COMPARISON OF DIFFERENT SYSTEMS OF VECTORCARDIOGRAPHY

BY

H. C. BURGER, J. B. VAN MILAAN, AND W. DEN BOER

From the Medisch-Physische Afdeling van het Physisch Laboratorium der Rijks-Universiteit and the Kliniek voor Inwendige Ziekten, Utrecht

Received December 20, 1951

It is usual for various investigators to use their own system of vectorcardiography. Such a system is characterized by the place of the electrodes and the way in which the vectorcardiogram is deduced from the potential differences obtained.

At present the system according to Duchosal and Sulzer (1949) and the one proposed by Wilson et al. (1947) are much in use. The equilateral tetrahedron proposed by the latter is a generalization of the equilateral triangle of Einthoven et al. (1913). In addition the present authors have proposed and used another fundamentally different method, based on the following line of thought. By this method, the principle of which is physically well founded (1946), the vectorcardiogram may be deduced from three potential differences. That is to say, if the electromotive force of the heart may be considered as that of a single dipole, there will be a linear relation between each potential difference $V_p - V_q$ and the three orthogonal components $X$, $Y$, $Z$ of the heart vector:

$$ V_p - V_q = aX + bY + cZ $$

The coefficients $a$, $b$, $c$ have been determined with the aid of a model, but this can also be done in another way, e.g. by cadaver experiments. From three similar equations, the three unknowns $X$, $Y$, $Z$ can be expressed in three potential differences.

These different systems have but rarely been compared with each other: Duchosal and Sulzer compared theirs, so far as it is applied to the frontal projection, with the system of Einthoven; Milnor et al. (1951) did so in a similar way, as regards Duchosal's and Sulzer's system and those of Wilson et al., and the one according to Milovanovich used in France (1948).

Lately Grishman et al. (1951) have recorded vectorcardiograms in three ways, namely with the aid of the regular tetrahedron, according to Duchosal and Sulzer, and the one according to Arrighi.

In this paper we shall report the results of a comparative investigation of three systems, namely the two we have proposed and used, and that of the equilateral tetrahedron.

THE TWO SYSTEMS USED BY US

In principle each set of four electrode positions can be used, but, in order to deduce the components of the heart vector from them, one has to use the coefficients corresponding with it (Burger and van Milaan, 1947). A choice of two sets, called here $B_1$ and $R_2$, has been made out of an infinite number of possibilities.

$B_1$. The electrodes were connected to the left arm (L), right arm (R), and left leg (F), while a fourth was placed on the sternum at the level of the axilla (B). The potential differences have been measured with respect to the right arm (R), taken as zero (Fig. 1). The component $X$ is the lateral, positive to the left. The component $Y$ is the sagittal, positive to the front. The component $Z$ is
the longitudinal, positive footward. The potential differences are indicated by the following abbreviation:

\[ V_L - V_R = LR \]

The components \( X, Y, Z \) of the heart vector have been composed out of the three potential differences \( LR, BR, \) and \( FR \) in the following way:

\[
\begin{align*}
X &= 54LR + 8BR + 16FR \\
Y &= -12LR + 40BR + 26FR \\
Z &= -10LR - 6BR + 26FR
\end{align*}
\]

These equations give relative values. The heart vector is obtained in absolute measure (volt. cm\(^2\)) if \( X, Y, Z \) is multiplied by about 25 according to these equations. The potential differences are expressed in volts.

\( R_2 \). Again an electrode is connected to the left leg (F). The other three (S, \( R_b \), \( L_b \)) are at the level of the axilla. \( S \) has been placed centrally on the vertebral column (Fig. 2). \( R_b \) and \( L_b \) are symmetrical at a distance of 50 per cent of the thorax breadth at the level of the axilla. In practice this means that the circular electrodes, 4 cm. in diameter, touch the midclavicular line at the medial side.

