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Comparison of Three Different Systems of Vectorcardiography

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The development of vectorcardiography is still hampered by the great number of different lead systems. To arrive at a greater uniformity a comparison of these systems is necessary. This has been done by several investigators,[1-8] but the ever-increasing number of lead systems makes it worth while to proceed with this work.

This investigation must not be restricted to phantom measurements, for it is essential to compare systems by applying them to real human bodies. This is the more urgent since vectorcardiography can become an important means of cardiac diagnosis only when the differences between the current lead systems are less than the small differences existing between normal and pathologic borderline cases.[9]

The number of lead systems proposed up until now is, however, so great that a two-by-two comparison would be an endless task. Therefore, we have confined our research to three systems, viz., those developed by Frank[10] and Schmitt,[11] and one of our own. As to the latter we have chosen a system with five electrodes, three at the extremities, one precordial, and one at the back.[12]

METHOD

In all three systems two forms, a more accurate one and a simplified one, have been proposed. To propagate the application of vectorcardiography in practice we have chosen the simplest form of each.

1. In Frank's paper describing his lead system[10] the more accurate method involves a determination of the height of a transversal section of the trunk on which five electrodes are situated,

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by means of an extra measurement. We have refrained from this refinement in applying these electrodes at the height mentioned by Frank as being adequate in most cases, viz., at the fifth intercostal space near the sternum.

The head electrode is not applied in the position chosen by Frank, but to the forehead. This makes little difference and is easier to perform.

The combination of the leads necessary to obtain the three orthogonal components of the heart vector is realized with the aid of our previously described universal vectorcardiograph.[13] The relatively great number of electrodes compels us to use two extra resistances, between subject and instrument, so as to arrive at the correct linear combination of lead voltages. The photographs of frontal and horizontal projections have to be taken successively.

2. The simpler Schmitt system SVEC II is used. The head electrode is applied to the forehead, just as in the preceding case. Frontal and horizontal projections are taken simultaneously.

3. Our own system is composed of two systems, as published earlier, B_1[1] and W_4''.[6] The first, with an electrode on the sternum, emphasizes the effect of the anterior part of the heart muscle, while W_4'' emphasizes its posterior part. We give them equal weight, so that the orthogonal components of the heart vector are the arithmetic means of the linear functions of the lead voltages of both systems, B_1 and W_4''. As a simplification we use a single electrode on the sternum and refrain from a fivefold precordial electrode as mentioned previously.[12] The frontal and horizontal projections are taken simultaneously.

The application of the electrodes is made with not more care than can be expected in clinical use, omitting the extra accuracy which could be attained in laboratory work. The number of electrodes of these three lead systems (Frank, Schmitt, and B_1W_4'') is 7, 6, 5, respectively. Their diameter is 2.5 or 4 cm., depending on the space available. The three systems have been compared on 65 normal subjects and 124 cardiac patients. Since in the systems of Frank and Schmitt the scale has been left undetermined by the authors, we have measured corresponding dimensions of the loops in the three systems and have so chosen the sensitivity that in the mean the loops of the three systems are of the same size.

As formerly,[1,6] we indicate the agreement of the vectorcardiograms from two different lead systems with a score of 0 to 10. Later, this method of grading has been applied by others[5,7] in a modified form. These authors have given a valve of 0, 1, or 2 to the total score, making an evaluation for each of five previously indicated details. We, however, have retained our former method, taking into consideration different details and giving attention to the spatial configuration and to the clinical importance of the details. In the papers cited we give examples of more or less satisfactory agreement and the scores given in these cases.

TABLE I

SYSTEMS COMPARED	DIFFERENCE BETWEEN SCORES (FRONTAL-HORIZONTAL)	S.E. OF DIFFERENCE
BF	1.8	0.15
SF	1.2	0.13
BS	1.0	0.16

RESULTS

To draw conclusions from the scores mentioned above we calculated their averages and their standard errors.

The first question is whether there is a difference between the scores for normal subjects and those for patients. The normal subjects appear to score 0.3 higher than the patients, a result that is not significant since it varies much with the systems compared. Therefore, we calculated averages for all subjects, normal subjects and patients together. In Fig. 1 the averages with their standard deviations are given for the three comparisons of the three systems, two by two, and for frontal and horizontal projections separately.

As has been shown in previous comparisons of different lead systems, here again the agreement between the frontal projections is much better than between the horizontal projections. The differences between the scores of the systems F, S, B (Frank, Schmitt, B_1W_4'') and their standard errors (S.E.) are shown in Table I. Without doubt these differences are a consequence of the fact that the linear dimensions of the heart in arterior-posterior direction is not a small fraction of the corresponding dimension of the trunk. Therefore, the evaluation of the component of the heart vector in this direction is subject to more error than that of its other components.

