Vectorcardiographic Diagnosis and Electrocardiographic Correlation in Left Ventricular Asynergy Due to Coronary Artery Disease

I. Severe Asynergy of the Anterior and Apical Segments

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SUMMARY

The transverse plane QRS loop vectorcardiogram (VCG) was analyzed in 102 consecutive patients, angiographically proven to have coronary artery disease (CAD), whose right anterior oblique left ventriculogram showed severe asynergy (akinesis or marked hypokinesis) of the anterior and apical segments. Eighty-four of the 102 loops were considered to be diagnostic of severe asynergy because similar loops were not found in patients with CAD with less severe asynergy of either or both segments or in normal control subjects. Eighty-two of the 84 showed a uniformly abnormal pattern. Posterior vectors exhibited partial or complete clockwise "rotation" and were much more prominent than early anterior forces. In fact, the latter were often absent. In the other two VCGs, at least the early half of the loop displayed prominent anterior vectors.

The ECGs showed marked variability of the QRS in leads V₃₋₉. Abnormal Q waves were present in only 63 of the 102. The number of these leads showing abnormal Q waves varied from one to all of these positions.

Additional Indexing Words:
QRS pattern Clockwise posterior forces Transverse plane
Variability of electrocardiogram

In patients with coronary artery disease (CAD) a relationship has been demonstrated between abnormal Q waves in the electrocardiogram (ECG) and asynergy proven by ventriculography.¹,² This correlation is not surprising since abnormal Q waves, indicative of myocardial infarction, might be expected to be associated with localized areas of diminished ventricular wall motion. Subsequent personal experience to be detailed below (table 1 and pp 472-473) indicated, however, that in the diagnosis of severe and extensive asynergy, abnormal Q waves are of limited value. Indeed, in many cases, there may be no abnormal Q waves at all. Since important physiological³ and therapeutic⁴ considerations are implicit in the diagnosis of severe and extensive asynergy, our attention turned to the potential use of the vectorcardiogram (VCG) in diagnosis.

The present report is specifically concerned with an appraisal of the value of the transverse plane VCG, as compared to the ECG, in the diagnosis of severe asynergy of the anterior and apical segments of the left ventricle in subjects with coronary artery disease.

Materials and Methods

Patient Population

The present report is based on VCG, ECG, and ventriculographic observations on 1004 consecutive patients proven by cinearteriography to have significant disease of one or more major coronary arteries. The ventriculograms of 102 of the 1004 patients showed severe asynergy of at least the anterior and apical segments (see below).

Patients with other significant causes of heart disease were excluded from this study. This excluded subgroup consisted of patients with 1) rheumatic heart disease, primary myocardial disease, hypertrophic subaortic stenosis, pulmonary embolism, primary pulmonary disease, and congenital heart disease; 2) blood pressure recordings above 160/90 or ven-
Table 1
ECG-VCG Correlation in the 102 Subjects with Severe Anterior and Apical Asynergy

<table>
<thead>
<tr>
<th>ECG</th>
<th>Abnormal Q waves</th>
<th>Poor R wave progression (no abnormal Q waves)</th>
<th>Reversed R wave progression (no abnormal Q waves)</th>
<th>VCG types A-C</th>
<th>VCG type misc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no. of precordial leads (V1-V6) in which present</td>
<td>no. of lead pairs</td>
<td>no. of lead pairs</td>
<td>LVH</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>in one lead</td>
<td>in two leads</td>
<td>in one pair of leads</td>
<td>in two pairs of leads</td>
</tr>
</tbody>
</table>

Abnormal Q waves were defined as being (a) QS or Q wave ≥ 0.04 see and depth of Q wave > 25% of following R wave in V1-V4; (b) Q waves ≥ 0.04 see and > 15% of total QRS amplitude in V2 and V4. Poor R wave progression was defined as R waves less than 2 mm in V3 and/or less than 4 mm in V4. Reversed R wave progression was defined as R in V5 < R in V4 and/or R in V6 < R in V3. (The particular leads involved by abnormal Q waves under the column labeled “no. of precordial leads (V1-V6) in which present” also showed marked variation). Abnormal Q waves were absent in V1-V6 in 30 of the 84 patients with diagnostic VCGs (types A, B, C, E, and F). Twelve of the 30 showed poor R wave progression. Eleven others showed reversed R wave progression. The remaining seven are analyzed in the column labeled “VCG Types A-C.”

Coronary Angiography and Ventriculography

Selective coronary cinearteriography was performed by either the Sones or Judkins technique. An arterial lesion was considered significant if 75% or more of the arterial lumen was obstructed.

