The Distribution of Cardiac Potentials Around the Chest in One Hundred and Three Normal Men

By Ernst Simonson, M.D.

Chest leads farther right to V_{1} and farther left to V_{5} have been suggested, and are increasingly used, for diagnosis of right ventricular or posterior wall lesions. Normal standards are provided for the regional distribution of seven arbitrarily defined patterns and amplitudes of main deflections, in five positional groups, in 15 leads around the chest, resulting in statistical evaluation of 600 electrocardiographic items. In general, the results favor a much more conservative interpretation than has been noted in the past. Some implications to electrocardiographic theory are discussed.

Although multiple precordial leads have been generally introduced in clinical routine electrocardiography, a normal sample adequate in size for normal standards of the leads V_{1} to V_{8} has not been available until very recently (Sokolow and Friedlander). For many years Kossmann and Johnston's material of only 30 normal subjects was used as a normal reference. In the series of 52 cases of Myers and co-workers the normality of the heart was shown by autopsy, but no statistical analysis was made; the presentation of their material was of a descriptive character. Even Sokolow and Friedlander's larger sample is not satisfactory because of the heterogeneous character of their group and the failure to differentiate between the electrical heart positions. Dolgin and associates investigated the differences between CR, CI, CF and V leads, but the samples were too small to be used for the calculation of normal standards.

It has been recognized that in conditions of pronounced clockwise or counterclockwise rotation around the long axis, the six conventional precordial leads V_{1} to V_{6} are not sufficient to arrive at a definite interpretation. Right lateral leads have been suggested for suspected right ventricular preponderance and V_{7}, V_{8} or other left back leads for suspected coronary insufficiency or infarct of the posterior wall. In the absence of normal-standard material, the standards for other leads, such as V_{1} or V_{R} for the right lateral leads, and V_{4}, V_{L} or V_{F} for the back leads, are used currently as criteria of normality.

In this paper information is provided on the distribution of electrocardiographic patterns around the chest at the level of the heart in 103 normal men. These should have immediate value as a background for clinical interpretation but the results also have a bearing on some theoretic aspects of unipolar electrocardiography.

**METHOD**

Fifteen leads were taken around the chest at the level of the heart, in addition to the three standard and three unipolar limb leads. Since this work was done with the view of application to clinical electrocardiography, the conventional precordial leads were taken in the supine position, following the customary routine. The back leads were taken in the sitting position. In control experiments on 23 normal men it was shown that the change of the body position from supine to sitting produces only minor changes in the precordial electrocardiogram, which were found in all but one item (R wave in V_{2}) to be statistically not significantly different from zero.

The change of body position, therefore, would not produce any appreciable error in the statistical analysis of amplitudes or pattern distribution.

For analysis of the distribution of electrocardiographic patterns, the leads were expressed in terms of angles (degrees) from a hypothetic center in the heart. The center was obtained from frontal chest plates in the following way: (1) one half of the long diameter, measured from the junction of the right

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atrium shadow with the aortic shadow to the most distant apical point, (2) arbitrary estimate of a central point.

The two approximations agreed very closely, the measured point tending to fall slightly below the estimated. At the level of the center, the transversal diameter was measured, and the position of the reference point (fig. 1). Each lead is expressed both in the conventional way and in terms of an angle. The 0°-180° line was arbitrarily chosen as the transversal line through the center, with the increase of the angle in clockwise rotation. Using this procedure, the location as well as the extent of the various patterns could be given in terms of the mid-

![Cross section of chest with lead positions, expressed as V leads and in degrees of angle with a hypothetic center (circle) in the heart. The transversal 0°-180° line through the center follows Bayley's triaxial reference system of the frontal plane, but does not correspond to any actual lead. Other three diagrams: Distribution of patterns in three heart positions. The circles are the average midpoints; the small vertical lines connected through a solid line denote the mean upper and lower endpoints, and the broken lines show the upper and lower limits for 95 per cent of normal population.