The components of the heart vector have now been composed out of three potential differences, \( L_b R_b, S R_b, F R_b \), according to the equations:

\[
\begin{align*}
X &= 34L_b R_b + 20SR_b + 20FR_b \\
Y &= 4L_b R_b - 36SR_b + 8FR_b \\
Z &= -8L_b R_b - 16SR_b + 22FR_b
\end{align*}
\]

As is seen in Fig. 2 the electrodes are situated at the level of the axilla alternatively between two electrodes of the system \( B_1 \), so that in this respect the two systems differ considerably. The \( R_2 \) system has been chosen from many other possibilities because it has a mathematical advantage. In this case one is far from the undesirable situation that the four electrode places lie in one plane in the image space (Burger and van Milaan, 1948). If this had been so, then the fourth potential difference could be deduced from the three and would be no independent datum. The coefficients from the equation \( (B_1) \) and \( (R_2) \) have been deduced from measurements on a model of the human body in a way, previously described (Burger and van Milaan, 1947).

**The System of the Equilateral Tetrahedron (W4)**

In this system three electrodes are connected to the arms and the left leg (R, L, F) while the fourth (W) is placed on the back at the level of the seventh thoracic vertebra and 2 cm. to the left of the vertebral column (Fig. 3). The relation of the heart vector and potential difference is presented by the authors (Wilson *et al.*, 1947) in geometrical terms. According to their opinion the four electrodes in the spatial diagram are located at the apices of an equilateral tetrahedron, of which the frontal place RLF is an equilateral triangle (as with Einthoven c.s.) in a perpendicular plane. This geometrical relation can also be expressed algebraically such that the components of the
heart vector appear as linear functions of three potential differences. From an elementary computation it follows, that:

\[
\begin{align*}
X &= 40LR \\
Y &= -23LR + 46FR \\
Z &= 16LR - 49WR + 16FR
\end{align*}
\]

In contrast to the two previous cases (B₁ and R₂) here the numerical coefficients are only determined as far as their ratio is concerned; they may be multiplied by any given factor. This factor has been chosen such that the correspondence with B₁ and R₂ is as nearly good as possible. This flatters, therefore, the correspondence between W₄ and the two other systems. On the other hand the relation of the scales of the other two systems has been determined by the measurement in the model, and the agreement or disagreement of the sizes of the vectorcardiogram of B₁ and R₂ is therefore a criterion of the correctness of our principal starting point, which does not hold for W₄.

**MEASUREMENTS**

The vectorcardiograms have been made by the universal vectorcardiograph, previously described (Becking et al., 1950). With the aid of the knobs on the frontplate, the coefficients B₁, R₂, W₄ had been adjusted successively. Of each vectorcardiogram the frontal and horizontal aspect is photographed. So there are six loops for the three compared systems. This has been performed for 115 normal and pathological subjects.

**COMPARISON OF THE THREE SYSTEMS**

To obtain a quantitative measure for the correspondence of the vectorcardiogram according to the different systems, the quality of this correspondence has been indicated by a mark. The mark 10 gives then an ideal correspondence, as is found with successive heart beats, measured by the same system, while 0 means that the two curves have not a single point of correspondence. These extreme cases were not encountered. 5 gives the border between sufficient and insufficient. Naturally, such an estimation is subjective but it can be used as a measure of correspondence. Independently of each other the authors have obtained marks in this way, after which a final opinion was drawn up. A few months later many of the marks were again determined, in which case there was rarely a difference of more than one unit. The significance of the marks is illustrated by Fig. 4, in which very good, very bad, and sufficient correspondence are shown. In estimating these marks a number of criteria played a part such as size, direction of the largest diameter, sense of rotation relation of right and left part, and details like notches.

For every subject the correspondence of the vectorcardiogram according to B₁, R₂ and W₄ was indicated by three marks for the frontal projection and three for the horizontal one. In order to be able to draw conclusions from the 6\(\times\)115=690 cases the averages were computed for 115 marks, representing the quality of correspondence respectively of the frontal, and of the horizontal projection of each set of two systems. Moreover, for each of these six averages the standard error has been computed.

Fig. 5 shows the result of these calculations. The standard error arose owing to superposition of the uncertainty in the estimation of each case and the difference between various subjects. As is seen the differences between the average marks for the three combinations B₁R₂, W₄B₁, and W₄R₂, are a few times larger than the error in each of these averages. So these differences may be considered to be significant. Fig. 5 shows that, for the frontal projection as well as for the horizontal one, the correspondence of B₁ and R₂ is the best, while W₄R₂ shows the worst result.

