Quantitative Comparison of Eight Vectorcardiographic Lead Systems

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The large number of different, but presumably equivalent, vectorcardiographic lead systems in current use makes it imperative that their degree of interchangeability be investigated, and that standardization on some compromise system be achieved if possible. The situation is reminiscent of the controversy over the CF, CL, CR, and V leads in the early forties. Large and erratic variations of spatial loop configuration, orientation, and magnitude among eight different, presumably orthogonal, vectorcardiographic lead systems were found, so that direct interchangeability is questionable. The discrepancies were far greater than those between the different types of chest leads. Standardization on a universally acceptable compromise vectorcardiographic lead system would be desirable, to avoid confusion in the rapidly accumulating body of vectorcardiographic material, even though the compromise falls short of a theoretic ideal.

Over 20 different, nominally orthogonal lead systems are now being used in vectorcardiography. As tested by homogeneous torso model methods, some of these lead systems show fair over-all orthogonality, but only a few show anything even approaching constancy in transfer impedance for every position within the myocardium, taken individually, and there are considerable discrepancies between the lead systems. Taking the additional factor of body inhomogeneity into account, we must anticipate very appreciable deviations between the vectorcardiograms (VCG's) recorded in these different systems. It must not be presumed that the lead system used alters merely the strength and projection planes, so that one system can readily be converted into another. A best compromise set of conversion constants can indeed be found from model data, but these corrections cannot compensate for spatial variability of transfer impedance, and can only adjust the average axes and strengths, not the point by point values, and even this correlation has yet to be tested adequately in man.

We were anxious to learn how great was the disparity between several of the popular lead systems in actual VCG's in order to learn whether for practical purposes statistical standards of interpretation could be interchanged for these systems.

We compared the following methods: conventional lead system, SVEC II (three bipolar anatomically orthogonal leads), SVEC III (three bipolar electrically orthogonal leads), Duchosal, Burch-Wilson, Grishman, Bril- ler, and Frank.

The bulk of the material (from 182 elderly men), was obtained with the conventional and the SVEC III lead systems. These lead systems were selected because the conventional lead system is universally accepted, and hence vectorial interpretation of conventional leads is of interest, while the SVEC III system, of all lead systems tested, showed the least over-all distortion in model experiments. The discrepancies between the different lead systems in different individuals, while highly reproducible, were so erratic that averaging, statistical evaluation, or accumulation of a larger material did not seem to be useful. Consequently only in 4 subjects were all eight systems compared.

For the SVEC III lead system with its 14 electrode positions and the standard precordial leads, a vest consisting of elastic bands...
was used, with electrodes along the three circumferential bands (fig. 1). With this arrangement, the leads X, Y, Z, three standard leads, and six precordial leads could all be taken in 10 minutes on a four channel Sanborn machine, using a specially constructed switch. We determined mean vectors by means of a null point method from the simultaneous time-based tracings, using a mechanical vector analyzer, while with the SVEC III computer, instantaneous maximum QRS and T vectors were read by means of electronic rotation in the direction of display of the maximal loop extension, in addition to projection on the frontal, sagittal and horizontal planes. The axes of the maximum instantaneous vectors were read directly from azimuth and elevation dials. The computer was also used to obtain the maximum instantaneous vectors in scalar time-based leads. The vectors are expressed in terms of azimuth (H°), elevation (V°), magnitude (Mag.), and angle between spatial QRS and T axes (dA°).

As an example of intraindividual changes, we also compared the changes from midrespiratory.

Fig. 1. Vest with adjustable electrode positions for the SVEC III leads and the precordial leads V₁ to V₅, taken at the level of the fifth intercostal space.

Fig. 2. Frontal and horizontal projection of QRS loops of one subject, recorded with four different lead systems (SVEC III, Burch, Frank, Grishman). Configuration, orientation, and magnitude of QRS loops show significant differences between the lead systems in midrespiration (broken lines) and inspiration (solid lines).
piration to maximum inspiration. In a previous study the distribution in different lead systems of vectorial respiratory changes was studied in 60 healthy elderly men, and this data is used as a reference basis for the present series.

RESULTS

Figure 2 shows the vectorial loops in midrespiration and maximum inspiration for one subject, as recorded with four different lead systems (SVEC III, Burch, Frank, Grishman) in the projection on the frontal and horizontal planes. Not only are the axes different, but so also is the whole loop contour, and this is true for the midrespiratory position as well as for the respiratory changes. The differences between lead systems in different individuals were erratic and large in every case, and therefore the example in figure 2 is fairly representative of the general situation.

