The Frontal Plane Vectorcardiogram in Old Inferior Myocardial Infarction

II. Mid-to-Late QRS Changes

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SUMMARY

The mid-to-late part of the frontal plane QRS loop (Frank lead system) of 150 consecutive subjects with an old inferior myocardial infarction was analyzed. During the acute episode all cases had to satisfy Myers' classical ECG criteria for the diagnosis. The vectorcardiogram was recorded months to years later.

As a result of this analysis and in order to prevent overlap with values found in 450 normal control subjects, four VCG criteria are proposed for this diagnosis.

The VCGs of 75 of the 150 patients fulfilled one or more of the four VCG criteria. The ECG, done at the time of VCG, satisfied Myers’ or Goldberger’s criteria or both criteria in 33 of these 75 patients, and an additional 24 of the 150 fulfilled either or both of these ECG criteria but had none of the four VCG criteria.

Among 131 consecutively catheterized subjects who had significant disease of one or more major coronary arteries, 40 fulfilled one or more of the VCG criteria. Thirty-six of the 40 showed significant stenosis of at least the right coronary artery, and the other four, of at least the left circumflex but not of the right coronary artery. Six of these 40 fulfilled Myers’ or Goldberger’s criteria. Five of the 131 fulfilled either or both of these ECG criteria but none of the four VCG criteria.

Additional Indexing Words:
Coronary cineangiograms
Coronary artery stenosis
VCG diagnostic criteria
Goldberger’s ECG diagnostic criteria
Myers’ ECG diagnostic criteria
Cardiac catheterization studies

This report will present an analysis of diagnostic changes in the mid-to-late part of the QRS $\alpha$ loop in the frontal plane vectorcardiogram (VCG) of subjects with old inferior myocardial infarction. A previous publication had described diagnostic changes in the early part of the QRS $\alpha$ loop.¹

In about 50% of subjects with old inferior myocardial infarction the electrocardiogram (ECG) does not show a diagnostic Q wave.¹⁻⁷ Several investigators have found that in these cases analysis of the early superior QRS vectors in the frontal plane of the VCG may add additional diagnostic information.¹,⁸⁻¹² But it was noted that the study of these early VCG forces still misses a considerable number of inferior infarcts or shows features which overlap with values found in normal subjects.

First and associates¹³ and Grant¹⁴ have described ECGs showing alterations from normal in the middle or late portion of the QRS complex in myocardial infarction. To be considered significant, however, it appeared to both groups of observers that concurrent changes must be present in the Q wave. In

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addition, First and associates\textsuperscript{13} stated that the total QRS duration must be prolonged. It appeared then that these changes would be of limited diagnostic value. Grant\textsuperscript{14} did suggest that mid-to-late QRS changes might be diagnostic even when the Q wave did not show classical changes, but his speculation was subsequently unsupported.\textsuperscript{15, 16}

Several investigators have described changes in the mid-to-late part of the QRS $s \bar{e}$ loop in myocardial infarction. To this portion of the curve has been ascribed the terms, "outpocketings," "bulges," "bites," "rapid changes in direction," and "slow inscription," among others. Milnor\textsuperscript{17} and others have emphasized that these findings are difficult to interpret because there are not enough quantitative data that may be statistically analyzed by independent observers.

To test the possibility that the middle-to-late part of the QRS $s \bar{e}$ loop might show changes that can be statistically analyzed and that might prove diagnostic of inferior infarction, a detailed quantitative reevaluation was undertaken of this portion of the curve in the frontal plane VCG projection. The findings were then correlated with the ECG and the coronary angiogram.

**Methods**

Vectorcardiograms were recorded in the supine position in all three planar projections by the Frank lead reference system.\textsuperscript{18} Electrodes were placed at the fourth interspace as suggested by Langner and associates\textsuperscript{19} for the supine position. A standard 12-lead ECG was recorded at the same time.

The frontal plane VCGs of 150 consecutive subjects with old inferior myocardial infarction were analyzed. One of the subjects originally selected was excluded because the VCG and ECG showed incomplete left bundle-branch block. No instance of right bundle-branch block was found in this series. In all patients the original acute infarction had occurred months to years before the VCG was recorded. Most subjects had no obvious cause for heart disease other than coronary arteriosclerosis. In a few hypertension was recorded at one or more of their numerous examinations.