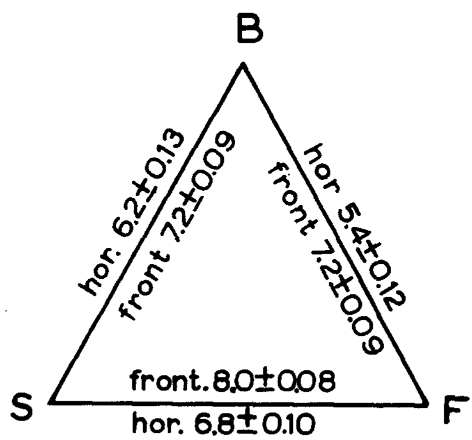

Fig. 1.—Correspondence two by two of frontal and horizontal projections of the three systems investigated, S,F,B, expressed by a score and its standard error.

It is obvious from Fig. 1 that the agreement between the Frank and Schmitt systems is significantly better than the agreement of either of them with our system B_1W_4''. Although this is a plea for these systems, it should be kept in mind that they are based on the same assumption, viz., that the trunk is equivalent to a homogeneous electrolyte. We, on the other hand, have reasons to assume that the conductivity of lung tissue is several times less than that of average human tissue, e.g., muscle tissue.[14] The discrepancy between our system and that of either Frank or Schmitt might be caused by a possible electrical heterogeneity of the human trunk.

Notwithstanding Frank's objection to the use of the left arm as an electrode[15] we have considered as paramount the advantage of using the extremities as electrodes. It is much easier and timesaving to apply an electrode to an extremity than to fix it to an exactly prescribed position on the trunk.

Another point to consider is the number of electrodes. It is obvious that we can expect a better result when a greater number of electrodes is used.

Looking at the results shown in Fig. 1 it is apparent that the agreement of the horizontal projections of the systems F and B is not satisfactory. A survey of all scores, as well as a detailed discussion of all vectorcardiograms on which this paper is based, indicate that the agreement in the majority of cases is satisfactory insofar as clinical use is concerned. However, the problem of the choice of a lead system has not yet been solved definitely. It must be hoped that it will be possible to find lead systems with essentially different positions of the electrodes which give practically identical vectorcardiograms.

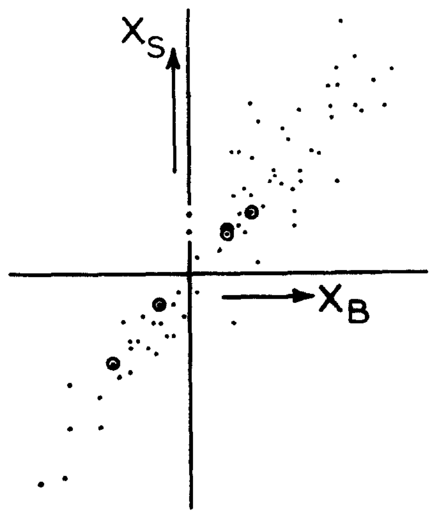

Fig. 2.—Correlation between the right-left components X_S and X_B of the heart vector in the system of Schmitt (S) and our own (B) for a part of all data. For this group of data the regression is expressed by $X_S = 1.2\ X_B$. A dot signifies a single point; an encircled dot signifies a double point.

Linear Relation Between the Two Lead Systems S and B.—It may be interesting to consider what causes a nonagreement of two lead systems. We must distinguish between individual and systematic effects. The first point will not be discussed here. As to systematic effects, there may be an inaccuracy of the factors with which the leads must be multiplied to find the components of the heart vector. These factors correspond to the lead-vector components in the simple case of four electrodes. They are the same for all subjects. In Frank's system they are represented by the network of resistances between subject and vectorcardiograph, while in Schmitt's system only equal factors occur.

A special and simple case of the relationship between two vectorcardiograms is the so-called linear transformation. This is a relationship between two vectorcardiograms or lead systems in which each of the three components of the heart vector in one system is a linear function of the three components in the other system. These three functions contain $3 \times 3 = 9$ numerical constants, the transformation coefficients. We shall not give the equations explicitly here but only mention some examples of a linear transformation. The simplest is that of identity, according to which each component in one system is equal to the corresponding component in the other system. Examples of more complicated transformations are a rotation or a homogeneous dilatation in one or more directions. All this can be expressed algebraically with the 3 × 3 transformation coefficients.

A glance at the vectorcardiograms in the three lead systems shows that the individual discrepancies are preponderant, so that we cannot expect to be able to transform all vectorcardiograms of one lead system into those of another system by one and the same set of nine transformation coefficients. But even if the average transformation is only slight compared with the individual effects, it might be worth while to investigate its systematic effect. We have restricted this investigation to the comparison of the Schmitt system (S) and our own (B).

The transformation coefficients could be determined analytically, that is by calculation. But as we can expect the systematic effect to be found to be only a fraction of the random individual effect, we have used a much less accurate method, viz., a graphical one.