Fig. 1. Upper left hand diagram:

Cross section of chest with lead positions, expressed as V leads and in degrees of angle with a hypothetic center (circle) in the heart. The transversal 0°-180° line through the center follows Bayley's triaxial reference system of the frontal plane, but does not correspond to any actual lead. Other three diagrams: Distribution of patterns in three heart positions. The circles are the average midpoints; the small vertical lines connected through a solid line denote the mean upper and lower endpoints, and the broken lines show the upper and lower limits for 95 per cent of normal population.

As an example, assume that one pattern (A)
extends from \( V_2 \) (\(-63^\circ\)) to \( V_7 \) (\(-45^\circ\)), and another pattern (B) from \( V_5 \) (\(-24^\circ\)) to \( V_6 \) (\(-297^\circ\)). The endpoints U and L for pattern A are then 73° and 35°, and for pattern B 35° and 290°. The midpoints would be \( \frac{73 + 35}{2} = 54^\circ \) and \( \frac{290 + 35}{2} = 162.5^\circ \), respectively, and the range 73 – 35 = 38° for A and 295 – 290 = 15° for B. This procedure made a statistical evaluation of the pattern distribution possible. The sagittal midline (broken line, fig. 1) and the transversal (0°–180°) line are given for orientation, although they do not correspond to any particular lead.

The outline of the chest was taken from an anatomic atlas representing a cross section at the fifth intercostal level.

The geometric distribution of the following patterns was analyzed:

1. \( rS_r, T^-; \)
2. \( rS, T^+; \)
3. \( qR, T^-; (q \text{ up to } 33 \text{ per cent of } R); \)
4. \( QR, T^-; Q_r, T^-; \)

Transitional potentials were defined:

between (1) and (2): appearance of isoelectric or diphasic T,

between (2) and (3): RS; T+ or appearance of small polyphasic potentials,

between (3) and (4): qR with isoelectric, diphasic, or negative T.

In addition to the analysis of pattern distribution, the magnitudes of the QRS and T deflections were analyzed in each of the 15 chest leads. The means, standard deviations and limits for 95 per cent of the normal population were calculated for the distribution of patterns as well as for the amplitudes.

The electrocardiograms were classified in five positional groups (vertical "V," semivertical "SV,'" intermediate "I,'" semihorizontal "SH,'" and horizontal "H") using criteria of Wilson and associates and Myers and Klein.

The subjects were 103 men between 45 and 55 years of age. Careful clinical and laboratory examinations, including various stress tolerance tests, as well as the history, failed to show any evidence of clinical abnormality. All subjects had been examined annually for three years in this laboratory, so that probably this group was more highly selected in regard to absence of clinical abnormality than normal control groups usually would be.

The distribution of electrical positions in our group does not represent a random sample; the 103 subjects discussed here were selected from a larger group in order to obtain a representative number of individuals in each positional group. The number of subjects in the positional subgroups were: 23 in V, 14 in SV, 33 in I, 11 in SH, and 22 in H.

**Results**

**Pattern Distribution**

A graphic presentation of the pattern distribution in three different electrical heart positions is shown in figure 1. The outlines of the heart and its geometric position are, of course, only an approximation.

The regions over which the indicated patterns extend are shown as lines around the thorax, the small circles giving the position of the means for the midpoints and the solid lines the means of the endpoints for these patterns. The broken lines show the extremes for these patterns which may be expected in 95 per cent of "normal" men. These latter limits, calculated from the standard deviations, afford a basis for the differentiation between "normality" and "abnormality" in routine clinical interpretation.

No differentiation was made between the right lateral QS, T− pattern and rSr', T− pattern, because they were found in the same location and because the differentiation becomes highly arbitrary in case of microscopically small r and r'. It was assumed, therefore, that both patterns are identical.

Analysis of figure 1 reveals:

1. There is a continuous transition from one pattern to the next, so that the precise differentiation between patterns is arbitrary;
2. there is considerable overlapping of pattern distribution;
3. mirror-patterns are found at opposite ends of projections through the heart;
4. the extent of most patterns is very wide and difficult to relate consistently to specific parts of the heart surface;
5. there are important differences of the pattern distribution, especially in the back and right lateral leads, in the five different electrical heart positions.