All 150 subjects, during their acute episode, fulfilled one or more of Myers' electrocardiographic criteria\textsuperscript{2} for inferior (posterior) myocardial infarction in lead aVF: (1) classical obvious Q-
wave changes, that is (a) QR complex of 0.5 mv or more from onset to nadir and a Q/R ratio over 25%, or (b) QR complex meeting some but not all of the requirements in "la" but associated with a Q wave measuring 0.04 sec or more from onset to nadir; (2) borderline less obvious Q-wave alterations meeting some but not all of the requirements listed under "la" provided that a previous tracing was perfectly normal; and (3) classical RS-T segment changes at the time of the acute episode even if the Q wave appeared entirely normal. Myers' criteria were chosen because they have been widely adopted and are based upon the largest number of autopsy-proven cases. It is to be emphasized, however, that many of the ECGs recorded after the acute episode and at the time of the VCG did not satisfy Myers' or Goldberger's criteria and thus could not be considered diagnostic (see "Results").

Based upon most commonly used vectorcardiographic and electrocardiographic criteria, about 20% of the 150 inferior infarctions appeared to be associated with infarction in other electrically manifest areas.

As a basis for comparison the Frank frontal plane VCGs of 450 normal adult subjects were analyzed (table 1). All patients showed no obvious heart disease on physical examination, nor did they give a history of possible causes of heart disease. A standard 12-lead ECG was recorded on all, and roentgenograms of the chest were taken on most. Although a few subjects had mild pectus excavatum, none had marked chest deformity or had undergone previous chest surgery. None was very obese.

A third group of subjects was analyzed as a further basis for comparison. This series consisted of 177 consecutively catheterized subjects who proved to be either normal (46) or showed significant disease in any one or more major coronary arteries but without any other cause for heart disease (131). In a few hypertension was recorded at least once during the course of their examinations.

Coronary cineangiograms were made utilizing either the Sones or the Judkins technic. The arteriograms were recorded utilizing a General Electric or Siemens 9 by 6-inch image intensifier with 16-mm cine film. All photographic records were analyzed by at least two observers who had no prior knowledge of the electrocardiographic or vectorcardiographic findings in the cases. An obstructive lesion was considered significant if 75% or more of the arterial lumen was obstructed. The inferoposterior wall was considered to be potentially ischemic if there was a significant lesion of either the right or the left circumflex coronary arteries or both.

### Table 1

<table>
<thead>
<tr>
<th>Age and Sex of 450 Normal Control Subjects</th>
<th>15-19</th>
<th>20-29</th>
<th>30-39</th>
<th>40-40</th>
<th>50-59</th>
<th>60+</th>
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<tbody>
<tr>
<td>Male</td>
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<td>58</td>
<td>67</td>
<td>71</td>
<td>47</td>
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</tr>
<tr>
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<td>10</td>
<td>50</td>
<td>22</td>
<td>49</td>
<td>31</td>
<td>11</td>
</tr>
</tbody>
</table>

### Table 2

Analysis of Type B Deformity Present in 13 Normal Subjects and 15 Subjects with Infarctions Whose Quadrant I Forces Were Completely Clockwise.

<table>
<thead>
<tr>
<th>Outer 1/4</th>
<th>Middle 1/4</th>
<th>Inner 1/4</th>
<th>Quotient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>±</td>
<td>+</td>
<td>+</td>
<td>20</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>133</td>
</tr>
<tr>
<td>0</td>
<td>+</td>
<td>+</td>
<td>20</td>
</tr>
<tr>
<td>0</td>
<td>+</td>
<td>+</td>
<td>100</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>17</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
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<td>+</td>
<td>+</td>
<td>15</td>
</tr>
<tr>
<td>±</td>
<td>+</td>
<td>+</td>
<td>15</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>±</td>
<td>+</td>
<td>25</td>
</tr>
</tbody>
</table>

13 normal subjects

15 subjects with infarctions

Explanation: The columns marked outer (most leftward) 1/4, middle 1/4, and inner 1/4 correspond to the projection (fig. 7, Xc through Xd to Xf) of this deformity (fig. 7 C through D to F) on the outer 1/4, middle 1/4, or inner 1/4 of the X axis between 0 and Xmax. + indicates that the projection completely occupied, ± only partially occupied, the designated portion of the X axis.
Examples of oval (loops 1 to 4) or linear (loops 5 to 7) shape of quadrant I forces among 192 normals that showed complete clockwise (cw) rotation of these vectors. These forces are completely cw; their efferent limb is above or to the left of the afferent limb, and the two limbs do not cross over. Loops 3 and 4 show irregularities or bumps, but their overall direction is still completely cw. The majority of normal, completely cw loops are oval or linear in shape. In loops 1, 6, and 7 the late quadrant I forces also comprise the terminal portion of the QRS.

