Comparison of Limb and Precordial Vectorcardiographic Systems

By Ernest Frank, Ph.D., and George E. Seiden, M.D.

Two advanced types of vectorcardiographic systems have been applied to 104 miscellaneous patients for the purpose of comparing practical features and electric results. The 2 systems showed satisfactory average agreement, as expected, but there were marked individual differences in many cases. Despite corrections for torso shape and typical eccentric ventricle location, the limb electrode system yielded results significantly outside attainable limits, and hence is considered unsatisfactory for quantitative work despite its practical advantages.

A recently described system of vectorcardiography1 that is practical for clinical use employs 7 electrodes (3 on the precordium) and has the advantages of (1) sound theoretic and physical basis, (2) corrections for shape of human torso, (3) exclusion of left arm electrode with its attendant errors, (4) insensitivity to individual variability of dipole location, (5) reasonable speed and ease of application, (6) better signal-to-noise ratio than in "remote electrode" systems, and (7) cost comparable to other systems. Its disadvantages are criticalness of location of some electrodes and need for rubbing the skin beneath electrodes (which can be avoided by use of cathode followers). An "average computing" system2 employing 4 electrodes (the minimum possible number) on highly practical body sites (R, L, F, B) incorporates corrections for torso shape, largely overcomes the disadvantage of critical electrode placement, and employs fewer electrodes. Therefore, it is easier and faster to apply, although the need for skin rubbing is still present. However, it has the disadvantages of errors traceable to individual dipole location variability among subjects and to individual variability of left arm electric characteristics. Also it produces only one half the signal amplitude of the precordial system and thus is more susceptible to muscle-tremor artifacts.

The practical advantages for clinical use of the average computing system suggest a comparative study to ascertain directly, in terms of vector loops on the same patient, the degree of correspondence between results of the 2 systems. The essential purpose of the study was to discover if the more accurate but more elaborate precordial system yields significantly different quantitative results in a sufficient number of cases to justify its use. The 2 systems were not expected to give the same results in all cases. A study3 of cardiac patients indicated significant differences in individual dipole location, and model studies4 indicated that dipole location effects introduce sizable error in the average computing system. Moreover, left arm variability was also anticipated as a source of error. Despite these negative theoretic indications, practical advantages of the average computing system were felt to be too attractive to discard without direct experimental evidence. Moreover, a comparative study of this type gives additional evidence (though less sharply than in other studies5, 6) concerning applicability of dipole potentials in 3-dimensional torso models to a wide assortment of patients.

Method and Material

Because choice of subjects can influence comparison of the 2 systems, a wide variety of patients, both male and female, with and without heart disease, and of varied age and body build, were chosen for study. Of the 104 patients selected, 69 were male and 35 were female. The age range was from 7 to 78 years (average 52). The range for height was 46 to 74 inches (average 68); for weight, 46 to 293 pounds (average 150). Clinical and standard V lead electrocardiographic diagnoses are given in table 1.

Five electrodes of the precordial system were

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attached around the thorax at the left side, A; right side, I; front, E; back, M; and on the left precordium, C, in locations that have been accurately prescribed. Electrode level was determined by an electrical technic previously described for each of the 104 patients. The remaining 2 electrode sites were left leg, F, and back of the neck, H. These electrode potentials were delivered through cathode followers (to avoid the need of skin rubbing) to the network of resistors shown in figure 1 (left), any 2 outputs of which could be amplified in a 2-channel vectorcardiograph and displayed on a cathode-ray oscilloscope.

The 4 electrodes of the average computing system were attached to the standard limbs (right arm, R; left arm, L; left leg, F) and on the back, B, 1 inch to the left of the midline at the same level as in the precordial system. These electrode potentials were delivered through cathode followers to the network of resistors shown in figure 1 (right), any 2 outputs of which were fed into the same vectorcardiograph as in the precordial system. The resistance network serves essentially as an analogue computer that, in effect, solves 3 equations of the type published previously that pertain to a typical dipole location designated as no. 22. The average computing system must not be confused with the Wilson tetrahedron, despite use of the same electrode sites.

