The Corrected Orthogonal Electrocardiogram
and Vectorcardiogram in 510 Normal Men
(Frank Lead System)

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A NUMBER of reports on normal ranges of corrected orthogonal electrocardiographic measurements have appeared in the literature.\textsuperscript{1-12} They were derived, however, from limited numbers of subjects and the types of electrocardiographic and vectorcardiographic measurements varied largely from one study to another. The reported results are therefore not always strictly comparable. In spite of these limitations, a striking similarity in results was found, together with a significant decrease in size of normal ranges as compared to conventional vectorcardiographic systems. Both these features can be attributed to the lead corrections used, which reduce markedly interindividual variations in effective electrical lead direction and lead strength.\textsuperscript{13} Data reported in the present study can, therefore, serve as standard for any of the corrected orthogonal lead systems.\textsuperscript{14-17} Discrepancies in direction are negligible for all practical purposes, and amplitude values can be easily converted from one system to another by use of standard conversion factors.\textsuperscript{18, 19} The Frank lead system\textsuperscript{15} used in the present study has been gaining widespread acceptance because of its ease of application.

No general agreement exists on optimal electrocardiographic and vectorcardiographic measurements for separation of normal from abnormal and differentiation between various diagnostic entities. It was found necessary, therefore, to include in the present study as many measurements as possible because many authors have advocated and used a variety of such measurements. Since all were derived from the same sample of "normal" subjects, a high degree of consistency and strict comparability of various results could be maintained. Measurements were taken from (1) scalar orthogonal leads; (2) frontal, sagittal, and horizontal plane projections of vector loops; and (3) spatial vectors in a Cartesian coordinate system. The age of the 510 "normal" male subjects ranged from 19 to 84

![Graph](http://circ.ahajournals.org/)

**Figure 1**

Age and race distribution of 510 normal male subjects. The shaded area in each age group depicts that fraction who were Negroes.
Materials and Methods

Records were taken from 510 "normal" male subjects who had been admitted to the Veterans Administration Hospitals, Washington, D.C., or West Roxbury, Massachusetts, for reasons other than cardiovascular disease. Selection of cases was based on a complete history, physical examination, and routine laboratory data. The majority had also chest x-rays and 12-lead electrocardiograms. Subjects with heart rates outside the range of 60 to 100 per minute or with electrocardiographic evidence of ventricular conduction defects were excluded. The age and race distribution is shown in figure 1.

Frank's lead system was used, with electrodes placed in the fourth intercostal space as recommended for patients in the supine position. The three orthogonal leads were recorded simultaneously on frequency modulated magnetic tape. Subsequently, they were digitized at a sampling rate of 1,000 per second for each lead. An IBM 7094 digital computer was used for further data processing and analysis. Details of the computational procedures have been reported previously.

Measurements from scalar leads X, Y, and Z included amplitudes and durations of P, Q, R, S, and T waves. The beginning of the T wave was omitted because of the gradual transition from the ST segment to the T wave. Furthermore, amplitude ratios were determined for Q/R, R/S, and R/T. For the P wave the TP segment was used as baseline. For all QRS measurements the PR segment served as baseline at the level of the first deflection of the QRS complex.

Durations of waves were determined in the following manner. At first a search was made for the first deflection in any one of the three simultaneously recorded leads. This point indicated the beginning of the wave or complex. The last deflection in any one of the leads was used as end-point. By this method measurements differ somewhat from those derived from single leads.

Maximal vectors for P, QRS, and T were determined in space and in the three commonly used plane projections, frontal, left sagittal, and horizontal. Since amplitude measurements depend upon projection planes, these maximal vectors are not necessarily identical in all planes. The reference frame for angular measurements is shown in figure 2.

Amplitude and direction of instantaneous vectors were determined at fixed time intervals of 0.01 second during QRS and 0.02 second intervals during the ST segment. Five such vectors were taken after the QRS onset up to 0.05 second. A similar series of five was determined for the terminal part of QRS beginning at the end and progressing in retrograde fashion.

Such absolute time measurements may lead either to a gap or an overlap in the middle of
QRS because of interindividual variability in QRS duration. In order to improve comparability of instantaneous vectors between different subjects the QRS duration was also normalized in time by dividing it into eight equal parts. An instantaneous vector was determined after each eighth. The same time normalization was used for the ST segment and T wave. The interval between the end of QRS and end of T was divided in time into eight equal parts for obtaining an instantaneous vector after each eighth (fig. 3).

Time integrals for the scalar leads X, Y, and Z were determined by measuring areas of electrocardiographic complexes above and below the baseline and subtracting the negative from the positive ones. The P wave was included in the time integrals because the atrial gradient is believed to be zero or nearly so. The time integrals of the three orthogonal leads were added vectorially to obtain a spatial vector for QRS (SA QRS) and T (SAT). The sum of these two vectors represents the well-known ventricular gradient vector (SVG).

The QRS-T angle was determined from the described time integrals. Angles were measured in space and in three plane projections.

Polar vectors and Eigenvectors were determined for P, QRS, and T loops. The polar vector is given by an axis perpendicular to the largest projection of a vector loop, also called its "broadside" projection. The magnitude of this vector corresponds to the area of the loop in this projection. The polar vector direction is such that it points away from the projection when the loop rotation is counterclockwise.

The polar vector represents one axis of an orthogonal reference frame which is based on the spatial orientation of the loop. This new orthogonal reference frame becomes, therefore, independent of the spatial loop orientation, which may differ from one subject to another. A second vector in this reference frame gives an indication of the length and a third of the width of the loop. All three are designated Eigenvectors, the polar vector representing one of the three. They are obtained by use of a mean least square fitting procedure as shown in figure 4. Ratios between Eigenvectors give an indication of loop configuration, i.e., the relationships between length, width, and planarity of the loops.