We determined the normal range limits from the percentile distribution in 182 healthy elderly men for the conventional and SVEC III lead systems. This is important in clinical application, for, in general, the narrower the normal range limits the better the differentiation between normal and abnormal. The range limits of mean spatial QRS and T vectors in midrespiration for 98 per cent of normal population are shown in figure 3 for QRS and T vector magnitude, in figure 4 for azimuth and elevation, and in figure 6 for the angle between spatial QRS and T vectors, determined with the conventional (outer rings) and the SVEC III lead systems (inner solid rings, figs. 4 and 6). The range limits for the vector magnitude and for the azimuth are nearly identical in the two lead systems. On the other hand, the normal range limits of the SVEC III lead system in midrespiration are appreciably narrower for the elevation (V°), but wider for dA° (fig. 6).

The projection of spatial vectors on a plane is highly sensitive to positional variability. We wish to point out that azimuth and elevation in figures 4 and 5 are true spatial orientation angles of spatial vectors, and not projections on a horizontal and frontal plane, as in the majority of the vectorcardiographic literature, and as shown in figure 2.

The normal range limits for 98 per cent of a normal population were used as criteria for comparison of the eight lead systems in each of the 4 healthy individuals (A.M., B.R., M.B. and R.T.), in midrespiration (fig. 3, 4, and
Fig. 4. The vectorial angles in midrespiration in normal subjects with eight different lead systems, as compared with the normal limits for SVEC III system (straight lines) and conventional lead system (xxxxx).

Fig. 5. Inspiratory vectorial angular shifts in four normal subjects with eight different lead systems, as compared with the confidence limits for inspiratory changes in SVEC III. Upper pair = azimuth; lower pair = elevation.

6), and for the changes in inspiration (figs. 5 and 6). The values for the eight different lead systems are widely scattered in all 4 subjects.

It is striking that the range of variation for one individual as measured in eight systems approached the total variation determined for 182 men, in the conventional or SVEC III lead systems. The particular lead systems which show the most extreme values are not the same in all vectorial items, nor are they the same for all individuals. The absolute values of some lead systems are very different from the normal range for the SVEC III system. More important, however, is the large range between the extremes of the various lead systems. The situation would have been similar had the normal range limits for some other lead system been used for comparison.

Figure 5 shows the situation for the vectorial changes from midrespiration to inspiration. Since comparison of intraindividual changes eliminates a number of variable factors accounting for differences between individuals, one might expect a better agreement between the different lead systems in the same individual. This, however, is not the case. The outer rings in figure 5 and 6 show the normal distribution range of vectorial changes in respiration, determined for 60 men. The range is, of course, smaller than that in midrespiration. However, the scatter of respiratory changes in the eight lead systems in respect to the smaller distribution range is proportionally at least as large as that in midrespiration. It may be noted that the Wilson-Burch lead system tends to rotate the QRS vector forward and the T vector backward in inspiration, in contrast to most other lead systems. We do not, at present, wish to make conclusions, however, as to superiority or inferiority of particular lead systems. We wish merely to emphasize the disparity between the various lead systems.

In spite of these disparities there is no doubt that most types of pathology can be
FIG. 6. Extremes of dA° in four normal subjects with eight different lead systems, as compared with the normal limits for the SVEC III system and conventional system.

recognized in any of the lead systems. This brings up the important question of a comparison of the diagnostic value of the several lead systems. Comparison of deviations of well chosen vectorial items in individual patients in terms of the normal range limits of each lead system is a key approach.

That lead system which shows the greatest relative deviation obviously gives the best separation between normal and abnormal. Table 1 shows the position of 6 patients, with typical patterns of anterior, lateral, and posterior infarct, left ventricular strain, extensive myocardial involvement, left and right bundle branch block, in respect to the normal range limits of mean QKS and T vectors for the conventional and SVEC III lead systems. To draw attention to significant deviations, numerical values are given only for items exceeding the respective normal limits; items inside the normal limits are shown by dashes. This table is for illustration of the procedure only, and not for any conclusion as to superiority or inferiority of the lead systems. A statistical study is now in progress for several hundred patients.

In some patients and some vectorial items, SVEC III leads deviate farthest from their normal limits, in others the conventional leads show greater shifts. This brings up a quite important question: A theoretically superior orthogonal lead system does not necessarily show the greatest separation between normal and abnormal in all types of pathology. Distortion in some lead systems may exaggerate some types of abnormality and thus give a better separation. A study of leads with planned distortion, i.e., exaggerated representation of various heart regions, is currently in progress.

