns in general.

One of the major shortcomings in vectorcardiography is failure of the records to present an adequate time scale. The records do not indicate the duration of the P-R interval, Q-T interval, or even the QRS itself. Until this disadvantage is overcome, spatial vectorcardiography cannot replace electrocardiography.

Attempts were made to derive the precordial leads from the superior plane projection of the spatial vectorcardiogram obtained with the use of the equilateral tetrahedron in 63 subjects and from the horizontal projection obtained with the use of the cuboidal reference frame in 25 subjects.\textsuperscript{13} Only general configurations were obtained. There was failure in those derivations in important details. For example, R' deflections, which by accepted criteria would indicate right bundle branch block or defective conduction in the right bundle branch, were obtained in leads V$_1$ and V$_2$ in records of normal subjects. Such R' waves did not exist in the actually recorded V$_1$ and V$_2$ leads. Large S waves were derived for V$_4$ and V$_6$ when actually recorded V$_4$ and V$_6$ did not reveal S waves. Errors in T-wave derivations were also obtained. When such errors are encountered in the derivation of the unipolar precordial leads from the spatial vectorcardiogram, similar errors in the construction of the
Spatial vectorcardiogram from the unipolar leads would be expected. One of the most important factors responsible for such errors is difference in electrode positions. The relative nearness, anatomically and electrically, of the precordial leads to the heart is especially important, in addition to the fact that the electrode positions for the precordial leads are different from those employed in recording the spatial vectorcardiogram.

It is not practical to construct the frontal plane projection of the spatial vectorcardiogram, with its detailed configuration, from the standard leads of the electrocardiogram. Significant differences existed between the constructed loops and those recorded by the cathode ray oscilloscope. As would be expected from the preceding paragraphs, the spatial vectorcardiograms constructed from the standard leads and the unipolar precordial leads were even more different from those recorded osillo- scopically. That such difficulties in construction were encountered is not surprising when the differences in the methods of recording are considered. Surely, for more thorough investigation of the spatial vectorcardiogram, the automatic recording by means of the oscillographic method is necessary. Certain general investigations are possible by manual construction, but the tedious nature and possible serious errors due to failure to reveal small but important factors and temporal variations may result in significant erroneous conclusions. Spatial vectorcardiograms constructed manually from the precordial leads with their semidirect electrode positions should be viewed with extreme skepticism and compared cautiously, if at all, with spatial vectorcardiograms recorded automatically from different electrode positions.

Obviously, it is, for the moment, absurd to refer to the “correct” or “absolutely true” complexes of the spatial vectorcardiogram. The configurations and orientations of the recorded spatial vectorcardiogram are determined in part by the method employed in the recording. It is better to refer to the spatial vectorcardiogram as having been recorded with a certain spatial reference frame.

The records used in these studies did not include an adequate time scale, which is a deficiency of the spatial vectorcardiogram as presently recorded. Although it was not possible, by means of the spatial vectorcardiogram, to detect any abnormalities related to certain temporal phenomena which might have existed, electrocardiograms recorded on the same occasion indicated that there were no such disturbances in these subjects.

Unfortunately, the P sE-loops were not satisfactory for analysis in every record. This was true to a lesser extent for the T sE-loops. Until the methods of recording are improved, vector quantities located near the isoelectric point will usually be obscured by the movement of the cathode ray beam near this point. This movement is produced by noises in the amplifier circuits, skin currents, extrinsic alternating currents, and currents from skeletal muscular contractions. Furthermore, with overexposure during photography, a small halo contributes to the obscuring difficulties. The vector forces of the QRS sE-loop near the isoelectric point are also obscured by these artefacts.

The irregularities along the efferent limb of the T sE-loop have concerned us for some time. Limited studies suggest that most of them are artefacts due to alternating current interference and to currents from skeletal muscle contractions. These artefacts produce more readily detectable irregularities in the afferent limb than in the efferent limb because the trace is usually moving slowly when the efferent limb is inscribed and rapidly when the afferent one is inscribed. These same artefacts are probably also responsible for some of the irregularities in contour of the P and QRS sE-loops. There is a decided need to study and differentiate the alterations in contour of the loops produced by artefacts from those produced by electric events originating in the heart. The cathode ray oscilloscope will record high frequency electric phenomena, cardiac and extracardiac in origin, which are not recorded in the conventional electrocardiogram. It will be necessary to become acquainted with them and to differentiate those which are cardiac from those which are extracardiac.
As indicated by Duchosal,\textsuperscript{2} the "electric dipole" of the heart shifts during the cardiac cycle and during respiration, not only because of events related to variations in the order of electric processes within the heart but also because of shifting of the heart within the chest as it beats. The influence of this changing position upon the configuration of the spatial vectorcardiograms and the spatial electrocardiograms has not been thoroughly evaluated. This drifting must influence the accuracy of the electrocardiogram manually constructed from the spatial vectorcardiogram and vice versa.

\textbf{Summary}

The spatial vectorcardiograms of 75 normal young adults, recorded with use of the equilateral tetrahedral reference system, have been studied with the following observations.

1. The normal QRS $s\vec{E}$-loops studied were of two basic forms, the majority being elliptoid and the remainder having a roughly circular contour.

2. There were wide variations in the orientation of the QRS $s\vec{E}$-loops about their anteroposterior, transverse, and longitudinal axes.

3. These variations in orientation accounted for the extreme variability in shape and direction of inscription of the plane projections of the QRS $s\vec{E}$-loop and of the electrocardiographic leads of these subjects.

4. The classification of two varieties of contour of the QRS $s\vec{E}$-loop, with a wide range of orientation, simplified recognition of normal spatial vectorcardiograms and their differentiation from the abnormal.

5. The factors which probably influence the form and orientation of the spatial vectorcardiogram are listed and discussed.

6. The T $s\vec{E}$-loops of these subjects also showed only two basic forms (elliptoid and circular) but had wide variations in orientation.

7. The relation of the precordial leads to the spatial vectorcardiogram was studied, and it was concluded that detailed characteristics of the form and magnitude of the precordial leads cannot be inferred from the vectorcardiogram.

8. The advantages of the equilateral tetrahedron as a reference system for spatial vectorcardiography are discussed.

\textbf{Sumario Español}

Los vectorcardiogramas espaciales de 75 sujetos normales han sido estudiados y algunas de las características de los trazados se describen. Se encontró que las defleciones QRS $s\vec{E}$ y T $s\vec{E}$ tienen solamente dos configuraciones espaciales básicas pero con una variedad de orientaciones que producen muchas diferentes proyecciones planares; en parte esto explica la variación tan grande del vectorcardiograma normal. El significado de este y otros hallazgos se discute y ciertos conceptos pertinentes del estudio del vectorcardiograma se presentan.

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Circulation. 1953;7:558-572
doi: 10.1161/01.CIR.7.4.558

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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