These 2 systems represent considerable contrast, especially regarding the transverse components, since one employs “remote” electrodes exclusively while the other has several electrodes in close anatomic proximity to the heart. Nevertheless, it was expected on the basis of model studies and experiments on a variety of subjects to find good agreement between the 2 systems in cases where the subject’s dipole location did not differ too much from location no. 22. However, the amplitude level of the precordial system is established by a minimum image vector of 136 units (for the head-foot component), while that of the average computing system is established by a minimum image vector of 71 units (for the front-back component). Thus, the amplitude ratio expected was 71/136 = 0.52; that is, the size of the vector loops produced by the average computing system was expected to be 0.52 times that obtained in the precordial system when the subject’s dipole location was no. 22. Accordingly, the standardization employed in the average computing system was routinely larger than in the precordial system by a factor of about 2 (1.8 was actually employed).

Subjects were studied in the sitting position except in cases where it was essential to employ the prone position because of excessive muscle-tremor interference in the low-signal average computing system. In each case frontal, sagittal, and transverse projections of the QRS loops of both systems were observed sequentially on the cathode-ray tube and photographed with a polaroid camera. In addition, scalar leads of the precordial system were displayed on the cathode-ray tube and photographed, and standard electrocardiograms of all subjects were obtained with a Visocardiette.

**Basis for Comparison of Loop Projections**

Comparison of projections of corresponding loops derived from the 2 systems is difficult to accomplish in quantitative terms. Since many of the QRS loops were qualitatively very similar, it was necessary to devise fairly exacting criteria for comparative purposes. A semiquan-
tative method was employed consisting of evaluation of 5 items covering pertinent characteristics of each projected loop (these items were not completely independent). Each item was given a score of either 2, 1, or 0 based on the criteria below, and a total evaluation score ranging from 10 to 0 was deduced for each pair of projected loops.

**Direction of Incription.** Direction of inscription of the projected loop was indicated by intensity modulation of the cathode-ray tube. A score of 2 was assigned when direction of inscription was clearly the same in corresponding loops. A score of 1 was given in cases that were not absolutely clear in the records or when definite doubt existed as to agreement in cases that displayed multiple crossings. A score of 0 resulted in cases where direction of inscription was clearly opposite in corresponding loops.

**Length-to-Width Ratio Comparison.** A rough measure of over-all shape of projected loop can be formulated by defining a length-to-width ratio as follows: length of maximum vector (distance from null point to point of maximum displacement of loop) divided by maximum width of the loop measured along a line perpendicular to the maximum vector. Length-to-width ratio of each projected loop was determined with this definition. A score of 2 was given when the ratio of the larger to the smaller length-to-width ratio was in the range 1.0 to 1.4; a score of 1 was given when this ratio was between 1.4 and 2.0; a score of 0 was given for ratios exceeding 2.0.

**Difference Between Angles of Maximum Vector.** The angle of the maximum vector as seen in projection was measured with respect to the following reference axes: frontal, right-to-left reference axis (angle measured clockwise as observed from the front of the subject); sagittal, front-to-back reference axis (angle measured clockwise as observed from the left side of the subject); transverse, right-to-left reference axis (angle measured counterclockwise as observed from the head of the subject). Difference between angles obtained in the 2 systems was evaluated as follows: score 2 for differences between 0° and ±10°, score 1 for differences lying between ±11° and ±25°, score 0 for differences exceeding ±25°.

**General Shape Agreement.** General shape was defined as a quality dealing with the over-all appearance of the projected QRS loop with special attention paid to the Q and S deflections. A score of 2 was given if the over-all shape agreement was excellent and if Q and S deflections were in good quantitative agreement. A score of 1 was assigned in cases where over-all agreement was good but with some departures in relative sizes of the Q and S deflections. A score of 0 was given in cases with poor correspondence in over-all shape or when gross discrepancies in Q and S deflections existed, such as a sizable S wave in one loop and none in the other.

**Fine Details of Shape.** When fine details of loop contour such as slight quirks and peculiarities of contour were distinctly present and consistent in the pair of loops, a score of 2 was assigned. If most of the fine detail showed good correspondence except for 1 or 2 minor aspects, a score of 1 was given. A score of 0 resulted when there was no correspondence between fine detail in one loop as compared with the other.