**Results**

Results of the present study are shown in tables 1 to 10. Most of these data are self-explanatory. Two sets of values are given for each item. On the upper line are shown the mean results with their standard deviations. Since the data distribution was found not to be normal in many instances 96-percentile ranges were also determined for each measurement. Such a range coincides approximately with the range obtained from a mean plus-minus 2 standard deviations when a normal

![Figure 4](http://circ.ahajournals.org/)  
Diagrammatic representation of the method for obtaining polar vectors and Eigenvectors. The upper diagram shows a QRS loop in "broadside" projection. The projection in the lower diagram is obtained after rotation of the QRS loop by 90 degrees. An "edge-wise" view is taken. The mutually perpendicular axes a, b, and c represent three Eigenvectors, forming an orthogonal reference frame based on the spatial orientation and configuration of the loop. Eigenvector c is identical with the polar vector, which is perpendicular to the QRS plane. The three axes a, b, and c are obtained through a least-square fitting procedure as indicated in the diagram. The ratios c/b, b/a, and c/a give an estimate of QRS configuration. Eigenvectors of P and T loops are obtained in the same manner. (Reprinted from Circulation Research by permission of the American Heart Association, Inc.)
Table 1

Measurements of P, QRS, and T in Scalar Orthogonal Leads X, Y, and Z

<table>
<thead>
<tr>
<th>Item</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>P amplitude mV.</td>
<td>0.06 ± 0.03</td>
<td>0.11 ± 0.07</td>
<td>0.03 ± 0.05</td>
</tr>
<tr>
<td></td>
<td>0.03 → 0.12</td>
<td>0.05 → 0.23</td>
<td>−0.06 → 0.10</td>
</tr>
<tr>
<td>Q amplitude mV.</td>
<td>0.10 ± 0.05 (306)</td>
<td>0.10 ± 0.07 (333)</td>
<td>0.41 ± 0.21</td>
</tr>
<tr>
<td></td>
<td>0.03 → 0.25</td>
<td>0.01 → 0.29</td>
<td>0.09 → 0.93</td>
</tr>
<tr>
<td>Q duration sec.</td>
<td>0.019 ± 0.004 (306)</td>
<td>0.021 ± 0.005 (333)</td>
<td>0.033 ± 0.007</td>
</tr>
<tr>
<td></td>
<td>0.012 → 0.028</td>
<td>0.008 → 0.032</td>
<td>0.020 → 0.048</td>
</tr>
<tr>
<td>R amplitude mV.</td>
<td>1.17 ± 0.37 (306)</td>
<td>1.03 ± 0.41 |</td>
<td>0.93 ± 0.35</td>
</tr>
<tr>
<td></td>
<td>0.51 → 1.97</td>
<td>0.35 → 1.95</td>
<td>0.36 → 1.79</td>
</tr>
<tr>
<td>R duration sec.</td>
<td>0.051 ± 0.016</td>
<td>0.061 ± 0.019</td>
<td>0.059 ± 0.010</td>
</tr>
<tr>
<td></td>
<td>0.028 → 0.088</td>
<td>0.028 → 0.100</td>
<td>0.032 → 0.080</td>
</tr>
<tr>
<td>S amplitude mV.</td>
<td>0.27 ± 0.15 (407)</td>
<td>0.18 ± 0.12 (274) |</td>
<td>0.28 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>0.06 → 0.68</td>
<td>0.03 → 0.49 |</td>
<td>−0.58 → −0.06</td>
</tr>
<tr>
<td>S duration sec.</td>
<td>0.039 ± 0.008 (407)</td>
<td>0.035 ± 0.010 (274) |</td>
<td>0.10 → 1.21</td>
</tr>
<tr>
<td></td>
<td>0.024 → 0.056</td>
<td>0.020 → 0.056 |</td>
<td>0.10 → 1.21</td>
</tr>
<tr>
<td>T amplitude mV.</td>
<td>0.27 ± 0.13 (407)</td>
<td>0.22 ± 0.13 |</td>
<td>−0.28 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>0.06 → 0.56</td>
<td>−0.11 → 0.48 |</td>
<td>−0.58 → −0.06</td>
</tr>
<tr>
<td>Q/R amplitude ratio</td>
<td>0.08 ± 0.04 (306)</td>
<td>0.10 ± 0.05 (333) |</td>
<td>0.49 ± 0.35</td>
</tr>
<tr>
<td></td>
<td>0.02 → 0.21</td>
<td>0.01 → 0.22 |</td>
<td>0.10 → 1.21</td>
</tr>
<tr>
<td>R/S amplitude ratio</td>
<td>5.74 ± 4.62 (407)</td>
<td>9.07 ± 9.39 (274) |</td>
<td>4.02 ± 2.66</td>
</tr>
<tr>
<td></td>
<td>1.40 →19.25</td>
<td>1.11 →38.51 |</td>
<td>1.12 →12.42</td>
</tr>
<tr>
<td>R/T amplitude ratio</td>
<td>5.44 ± 4.01 (407)</td>
<td>5.18 ± 3.25 |</td>
<td>4.02 ± 2.66</td>
</tr>
<tr>
<td></td>
<td>1.63 →20.16</td>
<td>1.67 →13.79 |</td>
<td>1.12 →12.42</td>
</tr>
<tr>
<td>Time from beginning of QRS to largest R peak-sec.</td>
<td>0.037 ± 0.005</td>
<td>0.039 ± 0.005 |</td>
<td>0.049 ± 0.006</td>
</tr>
<tr>
<td></td>
<td>0.028 → 0.048</td>
<td>0.028 → 0.052 |</td>
<td>0.036 → 0.064</td>
</tr>
</tbody>
</table>

The mean and standard deviation of each item is shown on the upper line. The second line indicates the limits of a 96-percentile range. Figures in parentheses show the actual number of measurements taken (e.g., Q waves in lead X were present in 306 cases only). Results not followed by a number in parentheses were obtained from the total series. All wave durations are based on the total QRS duration derived from the three leads. The earliest or last deflection in any one of the simultaneously recorded leads indicates onset or end of this complex.

distribution is present. The 96-percentile ranges are shown on the second line.