Left ventriculography in the 30° right anterior oblique view was performed using a Siemens 10-5 inch or a General Electric 9-6 inch dual-field image-intensifier system. A power injection into the left ventricle utilizing 30-50 ml of contrast agent was made through a multiholed catheter passed retrograde across the aortic valve. Cine films were recorded at 60-100 frames/sec using 16 mm film and were analyzed by at least two observers who had no prior knowledge of the VCG and ECG.

The end-diastolic and end-systolic ventriculographic silhouettes were traced. The apex and the aortic valve were used as fixed reference points. The long axis (midaortic valve to apex) and transverse diameters were superimposed on both the end-diastolic and end-systolic silhouettes. The apical, anterior, inferior, and basal segments and their hemiaxes were identified (fig. 1). For the purpose of this study only the anterior and apical segments were analyzed.

In the normal subject, shortening (difference in end-diastolic and end-systolic hemiaxes) amounts to 50-50% for the anterior and periapical transverse hemiaxes and 20-30%...
for the base-to-apex long axis. Akinesis of the anterior segment was defined as no shortening of its transverse hemi-axes. Hypokinesis (impaired or diminished shortening) of the anterior segment was graded as marked (<10% shortening of its transverse hemi-axes), moderate (10–19% shortening), or mild (20–29% shortening). Apical akinesis was defined as no shortening of both its transverse hemi-axes and its long axis. Apical hypokinesis was graded as marked (<10% shortening of its transverse hemi-axes and 5% or less shortening of its long axis), moderate (10–19% of its transverse hemi-axes and 6–10% of its long axis) and mild (20–29% shortening of its transverse hemi-axes and 11–15% of its long axis). If various parts of a segment showed different degrees of asynergy, the grade of the entire segment was the average change in multiple plotted hemi-axes of that segment.

For the purpose of this study both akinesis and marked hypokinesis were considered to be severe asynergy. The 102 patients here reported showed severe asynergy of the anterior and apical segments: 1) in 60, both segments were akinetic; 2) in 30, one segment was akinetic (usually the apex) and the other segment showed marked hypokinesis; 3) in the remaining 12, both segments showed marked hypokinesis. Since paradoxical ventricular motion, present in 18 of the 102, was found in all three groups (including those with and without ST-segment elevation), no attempt will be made to differentiate those with and without dyskinesis.

Vectorcardiography and Electrocardiography

A vectorcardiogram and a standard 12-lead electrocardiogram were recorded at the same time. The vectorcardiogram was obtained in the supine position in all three planar projections by the Frank lead reference system. Electrodes were placed at the fourth interspace, as suggested by Langner et al. for the supine position. Vectorcardiograms were recorded with 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 0.1 Hz. Since extreme range may introduce artifact, all VCG's were recorded in the above frequency range. Emphasis is placed on the high frequency response of the VCG amplifiers. A high frequency response of 100 Hz or less (generally the upper frequency response of conventional ECG amplifiers) may distort the planar phase relationships as well as decrease the magnitude of the deflections of the QRS loop herein described.

For the purpose of this report the transverse plane QRS loop was chosen for analysis. A study was made of 1) planar phase relationships, i.e., direction of "rotation," contour, the presence and location of crossovers, and the relative location of the efferent as compared with the afferent limb of the loop, and 2) quantitative criteria, i.e., the location of a particularly timed vector. Abnormalities of both of these parameters have been previously described in loops associated with myocardial infarction.

The loops and vector notations are presented and discussed in the standard manner. The loops' rightward, leftward, anterior, and posterior deviations are indicated by the symbols X, X, Z, and Z, respectively. Dash intervals of 2 msec duration are represented by "teardrops" whose blunt end indicates its leading edge.

In some of the photographs the P and T as well as the QRS vectors are shown. Since P and T may obscure the early part of the QRS, the initial portion of the QRS, with at least the T loop eliminated, is also shown beneath its correspond-
Type A

In 54 patients, both the efferent and afferent limbs of the posterior forces were mostly or completely clockwise. In seven, this posterior portion of the loop was predominantly or entirely to the right [type A1 (fig. 2)]. In 14, the posterior portion of the loop was deviated approximately equally to the right and left [type A2 (fig. 3)], and in 33, posterior vectors showed a predominantly or an entirely leftward orientation [type A3 (fig. 4)].

Type B

In nine, the efferent limb of the posterior forces was counterclockwise but the afferent limb was clockwise. In all nine, these vectors had a predominantly or entirely leftward orientation (fig. 5).

Type C

In ten, posterior forces formed a figure-of-eight pattern of which at least the early part of the efferent limb was counterclockwise and at least the early part of the afferent limb clockwise. In all ten, both limbs of these posterior vectors were predominantly or entirely to the left (fig. 6).

