The Validity of the Equilateral Tetrahedron as a Spatial Reference System

By J. A. Abildskov, M.D., G. E. Burch, M.D., and J. A. Cronvich, M.S.

The error involved in the use of the equilateral tetrahedron reference system for electrocardiographic or vectorcardiographic studies has been investigated by means of an electrical dipole placed in the esophagus. Vectors plotted from the potential differences between electrodes defining the reference system were found to correspond fairly closely to the actual position of the dipole, indicating that the error is small.

The study of spatial vectorcardiography in progress in this laboratory prompted an examination of the equilateral tetrahedron, which is the reference system employed. In this system the shoulders, the pubis, and a point on the back represent the apices of the figure, and the assumption of the Einthoven hypothesis that shoulders and pubis are sufficiently removed electrically from the heart to be considered equidistant must also be applied to the electrode position on the back. On a purely anatomic basis, this seems justified, since in a study of 30 normal subjects this point on the back was found to be of equal distance from the heart as the left shoulder or even more distant. It must also be assumed, as in the Einthoven hypothesis, that the body acts as an essentially homogeneous conducting medium.

It is generally agreed that these assumptions are approximations only, but are useful in frontal plane electrocardiography. If they can be applied with similar accuracy to a volumetric reference system, three dimensional vectorcardiography may provide new and valuable information.

In the report suggesting the use of the tetrahedron reference system, Wilson and coworkers presented the results of an experiment designed to test its validity. An electric field was produced in a cadaver by means of electrodes inserted in various positions in the region of the heart. The potentials at the points representing the apices of the tetrahedron were then compared with those predicted on the basis of the known dipole position. As the authors pointed out, the results were inconclusive because of the special conditions of the experiment. The effect of death on tissue resistance and the effects of accumulation of fluid in the dependent portions of the body made the data difficult to interpret.

In the experiments reported herein, the potential differences between limb electrodes and limb and back electrodes produced by a "dipole" placed in the esophagus of living subjects have been determined. It is recognized that a dipole so located is not entirely comparable to the heart in relation to points in the frontal plane, especially as regards the lateral wall of the left ventricle and its relation to the left shoulder. This objection has been overcome in part by selecting some patients in whom the esophagus deviated to the right or left at about the level of the heart.

Materials and Method

Twelve patients with chronic disease or convalescent after an acute illness were selected for study. A variety of body types and nutritional states was represented.

Smooth round German silver disks, 5 mm. in diameter, were fixed on the wall of a stomach tube near its end and were connected to an input circuit by insulated copper wire inside the tube. In six experiments the electrodes were separated by a distance of 6 cm. and in the remainder of the experiments by 2 cm. In all experiments the tube was
inserted a distance of 30 cm. or more as measured from the nose to the proximal electrode.

Essentially constant direct current of about 0.4 milliamperes was supplied to the disk electrodes by a 45 volt battery through a circuit with slightly more than 100,000 ohms resistance. With this circuit, no effects attributable to polarization at the disk electrodes were apparent.

The position of the electrodes in the thorax was determined fluoroscopically and with spot films, and in some cases by frontal and lateral thoracic radiograms. Observations on models with the electrodes in known positions indicated that the methods employed were accurate to within 5 degrees. The back electrode was placed in a position midway between the positive and negative electrodes of the esophageal dipole under fluoroscopic observation.

The leads recorded included the three standard leads and bipolar leads from the back and right arm, left arm and left leg, respectively. The standard leads were obtained on all subjects and bipolar leads from the back and right arm, left arm and left leg were obtained on 10 subjects.

While each lead was being recorded, the input circuit to the esophageal dipole was closed and opened at least nine times by means of a switch. Displacements of the baseline, similar to those which occur when an electrocardiogram is standardized, resulted. These were measured to the nearest 0.2 mm. and corrected for differences in standardization. The values so obtained were plotted on a triaxial reference system applied to each plane of the tetrahedron, to yield vector quantities which, if each apex of the tetrahedron is adequately remote from the dipole, should correspond in direction to the actual position of the dipole projected on the appropriate plane surface.

**Results**

Table 1 summarizes the data relative to the frontal plane. The actual position of the dipole

![Diagram](image-url)

**FIG. 1.—Projections of a dipole onto frontal, sagittal and right planes of the equilateral tetrahedron reference system.**

projected onto the frontal plane as determined by radiographic means is expressed in degrees from the horizontal and is compared with the direction of vectors constructed from the deflections in the standard leads. As shown, these directions differ by 10 degrees or less.

In one experiment (No. 9) an almost horizontal input was obtained with the electrodes in contact with the fundus of the stomach. As was the case with more nearly vertical positions of the dipole, there was close agreement between actual dipole position and vectors plotted from the standard lead deflections.
Tables 2 and 3 summarize the data relating to the back electrode. From the frontal and sagittal positions of the dipole as determined radiographically, the projected position of the dipole in the right plane of the tetrahedron was calculated. A typical case is illustrated in figure 1. Projections of the dipole onto

\[ \alpha = \arccos \left( \frac{1}{\sqrt{3}} \left( -x_a + \frac{2}{\sqrt{3}} y_a + \frac{2}{\sqrt{6}} z_a \right) \right) - 30^\circ. \]

Positive angles were measured clockwise from the reference axis RB, as is customary in electrocardiography.

The directions of the dipole projections in the left plane were not calculated but have been estimated with the use of a tetrahedron model. It was not considered necessary to make these calculations, since in the case of the right plane the directions as estimated with a model were essentially the same as those calculated.

The direction of the dipole projection in these planes has been expressed in degrees from the horizontal and has been compared with the direction of vectors plotted from the deflections in bipolar leads from the apices of the appropriate plane. The greatest discrepancy between the actual dipole position and the constructed vector direction was nineteen, and the average discrepancy was ten degrees. Since it is likely that the greatest errors in determining the actual dipole position were made in the case of the sagittal angles, these discrepancies would seem to be in the range of those encountered in the frontal plane.
Discussion

Experience with spatial vectorecardiography to date offers encouragement for the eventual clinical usefulness of that method, but preceding more extensive use it is desirable to have information relative to the errors involved.

The results of this study indicate in a gross fashion that a point on the back may be considered electrically remote from a dipole in the region of the heart with approximately the same error as is involved in considering the apices of the Einthoven triangle remote. Since the Einthoven concept is unquestionably valuable in frontal plane electrocardiography, it seems likely that the tetrahedron will prove useful for spatial studies of the action current.

Recently Wilson and his associates\(^1\) have reported the results of preliminary studies with the use of a dipole on the external surface of the thoracic wall to quantitate the error of the Einthoven hypothesis in individual cases and to investigate the possibility of constructing an Einthoven triangle for a given subject. It is hoped that further studies of a similar nature may yield more exact information regarding the errors inherent in applying reference systems to the human body than are now available and may suggest methods for reducing these errors.

Summary

1. The validity of the tetrahedron reference system has been investigated with the use of a "dipole" in the esophagus of living subjects to produce an electric field in that subject.
2. Results indicate in a gross manner that a point on the back can be considered electrically "remote" from the esophageal dipole with an error equivalent to that involved in considering the apices of the Einthoven triangle remote.

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