**Results**

With 104 subjects a total of 312 loop projections was obtained. Results of the QRS loop comparison based on 5 items mentioned are shown in table 2. Numbers in this table represent the number of cases in each category but are nearly equal to per cent, since 104 cases are included in the study. On the whole, it may be seen from this table that agreement in frontal projections, F, was consistently better than in sagittal, S, and transverse, T, projections in all items except direction of inscription, while sagittal and transverse agreement is closely comparable. The 16 cases of score 1 in direction of inscription for frontal projections are largely

<table>
<thead>
<tr>
<th>Score</th>
<th>Direction of inscription</th>
<th>Length-to-width ratio comparison</th>
<th>Difference between angles of maximum vector</th>
<th>General shape agreement</th>
<th>Fine details of shape</th>
</tr>
</thead>
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<tr>
<td>2</td>
<td>F 88 S 95 T 64 49 51</td>
<td>F 64 S 44 T 43</td>
<td>F 83 S 60 T 39 18</td>
<td>F 23</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>F 16 S 12 T 8 26 32 33</td>
<td>F 33 S 39 T 39</td>
<td>F 43 S 45 T 60 79 65</td>
<td>F 65</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>F 0 S 0 T 1 14 23 20</td>
<td>F 20 S 7 21 22</td>
<td>F 3 S 3 5 7 16</td>
<td>F 16</td>
<td></td>
</tr>
</tbody>
</table>
traceable to the fact that frontal loops were often nearly closed as compared with more open loops in the other views, with consequent ambiguity in direction of inscription in some cases.

Total evaluation scores for each pair of projected loops in 312 cases were distributed as follows: 16 received a score of 10, 60 a score of 9, 79 a score of 8, 74 a score of 7, 47 a score of 6, 15 a score of 5, 14 a score of 4, 6 a score of 3, and 1 a score of 2. Sample loops with corresponding over-all evaluation are shown in figure 2, and give a graphic idea of the exacting nature of the comparison criteria. However, it is not possible to give a representative record in each case, since there was an appreciable range of variation within each category. These over-all scores may be given descriptive designations as follows: score 10 excellent, 9 very good, 8 good, 7 fair, 6 fair-to-poor, 5 poor, 4 (or less) very poor. Scores based on purely subjective independent evaluation of the loops were usually within ±1 point of those obtained from the more elaborate semiquantitative criteria.

Additional data on correspondence of results are presented in table 3. It may be seen that mean differences in angle of maximum QRS vector were only 2 or 3 degrees, which is essentially perfect average agreement. However, the standard deviation (σ) indicates that about two thirds of the cases were within ±12° of the mean for the frontal loops, while the scatter in angle of the sagittal and transverse maximum vectors was approximately twice this amount. Amplitudes of corresponding QRS dipole components were, on the average, within ±10 per cent of expectations based on model studies, as can be seen in table 3 on comparison

Table 3.—Correspondence of QRS Results for 104 Patients

<table>
<thead>
<tr>
<th>Difference in angle of maximum vector, degrees</th>
<th>Ratio of peak-to-peak amplitudes of corresponding dipole components</th>
<th>Comparison evaluation score</th>
</tr>
</thead>
<tbody>
<tr>
<td>F S T</td>
<td>X Y Z</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-2.1 3.5 -2.5</td>
<td>0.53 0.47 0.42</td>
</tr>
<tr>
<td>σ.....</td>
<td>12.1 23.8 20.2</td>
<td>0.15 0.09 0.15</td>
</tr>
</tbody>
</table>

