Original Communications

COMPARISON OF TWO SYSTEMS OF VECTORCARDIOGRAPHY WITH AN ELECTRODE TO THE FRONTAL AND DORSAL SIDES OF THE TRUNK, RESPECTIVELY

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THE SYSTEM OF THE EQUILATERAL TETRAHEDRON (W_4)

THE application of vectorcardiography is hampered by a great number of systems that are being used side by side. The number of systems in daily use is not much smaller than the number of cardiologists who occupy themselves with vectorcardiography. It does not appear likely that in the near future a radical standardization will be brought about whereby one system will be maintained unanimously. A comparison of different systems is therefore necessary. This is not the first time we have undertaken such a study. We have investigated already three systems, viz: the "tetrahedron" system proposed by Wilson and associates,[6] which we called W_4, and the two systems suggested by us, B_1 and R_2 (Burger, van Milaan, and den Boer[5]). It then appeared that the agreement of W_4 and B_1 was better than of W_4 and R_2.

Since W_4 is very often used while, on the other hand, B_1 has the advantage of a physical foundation, we are of the opinion that a further comparison of W_4 and B_1 will be of importance. In doing so we have not confined ourselves to a simple comparison. We have tried, while maintaining the place of the electrodes of W_4, to improve the agreement of the vectorcardiograms according to both systems.

The relation between the three components X, Y, Z of the heart vector and the potential differences LR, FR, and WR between the four electrodes L, R, F, W of the system W_4 is given by the equation stated earlier:

$$
\begin{aligned}
\text{(lateral)} \quad & X = 40 \text{ LR} \\
\text{(sagittal)} \quad & Y = 16 \text{ LR} - 49 \text{ WR} + 16 \text{ FR} \qquad (1) \\
\text{(vertical)} \quad & Z = -23 \text{ LR} \phantom{- 49 \text{ WR}} + 46 \text{ FR*}
\end{aligned}
$$

The ratio of the coefficients follows, by means of a simple calculation, from the properties of the regular tetrahedron. It has been remarked earlier that

*In the cited article (Burger, van Milaan, and den Boer[5]) Z and Y in these equations (p. 403) have been interchanged.

Wilson and associates did not state the absolute quantity of the coefficients We have chosen it in such a way that the agreement with B_1 was as good as possible.

This chain of thought can further be continued by changing all coefficients of either of the systems W_4 or B_1 so that the agreement is further improved, in which case we have the choice of changing either W_4 or B_1. We decided on the first for two reasons, namely (1) B_1 is physically founded; (2) the horizontal and frontal projections of W_4 are often so small in the lateral direction (X) that particulars are difficult to estimate by it, especially so in the horizontal projection.

The changes of the coefficients may thoroughly change the aspect of the loop, but this is not very real *mathematically*. It is a so-called linear transformation, that is, a change of a well-defined simple type. Particular cases of linear transformation are rotation, one-sided enlargement, and similar enlargement or reduction. Every conspicuous local peculiarity like a nick or a notch remains in similar transformation. The form of the loop may thereby change, so that from stretched or elongated it may become about circular. Such a transformation is extremely important for the comparison of vectorcardiograms in practice.

DETERMINATION OF THE PLACE OF AN ELECTRODE IN THE IMAGE SPACE

As is known in the system of Wilson and associates (W_4), the image points (Burger and van Milaan[4]) of the electrodes L, R, F, W in the image space are to be found in the angular points of a regular tetrahedron, of which the plane LRF is vertical and the edge LR is horizontal. When adapting this to B_1 the points LRF are to be found in the angular points of a scalene-angled triangle not lying in a vertical plane. This triangle is determined by the coefficients pertaining to the system B_1. So there remains only the problem of determining the place of the back electrode W in the image space in which the triangle LRF is situated. This can be done by observations on subjects. Because of the differences in anatomy and electrical heterogeneity of the trunk of different individuals, these investigations must be carried out on a sufficiently large number of subjects.

For this purpose we first applied a method proposed by Becking.[2] It is based on the following simple but only mathematically representable reasoning.