Two of the 46 normals and 40 of the 131 subjects with coronary artery disease had VCGs that fulfilled one or more of the criteria that will be proposed herein for diagnosing inferior infarction. These 42 will be discussed under "Results."

Subjects referred to this unit for coronary artery disease study, that is, cardiac catheterization including coronary cineangiography generally were one of three types: (1) younger subjects (less than 45 years of age) with symptomatic, but not necessarily disabling, coronary artery disease who were included even when their ECG was not diagnostic (vide infra); (2) subjects with crescendo or recalcitrant angina pectoris, coronary insufficiency, or frank myocardial infarction for whom the question of surgical revascularization of the heart was being considered; and (3) subjects, generally but not always in the younger age group, with chest pain of uncertain origin whose ECG was either normal or nondiagnostic.

This catheterized group of subjects was studied...
(1) to determine whether the VCG evidence from which inferior infarction was diagnosed (vide infra for criteria) was also found in angiographically proven normals, and (2) to determine whether, in the subjects with coronary artery disease who fulfilled these VCG criteria, any artery perfusing the inferior surface of the heart was significantly narrowed.

Vectorcardiograms were recorded by a Hart Electronics instrument, model PV-3. The amplifiers were set at a high frequency response of 200 to 300 Hz and a low frequency of 0.2 Hz. Since extreme range may introduce an artifact, all VCGs were recorded in the above frequency range. Emphasis is placed on the high frequency response of the VCG amplifiers. In our experience a frequency response of 100 Hz or less (generally the upper frequency response of conventional ECG amplifiers) may "smooth-out" the QRS loop and thus mask the presence of abnormalities fulfilling the criteria herein discussed for diagnosing inferior infarction.

For the purpose of this study the leftward and inferior frontal plane QRS vectors were chosen for analysis. These forces, among all the mid-to-late frontal plane vectors, show the least variation in normal subjects and amongst patients with inferior infarction are most apt to show diagnostic changes. Moreover, changes in this portion of the curve represent, in part, alterations in the Y axis component of frontal plane vectors that theoretically might be expected to occur in inferior infarction.

The method of presentation of the frontal loop is shown in figure 1.

**Results**

The QRS loop of the frontal plane VCG in 138 of the 150 subjects with an old inferior infarction showed early superior forces that were followed by mid-to-late (not necessarily terminal) inferior and leftward (that is,
Examples among 47 normals with complete or almost complete clockwise (cw) mid-to-late inferior and leftward forces with type A deformity. As defined in the text, the loop was usually asymmetrical loops (1 to 6).

Loop 6 exemplifies a variant of type A deformity. Its mid-to-late inferior and leftward forces cross over at a point in their outer (most leftward) third and thus were almost completely cw. Near this point of crossover, upward directed quadrant I vectors temporarily reversed to a downward direction before their final ascent. The leftward distance between the point of beginning downward directed vectors (point C) and the point of final ascent (point B) becomes the numerator, and the distance of the most leftward vector (point A), the denominator in determining the quotient, that is, the respective X coordinates of points A, C, and B are expressed as the formula:

\[ \frac{X_B - X_C}{X_0 - X_{max}} \]

In a few loops with type A quotient of 16% or more, quadrant I forces were oval or linear (loops 7 and 8). The maximal frontal plane vector of these curves, particularly those with the greatest type A quotient, was among the most vertical in the normal series, that is, the maximal vector was between +65° and +90°. These loops retained the oval or linear shape since X_{max} was relatively small.