Fig. 2. Precordial system left, average computing system right. Sample records of projections of vector loops with accompanying comparison evaluation scores ranging from 10 through 5. F, S, T signify frontal, left sagittal, and transverse projections, respectively. Timing markers occur at a rate of 480/second, locked in at 8 times the line frequency. Bright spots immediately after blanked portions of trace reveal direction of inscription. Note additional muscle tremor in records on right, even though cleanest records were selected for this figure. Standardization employed in precordial loops was 1 inch/mv. and in average computing system 1.8 inch/mv. Faint lines have been drawn on records intersecting at the null point.
with the theoretic amplitude ratio of 0.52, previously mentioned. The y-component had a significantly smaller standard deviation than the x- or z-components. The reason why the z-component average amplitude was disproportionately lowest of the 3 was that, in about one third of the cases, its amplitude was markedly smaller (0.3 or less) in the average computing system. Comparative evaluation scores in table 3 indicate that frontal loop agreement was significantly better and more tightly clustered than sagittal or transverse, but that sagittal and transverse comparison was substantially the same on the average.

**Discussion**

There were 2 major departures between results obtained with the 2 systems, the most pronounced of which was poor agreement, in many cases, in the front-back component, p<sub>y</sub>. The most striking failure in correspondence of p<sub>y</sub> was markedly reduced amplitude and altered timing, which was anticipated to occur in the average computing system when dipole location is about 2 cm, or more anterior to design-center location no. 22. In approximately one third of the cases, the p<sub>y</sub> component was foreshortened by a relative factor of 2, or more, in comparison with the more accurate p<sub>x</sub> of the precordial system, and its shape was also markedly different. An example of this type of result has been published previously. A somewhat more pronounced example is shown in figure 2, score 5. The second important difference occurred in approximately 20 per cent of cases when the amplitude of the right-left component p<sub>x</sub> in the average computing system substantially exceeded reasonable limits anticipated from model experiments. An illustration of this finding is given in figure 2, score 6. This may be traceable to electric peculiarities of the left arm of the subject.

Despite the above differences, similarities in the results also deserve emphasis. Agreement in shape, timing, and amplitude, of the head-foot component p<sub>x</sub> was best of all 3 as expected, because the p<sub>x</sub> lead in both systems is, as observed in models, a very stable quantity. (As a practical matter, it should also be observed that the left leg electrode was involved in both systems as part of the p<sub>y</sub> lead, which of course would tend to improve the correlation.) Although individual discrepancies were pronounced in many cases, average agreement between the 2 systems in terms of the measured quantities was within the ±15 per cent error expected from applicability of model results to the human subject. This may be interpreted to mean that dipole location of subjects tested clustered around location no. 22. Good average agreement between these 2 distinctly different systems constitutes rough evidence of the applicability of dipole potentials in homogeneous 3-dimensional torso models to the human subject for a wide variety of normal and abnormal cases. However, the comparative study does not represent an exacting detailed test of model applicability.

Accuracy expected from the precordial system may be expressed roughly in terms of comparative evaluation scores. Scores between 8 and 10 cover the approximate range of absolute error expected in the precordial system. Therefore, it may be concluded that the frontal loops of the average computing system were, on the average, within the accuracy range of the precordial system but that both sagittal and transverse loops were, on the average, somewhat outside. In terms of individual cases, approximately 50 per cent of the 104 cases showed differences that were outside expected accuracy limits of the precordial system. The finding of best agreement in the frontal projection is consistent with that of a somewhat similar study of Burger and associates. However, average frontal agreement in Burger’s study ranged from 5.2 to 6.7 for various systems, rather than the 8.0 result obtained here. It is thought that this difference cannot be attributed to the subjective nature of the comparison basis, because very exacting criteria were used that would tend to lower our evaluation scores. The explanation would appear to reside in the fact that the precordial system, being less vulnerable to dipole location, provided a much more stable reference basis than in Burger’s cases, where the systems compared were all susceptible to this critical parameter.
Although 3 projections of the spatial QRS loop have been used in this study, it should not be misconstrued that this is the most useful approach for interpretation of vector loops. Correlation of vector loops with heart activity for clinical purposes must entail a study of the loops in space, because loop projections can be influenced markedly by slight changes in orientation of the spatial loop. However, in a comparative study of this kind where it is only desired to compare 2 loops independently derived by 2 different systems, analysis of loop projections provides a more exacting basis of comparison than analysis of the spatial loop. Slight changes in loop orientation can cause extreme changes in some of the quantities used as a basis of comparison, the most glaring example of which is length-to-width ratio. It is likely that a more favorable comparison would have resulted if the 2 spatial loops had been compared, but the sizable discrepancies observed in p would still be present.