Durations, amplitudes, and amplitude ratios of the scalar leads X, Y, and Z are shown in Table 1. For wave durations it has to be realized that the beginning and end of the entire QRS complex are taken as reference points as described above. A Q wave in lead X does not necessarily begin at the same time as the Q wave in lead Y or vice versa. The earliest deflection in any one of the three leads indicates not only the beginning of QRS but also the beginning of the first wave in each of the leads. The duration of the R wave was obtained by subtraction of Q- and S-wave durations from the total QRS duration. Measurements of P, QRS, and QT interval durations shown in Table 2 were obtained in the same manner; i.e., the first and last deflections in any one of the leads indicated onset and end of these waves or intervals.

Table 3 shows amplitude and direction of maximal P, QRS, and T vectors in three plane projections and in space. The spatial orientation is based on the reference frame shown in figure 2.

Instantaneous vectors of the QRS complex,
the ST segment, and T complex are shown in tables 4 to 8. The various procedures for obtaining these vectors are described above. Mean values and ranges are indicated for the three scalar leads, the three commonly used plane projections in addition to the spatial magnitude and orientation. These results can be used, therefore, as reference for almost any type of data display.

Time integrals of QRS and T together with their sum, the ventricular gradient, are shown in table 9. Here again scalar values, plane projections, and spatial magnitude and orientation are indicated.

A very important difference between vector projections in plane projections and in space needs to be realized. Any result in planar projection is derived by vectorial addition of two scalar components \((X+Y, Y+Z\) or \(X+Z\)). The truly spatial vectors, however, are based on vectorial addition of three scalar components \((X+Y+Z)\). The vector projection in a plane is, therefore, not necessarily identical with the spatial vector. Any third scalar component that is not used in a given plane may cause a significant deviation of

### Table 2

**Time Intervals Obtained from Three Simultaneously Recorded Leads**

<table>
<thead>
<tr>
<th>Item</th>
<th>Measurement, sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P duration</td>
<td>0.102 ± 0.016</td>
</tr>
<tr>
<td>P-R interval</td>
<td>0.068 → 0.140</td>
</tr>
<tr>
<td>P-R segment</td>
<td>0.153 ± 0.023</td>
</tr>
<tr>
<td></td>
<td>0.112 → 0.204</td>
</tr>
<tr>
<td>P duration</td>
<td>0.051 ± 0.019</td>
</tr>
<tr>
<td></td>
<td>0.012 → 0.096</td>
</tr>
<tr>
<td>QRS duration</td>
<td>0.093 ± 0.009</td>
</tr>
<tr>
<td></td>
<td>0.076 → 0.112</td>
</tr>
<tr>
<td>Q-T interval</td>
<td>0.367 ± 0.034</td>
</tr>
<tr>
<td>(uncorrected)</td>
<td>0.312 → 0.448</td>
</tr>
</tbody>
</table>

The method of measurement is the same as indicated for table 1.

### Table 3

**Maximal P, QRS, and T Vectors in the Frontal, Sagittal, and Horizontal Planes Together with Spatial Amplitude and Orientation**

<table>
<thead>
<tr>
<th>Item</th>
<th>Maximal P vector</th>
<th>Maximal QRS vector</th>
<th>Maximal T vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude, mV.</td>
<td>0.18 ± 0.06</td>
<td>1.57 ± 0.42</td>
<td>0.36 ± 0.14</td>
</tr>
<tr>
<td>Direction, degrees</td>
<td>67 ± 18</td>
<td>41 ± 14</td>
<td>40 ± 20</td>
</tr>
<tr>
<td></td>
<td>22 → 91</td>
<td>14 → 71</td>
<td>4 → 74</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude, mV.</td>
<td>0.17 ± 0.06</td>
<td>1.32 ± 0.45</td>
<td>0.36 ± 0.13</td>
</tr>
<tr>
<td>Direction, degrees</td>
<td>87 ± 23</td>
<td>48 ± 30</td>
<td>142 ± 23</td>
</tr>
<tr>
<td></td>
<td>54 → 129</td>
<td>343 → 114</td>
<td>93 → 180</td>
</tr>
<tr>
<td>Horizontal plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude, mV.</td>
<td>0.09 ± 0.03</td>
<td>1.39 ± 0.36</td>
<td>0.40 ± 0.14</td>
</tr>
<tr>
<td>Direction, degrees</td>
<td>349 ± 41</td>
<td>327 ± 34</td>
<td>46 ± 19</td>
</tr>
<tr>
<td></td>
<td>285 → 91</td>
<td>245 → 29</td>
<td>8 → 83</td>
</tr>
<tr>
<td>Spatial amplitude mV.</td>
<td>0.18 ± 0.06</td>
<td>1.73 ± 0.44</td>
<td>0.46 ± 0.16</td>
</tr>
<tr>
<td>Spatial orientation</td>
<td>0.09 → 0.32</td>
<td>0.92 → 2.75</td>
<td>0.18 → 0.82</td>
</tr>
<tr>
<td>Azimuth, degrees</td>
<td>342 ± 38</td>
<td>331 ± 27</td>
<td>44 ± 19</td>
</tr>
<tr>
<td></td>
<td>277 → 75</td>
<td>263 → 23</td>
<td>4 → 79</td>
</tr>
<tr>
<td>Elevation, degrees</td>
<td>63 ± 17</td>
<td>35 ± 13</td>
<td>29 ± 13</td>
</tr>
<tr>
<td></td>
<td>20 → 86</td>
<td>7 → 60</td>
<td>2 → 58</td>
</tr>
</tbody>
</table>

The vectors in the plane projections were obtained from XY, YZ, and XZ leads, respectively, and do not therefore represent projections of the spatial maximal vectors onto these planes. The difference between planar and spatial vectors is illustrated in figure 5.