In five infarctions, whose quadrant I forces were completely cw, type A deformity quotient was more than 45%, but the most inferior portion of these vectors formed a well-defined apogee (loops 10 and 11) like that seen in the oval or linear loops. In these five infarctions, the maximal frontal plane vector was above, that is, less than +40°, contrasting with normals whose quotient exceeded 45%, but whose maximum vector lay between +68° and +90°. Thus, in these five instances of infarctions the loop was deformed because X_{max} was relatively large whereas the normals (fig. 6, loops 1 to 3) retained an oval or linear shape because X_{max} was small.
Examples among the 126 inferior infarctions with complete or almost complete clockwise (cw) quadrant I forces showing either type A deformity or an oval or linear shape. Illustrations of complete cw curves are shown by loops 1, 2, 4 to 7, and 10 to 11, and of almost complete cw curves by loops 3, 8, and 9. A late small segment of quadrant I forces in loop 11 coils upon itself; the curve is here considered to be completely cw. Examples of the oval or linear form are illustrated by loops 1 to 3, and examples of type A deformity, by loops 4 to 11. Eight loops showed the variant of type A already defined in legend of figure 4 and demonstrated by loop 6 of the same figure. (Continued on page 1148)
Figure 6

Detailed analysis of VCGs of nine normal subjects with type A deformity quotient exceeding 45%. Loops 1 to 9, corresponding to similarly numbered loops in graph 1, each showed one of three other unusual planar features which permitted differentiation from infarctions with type A deformity:

1. Position of maximal QRS vector. Loops 1 to 4 were vertical with a frontal plane maximal QRS vector be-
mid-to-late QRS loop deformities in the 150 inferior infarctions.

<table>
<thead>
<tr>
<th>Column 1: Deformity</th>
<th>Column 2: +</th>
<th>Column 3: M or G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>37</td>
<td>21</td>
</tr>
<tr>
<td>A + C</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>33</td>
</tr>
</tbody>
</table>

Explanation: Column 1 indicates the type of VCG deformity and column 2 shows the distribution of these deformities, column 3, marked M or G, indicates the number of subjects whose ECGs, taken at the time of VCGs, fulfilled either Myers’ or Goldberger’s criteria pertaining to the Q wave in lead aVF.

Among the 150 patients, besides the 33 patients with VCG deformity, 4 additional patients fulfilled either Myers’ or Goldberger’s criteria, for ECG diagnosis of myocardial infarction, but their VCG did not show any of the four types of diagnostic changes. Since this series of 150 had to fulfill Myers’ criteria at the time of the acute infarction, this selection of subjects was biased in favor of their showing a diagnostic Q wave at time of VCG.

quadrant I) vectors. The inferior and leftward forces in these 138 subjects are compared with similarly timed and located vectors recorded in the 450 normals (fig. 1).

In the other 12 subjects with infarctions all of the leftward forces were superior to the null point and thus differed from all the normals. The diagnostic features of these abnormal loops have been described previously.1

mid-to-late inferior and leftward (quadrant I) QRS vectors

Type A Deformity

Among the 450 normals, mid-to-late inferior and leftward forces were completely clockwise (cw) in 192 (fig. 2) and almost completely cw in 60 (fig. 3). These quadrant I vectors were usually oval or linear in shape: (1) their most leftward point corresponded to their most inferior point as well as to their maximal deviation, and (2) subsequent to this frontal plane maximal vector, the afferent limb ascended toward the null point. Consequently, the most inferior portion of these leftward forces formed a well-defined apogee.

In 47 of the 252 normals a variation from this oval or linear form was found, here called type A deformity (fig. 4, loops 1 to 6). Quadrant I forces formed an asymmetrical pattern: (1) after the most leftward deviation, the loop continued downward and toward the right (though still to the left of the null point) before ascending toward the 0 point, and (2) the maximal vector corresponded to the most leftward but not the most inferior point. Consequently, the most inferior portion of quadrant 1 forces was usually squared-off or rounded.

The loop was judged quantitatively to show type A deformity if the difference in leftward deviation of the point at which forces begin their ascent (B in fig. 1) and the most leftward point (A in fig. 1) measured 16° or

tween +68° and +90°. These loops retained an oval or linear shape for reasons already discussed in the legend of figure 4. In one of the catheterized subjects with a normal coronary angiogram the QRS loop resembled that of loop 4. By contrast, not one of the 150 patients with infarctions had a maximal vector between +65° and +90°. One loop, showing anterior as well as inferior infarction, had two points equally representing a maximal frontal plane vector, one at +10°, the other at +110°.