It should be emphasized that the average computing system is not equivalent to the Wilson tetrahedron despite use of the same electrode sites. The essential difference is that the average computing system corrects for human torso shape and for a typical eccentric dipole location, while the Wilson tetrahedron applies to a spherical boundary with a centric dipole. Since the latter representation is inferior to the former, correspondence of results between the Wilson tetrahedron and the precordial system may be expected to be much poorer than obtained here.

Many interesting characteristics of QRS loops found in this study include such quantities as absolute amplitude of components, angles of maximum vectors, directions of inscription, length-to-width ratios, and degree to which the spatial loop is confined to a plane. None of these data are considered worthy of reporting at this time because of the extreme heterogeneity of the group of subjects and insufficient number of cases of a given kind. Therefore, only relative and comparative data have been presented.

The essential conclusion reached after thorough analysis of results is that the precordial system is worth the additional effort for 3 reasons:

1. While agreement is quite satisfactory on the average, individual differences in 50 per cent of the cases were quantitatively significant.

2. Marked discrepancies in the front-back component in the average computing system (in one third of the cases) and significant differences in the right-left component (in one fifth of the cases) represent excessive individual departures giving results in some cases that are even qualitatively different.

3. As a purely practical matter, the muscle tremor interference in the average computing system was severe in many cases and gave difficulties that tended to offset its practical clinical advantages. This conclusion tacitly assumes that quantitative vectorcardiography will reveal information not heretofore found on a qualitative basis. The degree of inherent scatter of data for heart patients that is not presently known is, of course, a pertinent factor. It would seem advisable to use the best possible practical system until further basic data are obtained concerning inherent scatter. However, failure to obtain a consistently satisfactory p in the average computing system would seem to rule this system in any event.

Summary

Results obtained with 2 advanced types of vectorcardiographic systems applied to an assorted group of 104 subjects are compared in quantitative terms. While average agreement between the 2 systems was satisfactory, individual differences in 50 per cent of cases were quantitatively significant. The most glaring defect of the limb electrode system was failure to render an accurate front-back dipole component in one third of the cases.

Acknowledgment

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Summario in Interlingua

Es comparar quantitativemente le resultatos obtenite in duo avantiate typos de systemas vectorcardiographique, applicate a un assortmento
de 104 subjectos. Le accordo median del duo systemas eseva satisfactori, sed in 50 pro cento del casos le differentias individual eseva quan-
titativamente significative. Le plus serie defecto del sistema a electrodos extremitatal eseva le facto que illo non provideva un accurate com-
ponente dipolic fronto-dorsal in un tertio del casos.

REFERENCES


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6 ——: Determination of the electrical center of ven-


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Four men, aged 24 years, were studied during a control period and during a 4-week period in which the caloric intake was doubled but the fat intake was kept constant at the control level. During this time the subjects were required to maintain their body weights within 5 pounds of the mean control weight by strenuous exercise. They were also studied during a third period of similar high caloric intake but without high energy expenditure, and finally, they were studied during a period of restricted caloric intake to remove the fat deposited during the third period. One of the 4 subjects left the experiment because of inability to maintain a constant weight during the period of high intake and high energy expenditure. The observations indicated that the subjects were able to double their caloric supply without increasing the level of their serum lipids so long as the excess energy was dissipated as exercise. When the excess energy was no longer dissipated as exer-
cise, it was diverted to adipose tissue in 2 of the 3 subjects with an increase of serum cholesterol, phospholipid, and lipoprotein levels.

The experiment is felt to simulate in miniature the nutritional progress of an American male adult from early adulthood with high energy turnover associated with athletic endeavors, through a long period of diminishing activity but with unchanged dietary habits. The authors state that this leads in a variable time to an obese person at middle age, with poor muscular development and with elevated serum cholesterol and β-lipoprotein levels although without visible lipemia. The authors propose that the positive caloric balance over a long period elevates the serum lipid levels and contributes to atherogenesis.

Rosenbaum
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