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### Table 4

**Quantitative Analysis of Early QRS Vectors**

<table>
<thead>
<tr>
<th>Instantaneous vectors *</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Planar direction, degrees</th>
<th>Spatial magnitude and orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scalar amplitude, mV.</td>
<td>Frontal</td>
<td>Sagittal</td>
<td>Horizontal</td>
<td>Amplitude mV.</td>
</tr>
<tr>
<td>0.01 Sec. after</td>
<td>-0.04 ± 0.04</td>
<td>-0.03 ± 0.06</td>
<td>-0.11 ± 0.06</td>
<td>210 ± 61</td>
<td>189 ± 36</td>
</tr>
<tr>
<td>QRS onset</td>
<td>-0.14 ± 0.07</td>
<td>-0.13 ± 0.08</td>
<td>-0.25 ± 0.01</td>
<td>59 ± 330</td>
<td>79 ± 242</td>
</tr>
<tr>
<td>0.02 Sec. after</td>
<td>-0.05 ± 0.14</td>
<td>-0.01 ± 0.13</td>
<td>-0.31 ± 0.15</td>
<td>325 ± 87</td>
<td>180 ± 25</td>
</tr>
<tr>
<td>QRS onset</td>
<td>-0.19 ± 0.38</td>
<td>-0.25 ± 0.29</td>
<td>-0.68 ± 0.06</td>
<td>162 ± 136</td>
<td>117 ± 220</td>
</tr>
<tr>
<td>0.03 Sec. after</td>
<td>0.56 ± 0.27</td>
<td>0.35 ± 0.25</td>
<td>-0.20 ± 0.32</td>
<td>29 ± 23</td>
<td>120 ± 40</td>
</tr>
<tr>
<td>QRS onset</td>
<td>0.06 ± 1.19</td>
<td>-0.06 ± 0.97</td>
<td>-0.89 ± 0.48</td>
<td>350 ± 59</td>
<td>41 ± 186</td>
</tr>
<tr>
<td>0.04 Sec. after</td>
<td>1.05 ± 0.37</td>
<td>0.86 ± 0.37</td>
<td>0.34 ± 0.46</td>
<td>40 ± 16</td>
<td>72 ± 27</td>
</tr>
<tr>
<td>QRS onset</td>
<td>0.33 ± 1.79</td>
<td>0.24 ± 1.79</td>
<td>-0.59 ± 1.26</td>
<td>14 ± 66</td>
<td>28 ± 139</td>
</tr>
<tr>
<td>0.05 Sec. after</td>
<td>0.65 ± 0.51</td>
<td>0.74 ± 0.47</td>
<td>0.77 ± 0.40</td>
<td>52 ± 36</td>
<td>42 ± 24</td>
</tr>
<tr>
<td>QRS onset</td>
<td>-0.27 ± 1.76</td>
<td>-0.09 ± 1.74</td>
<td>-0.01 ± 1.67</td>
<td>343 ± 147</td>
<td>351 ± 89</td>
</tr>
</tbody>
</table>

* Scalar components, plane projections, spatial magnitude, and orientation of five initial instantaneous QRS vectors taken at 0.01-second intervals after the onset of QRS. As in all other tables the beginning of QRS is taken at the earliest deflection in any one of the simultaneously recorded scalar leads. In this as in all consecutive tables the ranges for azimuth are to be followed in clockwise direction.

### Table 5

**Quantitative Analysis of Late QRS Vectors**

<table>
<thead>
<tr>
<th>Instantaneous vectors *</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Planar direction, degrees</th>
<th>Spatial magnitude and orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scalar amplitude, mV.</td>
<td>Frontal</td>
<td>Sagittal</td>
<td>Horizontal</td>
<td>Amplitude mV.</td>
</tr>
<tr>
<td>End of QRS</td>
<td>0.01 ± 0.03</td>
<td>0.03 ± 0.04</td>
<td>-0.07 ± 0.04</td>
<td>79 ± 74</td>
<td>160 ± 30</td>
</tr>
<tr>
<td>or point J</td>
<td>-0.06 ± 0.08</td>
<td>-0.06 ± 0.10</td>
<td>-0.17 ± 0.00</td>
<td>279 ± 241</td>
<td>95 ± 227</td>
</tr>
<tr>
<td>0.01 Sec. before</td>
<td>-0.01 ± 0.06</td>
<td>0.01 ± 0.08</td>
<td>0.01 ± 0.08</td>
<td>156 ± 89</td>
<td>77 ± 97</td>
</tr>
<tr>
<td>end of QRS</td>
<td>-0.13 ± 0.10</td>
<td>-0.13 ± 0.15</td>
<td>-0.15 ± 0.16</td>
<td>4 ± 315</td>
<td>267 ± 250</td>
</tr>
<tr>
<td>0.02 Sec. before</td>
<td>-0.09 ± 0.12</td>
<td>0.00 ± 0.16</td>
<td>0.24 ± 0.19</td>
<td>173 ± 73</td>
<td>358 ± 53</td>
</tr>
<tr>
<td>end of QRS</td>
<td>-0.36 ± 0.12</td>
<td>-0.30 ± 0.33</td>
<td>-0.10 ± 0.67</td>
<td>31 ± 305</td>
<td>242 ± 122</td>
</tr>
<tr>
<td>0.03 Sec. before</td>
<td>-0.03 ± 0.32</td>
<td>0.18 ± 0.33</td>
<td>0.60 ± 0.28</td>
<td>128 ± 74</td>
<td>12 ± 32</td>
</tr>
<tr>
<td>end of QRS</td>
<td>-0.51 ± 0.95</td>
<td>-0.39 ± 1.01</td>
<td>0.05 ± 1.14</td>
<td>353 ± 268</td>
<td>290 ± 68</td>
</tr>
<tr>
<td>0.04 Sec. before</td>
<td>0.46 ± 0.59</td>
<td>0.61 ± 0.49</td>
<td>0.77 ± 0.37</td>
<td>69 ± 55</td>
<td>35 ± 29</td>
</tr>
<tr>
<td>end of QRS</td>
<td>-0.54 ± 1.70</td>
<td>-0.31 ± 1.66</td>
<td>-0.04 ± 1.52</td>
<td>341 ± 214</td>
<td>336 ± 93</td>
</tr>
<tr>
<td>0.05 Sec. before</td>
<td>0.87 ± 0.48</td>
<td>0.81 ± 0.41</td>
<td>0.49 ± 0.50</td>
<td>46 ± 27</td>
<td>65 ± 32</td>
</tr>
<tr>
<td>end of QRS</td>
<td>-0.28 ± 1.75</td>
<td>0.05 ± 1.80</td>
<td>-0.47 ± 1.56</td>
<td>13 ± 131</td>
<td>7 ± 148</td>
</tr>
</tbody>
</table>