2. Convexity-toward-the-right deformity. In loops 5 and 6 all of the downward directed quadrant 1 forces up to the maximal leftward point were bowed, that is, convex toward the right. This pattern was not observed in any subject with infarction.

3. Early deformity of loop. Loops 7 to 9 had unusual early forces as well as quadrant 1 vectors with type A deformity. Loop 7 showed the variant of type A. In loops 7 and 9 the very beginning of the QRS was slightly superior, being figure-of-eight in the former and superimposed in the latter curve; in loop 8 the beginning of the QRS was inferior. In all three curves initial forces then passed very close to the null point and the subsequent early vectors proceeded clockwise, deviating markedly to the left but only slightly superior. These unusual early forces have been described previously1; they have not been observed in infarct subjects. (Three subjects, loops not shown in this figure, with normal coronary angiograms, had loops whose overall pattern, that is, early forces and quadrant 1 vectors resembled those of loops 7 to 9).
Analysis of the VCGs of 47 normal subjects with type A deformity. Ordinate equals 0 to $X_{\text{max}}$ expressed as millivolts, and abscissa equals the quotient of type A deformity. The angular position of the maximal frontal plane vector is noted above each subject. The nine cases in which the quotient of 45% or more (right side of graph) are numbered in parentheses under each subject; these numbers correspond to loops 1 to 9 of figure 6.

The ordinate plot shows that generally, the greater (more vertical) the angular position of the maximal vector, the less the value of $X_{\text{max}}$.

Graph 1

more of the distance of the most leftward vector from the null point, that is if $X_B$ to $X_{\text{max}}$, equalled a quotient of 16% or more. In addition, the loop from points A to B had to be directed downward without reversal to an upward direction.

In 104 of the 138 infarctions mid-to-late leftward and inferior vectors were completely cw and in 22 almost completely cw (fig. 5). In 64 of these 126 the usual normal oval or linear shape was retained (fig. 5, loops 1 to 3). In the other 62 (fig. 5, loops 4 to 11) their form was distorted by type A deformity similar to the 47 normals noted above.

Graphs 1 and 2 show the distribution of the quotients of type A deformity in the normal and the infarction groups, respectively. Except for nine normal subjects, a quotient of 45% or more separates 42 of the 62 infarctions with type A deformity from the 47 normals with similar deformity. In addition these nine
Graph 2

Analysis of 62 infarctions with type A deformity. Ordinates, abscissae, and angular position of maximal frontal plane vector were derived as in graph 1. The angular position of the maximal frontal plane vector is not correlated with A_{max}. Thus, the ordinate plot here contrasts with that of graph 1. Eight cases of the variant of type A are designated by clear circles; the remainder by solid circles.
Prototype of type B deformity of the inferior and leftward vectors. The method of analyzing this deformity (C through D to F) is detailed in the text. If a part of this deformity continued to the right of the null point, like that in loop 3 of figure 4, only that portion of this abnormality to the left of the null point was analyzed in table 2.

Figure 7

Examples among 13 normals with completely clockwise quadrant I forces and type B deformity (loops 1 to 9). In loops 10 and 11 more than half of the upper part of this deformity was straight, paralleling the X axis, and thus did not qualify for type B deformity. Further examples of type B deformity are loops 3 and 4 of figure 2.

Figure 8
normals each showed one of three other unusual planar features that permitted differentiation (fig. 6).

**Type B Deformity**

Among the 192 normals whose quadrant I forces were completely cw, the more inferior portion of these vectors usually formed a smooth loop, without outpocketings or indentations (fig. 2, loops 1, 2, and 5 to 7). However, in 13 of these 192, the more inferior portion of these quadrant I vectors was deformed by an upward-bowed convexity, here designated as type B deformity (fig. 7). This abnormality consisted of an ascending and descending limb that formed an obtuse angle (fig. 2, loops 3 and 4, fig. 4, loop 3, and fig. 8, loops 1 to 9).

Fifteen of the 102 patients with infarction with complete cw inferior and leftward vectors also displayed type B deformity exemplified by figure 9 (loops 1 to 8).