The continuous trends were true for each segment of the pattern, but there was considerable interindividual variability, even greater than can be seen in figure 1 which shows only the variability of the endpoints for each pattern. It is well known, from experience with the precordial leads V1 through V6, that
in normal persons a small Q wave may appear in V₃, associated with a transitional RS complex, or may not be seen in V₆ with a monophasic R or an RS complex. A similar situation in regard to other segments obtains in other regions which are less explored. For instance, the so-called left ventricular epicardial pattern, qR, T+ with its average midpoint around 340°, changes in the direction to the midline of the back in three ways: the R wave decreases, Q increases and T becomes isoelectric or inverted when the R wave is still relatively large, with a prominent Q wave, simulating the pattern of coronary insufficiency or posterior-lateral infarct in the regions V₇ to V₉. In regions V₇ and V₉, the electrode still faces the left ventricular wall.

Although the continuity of trends makes the differentiation and definition of patterns arbitrary, they prove, at the same time, the general validity of our procedure of evaluation. Any other definition of patterns would have resulted in similar distribution diagrams, rotated clockwise or counterclockwise with reference to the diagrams in figure 1, according to the arbitrarily defined pattern limits.

The broken lines in figure 1 include the region where a given pattern may be found in 95 per cent of normal population, but the individual range for any pattern is exaggerated. The limits were obtained from the standard deviations of the endpoints; it is highly unlikely that any individual would be extreme both in the upper and lower endpoint. The upper and lower limits for the range of the pattern, defined as the difference between the endpoints in each individual and calculated from the S.D., give more precise information (table 1). Even so, the upper range limits, especially for the rS, T- (or rSr', T-) pattern and the qR, T+ pattern are very wide. The narrow low range limits are also of interest. They are so small in several patterns (for instance rS, T- or QR, T-) that they may be missed entirely at the usual electrode distance.

The question may arise whether the arbitrary determination of angles and the hypothetic center in the heart might be a contributing factor to the large variability of pattern distribution and range. The arbitrary choice of the zero point is irrelevant for the validity of our procedure, but an incorrect position of the center for a given individual would change the projection of patterns onto the lead locations. However, this error was probably small. A difference of a few centimeters in the location of the center would not greatly change the situation, and the variability of the location of the center was comparatively small. The uncertainty of the correct position of the center does not limit the usefulness or applicability of the normal limits of pattern distribution and range, as presented in figure 1 and table 1. The situation is the same for any patient to whom the standards are applied as for any individual of our group in whom the standards were obtained. The only pattern where information about location and range is available is the "transitional" RS, T+ pattern, because its limits are included within the routinely taken

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Vertical</th>
<th>Semivertical</th>
<th>Intermediate</th>
<th>Semihorizontal</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>rS (r') T-</td>
<td>95.0</td>
<td>2.0</td>
<td>121.1</td>
<td>0.0</td>
<td>118.6</td>
</tr>
<tr>
<td>rS T+</td>
<td>55.8</td>
<td>12.8</td>
<td>101.1</td>
<td>2.3</td>
<td>52.5</td>
</tr>
<tr>
<td>RS T+</td>
<td>86.7</td>
<td>11.9</td>
<td>83.3</td>
<td>12.5</td>
<td>84.9</td>
</tr>
<tr>
<td>qR T+</td>
<td>138.0</td>
<td>75.4</td>
<td>152.0</td>
<td>64.2</td>
<td>159.9</td>
</tr>
<tr>
<td>qR T-</td>
<td>46.9</td>
<td>0.0</td>
<td>38.6</td>
<td>3.6</td>
<td>40.2</td>
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<tr>
<td>qR T+</td>
<td>77.6</td>
<td>0.0</td>
<td>48.7</td>
<td>0.0</td>
<td>46.3</td>
</tr>
<tr>
<td>QR (r) T-</td>
<td>119.1</td>
<td>2.7</td>
<td>86.8</td>
<td>0.0</td>
<td>96.0</td>
</tr>
<tr>
<td>QS T- (rSr') T-</td>
<td>62.3</td>
<td>11.5</td>
<td>59.6</td>
<td>23.6</td>
<td>75.0</td>
</tr>
</tbody>
</table>
distribution (fig. 1, table 1) are difficult to explain on the basis of the theory that the chest leads represent projections of local patterns from specific parts of the heart. The limits are, of course, not a result of calculations, but can be found in actual tracings. For example, figure 2 shows two examples of extreme "clockwise" rotation around the long axis of the heart, so that the essentially monophasic R, T+ pattern appears in V5. The QR, T− pattern extends from V8R to V5R in case 460 (inner circle) and the qR, T− pattern from