![Fig. 3. Position of the electrodes in the system W₄. R=right arm, L=left arm, W=electrode on the back.](image)
The rather favourable result of the comparison $W_4B_1$ frontal must be attributed to the fact that the frontal projection of $W_4$ and $B_1$ is mainly composed of the same potential differences, be it with other coefficients. There is therefore approximately a mathematical relation (linear transformation) between these curves. All kinds of details (e.g. notches) occur with both. As a result of this relation the standard error of the marks for $W_4B_1$ frontal is small ($0.07$).

The quality for the horizontal projection is less satisfactory than for the vertical ones. This is a result of the uncertainty in the sagittal component of the heart vector in each of these methods. This again is connected with the small sagittal dimension of the thorax, which is not so very much larger than the corresponding dimension of the heart. The large longitudinal dimension of the thorax, on the other hand, enables us to say with a fair degree of certainty, something about the vertical component of the heart vector.

If a choice has to be made between the three systems $B_1$, $R_2$ and $W_4$, and this choice has to be based on the quality of their correspondence, then $B_1$ and $R_2$ are to be preferred to $W_4$. These first two systems are also preferable because of their being rationally founded. Generally they give in practice a satisfactory correspondence. Furthermore, $W_4$ has the practical drawback that the sagittal component is often so small that the horizontal projection shows no details. But, on the other hand, $W_4$ has unquestionably advantages, namely the use of extremity leads, and the position of the back electrode, which is located farther from the heart than the chest electrodes in our systems $B_1$ and $R_2$.

By means of a suitable selection of the coefficients, while maintaining the places of the electrodes, a rationally founded $W_4$ could be obtained which would contain the advantages mentioned.

In general, however, the three systems so far used by us do mostly give pathological particulars
COMPARISON OF DIFFERENT SYSTEMS OF VECTORCARDIOGRAPHY

in an analogous way. By all three systems, these particulars are most strikingly visualized with left bundle branch block.

THE CAUSE OF UNSATISFACTORY CORRESPONDENCE

A. If the electrical action of the heart can really be described by a single dipole, there must be a simple mathematical relation between the vectorcardiograms of one patient, recorded according to different systems. It must be possible to transform one curve into another by a so-called linear transformation. By this we understand a mathematical transformation of a figure, e.g. by rotation or enlargement. When rotation and enlargement, etc., are small, the correspondence is considered to be good. If that is not the case the reason of such a bad correspondence has to be looked for in the tissues surrounding the heart, which define the electrical properties of the thorax. By making another choice of the coefficients previously mentioned, the correspondence could be improved. However, this holds good only for the investigated subject. The differences between the individuals are so great, however, that it will not be possible to come to a satisfactory correspondence for all cases, when using one and the same set of coefficients. On the other hand, we are not in a position to determine the coefficients for each individual.

B. Another possibility is that a bad correspondence between two systems is a result of the fact that the electrical action of the heart cannot be thought of as being the effect of one single dipole. In fact in the heart will always be a spatially distributed dipole action, and as the heart is not so very small in respect to the thorax, the dipole in one part of the heart will give another potential distribution than an equal dipole in another part of it. The dipoles may then not simply be added. This condition might be specially important when one of the electrodes is placed close to the heart. In a case like that, it would be possible, for instance, for one system to show a local peculiarity in the vectorcardiogram, which is not to be found in the other system, not even in a deformed position.

That the large dimensions of the heart can be of importance, is seen with extrasystoles. The electrical action of the heart is here different from that in a normal heart contraction, but the surroundings of the heart, which define the connection between heart vector and lead, are the same. Yet it is sometimes seen that the correspondence of the vectorcardiogram in different systems is better with the normal beat than with an extrasystole or the reverse. This can only be a result of the different position in the heart where the excitation originates, and the different spatial distribution of it during the systole and diastole.

SUMMARY

Three systems of vectorcardiography, using different positions of the electrodes, are compared. The correspondence of two systems of the authors is sufficient; that of these two with the system of the equilateral tetrahedron is less satisfactory. Possible causes of bad correspondence in some cases are discussed.

REFERENCES