Table 2 analyzes type B deformity in the 13 normals and the 15 infarction subjects. To avoid overlap with values found in the 13 normals, this deformity (C through D to F in fig. 7) is considered diagnostic in 12 of the 15 infarctions: (1) Its X axis projection (Xc through Xd to Xf) occupies at least the middle half of the X axis from 0 to Xmax, and (2) its descending limb's Y axis projection (Yd to Yf) divided by its ascending limb's Y axis pro-

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**Figure 9**

Examples among the 15 infarctions with completely clockwise quadrant I forces and type B deformity (loops 1 to 8). In loop 9 more than half of the upper part of this deformity was straight, paralleling the X axis, and thus this loop did not qualify as a type B deformity.
Figure 10

Type C deformity in infarctions. Generally this deformity was entirely inferior. Occasionally, as in loop 11, a portion of this deformity was slightly above the null point, but its beginning and end were inferior. In type C variant (loop 2) the upward directed vectors coiled upon themselves. In some loops, such as 6 and 9, more than one "bite" was apparent, but usually only one of these corresponded to type C. Loop 2 has two type C deformities, one being the variant of C.

This deformity was apparent to the naked eye when the resultant photographs showed about a 1:1 image-to-object ratio and sensitivity of amplifiers was set so that a 1-mV deflection equalled 3 to 6 cm. In all cases this deformity was at least 0.01 sec.
VCG IN INFERIOR MYOCARDIAL INFARCT

Figure 11
False type C abnormality. Six normal loops (all curves in this figure and in fig. 2, loops 3 and 4) showed a deformity of quadrant I forces that might be confused with type C. In contrast to the infarctions, the deformity in these six was confined to the outermost (most leftward) half of these inferior vectors and its two limbs formed an obtuse angle.

jection (Y_c to Y_d) yielded a quotient of at least 33.3%, that is, Y_d to Y_f = 33.3% or more in figure 7.

Type C Deformity
Among the 138 infarctions with quadrant I forces, 19 displayed a localized sharp reversal to a downward direction of the ascending, afferent limb of these vectors. This abnormality, here called "type C deformity," resembled an inverted V because its ascending and descending limbs formed an acute angle. Sometimes this angle would vary from beat to beat, but in some cycles the angle was 90° or less. At least a portion of type C deformity was inscribed median to the outermost (most leftward) half of quadrant I forces. Examples of type C deformity are shown by all loops of figure 10 and loops 10 and 11 of figure 5.

None of the normals showed such a distinct niche though the loops of six of these might be confused with this abnormality (fig. 11, loops 1 to 4 and fig. 2, loops 3 and 4).

Type D Deformity
Among the 138 infarctions with quadrant I forces, eight displayed a figure-of-eight configuration of these inferior vectors, its crossover point projecting medial to the outermost (most leftward) half of the X axis between O and X_max (fig. 12, loops 1 to 8). In all eight at least one half of the afferent limb was above the efferent limb, that is, directed counterclockwise.

In seven of the eight (fig. 12, loops 1 to 7) quadrant I forces showed type D deformity: (1) Their upward directed afferent limb reversed to a downward direction at a point that projected on the outer (most leftward) half of the X axis between O and X_max. (2) The descending portion of the afferent limb projected on at least a third of the X axis between O and X_max. (3) Although in four of the seven a portion of the afferent limb was superior to the null point, the beginning of the ascent and the end of the descent of this limb were inferior in all of these curves.

Seventy of the 450 normals also showed a figure-of-eight with its crossover point projecting medial to the most leftward half of the X axis between O and X_max. In 67 of the 70, the afferent limb of these quadrant I vectors continued upward toward the null point without reversing to a downward direction (fig. 13, loops 1 to 4) thus contrasting with type D deformity. The other three showed some variation from this normal pattern that might be confused with type D deformity (fig. 13, loops 5 to 7).

Summary of VCG Findings and ECG Correlation
Table 3 shows the incidence, among the 150 patients with inferior infarctions, of the four diagnostic types of mid-to-late frontal plane QRS deformities. These VCG findings are correlated with the ECG.