precordial leads V1 through V6. Our range limits agree with the available information4.

The upper and lower range limits of pattern

precordial leads V1 through V6. Our range limits agree with the available information4.

The upper and lower range limits of pattern
398: outer circle; case 446: inner circle), the
T- waves become isoelectric when R is still
relatively high (V5 in case 446; V6 in case 398),
and the range of the isoelectric T extends in
both cases to V9.

The effect of heart position, defined as rotation
around an anteroposterior axis, on the
horizontal pattern distribution is revealed by
inspection of figure 1, but such comparison does
not afford convenient visualization, and also
lacks quantitative characterization. Figure 5
shows more directly the distribution of the QR
or qR pattern, and their mirror pattern (RS or
rS) in the back and right lateral leads V8 to
Vsr.

These leads were chosen because positional
differences were more obvious than in the pre-
cordial leads. The reason might be the eccentric
location of the heart, magnifying positional
effects in V8 to Vsr (fig. 1). The values (ordi-
нате) are given in per cent of the incidence of the
patterns. For this type of analysis, the
groups V and SV, as well as H and SH, were
combined in order to obtain numerically nearly
identical positional groups (V + SV = 37
subjects; I = 33 subjects; H + SH = 33
subjects).

The regional trends are reversed for the QR
(or qR) and the RS (or rS) pattern. The inci-
dence of the QR (or qR) pattern is greatest in
the group V + SV, and smallest in group
H + SH. In contrast, the incidence of the RS
(or rS) pattern is greatest in group H + SH
and smallest in group V + SV.

Table 2 shows statistically significant differ-
ences between positional groups V and H in
the regional pattern distribution, as calculated
by means of the t test and the Cochrane-Cox
test. The t test can be used only when the
variances in the two samples are of approxi-
mately the same magnitude. This was the case
only for the midpoint of the QR, T- pattern.
The Cochrane-Cox test was used for the other
items, because it requires no assumption of
similar variances. Table 2 shows both the t

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{Pattern} & \text{Group V} & \text{Group H} & \Delta M & t & t \text{ corr.} & \text{Signif.} \\
\cline{2-7}
 & M & S.D. & M & S.D. & & & \\
\hline
\text{Midpoint} & & & & & & & \\
\text{rS, T-} & 139.0 & 13.71 & 170.5 & 21.71 & 31.5 & 5.79 & 3.81 & 0.001 \\
\text{qR, T-} & 253.5 & 17.70 & 269.1 & 12.25 & 15.6 & 3.85 & 2.82 & 0.01 \\
\text{QR, T-} & 209.9 & 22.29 & 246.3 & 16.25 & 36.4 & 6.23 & - & 0.001 \\
\text{QS, T-} & 185.2 & 15.95 & 222.8 & 29.22 & 37.6 & 5.33 & 3.81 & 0.001 \\
\hline
\text{Range} & & & & & & & \\
\text{rS, T-} & 48.5 & 23.77 & 83.1 & 34.39 & 34.6 & 3.91 & 3.81 & 0.001 \\
\text{qR, T-} & 34.1 & 22.19 & 22.6 & 9.19 & 11.5 & 2.29 & 2.07 & 0.05 \\
\text{QR, T-} & 60.9 & 20.69 & 29.8 & 15.22 & 31.1 & 4.45 & 3.80 & 0.001 \\
\hline
\end{array}
\]

value and the corrected t values (columns 7
and 8). All differences are highly significant
except that of the range of the qR, T- pattern,
which is significant at the 0.05 level. In five
items, there is only a 1:1000 probability that
the results could be due to chance.