* Scalar components, plane projections, spatial magnitude and orientation of five terminal instantaneous QRS vectors taken in retrograde fashion from the end of QRS at 0.01-second intervals.
CORRECTED ORTHOGONAL ELECTROCARDIOGRAM

Quantitative Analysis of ST Segment

<table>
<thead>
<tr>
<th>Instantaneous vectors</th>
<th>X</th>
<th>Scalar amplitude, mV</th>
<th>Y</th>
<th>Z</th>
<th>Amplitude mV</th>
<th>Spatial magnitude and orientation Azimuth degrees</th>
<th>Elevation degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02 Sec. after point J</td>
<td>0.01 ± 0.03</td>
<td>-0.02 ± 0.04</td>
<td>-0.10 ± 0.04</td>
<td>-0.11 ± 0.04</td>
<td>82 ± 22</td>
<td>12 ± 20</td>
<td></td>
</tr>
<tr>
<td>0.04 Sec. after point J</td>
<td>-0.06 → 0.08</td>
<td>-0.06 → 0.10</td>
<td>-0.19 → -0.02</td>
<td>0.04 → 0.21</td>
<td>37 → 127</td>
<td>-35 → 55</td>
<td></td>
</tr>
<tr>
<td>0.06 Sec. after point J</td>
<td>0.03 ± 0.03</td>
<td>-0.03 ± 0.04</td>
<td>-0.11 ± 0.05</td>
<td>0.13 ± 0.05</td>
<td>77 ± 20</td>
<td>13 ± 19</td>
<td></td>
</tr>
</tbody>
</table>

Quantitative Analysis of Eight Instantaneous QRS Vectors

<table>
<thead>
<tr>
<th>Instantaneous vectors *</th>
<th>X</th>
<th>Scalar amplitude, mV</th>
<th>Y</th>
<th>Z</th>
<th>Amplitude mV</th>
<th>Spatial magnitude and orientation Azimuth degrees</th>
<th>Elevation degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 QRS</td>
<td>-0.04 ± 0.05</td>
<td>-0.03 ± 0.07</td>
<td>-0.14 ± 0.08</td>
<td>0.18 ± 0.07</td>
<td>108 ± 27</td>
<td>-10 ± 26</td>
<td></td>
</tr>
<tr>
<td>2/8 QRS</td>
<td>-0.16 → 0.09</td>
<td>-0.18 → 0.10</td>
<td>-0.31 → 0.00</td>
<td>0.06 → 0.36</td>
<td>51 → 156</td>
<td>-50 → 54</td>
<td></td>
</tr>
<tr>
<td>3/8 QRS</td>
<td>0.17 ± 0.17</td>
<td>0.05 ± 0.13</td>
<td>-0.34 ± 0.19</td>
<td>0.44 ± 0.19</td>
<td>63 ± 27</td>
<td>7 ± 19</td>
<td></td>
</tr>
<tr>
<td>4/8 QRS</td>
<td>-0.11 → 0.61</td>
<td>0.21 → 0.34</td>
<td>-0.82 → 0.00</td>
<td>0.14 → 0.83</td>
<td>359 → 110</td>
<td>-30 → 50</td>
<td></td>
</tr>
<tr>
<td>5/8 QRS</td>
<td>0.87 ± 0.31</td>
<td>0.63 ± 0.30</td>
<td>0.03 ± 0.40</td>
<td>1.17 ± 0.37</td>
<td>359 ± 25</td>
<td>33 ± 11</td>
<td></td>
</tr>
<tr>
<td>6/8 QRS</td>
<td>-0.33 → 1.63</td>
<td>0.17 → 1.44</td>
<td>-0.74 → 0.90</td>
<td>0.59 → 2.19</td>
<td>308 → 47</td>
<td>12 ± 55</td>
<td></td>
</tr>
<tr>
<td>7/8 QRS</td>
<td>0.89 ± 0.49</td>
<td>-0.89 ± 0.44</td>
<td>0.70 ± 0.44</td>
<td>1.58 ± 0.48</td>
<td>320 ± 26</td>
<td>34 ± 14</td>
<td></td>
</tr>
<tr>
<td>8/8 QRS</td>
<td>-0.15 → 1.84</td>
<td>0.02 → 1.85</td>
<td>-0.05 → 1.74</td>
<td>0.70 → 2.62</td>
<td>261 → 3</td>
<td>2 → 61</td>
<td></td>
</tr>
</tbody>
</table>