Catheterized Subjects
Subjects with coronary artery disease catheterized in this laboratory and undergoing coronary cineangiography usually correspond to one of the three clinical types discussed in "Methods." One hundred thirty-one were proven by angiography to have significant coronary disease, that is, at least 75% stenosis of at least one of the major coronary arteries. Many of them apparently had never had a diagnostic ECG at any time. This negative
finding in many instances had prompted their referral for angiography. Thus, this was a selected series biased in favor of those subjects with coronary artery disease having a normal ECG at the time the VCG was done.

The VCGs of 40 of these 131 patients showed one or more of the four types of mid-to-late QRS deformities described above and diagnostic of inferior infarction. Thirty-six of the 40 had significant stenosis of at least the right coronary artery, the other four at least of the left circumflex but not of the right coronary artery. Table 4 presents a summary of these VCG findings in the 40 cases and correlates these abnormalities with the ECG.

Figure 12

Type D deformity, abnormal figure-of-eight, seen in seven infarctions (loops 1 to 7). Although in all seven the crossover point projected medial to the leftward half of to Xmax, in some cycles of loop 7, varying with respiration, the crossover point projected slightly lateral to the medial half.

Though it does cross over, loop 8 does not qualify as a type D deformity because the afferent limb is directed almost entirely upward. It does show type C deformity.

Figure 14 shows examples of some of these loops.

Forty-six subjects were normal by coronary angiography. From a clinical viewpoint, this was a selected series of normals biased in having chest symptoms, though not usually typical of coronary artery disease. Forty-two of the 46 had normal ECGs. The other four had T-wave changes, usually transient, considered to be possible normal variants.

Two of these 46 normals fulfilled the VCG criterion pertaining to deformity A for diagnosing inferior infarction. These two are discussed in figure 15. The other 44 fulfilled none of the four diagnostic VCG criteria.
Figure 13

Figure-of-eight contour in normals simulating type D deformity. These loops contrasted with the infarctions: (1) In 67 of them, exemplified by loops 1 and 2, the afferent limb of quadrant 1 forces continued entirely upward toward the null point. (2) In loops 3 and 4 the ascending afferent limb paralleled the X axis before its final ascent. (3) In loops 5 to 7 the afferent limb’s point of reversal to a downward direction projected on the medial half of 0 to $X_{max}$. Moreover, in these three, the projection on the X axis of the downward directed portion of the afferent limb was less than one third of 0 to $X_{max}$.

To avoid all possible confusion with type D, loops 8 and 9 are included; quadrant 1 forces are completely counterclockwise in each curve; yet the proximal portion of their two limbs is so close as to seem to cross over. Even in these two loops the point of downward reversal of the afferent limb projects on the medial half of 0 to $X_{max}$.

Discussion

The normal QRS loop, pursuing a smooth uninterrupted course, has an ovoid or almost linear contour. Variations from this normal pattern have been described in patients who may or may not have had myocardial infarction. The resulting deformities of the curve have been referred to by such imprecise and qualitative designations as “rapid changes in direction,” “bites,” “notches,” “indentations,” “excavations,” “figures-of-eight,” “coils,” “hairpin deformities,” or the like. But these are inexact, subjective, and impressionistic and might have one meaning to one observer and a quite different meaning to another. They are, therefore, unsatisfactory.

For this reason this report has emphasized the importance of a point-to-point study of the mid-to-late part of the frontal plane QRS loop in the diagnosis of inferior myocardial infarction. The four diagnostic VCG criteria herein proposed comprise a pure quantitative, mor-
Mid-to-late QRS loop deformities in 131 subjects with angiographically proven coronary disease. Forty showed one or more of the four types of quadrant I deformities exemplified by the following curves:

Loops 1, 2, and 4 to 7 show type A deformity (loop 6 is the variant of type A). Loops 8 and 9 show type B deformity. Loop 3 shows both type A and type C deformity. Loop 10 shows type C, and loop 11, the variant of type C. Loops 12 and 13 show type D deformity. Loop 13 also shows type C.

