Day-to-Day Variation of the Normal Orthogonal Electrocardiogram and Vectorcardiogram

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SUMMARY
Day-to-day variation of the corrected orthogonal electrocardiogram was investigated in 20 normal subjects. Ten recordings were made in each individual with chest electrode positions left unmarked first, after which 10 subjects underwent another series of 10 consecutive daily recordings with marked electrode locations. Mean and maximal day-to-day variations of durations and amplitudes of different deflections of scalar leads as well as variations of directions and magnitudes of several QRS axes and T spatial vectors have been studied using computer techniques for measurement and analysis.

Repeat variability in the unmarked recordings was relatively large. For example, the maximum (96%) variability in QRS spatial maximum and in R-wave amplitudes in leads X and Z were, respectively, 0.50, 0.61, and 0.35 mv. Marking of the chest did reduce variability of amplitude and angular measurements by approximately 25%, but even then a substantial variation from day-to-day remained. Relative changes in T-wave amplitude and direction were greater than those of the QRS complex.

The results presented can be used as standards to assess ECG changes observed in serial electrocardiography.

Additional Indexing Words:
Repeat variability Serial electrocardiography Normal ranges
Electrode positioning

VARIOUS STUDIES on beat-to-beat and observer variation of electrocardiographic measurements have been published recently.1-4 Knowledge of the day-to-day variability of the orthogonal ECG and VCG, however, is very limited. Since the first systematic study on intra-individual variability in 1949 by Simonson et al.,5 few new observations have been added to illuminate this problem.6-8 Nevertheless, knowledge of the normal repeat variation is essential for the effective use of serial electrocardiography in patients, during epidemiologic studies and in investigations of changes induced by hemodynamic alterations and by pharmacologic or other agents.5,7

In the present study, normal day-to-day variation of selected scalar and vectorial ECG measurements have been investigated. We hope this will assist the clinician in reaching valid conclusions on whether serial ECG changes should be considered abnormal or might still be within normal day-to-day variability ranges.

Material and Methods
Corrected orthogonal electrocardiograms using the Frank lead system were recorded on magnetic
tape on 10 occasions from each of 20 normal volunteers, 13 of whom were male and seven female. All were employees in our department, ranging in age from 22 to 58 years. The records were taken by two trained technicians who were aware of the purpose of the study. However, in order to simulate routine practice as fairly as possible, there was no special supervision of them. No special restrictions were imposed on the subjects either. Records from each patient were taken at almost the same time during the day over a 14-16-day period, after a rest period of 5-10 min. None of the subjects reported ill during the recording period.

Of the original group of 20, 10 underwent another session of 10 recordings, immediately following the first. The two technicians were asked to mark the placement of the electrodes on the chest with a colored skin marker at the first of this new set of recordings. They were instructed to place the electrodes on identical locations in the subsequent sessions and to keep the markings visible throughout the whole 2-week period. Subjects who were recorded with marked electrode positions had their unmarked ECGs recorded by the same technician. Both technicians used the same standardized equipment, and each completed the recordings in half of the subjects. The patient cable of one acquisition system had to be repaired on the third day of the study because of a loose connection. No other technical problems were encountered.

The fourth intercostal space with the subjects in the recumbent position was used as level for placement of the Frank leads. Recording technic, amplitude-frequency characteristics of the equipment, and computer methods used for analysis of the tracings have been published previously.9

The day-to-day variation of the following measurements was investigated.

1. Time measurements: P and QRS duration, heart rate, P-R interval, duration of Q, R, and S waves, and the time from the beginning of depolarization to the peak of the R wave (R peak time) in the three orthogonal leads.

2. Amplitude measurements: Peak amplitudes of individual Q-, R-, S-, and T-wave deflections in each of the orthogonal leads and magnitudes of spatial maximum QRS and T vectors and of maximal QRS and T vectors in the frontal (XY), sagittal (YZ), and transverse (XZ) planes.

3. Angular measurements: directions of maximal QRS and T vectors in the three planes and azimuth and elevation of spatial maximal QRS and T vectors.

4. Ratios between Q- and R-wave amplitudes (Q/R ratios) and between R and S (R/S ratios) in X, Y, and Z leads.

These measurements were obtained by computer technic for all beats available in 6 sec of time, covering at least one respiratory cycle.9 Mean values of the above-described parameters were calculated as being representative for each day, after discarding any extreme values. By this procedure, beat-to-beat variability and respiratory changes could almost totally be eliminated as a contributing source to daily variation.