The graphs and tables presented so far give
information about normal regional pattern dis-
tribution and their variability in different
positional groups. The relatively large variability within each positional group raises the question of the interindividual correlation between the location of various patterns. The qR, T+ pattern was arbitrarily chosen as a reference, and the correlation coefficients between its midpoint and the midpoints of the rS, T−; rS, T+; QR, T−; and qR, T0 or T± patterns were calculated for the positional group I. They were, in above order, 0.59, 0.46, 0.31 and 0.82.

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

FIG. 6. Mean amplitudes of QRS and T deflections around the chest. Position is given in terms of V leads and degrees of angle.

All except the correlation to QR, T− were significantly different from zero, but they were also significantly different from 1 (perfect correlation). This means, that the position of one pattern determines also the position of the other patterns, but only to a certain degree. Other, nonspecified factors, interfere so that the correlation is not perfect.

Amplitudes

Since the transition of one pattern to the next is continuous, it can be implied that the amplitude trends around the chest are also continuous. This is shown in figure 6. The abscissa is the location on the chest, both in terms of leads and degrees, and the ordinate refers to the mean amplitude (0.1 mv) or Q, R, S and T. The average magnitude and contour of the QRS-T deflections can be easily obtained from figure 6 for any location on the chest at the level of the heart, and for four electrical heart positions.

Since there are positional differences of the pattern distribution, positional effects on the amplitudes should also be expected. This is revealed by figure 6 and, more directly, by figure 7 and table 3. Table 3 shows a rather large number of items with positional amplitude differences reaching the level of statistical significance. The comparison was made between extremes of amplitudes in the direction from horizontal to vertical position. The results are quite consistent; the R wave in the precordial leads V2 to V6 is consistently smaller in the
more vertical position and consistently greater in the back and right lateral leads. The trends of the Q wave are reversed, with the dividing line approximately at $V_5$. The $T$-wave is consistently larger (or more positive) in leads $V_1$ to $V_6$. The absence of significant reversed $T$-wave trends in the opposite right lateral leads is probably due to its small magnitude. Figure 7 shows the positional trends in some of the items of Table 3.

There is a considerable interindividual variability of the amplitudes of all deflections, comparable to the interindividual variability of pattern distribution, with S.D.'s amounting to one-third or more of the means. *

**DISCUSSION**

It is not surprising that the rotation of the heart around a sagittal axis, as defined by the five “electrical” heart positions, has a definite effect on the pattern distribution and magnitude of amplitudes in the horizontal plane (rotation around the long axis of the heart). The arbitrary definition of the three axes of rotation (sagittal, transversal, long axis) has been recognized for some time. 

The actual displacement of the heart, with reference to a “normal” position, is always three-dimensional, involving all axes. However, until now there has been available no quantitative material, in the sense of our analysis, which could be used as a background for routine electrocardiographic interpretation.

The potential value of the present material for clinical electrocardiography may be illustrated by discussion of the distribution of the $qR$, $T$-pattern. Appearance of this pattern in $V_1$ is usually diagnosed as right ventricular preponderance. In the absence of such a pattern in $V_1$ in suspected right ventricular preponderance, it has been suggested to take leads farther to the right. 

Our material shows that the $qR$, $T$-pattern extends much farther to the right in the vertical position than in the horizontal position. A $qR$, $T$-in $V_{6R}$ would still be within the 95 per cent normal limits in a person with a vertical heart, while it would be outside the normal limits, and probably indicative of right ventricular preponderance in a patient with horizontal, semihorizontal or intermediate heart position. It should be kept in mind that the 95 per cent range limits are conservative, that is, in 5 per cent of normal
population a qR, T— might be found even farther anterior-lateral, for instance in V6R. Since right ventricular preponderance is usually associated with vertical or semivertical heart position, the validity of the diagnosis of right ventricular hypertrophy from the presence of a qR, T— pattern in leads to the right from V1 is questionable.