Quantitative Analysis of ST and T Vectors

<table>
<thead>
<tr>
<th>Instantaneous vectors *</th>
<th>X</th>
<th>Scalar amplitude, mV</th>
<th>Y</th>
<th>Z</th>
<th>Amplitude mV</th>
<th>Spatial magnitude and orientation Azimuth degrees</th>
<th>Elevation degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 (ST-T)</td>
<td>0.02 ± 0.02</td>
<td>0.00 ± 0.02</td>
<td>-0.04 ± 0.03</td>
<td>0.06 ± 0.02</td>
<td>67 ± 36</td>
<td>1 ± 29</td>
<td></td>
</tr>
<tr>
<td>2/8 (ST-T)</td>
<td>-0.02 → 0.06</td>
<td>-0.05 → 0.05</td>
<td>-0.10 → 0.02</td>
<td>0.02 → 0.10</td>
<td>317 → 133</td>
<td>-49 → 58</td>
<td></td>
</tr>
<tr>
<td>3/8 (ST-T)</td>
<td>0.04 ± 0.03</td>
<td>0.02 ± 0.03</td>
<td>-0.07 ± 0.04</td>
<td>0.10 ± 0.04</td>
<td>59 ± 23</td>
<td>11 ± 21</td>
<td></td>
</tr>
<tr>
<td>4/8 (ST-T)</td>
<td>-0.01 → 0.11</td>
<td>-0.04 → 0.08</td>
<td>-0.16 → 0.01</td>
<td>0.03 → 0.19</td>
<td>353 → 98</td>
<td>-33 → 52</td>
<td></td>
</tr>
<tr>
<td>5/8 (ST-T)</td>
<td>0.08 ± 0.05</td>
<td>0.05 ± 0.04</td>
<td>-0.12 ± 0.06</td>
<td>0.16 ± 0.07</td>
<td>55 ± 19</td>
<td>17 ± 15</td>
<td></td>
</tr>
<tr>
<td>6/8 (ST-T)</td>
<td>0.00 → 0.19</td>
<td>-0.03 ± 0.15</td>
<td>-0.27 → -0.02</td>
<td>0.05 → 0.33</td>
<td>13 → 87</td>
<td>-16 → 48</td>
<td></td>
</tr>
<tr>
<td>7/8 (ST-T)</td>
<td>0.15 ± 0.08</td>
<td>0.10 ± 0.07</td>
<td>-0.19 ± 0.09</td>
<td>0.28 ± 0.11</td>
<td>52 ± 17</td>
<td>21 ± 12</td>
<td></td>
</tr>
<tr>
<td>8/8 (ST-T)</td>
<td>0.02 → 0.35</td>
<td>-0.01 → 0.29</td>
<td>-0.42 → -0.03</td>
<td>0.09 → 0.56</td>
<td>14 → 85</td>
<td>-3 → 47</td>
<td></td>
</tr>
<tr>
<td>9/8 (ST-T)</td>
<td>0.23 ± 0.11</td>
<td>0.18 ± 0.10</td>
<td>-0.25 ± 0.12</td>
<td>0.40 ± 0.15</td>
<td>46 ± 19</td>
<td>27 ± 12</td>
<td></td>
</tr>
<tr>
<td>10/8 (ST-T)</td>
<td>0.04 → 0.51</td>
<td>0.02 → 0.43</td>
<td>-0.51 → -0.02</td>
<td>0.14 → 0.73</td>
<td>6 → 81</td>
<td>5 → 55</td>
<td></td>
</tr>
<tr>
<td>11/8 (ST-T)</td>
<td>0.22 ± 0.12</td>
<td>0.20 ± 0.10</td>
<td>-0.17 ± 0.11</td>
<td>0.37 ± 0.14</td>
<td>37 ± 28</td>
<td>35 ± 15</td>
<td></td>
</tr>
<tr>
<td>12/8 (ST-T)</td>
<td>0.00 → 0.49</td>
<td>0.02 → 0.43</td>
<td>-0.38 → 0.02</td>
<td>0.06 → 0.68</td>
<td>352 → 81</td>
<td>8 → 68</td>
<td></td>
</tr>
<tr>
<td>13/8 (ST-T)</td>
<td>0.07 ± 0.05</td>
<td>0.08 ± 0.04</td>
<td>-0.04 ± 0.04</td>
<td>0.12 ± 0.06</td>
<td>28 ± 47</td>
<td>40 ± 22</td>
<td></td>
</tr>
<tr>
<td>14/8 (ST-T)</td>
<td>-0.02 → 0.17</td>
<td>-0.01 → 0.18</td>
<td>-0.11 → 0.03</td>
<td>0.02 → 0.24</td>
<td>244 → 163</td>
<td>-29 → 78</td>
<td></td>
</tr>
</tbody>
</table>

* Obtained after each eighth of the QRS duration as shown in figure 3.

Table 8

* Determined through time normalization as shown in figure 3.

Circulation, Volume XXX, December 1964
Table 9

Time Integrals of QRS and T Derived from Scalar Leads X, Y, and Z

<table>
<thead>
<tr>
<th>Item</th>
<th>Planar direction, degrees</th>
<th>Scalar amplitude μV. sec.</th>
<th>Spatial magnitude, orientation, and spatial angles Azimuth degrees</th>
<th>Elevation degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frontal</td>
<td>Sagittal</td>
<td>Horizontal</td>
<td>X</td>
</tr>
<tr>
<td>SÀ QRS</td>
<td>44 ± 33</td>
<td>53 ± 27</td>
<td>323 ± 25</td>
<td>22.20 ± 11.18</td>
</tr>
<tr>
<td>SAT</td>
<td>351→85</td>
<td>355→110</td>
<td>274→14</td>
<td>1.23 → 46.97</td>
</tr>
<tr>
<td>SVČ</td>
<td>33 → 84</td>
<td>152 ± 21</td>
<td>52 ± 18</td>
<td>29.09 ± 15.78</td>
</tr>
<tr>
<td>QRS-T</td>
<td>40 → 14</td>
<td>114 ± 23</td>
<td>21 ± 19</td>
<td>51.29 ± 20.79</td>
</tr>
<tr>
<td>Angle</td>
<td>9→87</td>
<td>71→159</td>
<td>340→58</td>
<td>15.30 → 102.55</td>
</tr>
</tbody>
</table>

Combinations of two scalar components lead to planar projections in the frontal, sagittal, and horizontal planes. Spatial magnitude and orientation are obtained by vectorial addition of all three scalar components. Addition of the time integrals of QRS and T results in the ventricular gradient (VČ). The P wave was included in the QRS time integral as described in the text. The QRS-T angle is derived from the two vectors of the respective time integrals.