Day-to-day variation of 48 measurements was computed for each individual separately and for different subgroups made according to sex, technician, and to whether tracings were recorded with marked or unmarked chest locations.

Maximal day-to-day variation was obtained in a similar way as maximal beat-to-beat variation reported previously.3,4 Means were calculated for each ECG measurement in each subject separately using the daily observations. Absolute deviations from the mean measurements were computed next, providing 10 deviations from the mean for each of the 48 measurements in each of the subjects. The deviations were then pooled for all subjects in different subgroups, and the 90 and 96 percentiles, means, and standard deviations of the pooled data were calculated. The 96% values of these absolute intraindividual changes represent the extremes of day-to-day variability.

Furthermore, in order to make a comparison possible of daily variation in different electrocardiographic items, we computed coefficients of variation, defined as standard deviation × 100/mean for each measurement and each individual. Angular measurements were excluded.

Standard t tests were applied to test differences between male and female subjects and between records taken by different technicians. A paired t test was used to judge statistical differences between values obtained from marked and unmarked recordings, made in the same subject.

A total of 290 tracings was available for statistical analysis. Three of the marked and three of the unmarked recordings could not be processed because of technical reasons beyond our control, in addition to four missing records. A Q wave was present in leads X and Y in 206 and 168 tracings, respectively, in those leads. All the other measurements could be derived from the 290 recordings, of which 193 were obtained with unmarked and 97 with marked chest locations.

Mean values of durations and amplitudes of different ECG deflections and of directions of angular measurements in the 20 subjects studied were almost identical to corresponding results published previously10 in a large group of normal subjects.

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Results

No significant sex differences were found in coefficients of variation or in mean and maximal day-to-day variability of the different electrocardiographic parameters under study. Neither were there important differences between the results of recordings made by the two technicians. Pooling of the data was therefore justified, and only results obtained from "marked" and "unmarked" recordings will be presented further.

Of 48 measurements, 45 showed a reduction in daily variability by the procedure of marking the chest electrode locations. Coefficients of variation decreased by an average of 22% (range, 0.24-39.6%) in the 39 measurements where they could be computed. Statistically significant ($P < 0.05$) reduction occurred in the variability of 14 parameters. Reduction of variation of 10 other measurements approached the 0.05 significance level ($P < 0.10$).

Day-to-Day Variability of Time Measurements

Daily variability measurements of time parameters are listed in table 1. Absolute figures for daily variation of R peak times in leads X, Y, and Z were almost identical to the results for Q duration. Their respective coefficients of variations varied between 3 and 7%. Coefficients of variation of R-wave durations in leads X, Y, and Z varied between 6 and 9%. The mean absolute day-to-day variation of R-wave durations was 3.2 msec, 10 and 15 msec being the 90 and 96% ranges, respectively. Time measurements in general showed the least day-to-day variation of all items studied. They were only slightly influenced by marking of the chest locations. The mean coefficient of variation of all the time measurements combined was $8.2 \pm 3.7$ (sd) in the unmarked and $7.2 \pm 3.9$ in the marked recordings.

Day-to-Day Variation of Amplitude Measurements

Percentage and absolute measurements of daily variability of amplitudes of R and Q deflections in scalar leads and of the spatial maximal QRS vector are represented in table 2. Daily variation in millivolts of the magnitude of maximal QRS vectors in the three planes was almost identical to the values obtained for QRS spatial maximum, shown in table 2. The coefficient of variation of these vectors varied between 9.5 and 15 in the unmarked and between 6 and 8 in the marked recordings. Corresponding figures for the S-wave amplitude in leads X and Y were 32 and 22, respectively.

By marking of the electrode locations, it was possible to obtain a significant ($P < 0.05$) reduction in magnitude of spatial maximal QRS vectors, in maximal QRS vectors in the frontal and transverse planes and in R-wave amplitude variation in leads X and Z, while variation of the R in lead Y remained essentially unchanged.

Extreme changes were observed in two of the 20 subjects studied (figs. 1-3). The variants in figure 1 A were experimentally reproducible by minor displacements of the A electrode not exceeding 2.5 cm.