The potential difference W R of the back electrode W and the right arm R, chosen as the zero electrode, is a linear function of the components X, Y, Z of the heart vector:

$$WR = aX + bY + cZ \text{ (Burger and van Milaan}^3) \tag{2}$$

In this formula WR, X, Y, Z, are functions of time and a, b, c are constant. These constant coefficients are the coordinates of the desired point W in the image space (Burger and van Milaan[4]). In order to determine a, b, c we express

the components X, Y, Z of the heart vector in potential differences LR, FR, BR, which play a part in the system B_1. We found in relative measure:

$$B_1 \quad \begin{cases} X = 54 \text{ LR} + 8 \text{ BR} + 16 \text{ FR} \\ Y = -12 \text{ LR} + 40 \text{ BR} + 46 \text{ FR} \\ Z = -10 \text{ LR} - 6 \text{ BR} + 26 \text{ FR} \end{cases} \qquad (3)$$

(Burger, van Milaan, and den Boer[5])

Since X, Y, Z are the same components of the heart vector as those occurring in equation (2) for WR, we may substitute the last three equations in those for WR. After a very elementary calculation we find: WR = (54a − 12b − 10c) LR + (8a + 40b − 6c) BR + (16a + 46b + 26c) FR, or in brief:

$$\text{WR} = p \text{ LR} + q \text{ BR} + r \text{ FR}. \qquad (4)$$

In this formula, during the heart beat, WR, LR, BR, and FR change with time, while the quantities between brackets (p,q,r) remain constant. Thus it appears that the voltage of W with regard to R is a linear function of the three leads LR, BR, and FR used in the system B_1. This linear relation holds during the whole heart beat. It should be borne in mind that this theorem is of value only when the electrical activity of the heart can be described as that of a single dipole, wherever the latter may be situated.

Whether a linear relation as indicated by the last equation actually exists can be verified on a subject. For that purpose we used the earlier described universal vectorcardiograph (Becking, Burger, and van Milaan[1]).

The voltages LR, BR, and FR are amplified in an adjustable way and the results thus obtained are added up (with + or − sign). This total voltage is used to make the spot on the screen of a cathode ray tube deviate horizontally. The voltage WR (after amplification) is used to make this spot deflect vertically. If the quantities between brackets, (54a − 12b − 10c) = p, etc., in the linear combination (second member of equation[4]), have been chosen correctly, that is, in such a way that (4) has been fulfilled, then the horizontal and vertical deviations of the spot are equal at any moment, and the spot on the screen of the cathode ray tube moves over a straight line which makes an angle of 45° with the horizontal and vertical directions.

If the factors p, q, r have not been chosen correctly a curve is seen on the screen, which, just as a projection of a vectorcardiogram, consists of P, QRS, and T loops. It is now tried, by turning the knobs of the instrument (and possibly changing the sign of one or two of the factors) to reduce these loops to one line under 45°. We did this with ninety-six subjects with normal hearts. With some of them we succeeded very well in reducing the loops to the desired line. A case may occur in which with different combinations of the factors nearly as reasonable a result is obtained. This may be connected with the form of the vectorcardiogram. We will not go further into this. By these means determination of the value of the three factors becomes inaccurate in these cases.

It may also be found that one has not succeeded in making the loop resemble a straight line in a satisfactory way. Of course then the determination of the factors also is uncertain.

Once the three factors p, q, r of a subject have been determined, the observation on the subject will have illustrated that for him, during the heart beat, the equation

$$WR = p\ LR + q\ BR + r\ FR \qquad (5)$$

holds.

In this formula p, q, and r are numerically known. Comparison of (5) with (4), which have to hold for all time, that is, for all kinds of values of LR, BR, and FR, informs us that then the factors in (4) and (5) must be equal:

$$
\begin{aligned}
54\ a\ -\ 12\ b\ -\ 10\ c &= p \\
8\ a\ +\ 40\ b\ -\ 6\ c &= q \qquad (6) \\
16\ a\ +\ 26\ b\ +\ 26\ c &= r
\end{aligned}
$$

In these equations p, q, r have been found experimentally and are therefore known. Three unknowns, a, b, c, can be calculated from them. As has been remarked already these are the required coordinates of the image point of the electrode position W. The result in the ninety-six subjects is presented in Figs. 1 and 2. In these figures in horizontal and frontal projection these points are shown and moreover the tetrahedron LRFB of the system B_1 is represented.
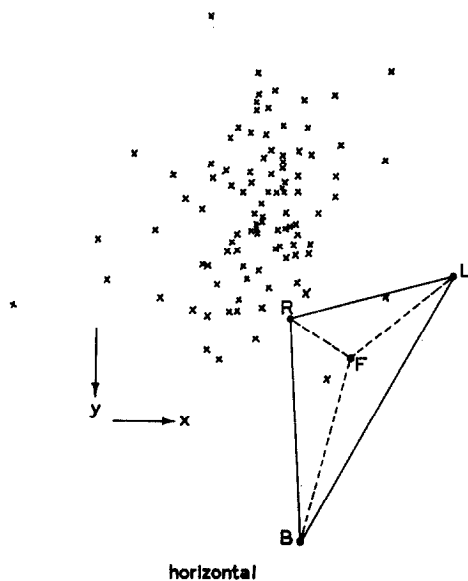