Maximal QRS vectors in the frontal and horizontal planes are shown as solid lines in the vector loops on the left. Such maximal vectors are not shown in the frontal planes. The maximal vectors in the horizontal plane are not shown in all planes. They represent one identical instantaneous vector in space. As shown in the diagram, the maximal vector onto the horizontal plane and that of the frontal plane on the left. Such maximal vectors are not shown in the frontal planes. The maximal vector onto the horizontal plane and that of the frontal plane is represented by the planar maximal vector. It becomes obvious that such planar maximal vectors are not representing the same instantaneous vector and need not to be treated separately. The maximal spatial QRS vector in the loops on the right. They represent one identical instantaneous vector in space. As shown in the diagram, the maximal vector onto the horizontal plane and that of the frontal plane is represented by the planar maximal vector. It becomes obvious that such planar maximal vectors are not representing the same instantaneous vector and need not to be treated separately.

This basic difference between the plane projections of the spatial vector and the true spatial data in a Cartesian reference frame is further emphasized by the spatial orientation of the loops. In addition, the magnitude of the polar vector, based on the area "broadside" loop projection, for instance, may deviate from the spatial vector considerably, away from the spatial vector, for instance, may deviate from the spatial vector considerably, away from the spatial vector, for instance, may deviate from the spatial vector considerably, away from the spatial vector, for instance, may deviate from the spatial vector considerably, away from the spatial vector.
tion, is indicated. The Eigenvector ratios give an estimate of the loop configuration, i.e., whether the loop is long and narrow, broad and short, etc. Similar ratios for a smaller group of normal subjects have been reported previously. In contrast to this study, however, the longest Eigenvector does not necessarily pass through point $f$ of the loop due to the method of computation shown in figure 4.

**Discussion**

The difficulties in selecting a "normal" sample from the general population are well known. In any such sample certain limitations have to be taken into account. This is particularly true when the age range of the sample extends to the ninth decade as in the present study. In this as in most other investigations of this type "normal" means essentially free from overt heart disease past or present. Complete exclusion of cardiovascular pathology particularly in the older age groups, is impossible for obvious practical reasons. As long as the limitations of such "normal" samples are kept in mind the practical usefulness of normal standards will outweigh obvious shortcomings.

In the present study great care was taken to exclude subjects with diseases which frequently predispose to cardiovascular disease. Cases with diabetes mellitus, pulmonary disease, renal disease, hypertension, anemia, collagen vascular disease, or any other type of peripheral vascular disease were not included.

The present series of subjects was limited

**Table 10**

| Eigenvectors A, B, and C of the P, QRS, and T Loops |
|---------------------------------|-------|-------|-------|
| Item                           | P loop | QRS loop | T loop |
| Eigenvector c                  |       |       |       |
| (polar vector)                 |       |       |       |
| Azimuth, degrees               | 35 ± 34 | 339 ± 30 | 337 ± 24 |
| 304 → 95                      | 285 → 46 | 292 → 36 |
| Elevation, degrees            | -14 ± 15 | -50 ± 12 | -31 ± 17 |
| -50 → 11                      | -73 → -25 | -63 → 8 |
| Eigenvector b                  |       |       |       |
| Azimuth, degrees               | 122 ± 31 | 65 ± 37 | 97 ± 33 |
| 64 → 183                      | 329 → 143 | 27 → 170 |
| Elevation, degrees            | 11 ± 15 | 3 ± 23 | -37 ± 18 |
| -26 → 43                      | -45 → 49 | -69 → 6 |
| Eigenvector a                  |       |       |       |
| Azimuth, degrees               | 352 ± 35 | 332 ± 42 | 39 ± 21 |
| 293 → 79                      | 244 → 56 | 354 → 79 |
| Elevation, degrees            | 62 ± 20 | 30 ± 15 | 31 ± 15 |
| 0 → 84                        | -6 → 57 | 1 → 61 |
| Eigenvector ratios             |       |       |       |
| $c/b$                          | 0.20 ± 0.16 | 0.02 ± 0.04 | 0.05 ± 0.09 |
| 0.00 → 0.05                   | 0.00 → 0.10 | 0.00 → 0.38 |
| $b/a$                         | 0.21 ± 0.17 | 0.41 ± 0.20 | 0.17 ± 0.13 |
| 0.00 → 0.06                   | 0.06 → 0.85 | 0.01 → 0.51 |
| $c/a$                         | 0.03 ± 0.03 | 0.01 ± 0.01 | 0.01 ± 0.01 |
| 0.00 → 0.14                   | 0.00 → 0.03 | 0.00 → 0.03 |
| Spatial amplitude of the      | 6.16 ± 3.43 $\times 10^{-3}$ | 1.62 ± 0.85 | 5.03 ± 3.48 $\times 10^{-2}$ |
| polar vector (area of          | 1.69 ± 15.76 $\times 10^{-3}$ | 0.45 → 3.89 | 0.66 → 14.76 $\times 10^{-2}$ |
| "broadside" projection of      |       |       |       |
| the spatial loop). mV²         |       |       |       |

The polar vector is identical with Eigenvector c. The ratios between Eigenvectors give an estimate of the planarity of the loop and its configuration. The magnitude of the polar vector is based on the area of the loop in its "broadside" projection. A multiplication constant was used for P and T because of their small magnitude. For method of determination see figure 4 and text.
to men only. Simonson,\textsuperscript{31} who has carefully evaluated sex differences in the 12-lead electrocardiogram, found discrepancies in amplitude of precordial leads most significant. R/S ratios were found similar for both sexes, however, which would indicate an over-all reduction in amplitude of the electrocardiogram of the normal women. Transition zones in the precordium did not differ significantly, which suggests essential similarities in QRS orientation. PR intervals and QRS durations were found, generally, to be shorter in women; this was attributed to the smaller heart size.\textsuperscript{31}

In a previous study from this laboratory a mixed normal sample of male and female subjects was used.\textsuperscript{18} When the data were separated according to sex, no statistically significant differences were found. This comparison needs to be corroborated, however, in larger samples. Correlations between normal electrocardiographic data and different age groups, race, and body habitus will be reported separately.