Relative changes in T-wave amplitudes were more marked compared to variations in

Table 1

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Coeff variation (%)</th>
<th>Absolute changes (msec)</th>
<th>Coeff variation (%)</th>
<th>Absolute changes (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>At 90</td>
<td>At 96</td>
<td>Mean</td>
</tr>
<tr>
<td>P</td>
<td>6.6</td>
<td>6.0</td>
<td>18</td>
<td>26</td>
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<td>PR</td>
<td>4.8</td>
<td>5.6</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>QRS</td>
<td>3.1</td>
<td>2.1</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Q in lead X</td>
<td>10.1</td>
<td>1.3</td>
<td>3.4</td>
<td>4.1</td>
</tr>
<tr>
<td>Q in lead Y</td>
<td>10.2</td>
<td>1.4</td>
<td>3.5</td>
<td>3.9</td>
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<tr>
<td>Q in lead Z</td>
<td>10.8</td>
<td>2.5</td>
<td>8.8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

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Table 2

Coefficient of Variation and Day-to-Day Variation of Amplitude Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unmarked recordings</th>
<th>Marked recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coeff variation (%)</td>
<td>Absolute changes (mv)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>At 90%</td>
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<tr>
<td>R in lead X</td>
<td>17.6</td>
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<tr>
<td>R in lead Y</td>
<td>9.4</td>
<td>0.06</td>
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<td>R in lead Z</td>
<td>17.6</td>
<td>0.09</td>
</tr>
<tr>
<td>QRS spatial max</td>
<td>10.1</td>
<td>0.11</td>
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<tr>
<td>Q in lead X</td>
<td>19.6</td>
<td>0.011</td>
</tr>
<tr>
<td>Q in lead Y</td>
<td>20.3</td>
<td>0.012</td>
</tr>
<tr>
<td>Q in lead Z</td>
<td>17.9</td>
<td>0.038</td>
</tr>
</tbody>
</table>

Figure 1

Extreme variants of serial orthogonal ECGs recorded in a 31-year-old healthy male with a near-vertical loop in the frontal plane. Note the marked variability in configuration in leads X and Z during the unmarked series (A), while the marked tracings show much less variability (B). The numbers on top refer to the consecutive recording sessions. The vertical bars represent 2-mv calibration.

amplitude measurements derived from the QRS complex (table 3). The changes in T wave from day-to-day were minimally influenced by marking of the chest locations.
VARIATIONS IN ECG AND VCG

Figure 2

Scalar leads of unmarked repeat recordings in a 33-year-old healthy woman. Note the diminution of the Q wave in lead Z in recording 3 and the total loss of anterior forces in recording 4. The five other recordings not presented in this figure resembled tracings 5 and 9.

The mean coefficient of variation of all amplitude measurements combined was 20.7 ± 9.8 in the unmarked and 15.1 ± 8.8 in the marked series of recordings.

Day-to-Day Variation of Angular Measurements

Mean and maximal day-to-day variation of angular parameters are represented in table 4. Variations in the frontal (XY) plane were smaller than in the transverse (XZ) or sagittal (YZ) planes. The maximal (96%) variation on either side of the mean for the QRS axis in the frontal plane was 23°, which would leave a total variation of 46°.

Variation values of directions of maximal T-wave vectors in the three planes were twice as large as corresponding figures for maximal QRS vectors, listed in table 4.

Reduction in daily variation of angular measurements by marking of the chest locations was significant (P < 0.05) for QRS angle in the sagittal plane and approached the significant level (P < 0.10) for direction of QRS vectors in the other planes and also for the T-wave direction in the frontal plane.

Q/R and R/S Ratios

The average coefficient of variation of Q/R and R/S ratios derived from leads X, Y, and Z was 22.1 ± 6.7 (range, 17–32) on the unmarked and 15.6 ± 5.5 (range, 10–22) on the marked recordings. The maximal (96%) absolute change in Q/R ratio in leads X, Y, and Z was 0.032, 0.053, and 0.759, respectively, in the unmarked series and 0.032, 0.020, and 0.348 in the marked series of recordings. These

Table 3

Coefficient of Variation and Day-to-Day Variation of T-Wave Amplitude Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unmarked recordings</th>
<th>Marked recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coeff variation (%)</td>
<td>Absolute changes (mv)</td>
</tr>
<tr>
<td>T in lead X</td>
<td>27.0</td>
<td>0.038 0.099 0.131</td>
</tr>
<tr>
<td>T in lead Y</td>
<td>36.8</td>
<td>0.026 0.068 0.113</td>
</tr>
<tr>
<td>T in lead Z</td>
<td>45.8</td>
<td>0.028 0.073 0.090</td>
</tr>
<tr>
<td>T spatial max</td>
<td>19.3</td>
<td>0.039 0.104 0.139</td>
</tr>
</tbody>
</table>

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findings indicate that Q/R ratios advocated for recognition of myocardial infarction, especially those obtained from leads X and Y, are relatively stable measurements.