horizontal

Fig. 1.—Place of the back electrode W in the image space in horizontal projection, determined according to the method of Becking. Each cross gives the result of the measurement on one subject.
R = right arm, L = left arm, F = left leg, B = chest electrode. These form the tetrahedron in the system B_1.

It will be noticed that the scattering of the found points is of the order of the dimensions of the tetrahedron, and can certainly not be considered small. This is partly due to the errors in the determination of each of the points. But the scattering is certainly for the greater part real; there is a difference between different individuals.

The mean of all values found gives the coordinates a, b, c of the center of gravitation W in Figs. 1 and 2.   These values of a, b, c are substituted in (2).

The system in which these coefficients are used we call W_4'.   The components X, Y, Z of the heart vector expressed in LR, FR, and WR can be found from (3) and (2) by eliminating BR from these four relations.

$$W_4' \begin{cases} X = \quad 53 \text{ LR} - 16 \text{ WR} + 15 \text{ FR} \\ Y = -24 \text{ LR} - 76 \text{ WR} + 23 \text{ FR} \\ Z = - \ 8 \text{ LR} + 13 \text{ WR} + 27 \text{ FR} \end{cases} \qquad (7)$$

VECTORCARDIOGRAMS WITH THE IMPROVED SYSTEM W_4'

With these coefficients we have recorded vectorcardiograms from many of the former subjects.   For this purpose the previously described universal vector-cardiograph was used (Becking, Burger, and van Milaan[1]).   The result was better than might have been expected on the ground of the scattering repre-
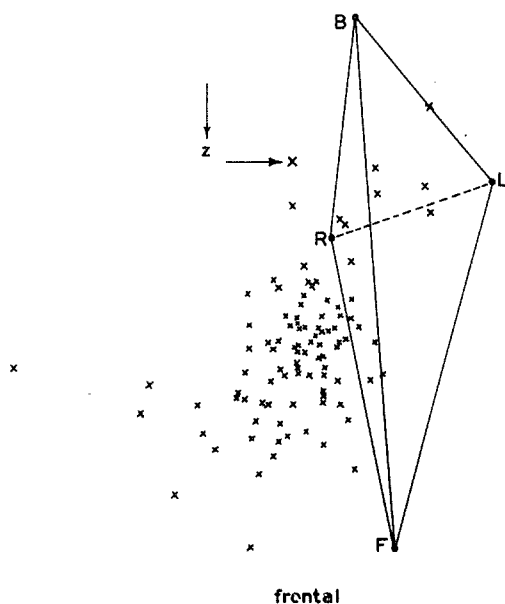

frontal

Fig. 2.—Place of the back electrode W in the image space in frontal projection, determined according to the method of Becking.   Each cross indicates the result of the measurement on one subject.

sented in Figs. 1 and 2; the agreement of W_4' with B_1 was satisfactory.   This holds not only for the frontal projection, for which the agreement is to be expected.   Here the electrodes W and B, respectively, on back and chest play but a small part.   These electrodes serve mainly to find the sagittal component that is decisive for the form of the horizontal projection.   Also for the latter the agreement was better, however, than that between the original W_4 (according to Wilson and associates) and B_1.

FURTHER IMPROVEMENT OF THE SYSTEM OF COEFFICIENTS (W_4'')

Further consideration of the vectorcardiograms revealed that there is a slight systematic deviation between the horizontal projection of W_4' and B_1; the loops of W_4' must be rotated clockwise an average of 20° in order to get the direction of that of B_1. This rotation, together with a small enlargement of the loops in the X direction, leads to a correction of the coefficients of (7).
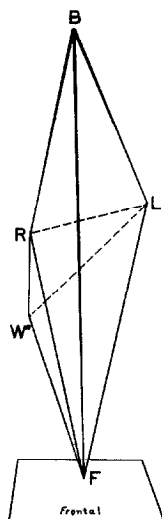

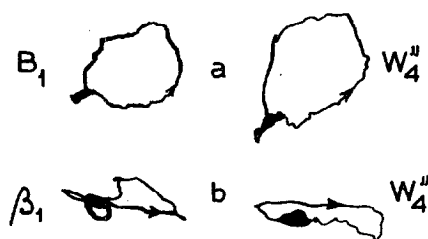Fig. 3.—Tetrahedron BRLF and W''RLF of the systems B_1 and W_4''.