**Discussion**

These results seem to be at variance with the recent study by Langner et al., who concluded that the Schmitt-Simonson, Frank, McFee-Johnston, and Helm lead systems are interchangeable in all normal individuals. The comparison was based on a qualitative group rating of similarity of loop contour. Out of 27 normal subjects, the similarity of the QRS loops in the different X leads was rated excellent (group I) in 13.

It is possible that the quantitative evaluation used in our series may reveal differences which may escape inspection. The similarity of loops in the illustrations of studies by Langner et al. is so close, however, that only comparatively minor differences in actual measurements are likely. The important difference between the study by Langner et al. and ours is in the technic of comparison. Langner et al. did not compare each lead system as a unit, but instead the three leads of each orthogonal system were compared individually, paired with a common lead to produce a loop. For instance, either a constant Z or Y lead was paired consecutively with different X leads. Furthermore, the gain was adjusted so that the peak excursion was the same for all loops. This procedure will emphasize the similarity between the compared leads. Accepting their results as valid, one must conclude that comparison of whole lead systems results in greater differences than comparison of individual lead components. In practical application, of course, whole lead systems are used. It also should be noted that the four lead systems compared by Langner et al. are more similar in design than the eight lead systems compared in our study. Therefore, there is not necessarily a discrepancy between our results and those of Langner et al.
TABLE 1.—Deviations of Mean Spatial QRS and T Vectors, Constructed from the Conventional and SVEC III Leads, from the Normal 95% Limits in Cardiac Patients

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Subject</th>
<th>System</th>
<th>QRS vector</th>
<th>T vector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>H° V° Mag. (mm.)</td>
<td>H° V° Mag. (mm.)</td>
</tr>
<tr>
<td>LVH &amp; S</td>
<td>J.S.</td>
<td>Conv.</td>
<td>72.6 47.2 0.2</td>
<td>71.7</td>
</tr>
<tr>
<td>int. pos.</td>
<td>J.M.</td>
<td>Conv.</td>
<td>8.8   5.5 11.0</td>
<td>37.8</td>
</tr>
<tr>
<td>LBBB</td>
<td>R.R.</td>
<td>Conv.</td>
<td>19.4  5.6 19.4</td>
<td>39.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVEC III</td>
<td>139.6</td>
<td>21.7</td>
</tr>
<tr>
<td>Ant. inf.</td>
<td>B.S.</td>
<td>Conv.</td>
<td>-40.0 -50.7 0.4</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVEC III</td>
<td>93.1  32.2 0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>57.1  93.1 32.2</td>
<td></td>
</tr>
<tr>
<td>Lat. post. inf.</td>
<td>E.P.</td>
<td>Conv.</td>
<td>56.2  3.2 0.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVEC III</td>
<td>57.2  0.4 0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Post. inf.</td>
<td>J.G.</td>
<td>Conv.</td>
<td>138.6</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVEC III</td>
<td>138.6</td>
<td></td>
</tr>
</tbody>
</table>

*— Indicates 'within normal limits.'

We feel that our data cautions us forcibly against interchanging results too freely between investigations made by using different but presumably orthogonal lead systems. The differences are substantially greater than was anticipated from the homogeneous model experiments, and so inhomogeneity is chargeable with a substantial part of the difference. As long as different lead systems are used by various authors, conflicting results and confusion must be expected.

Agreement on a best compromise lead system for universal use is, perhaps, one of the most important steps for wider clinical application of vectorcardiography.

Since some of the important discrepancies between the various lead systems may be due to the residual components not referable to a simple concentrated dipole, we would recommend that some analysis of these components be pursued as a hedge against possible inadequacy of the simple vector treatment as a total data source.

SUMMARY

Eight different nominally orthogonal vectorcardiographic lead systems were compared using 4 normal subjects. To establish normal range limits for this study, mean spatial QRS and T vectors for 182 normal men were determined with both conventional and SVEC III lead systems. Large discrepancies between the lead systems were noted in the orientation and magnitudes of mean and maximum QRS and T vectors and of the loop contour. In the 4 subjects studied, the values of the directional angles for the eight different lead systems were widely scattered, and varieties were not systematically related. Vectorial respiratory shifts as measured in the various lead systems were large and mutually inconsistent. It is concluded that the various lead systems are not freely interchangeable.
esseva estensamente dispergite, e le variations non mostrava un interrelation systematic. Le deviationes vectoral respiratori mesurate in le varie systemas de derivation esseva grande e sin interrelation regular. Le conclusion es que le varie systemas de derivation non es liberemente intercambiabile.

REFERENCES
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