Type D

In 12, at least the early part of the efferent limb of posterior forces was clockwise but the afferent limb was counterclockwise. In all 12 both limbs were predominantly or entirely to the left (fig. 7).

Type E

In nine, showing right bundle branch block (RBBB), the terminal anterior and rightward forces of RBBB were preceded by posterior vectors of which at least the efferent limb was mostly or completely clockwise (fig. 8).

In the nine cases of type E, the loop was deviated posteriorly ($Z^+$) 0.76, 0.66, 0.45, 0.33, 0.30 (3 cases), 0.25, and, 0.22 mV, respectively. By contrast, $Z^+$ in types A–D had a mean of 1.07 mV with a sp of 0.4 mV, the range varying from 0.53 to 2.00 mV. This less marked posterior deviation in type E may be due to the fact that RBBB, in itself, may bring even the midportion of the loop to a more anterior or less posterior position.\(^\text{17}\)

Examples of loops designated as type A2. Posterior vectors (1) are considered to be mostly or completely clockwise because (a) their efferent limb is predominantly or entirely to the right of their afferent limb and (b) their efferent limb is partly or completely convex (bowed) in a rightward direction and (2) are approximately equally deviated to the right and left ($X = X^+$). The last loop is considered to be mostly clockwise because it shows a crossover at its distal portion (see 1a above). In addition, this loop is so narrow that, varying with normal respiration, the two limbs become almost completely superimposed in some cycles. Again note variation in location of initial vectors.

Examples of loops designated as type A3. Posterior vectors (1) are considered to be mostly or completely clockwise because (a) their afferent limb is predominantly or entirely more leftward and/or less posterior than their efferent limb and (b) their efferent limb is partly or completely convex (bowed) in a rightward and/or posterior direction and (2) are predominantly or entirely to the left ($X^+ > X$ or X absent). The last loop (T wave not shown) is considered to be mostly clockwise for reasons stated in 1a. Again note variation in location of initial vectors.
Examples of loops designated as type B. Posterior vectors’ (1) efferent limb is considered to be counterclockwise because it is convex (bowed) in a leftward and/or anterior direction, (2) afferent limb is considered to be clockwise because it is convex (bowed) in a leftward and/or anterior direction, and (3) both limbs are predominantly or entirely to the left (X⁺ > X or X absent). In all examples excepting the last, the afferent limb is almost entirely or entirely more leftward than the efferent limb. The last loop is considered to be a variant of type B. In contrast to the first three loops, its two limbs cross over at their proximal part so that a good portion of the efferent limb is more leftward than the afferent limb; nevertheless, a part of the latter is convex in a leftward direction as in the other three loops. Again note variation in location of initial vectors; in the third loop the initial forces are briefly posterior, then anterior.

Type F

In two cases at least the early half of the QRS loop was deviated anteriorly and the entire loop was predominantly or entirely rightward (fig. 9).

Miscellaneous Group

Among the remaining six of the 102, the QRS loop was normal in two and showed RBBB without any other abnormality in one. The other three showed minimal QRS changes (fig. 10).

Differential Diagnosis

Types A, B, C, E, and F loops were not found in the other 902 patients, angiographically proven to have coronary artery disease, but who had less than severe asynergy of the anterior and/or apical segments. Moreover, these five types of loops, as well as type D loops, were not found in a group of 600 normal control subjects, including 80 who had undergone cardiac catheterization with coronary angiography and ventriculography.

In four subjects with severe asynergy of the apex but moderate hypokinesis of the anterior segment, the pattern of the loop simulated type A₃ in three and type C in the fourth (fig. 11). In these four patients, however, Z⁺ was less than 0.5 mV (0.43, 0.40, and 0.35 mV in the three exceptions and 0.3 mV in the other). By contrast, the smallest Z⁺ value found in type A was 0.67 mV and in type C, 0.53 and 0.63 mV, respectively. In all other loops in group A–D, Z⁺ was 0.7 mV or greater (also see type E under Results). Other more subtle differences between the first three of the above four loops and type A loops are illustrated in figure 11.

In 30 patients with severe asynergy of the apex but moderate hypokinesis of the anterior segment, the VCGs were similar in all respects (including the value of Z⁺) to type D loops.

As might be expected the VCG patterns found in the Miscellaneous group were frequently found in cases associated with mild hypokinesis or no asynergy at all of the anterior and/or apical segments.