The same pattern (qR, T—) which would be diagnosed as right ventricular preponderance in right lateral leads, might be diagnosed as coronary insufficiency when found in the left lateral or left back leads. This pattern extends to approximately V4 in vertical heart position and to V7 in the other heart positions.

Using the criteria of other leads (V6, V3L or V5), in the absence of direct information, for the interpretation of back leads19 may lead to a false diagnosis of coronary insufficiency in an appreciable proportion of normal subjects. The incidence of the qR, T— or the QR, T— pattern in the left back leads might be considerably higher in a population of patients with coronary insufficiency, but the overlapping of normal population and a population of patients interferes with the use of this pattern in that particular location for diagnostic differentiation.

We have used the five "electrical" heart positions for the subdivision of positional groups, following accepted electrocardiographic routine. Several authors found a high correlation between anatomic and electrical heart position in the frontal plane,17–19 but marked ventricular enlargement might interfere with the correlation. Actually, the demonstration of significant differences of pattern distribution and amplitudes in the five positional groups shows the validity of this procedure for electrocardiographic differentiation.

The correlation between anatomic and electrical heart position was much less pronounced in the horizontal plane.19 This might explain, in part, the fact that the interindividual correlation between the location of the qR, T+ pattern (as reference) and the location of other patterns is not perfect.

The results have some bearing on the fundamental theory of electrocardiographic interpretation. The extremes of pattern distribution cannot be easily reconciled with the projection of specific local patterns to the nearest electrode position.

Duchosal and Sulzer,20 starting from vectorcardiography, arrived at the conclusion that the patterns found on the surface of the chest are projections of an integrated central vector, and this view was supported by Meyer and Herr,21 by Grant,22 and by Scherlis and Grishman.23 This hypothesis implies that mirror patterns will be found at opposite ends, with reference to a center in the heart.

In our material, the average difference of the midpoints of the mirror patterns qR, T+ and rS, T— pattern was 190.2 degrees and was statistically not significantly different from a straight line (180 degrees). This agrees with the expectation of mirror patterns at opposite ends, and also shows that the arbitrary determination of our center must have approached its average location.

It should be noted, however, that the interpretation of mirror patterns, by way of inspection, ignores possible phase differences. A more direct approach was developed,24, 25 and will be discussed in forthcoming communications.

It should be emphasized, however, that the main purpose of this study was to present actual material on a sound basis of statistical evaluation, regardless of electrocardiographic theory.

**Summary**

1. In 103 healthy middle-aged men, subdivided in five groups according to the electrical heart position (vertical, semivertical, intermediate, semihorizontal, horizontal), 15 symmetrically spaced leads were taken around the chest.

2. The location of the leads was defined in terms of degrees with reference to a hypothetic center in the heart which was obtained by means of measurements on frontal chest films.

3. The means, standard deviations and upper and lower limits for 95 per cent of the normal population were calculated for the midpoints and endpoints of the following patterns: rS, T—; rS, T+; RS, T+; qR, T+; qR, T0; qR, T—; QR, T+; QS, T+.

4. There is a continuous transition from one
pattern to the next, together with a considerable interindividual overlapping of pattern distribution.

5. The range (defined as the difference of the endpoints) of most patterns shows also large variability. It may be so wide that it is difficult to relate it consistently to specific parts of the heart, and it may be so narrow that it could be missed at the usual distance between electrode positions.

6. Significant differences in the pattern distribution were found in the different positional groups.

7. There was a significant correlation between the location of the qR, T+ pattern as reference and four other patterns, but the correlation was not perfect.

8. The means of the amplitudes of Q, R, S and T versus location (degrees or lead) are presented in graphs which permit interpolation and reconstruction of the average electrocardiogram for any location on the chest circumference, and for any heart position.

9. There were significant amplitude differences in the various positional groups.

10. The interindividual variability of the amplitudes is also quite large, comparable to that of pattern distribution.

11. The material presented can be used as normal standards for back and lateral leads. The significance for diagnosis of right ventricular preponderance and coronary insufficiency of the posterior-lateral wall is discussed.

12. The bearing of the results on some theoretic aspects of electrocardiographic interpretation is discussed.

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