Discussion
Our study was designed to establish standards whereby changes occurring in serial unmarked as well as marked recordings can be assessed. Only when normal limits of maximal day-to-day or repeat variability are exceeded are conclusions of abnormality valid and reliable.

In the present material no statistical differences of daily variation between male and female could be demonstrated. Positioning of chest electrodes, however, may pose some problems especially in obese women, and it is conceivable that in a larger population differ-
Day-to-day variation in angular measurements was greatest for small deviations, Q and S waves, but was also unexpectedly high for the R-wave amplitudes in leads X and Z (table 2). Problems in positioning of the chest electrodes play an important role here. The influence of changes in electrode position on amplitudes recorded by orthogonal lead systems has been studied thoroughly. The displacement of Frank electrodes in different directions by 2.5 cm resulted in maximal absolute deviations up to 0.38 mv in a group of 10 normal subjects. The coefficient of variation of the R-wave amplitude in lead X in another study varied between 8.2 and 32.7 (mean 18.5) in four subjects as a result of various electrode displacements by 1-2 cm. This mean value is almost identical to the mean coefficient of variation of R-wave amplitude in X found in the present study in unmarked recordings (table 2). Errors in placement of chest electrodes are common in routine practice, as demonstrated by Kerwin et al. for standard precordial leads. These authors found a considerable variation, up to 3 cm in both horizontal and vertical directions, in marking the points of electrode position by different electrocardiographers or technicians.

Marking of the chest locations did reduce the coefficient of variation of the R-wave amplitude in leads X and Z from 17.6 to 9.0, whereas the variation of R in lead Y was almost unaffected. The latter is expected, since positioning of the electrodes which contribute most to the Y lead poses no real problems. The Y lead is mainly a limb lead. Daily variability of R-wave amplitudes was previously found to be definitely larger in chest than in the limb leads. No figures are available for unmarked recordings of conventional 12-lead electrocardiograms, but undoubtedly higher values are to be expected.

The daily variation of T-wave amplitudes was relatively high. T waves are known to be rather labile. Coefficients of variation varied between 20 and 47 (table 3). Results of others on daily T-wave changes were similar to ours.

To be abnormal, serial changes in R- and T-wave amplitudes have to exceed at least the reported ranges. To be significant, a change in R-wave amplitude in lead Y, mainly a limb lead, should exceed 0.25 mv, whereas a change of at least 0.35 mv would be required for lead Z and even more for lead X. To be considered significant, the QRS axis should shift by at least 46° according to our findings. Such a change in axis should be considered

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**Table 4**

*Day-to-Day Variation of Angular Measurements*

<table>
<thead>
<tr>
<th>Measurement (direction)</th>
<th>Unmarked recordings</th>
<th>Marked recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute changes (degrees)</td>
<td>Absolute changes (degrees)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>At 90%</td>
</tr>
<tr>
<td>Maximum QRS in XY plane</td>
<td>5.0</td>
<td>18</td>
</tr>
<tr>
<td>Maximum QRS in XZ plane</td>
<td>9.3</td>
<td>30</td>
</tr>
<tr>
<td>Maximum QRS in YZ plane</td>
<td>10.3</td>
<td>38</td>
</tr>
<tr>
<td>Azimuth QRS spatial max</td>
<td>7.2</td>
<td>26</td>
</tr>
<tr>
<td>Azimuth T spatial max</td>
<td>8.8</td>
<td>27</td>
</tr>
</tbody>
</table>
abnormal even if the new observed value is still within normal limits.

Extreme changes in R/S ratio in lead X were observed in a patient with a near vertical loop in the frontal plane. Vertical displacement of the A electrode changes the effective lead strength and direction of the X lead and can result in quite different QRS complexes in X in such patients. Total temporary disappearance of the Q wave in lead Z and concomitant complete loss of anterior forces were observed in another subject. The findings were reproducible through displacement of chest electrodes. Such extreme changes occurring in normal subjects may be unusual, but should serve as a warning for too enthusiastic diagnostic or therapeutic interventions. A repeat tracing may prevent severe "heart disease of electrocardiographic origin."14

Technical variability should always be remembered as a source in repeat variability of electrocardiographic measurements. Standardization of methods and procedures, in which the American Heart Association has played a major part15 does not exclude the possibility of accidental wire breaks or short circuiting, skin electrode impedance problems,16 and amplifier breakdowns. Regular checkups of instrumentation are a necessity in quantitative modern electrocardiography. Above all, however, care and precision in recording should be practiced, and technicians should receive careful instructions in order to reduce variation in electrode placement, which is a major source in daily ECG variation in clinical practice.

Acknowledgment

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