II. Quantitative Criteria

The most useful and established quantitative criteria for diagnosing anterior infarction are: (A) for antero-septal or localized anterior infarction, a posterior location of the 0.02 sec vector and (B) for antero-lateral infarction a duration of initial rightward
forces greater than 0.022 second. The application of these two criteria to the 102 cases of severe anterior and apical asynergy showed that 30 loops fulfilled both criteria A and B, 16 only A, 17 only B, and 19 loops fulfilled neither criteria. Criterion A, the more sensitive of the two criteria, was also fulfilled by 65 of the 902 patients who had less or no asynergy of either or both the anterior and apical segments than the 102. Among the 84 loops that were considered diagnostic according to abnormalities in planar phase relationships (types A, B, C, E, and F loops), 29 fulfilled both criteria A and B, 26 only A, 16 only B, and 13 loops neither criteria.

Results — Electrocardiography

Since a relationship between abnormal Q waves and asynergy has been demonstrated, the QRS in the left precordial leads V2-V6 was analyzed in the 102 cases with severe asynergy of the anterior and apical segments. Table 1 gives a detailed analysis of the ECG findings and correlates them with the VCG.

Figure 12 shows two pairs of ECGs; the first pair is associated with VCG type A and the second pair with VCG type B abnormality. The first example of each pair shows in one or more left precordial leads an ini-

Figure 7

Examples of loops designated as type D. Posterior vectors' (1) efferent limb in at least its early portion is considered to be clockwise because it is convex (bowed) in a rightward and/or posterior direction, (2) afferent limb is considered to be counterclockwise because it is more rightward and/or more posterior than efferent limb and (3) both limbs are predominantly or entirely to the left (X+ > X or X absent). In type D loops the maximal leftward vector is −40° or more posterior. Note the variation in the degree of bowing as well as in the length of the convexity of the efferent limb. In the last loop the bowing is very slight. In all VCGs leftward and anterior forces are minimal (loop #1) or absent.

Figure 8

Examples of loops designated as type E. (1) Right bundle branch block is present and (2) the late anterior and rightward forces of RBBB are preceded by posterior vectors of which at least the efferent limb is mostly or completely clockwise. In loops #1 and #2 posterior vectors' efferent limb is considered to be mostly or completely clockwise because most or all of this limb deviates to the right (loop #2) or bows (convex) in a rightward direction (loop #1); the posterior forces' afferent limb is considered to be counterclockwise because it is located more to the right and/or more anterior than the efferent limb. In loops #3 and #4 posterior forces are clearly completely clockwise. Note that in all VCGs leftward and anterior forces are minimal (loop #3) or absent.

This report demonstrates the value of the VCG in the diagnosis of severe asynergy of the anterior and apical segments of the left ventricle in patients with coronary artery disease. Diagnostic loops were found...
Two unusual loops were designated type F because (1) at least the early half of the QRS is anterior and (2) the entire loop is hardly or not at all deviated to the left (X' minimal or absent). In the first VCG the early half of the loop, except for a crossover, is clockwise. Variations in "rotation" in the late part of the QRS may be due to the rightward and anterior appendage of RBBB that is also present. In the second VCG, all of the loop is clearly clockwise.

in 84 of the 102 patients. Types A, B, C, and E VCGs, 82 of the 84, showed a uniformly abnormal pattern. Posterior vectors were much more prominent than early anterior forces and exhibited partial or complete clockwise "rotation." In the other two VCGs, type F, at least the early half of the loop displayed prominent anterior vectors.

The ECGs showed marked variability of the QRS in leads V_{2}-V_{6}. Abnormal Q waves were present in 63 of the 102. However, the number of these leads showing abnormal Q waves varied from one to all of these positions. Less definite electrocardiographic evidence of myocardial infarction (poor R wave or reversed R wave progression) was present in 26 other patients. In the remaining 13, the ECGs were not at all suggestive of infarction. These results are at variance with the findings of Miller et al. who noted that "the quantity of dyssynergy was directly related to the precordial extent of pathologic Q waves." 2

Since 96 of the 102 cases of severe asynergy here described were associated with marked changes in the transverse plane QRS loop (Types A–F), it is not unexpected that these changes would be associated with myocardial infarction. Indeed, in our experience and that of others, 11-14 VCG patterns similar to these have been proven, at autopsy or at heart surgery, to be associated with infarction of the anterior wall.

Although not defined in such detail as in the present report, many abnormalities in planar phase relationships (morphologic changes) described here as associated with asynergy have been described previously in various types of anterior infarction. These abnormalities have been characterized by phrases similar to some of those used here such as "figure-of-eight," "complete clockwise rotation," the "effenter limb may be clockwise but the rest of the loop counterclockwise," etc. 11-14

For the most part, however, it has become common practice to emphasize or even to require a particularly timed vector to be in a certain position (quantitative criteria) in order to make the diagnosis of infarction.