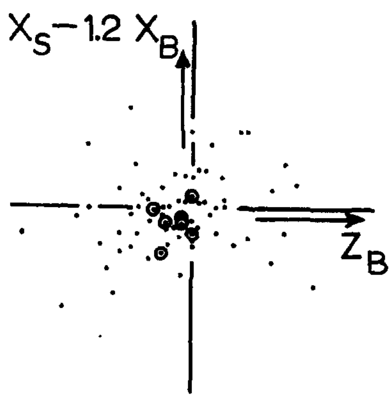

Fig. 3.—Correlation between the "error" $X_S - 1.2\ X_B$ and the anterior-posterior component Z_B. For this group of data the regression is expressed by $X_S - 1.2\ X_B = +\ 0.5\ Z_B$. A dot signifies a single point; an encircled dot signifies a double point.

Comparing two projections of a vectorcardiogram in the lead systems S and B respectively, we have chosen a few corresponding (synchronous) points on the loops. The coordinates of these points are measured and the six values for each point tabulated for all subjects. From these tables the coefficients have to be determined.

When the components of the heart vector are denoted by XYZ,* with an index S and B for the two lead systems, we have to evaluate the coefficients abc in the equation for the right-left component:

$$X_S = aX_B + bY_B + cZ_B$$

and in the two analogous equations for Y_S and Z_S. In an ideal case we could

*In our first paper (1946) on vectorcardiography we introduced the axes XYZ, that is, X was directed from right to left, Y was posterior-anterior, Z was head-foot. To prevent confusion we have adapted this paper to the American system: X = right-left, Y = head-foot, Z = anterior-posterior.

expect $a = 1$, $b = 0$, $c = 0$, so: $X_S = X_B$. To find out whether this is approximately true, the values of X_S and X_B for all subjects and for each subject for a few points on the loops are plotted. In Fig. 2 this is shown for a part of the total number of points.

The scattering of the points around a straight line through the origin of coordinates is due to different causes, among which are not only the inexactness of the linear transformation for each subject and the individual effects in different people but also the influence of the coefficients b and c not being zero.

The slope of the line gives the coefficient a, neglecting the influence of the terms bY_B and cZ_B. In Fig. 2 we have estimated the inclination by eye. This procedure, although not exact, is applied throughout this investigation to simplify the method. We read from the figure: $a = 1.2$, so $X_S = 1.2X_B$ or $X_S - 1.2X_B = 0$. For each point of Fig. 2, however, $X_S - 1.2X_B$ is not zero. The value of this "error" contains, apart from other contributions, the terms cZ_B and bY_B. A possible contribution of cZ_B can be found by plotting $X_S - 1.2X_B$ as an ordinate and Z_B as an abscissa (Fig. 3). Although the scattering is appreciable, we see by eye that there is a correlation. An approximate line gives:

$$X_S - 1.2X_B = +\ 0.5Z_B$$

or

$$X_S - 1.2X_B - 0.5Z_B = 0$$

Now the approximation can be continued by plotting $X_S - 1.2X_B - 0.5Z_B$ against Y_B. The inclination of the regression line (−0.1) gives the coefficient c. In this way we find:

$$X_S = 1.2X_B - 0.1Y_B + 0.5Z_B$$

It would be possible to start from this expression to find a second order approximation, but the systematic effect is so small compared with the random effects that we consider the last equation as the final one.

This procedure has been applied to the three components X_S, Y_S, Z_S and to all experimental points. After reducing the scale of S so that the average dimensions of the loops are the same in the two lead systems, we find the following linear transformation:

$$\begin{aligned} X_S &= +\ 1.0\ X_B - 0.1^5\ Y_B + 0.2^5\ Z_B \\ Y_S &= -\ 0.0^5\ X_B + 1.0\ Y_B - 0.1\ Z_B \\ Z_S &= -\ 0.2\ X_B + 0.6\ Y_B + 0.9\ Z_B \end{aligned}$$

From these equations, $X_BY_BZ_B$ can be solved and expressed in $X_SY_SZ_S$. The standard error of the coefficients is of the order of 0.1. This is, however, not an indication of great precision, because the random errors are much greater than the errors caused by the uncertainty of the coefficients of the linear transformation.

This transformation is not very far from identity since the three transformation coefficients in the diagonal are not far from unity, and five of the remaining coefficients are small. The main transformation effect is given by the coefficient 0.6 of Y_B in the third equation. This indicates that a footward loop is directed more posteriorly in the Schmitt system than in the B system.

A following point of the program could be to apply the linear transformation to the B system by using new adjustments of the potentiometers of the universal vectorcardiograph. In an ideal case the vectorcardiograms obtained in this way would be identical with the vectorcardiograms in the Schmitt system. The correspondence, however, cannot be expected to be so excellent; the only effect of the transformation would be to improve the scores given for the agreement of the transformed B and the S systems. This we have not done.

SUMMARY

The lead systems of Frank (F), Schmitt (S), and one of our own (B) are compared and the agreement is expressed by a score. On the whole, the agreement is satisfactory, but the anterior-posterior component of the heart vector is uncertain and spoils the correspondance, especially in comparing the F and B systems. A linear transformation is deduced to describe the average relation between the S and B systems.

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