Although many of the VCGs among the 40 were atypical, the telltale evidence of one or more of the four types of diagnostic quadrant I deformities was present in all of these loops. Variations are exemplified in the following curves:

In loop 5 early quadrant I forces were bowed downward but mid-to-late forces showed obvious type A deformity.
Table 4
Mid-to-Late QRS Loop Deformities in 131 Subjects with Angiographically Proven Coronary Disease

<table>
<thead>
<tr>
<th>Deformity</th>
<th>+</th>
<th>M or G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>A + C</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>C + D</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>6</td>
</tr>
</tbody>
</table>

Explanation: Method of presenting data is identical with that of table 3. Among the 131, besides the six listed, five additional patients had ECGs that fulfilled either Myers’ or Goldberger’s ECG criteria for diagnosis of infarction but their VCGs did not show any of the four types of diagnostic deformities described.

Phyologic analysis of the spatial loop abnormalities as they are projected on the frontal plane.

Emphasis was placed on the differential diagnosis of several normal curves that somewhat resembled the infarction loops. These similarities were due to normal variations in the up-down scalar component of the frontal plane vectors. In most of these VCGs it was shown that when these Y-axis findings were related to its X-axis component, the resultant planar measurement established the differential diagnosis. In addition to this planar dimension, a few unusual normals required the use of one other planar parameter for diagnosis.

In some subjects of both groups noted above, who were proven by angiography to be normal or to have coronary disease, slurs or notches appeared on the downstroke of the R wave in lead aVF, recorded by a direct-writer instrument. Since lead aVF is more or less equivalent to the up-down scalar component

Figure 15
Type A deformity with normal coronary angiograms. Two subjects (loops 1 and 2) had VCGs satisfying the diagnostic criterion for type A deformity.

Loop 1 was from a 42-year-old hypertensive white woman with recurrent chest pain. She had never menstruated and generally showed frequent premature ventricular beats. Her ECG showed negative T waves in leads V1 to V3, slightly prolonged Q-T interval, and a P-R interval of 0.08 sec. Among possible explanations for her abnormal VCG was a peculiar type of ventricular abbreviation associated with an A-V junctional rhythm.

Loop 2 was from a 30-year-old, hypercholesterolic (450 mg/100 ml) white male with recurrent chest pain, once hospitalized for chest pain associated with serial nonspecific T-wave changes.

In neither subject was blood sampling for lactate obtained from the inferoposterior portion of the heart. The explanation for the abnormal VCG is not known in either case.

Loop 7 was unusual in that the maximal vector in quadrant I corresponded to all points of the curve from A to B, that is from +50° to +90°, and that the actual maximum vector (point C in quadrant II) was further from the null point than any vector in quadrant I. This curve shows a markedly distorted shape of quadrant I forces that fulfilled the criterion for type A deformity. The patient exhibiting loop 7 also had an associated anterior infarct.

Loop 14 was unique among the 40. This curve was considered to show a variant of type D deformity because it was similar to type D except that there was no crossover of quadrant I forces. In most inferior infarcts early forces are usually clockwise and pass quickly to the left of the null point. Thus, if the latter part of quadrant I forces is counterclockwise (loops 12 and 13), these vectors usually cross over the efferent limb. In this unusual loop (curve 14) early forces, entirely normal, remain to the right and all of the quadrant I forces are completely counterclockwise.

Many loops, among the 40, were atypical and not at all suggestive of inferior infarct because the early superior forces were entirely normal (loops 2 to 6, 11, 12, and 14).
of the frontal plane VCG, these ECG findings are not unexpected. Nevertheless, these results reaffirm the doubts of many experienced electrocardiographers regarding the diagnostic specificity of slurs or notches recorded by a standard ECG instrument. A recent report has suggested otherwise.21

The large percentage of catheterized subjects diagnosed by one or more of these four VCG criteria as having inferior myocardial infarction is noteworthy; yet the ECG was conclusive in only a small number. In fact, in many of these subjects there was no discernible Q wave in lead aVF. Although this series of catheterized subjects did represent biased patient selection, the results indicate that in atypical subjects, that is, those with a normal ECG, the mid-to-late part of the QRS loop may contain the only diagnostic clue.

Preliminary observations have indicated that the use of the VCG criteria herein proposed together with the criteria previously published,1 8 9 related to the early part of the QRS loop, results in a very high yield of positive diagnoses without overlap with values found in normals. A study is now in progress evaluating the combined use of early and late VCG QRS changes in the diagnosis of myocardial infarction in the inferior and other areas of the heart. The relationships of these findings to the ECG, coronary angiogram, ventriculogram, and lactate studies will also be evaluated.

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