The results of this study show that quantitative criteria for (A) antero-septal or localized anterior and for (B) antero-lateral infarction were as sensitive as certain abnormalities in planar phase relationships in diagnosing 102 cases of severe anterior and apical asynergy. Eighty-three of the 102 loops satisfied either or both quantitative criteria; 84 showed specific abnormalities in planar phase relationships. However, quantitative criteria were not specific. Thirty-six of the 83 VCGs fulfilled only criterion A. This criterion was also met by loops associated with less asynergy. By contrast the morphologic abnormalities found in the 84 were specific because they were not found in loops associated with less asynergy. This experience emphasizes that although quantitative criteria are useful in defining the total pattern of the loop, it is most important to analyze these other morphologic features of the VCG in order to make the specific diagnosis of severe anterior and apical asynergy.

Lichtlen and Albert described the VCG in 33 aneurysms proven by ventriculography and involving various parts of the anterior cardiac silhouette. 39 Since only cases with "lack of any systolic inward movement, rather showing an outward paradoxical motion" were included, their cases are not entirely comparable to those in the present study. Among the 33, they showed VCGs similar to some type AI loops (loops #1, #2, and #3 in fig. 2) associated with extensive

Circulation, Volume 51, March 1975
YOUNG ET AL.

Figure 10

Examples of loops designated Miscellaneous group. The QRS (1) is normal or (2) shows "minor" abnormalities. Loop #1 shows RBBB without any other QRS change. Loop #2 is one of two cases in which the QRS is entirely normal. Loop #3 is one of two cases in which the initial vectors are slightly abnormal, being hardly anterior in the initial portion, but the remainder of the loop is normal. In loop #4 the only abnormality is a "bite" of its afferent limb. Contrast these loops with types A-E that showed marked changes in the QRS.

aneurysm involving the antero-basal, anterior, and apical segments. In the present series, by contrast, the transverse plane VCG was not reliable in the diagnosis of severe asynergy of the antero-basal segment.

Type D and the Miscellaneous type loops were found among the 102 patients with severe anterior and apical asynergy; type D loops were also associated with somewhat less asynergy and the Miscellaneous type loops with little or no asynergy.

This overlap may conceivably be explained by

Figure 11

Simulants of type A3 and type C abnormality. In the first three loops posterior vectors are mostly clockwise (similar to the last loop of type A3 in fig. 4); the fourth loop shows a figure-of-eight pattern (similar to type C loops in fig. 6). In contrast to type A3 and C loops, however, the maximal posterior vector (Z+) in these four loops is less than 0.5 mV (see also section on differential diagnosis). These four loops are "pancaked," i.e., more parallel to the X axis. Moreover, in contrast to most type X loops, the afferent limb of the first loop shows a prominent "bite" and the afferent limb of the second and third loops returns abruptly to a more posterior location instead of continuing forward before returning to the null point.

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ECGs of four patients with severe asynery of the anterior and apical segments. The first pair is associated with VCG type A1 abnormality (fig. 2, loops #3 and #1 respectively) and the second pair with VCG type B abnormality (fig. 5, loops #2 and #1 respectively). In ECG #1 (top tracings) there is reversed R wave progression in the left precordial leads (rsR'S' in V1) and in ECG #3 the QRS is within normal limits; in neither case would one suspect the extent and severity of the asynery that is present and also suggested by their counterparts ECGs #2 and #4. In both ECG #1 and #3 the masking effect of an initial R wave is associated with initial leftward and anterior vectors (see also text). The standard in the first ECG applies to the other three tracings.

Ischemia. Observations at autopsy and at heart surgery in many of these patients tend to support this hypothesis. In contrast with A, B, C, E, and F loops, type D VCGs were associated with less extensive infarction of a zone corresponding to the anterior and apical segments, and the Miscellaneous type loops with little or no infarction. Nevertheless, the correlation of the VCG patterns here described with the specific location and cubic volume of infarcted muscle — and with the extent to which ischemia, rather than infarction, may play a role in severe anterior and apical asynery — remain to be determined.

This study demonstrates the sensitivity and specificity of morphologic changes in the VCG loop in the diagnosis of severe anterior and apical asynery. By contrast, quantitative (location of a particularly timed vector) criteria for infarction, though sensitive in defining other aspects of the loop, fell short of being specific for the diagnosis of severe anterior and apical asynery. The results emphasize the importance of a "total pattern" approach in interpreting the VCG. In addition, a prospective series of patients is needed to confirm the results of this retrospective study.

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