The primary goal in establishing normal ranges is the separation of normal from abnormal. Corrected orthogonal lead systems represent a significant improvement for diagnostic differentiation. The marked decrease in size of normal ranges, as compared to those obtained from conventional bipolar and unipolar leads, could be confirmed again in the present study based on a much larger sample of normal subjects. This decrease in size of normal ranges is one of the main reasons why the separation between normal and abnormal electrocardiographic records appears significantly enhanced when corrected orthogonal rather than conventional leads are applied.\textsuperscript{28, 32}

Another finding in the present series was the striking similarity of results with those reported previously.\textsuperscript{1-12} Discrepancies were due mainly to differences in methods of measurement. This was particularly obvious for instantaneous vectors. These can be identified only with great difficulty in vector loop displays. Part of the QRS loop is frequently hidden by P or T loops or it may not be represented at all when a portion of QRS happens to be perpendicular to a given plane projection. Reliable measurements can be obtained, therefore, from simultaneously recorded scalar leads only.

Another frequently neglected cause for discrepancies in results has been shown in figure 5. Maximal, instantaneous, and other vectors of different plane projections are frequently not identical because two scalar components only are used for each plane. When projections of a spatial vector onto various planes are used, however, one single vector is truly depicted. In each case the method of measurement needs to be clearly identified.

It was interesting to note the essential similarity between the present series and those reported previously from this laboratory.\textsuperscript{1, 2} The data reported earlier were obtained from mixed samples of considerably smaller size comprising both sexes. Furthermore, Schmitt’s SVEC III lead system had been used, whereas Frank’s system was used in the present study. These are for all practical purposes interchangeable for vector directions but a conversion constant has to be used for amplitude data.\textsuperscript{18, 19} A further difference between previous studies and the present one is the application of a digital computer for all electrocardiographic measurements. The computational procedures did not seem to lead to any appreciable differences in results.

One notable discrepancy in results was found in the duration of S waves in leads X and Y. These were found longer in the present study by a mean difference of 13 and 12 milliseconds, respectively. Since the end of the total QRS complex was used as end-point for all S waves the discrepancy can be explained by the different method of measurement. In most QRS complexes lead Z is found longer than X and Y, which leads to longer S durations in X and Y. The range for total QRS durations was practically identical in both studies, which rules out computational errors in the determination of the end of QRS.

Particular emphasis was put on detailed measurements of instantaneous vectors of QRS, ST, and T. In a previous study it could
be shown that series of instantaneous vectors contain most of the diagnostic electrocardiographic information. A novel method for the determination of instantaneous vectors was used. The QRS complex, ST segment, and T wave were normalized in time. This was done in order to eliminate the interindividual variability in duration of these electrocardiographic components. When instantaneous QRS vectors are determined at fixed time intervals of 0.01 second, for instance, the terminal vectors are not strictly comparable because total QRS duration may vary from one subject to another. Another method for achieving better data comparability consists of absolute time measurements from both ends of QRS. A series of five instantaneous vectors taken from both QRS onset and end converges toward the middle. This procedure leads, however, either to an overlap or a gap in the middle as was shown previously. Time normalization by dividing QRS in eight equal parts leads to greater uniformity of results. Since the latter method is difficult to apply without the help of a computer, normal ranges of both procedures were given in the present study.

Establishment of normal standards in electrocardiography is becoming of increasing importance because more and more quantitative terms are introduced and applied in data analysis. This development is furthered by the more recent advent of computer methods in handling electrocardiographic data. The numerical processes used in such procedures require a high degree of precision in definition of analytical terms which should enhance both the comparability of data and the diagnostic recognition of electrocardiographic abnormalities. Limitations in character and size of record samples should become more obvious in the same process.

Summary

Corrected orthogonal electrocardiographic records were taken from 510 normal male subjects. Their age ranged from 19 to 84 years. Data processing and analysis were performed by means of a digital computer. Measurements were taken from the three scalar orthogonal leads and from a variety of spatial vectors in a Cartesian reference frame. Main emphasis was put on series of instantaneous vectors of the QRS complex, the ST segment, and the T wave. In order to eliminate interindividual variability in electrocardiographic wave durations, time normalization was applied by dividing QRS, ST, and T into equal parts in time. Results for instantaneous vectors were also obtained in absolute time at intervals of 0.01 second. In addition, time intervals, polar vectors, and Eigenvectors were determined for P, QRS, and T. Normal ranges were computed for both normally and abnormally distributed results.

References

11. McCall, B. W., Wallace, A. G., and Estes, E. H.: Characteristics of the normal vectorcardiogram recorded with the Frank lead sys-

Scientific Hypothesis

In reality, it is not the pomp of language, the "whistling of a name," or the simplicity or ingenuity of a pathological theory, that can long give it currency with mankind. The sole point is, whether it is a just arrangement of actual phenomena, of which the operation of remedies form an indispensable part. If it does not include these operations, it is defective; if it is inconsistent with what is known of them, it is mischievous. By this test every medical work ought to be tried, and by it the present work must stand or fall.—Preface, Bath, October, 1811. Collections from the Unpublished Medical Writings of the Late Caleb Hillier Parry, M.D.F.R.S. Vol. I., London, Underwoods, Fleet-Street, 1825, p. 55.
The Corrected Orthogonal Electrocardiogram and Vectorcardiogram in 510 Normal Men (Frank Lead System)

HAROLD W. DRAPER, CATHERINE J. PEFFER, FRIEDEMANN W. STALLMANN, DAVID LITTMANN and HUBERT V. PIPBERGER

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