Fig. 4—a, Example of good agreement of the horizontal projection.   Estimation mark 8.
b, Example of bad agreement of the horizontal projection.   Estimation mark 3.

The new coefficients are those of the following equations:

$$W_4'' \begin{cases} X = 58 \ LR - 17 \ WR + 16 \ FR \\ Y = -6 \ LR - 81 \ WR + 28 \ FR \\ Z = -8 \ LR + 13 \ WR + 27 \ FR \end{cases} \qquad (7a)$$

The situation in the space image is represented by Fig. 3.   In it we see the two tetrahedrons LRFB (system B_1) and LRFW (system W_4'') which have the frontal plane LRF in common.   The first lies before this plane, the second behind it.

With the coefficients of (7a) vectorcardiograms were recorded (system W_4'') and compared with those according to system B_1 (cf. [3]). The agreement of the horizontal projections has indeed improved by the last correction. The frontal projection regularly yielded an excellent agreement, which was to be expected. Fig. 4 is an example of a good and a less good agreement.

Just as formerly, we (Burger, van Milaan, and den Boer[5]) have indicated the agreement of two projections with a mark, whereby 10 represents an ideal agreement and 0 the complete absence of it. The figures pertaining to the cases in Fig. 4 are stated in the legends.

CONCLUSION

The mean figure for sixty-four normal subjects is 6.4 ($\pm$ 0.2) and that for ninety-six patients 6.5 ($\pm$ 0.2), both for the horizontal projection. The vertical projection gives, as was to be expected, an even better agreement, namely 8.8 ($\pm$ 0.2).

The comparison of the original system of Wilson and associates with our system B_1 has earlier been given the mark 5.1 ($\pm$ 0.1) (Burger, van Milaan, and den Boer[5]). The application of the rationally chosen coefficients has thus led to a significant improvement in the agreement. In only about 10 per cent of the cases was the agreement of the horizontal projections in our estimation insufficient. For the clinical application the systems W_4'' and B_1 are easily in most cases to be considered as being equivalent.

DISCUSSION

The system of the equilateral triangle (W_4) proposed by Wilson and associates[6] has several advantages and is often used. It has, however, the disadvantage that it has no correct physical foundation. The system B_1 (Burger, van Milaan, and den Boer[5]), on the other hand, is based on physical principles and measurements, but is not used by many clinicians. A comparison of these two systems seemed worth while.

The measurements just described demonstrate that it is possible to obtain physically founded vectorcardiograms, while the electrode positions of the system of Wilson and associates are maintained. The coefficients of this new system (W_4'') are then to be chosen according to the equations (7a). The vectorcardiograms according to W_4'' give a far better agreement with our system B_1 than did the original system W_4 of the equilateral tetrahedron. In the majority of cases the agreement is clinically satisfactory.

The technical difficulties in applying physically founded coefficients are not serious. In a previous paper (Becking, Burger, and van Milaan[1]) a satisfactory method was described. Even a simpler way could be followed, though it will not be discussed here. It must be emphasized, however, that, once the instrument has been constructed, the clinician is no longer troubled with the application of "coefficients." In practice the use of a method with correct coefficients is just as simple as following a procedure of the "intuitive" type.

SUMMARY

The agreement of the system of the regular tetrahedron with the physically founded system B_1 is not very satisfactory in horizontal projection. This agreement becomes satisfactory and clinically useful by application of suitable coefficients, while maintaining the electrode places, as indicated by Wilson and associates.

SUMMARIO IN INTERLINGUA

Le accordo del systema del tetrahedro regular con le systema B_1 a fundamento physic (Burger, van Milaan, den Boer) es pauco satisfacente in le projection horizontal. Le accordo deveni satisfacente e clinicamente utile per le application de appropriate coefficientes durante que le sitos del electrodos es mantenite como Wilson e su associatos los indicava.

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