Vectorcardiographic Criteria for the Diagnosis of Anterior Myocardial Infarction

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SUMMARY  Frank lead vectorcardiograms (VCG) from four carefully selected patient subgroups (226 patients) were analyzed to develop optimal criteria for the diagnosis of anterior myocardial infarction. Specificity was evaluated using 100 healthy volunteers under age 30 and 80 patients with normal left ventriculogram and normal coronary arteriograms. Sensitivity was determined using 25 patients with evolutionary ST-T wave changes (V1-3), and LDH and CPK isoenzyme evidence of acute myocardial infarction; and 21 patients with anterior wall akinesia or dyskinesia and > 70% occlusion of the left anterior descending coronary artery. Patients with VCG evidence of bundle branch block, left or right ventricular hypertrophy were excluded.

The criterion for the diagnosis of anterior myocardial infarction which was found to give the highest sensitivity with ≥ 95% specificity was: initial anterior QRS forces must not exceed 0.1 mV in maximal amplitude and also must not exceed 24 msec in duration. The performance of this proposed criterion was then tested using four similarly defined patient subgroups consisting of a total of 222 patients. The incidence of false positive diagnosis in these test subgroups was < 1% with a sensitivity of > 95%. The overall performance of the proposed criterion was found to be significantly superior to both the widely accepted VCG and ECG criteria for anterior myocardial infarction. Thus, this quantitative criterion using both time and duration of initial anterior forces is both a highly specific and a sensitive indicator of anterior myocardial infarction.

SEVERAL STUDIES have shown that vectorcardiographic (VCG) criteria for anterior myocardial infarction (AMI) can be significantly more sensitive than traditional electrocardiographic (ECG) criteria. The purposes of this study were 1) to develop improved VCG criteria to discriminate between patients with AMI (but without either ventricular hypertrophy or bundle branch block) and patients with normal hearts and 2) to test these criteria using similar patient groups.

The patient groups were selected using clinical and cineangiographic descriptors to avoid the problem inherent in most autopsy material, i.e., multiple sites of infarction. This approach has been used previously to identify new VCG criteria for diagnosis of inferior myocardial infarction which were significantly more specific than previously published criteria.

Methods

Patient Selection

Our purpose was to evaluate the quantitative descriptors of the QRS complex in living patients who had strong evidence for AMI and in subjects who had a normal myocardium by clinical criteria. Patients were divided into two groups. Data from the first were used to develop the criteria (criterion group) and from the second to test these criteria (test group).

The criteria group (226 patients) included two subgroups (A and B) in which the presence of AMI was most unlikely and two subgroups (C and D) in which the diagnosis of AMI was established without regard to descriptors of the QRS. Subgroup A was composed of 100 healthy volunteers aged 20-29, without history of heart disease or hypertension. Subgroup B was composed of 80 patients who had undergone coronary arteriography because of chest pain...
suggestive of angina and in whom both normal ventricular contraction and normal coronary arterial anatomy were proven. Subgroup C was composed of 25 patients admitted to the Coronary Care Unit of the Duke University Medical Center or the Durham VA Hospital with a history compatible with an acute myocardial infarction and with evolutionary ECG changes of repolarization in leads V_{1} and V_{2} consisting of both ST elevation and T-wave inversion. The presence or absence of Q waves did not influence inclusion in this subgroup. To be included in subgroup C patients must have shown transient appearance of 1) serum CPK-MB \(^{1}\) and 2) LDH, greater than LDH.\(^{2}\) Subgroup D was composed of 21 patients with a history of remote myocardial infarction who at cardiac catheterization showed both the presence of a 70 to 100% occlusion of the left anterior descending coronary artery and localized akinsesia or dyskinesia of the anterior left ventricular myocardium. Inclusion in this subgroup was not dependent on the presence or absence of Q waves on the ECG.

Patients were excluded from the study if any one of the following was observed: a) either VCG\(^{3}\) or ventriculographic evidence of inferior or true posterior infarction, b) QRS duration of 120 msec or greater, c) evidence of left ventricular hypertrophy indicated by a maximal QRS magnitude in the transverse plane of 1.8 mV or greater in patients over 50 years of age or 2.2 mV or greater in patients less than 50 years of age\(^{4}\) or d) transverse plane evidence of right ventricular hypertrophy indicated by 1) transverse plane QRS loop area in right posterior quadrant greater than 20% of the total or 2) anterior and rightward QRS loop area greater than 70% of the total.\(^{5}\)

The test group was also made up of two subgroups of normal subjects and two subgroups with AMI. Subgroup A' (100 volunteers), B' (76 patients), C' (25 patients) and D' (21 patients) were composed of persons meeting the same selection criteria as subgroups A, B, C and D, respectively. Assignment of patients to either the criteria or the test subgroups was performed randomly.

**Data Collection**

In the appropriate subgroups (B, B', D and D') right and left heart catheterization was performed using standard techniques described in an earlier study.\(^{6}\) In each case, the left ventriculogram was analyzed before the coronary arteriograms were visualized, and the analysis was done by an independent observer without knowledge of the VCG or ECG data.

Standard 12 lead ECGs were recorded in the supine position using a Hewlett-Packard 1515B cardiograph and manual measurements were made from the QRS complexes in V_{1}.\(^{7}\) The VCGs were recorded using the Frank lead system with a Hewlett-Packard 1507A vectorcardiograph or an Instruments for Cardiac Research VCG-1B vectorcardiograph modified with a Hewlett-Packard oscilloscope and camera. The chest electrodes (A, C, E, and I) were placed in the fourth intercostal space as recommended for the supine position.\(^{8}\) A calibration of 1 mV per 2 to 4 cm deflection was used depending on the size of the total loop. The initial QRS forces were recorded with a calibration of 1 mV per 10 cm deflection with the P and T loops excluded. The VCG trace was interrupted each 2.5 msec (Hewlett-Packard) or 2.0 msec (Instruments for Cardiac Research) depending on which machine was used. VCGs were recorded within one week prior to cardiac catheterization (subgroups B, D, B' and D') or within two weeks after acute myocardial infarction (subgroups C and C'). All measurements were made manually from Polaroid prints (type 107 film) of the VCG loops.

The following parameters were measured in the transverse plane: a) duration (msec) of initial anterior forces, b) amplitude (mV) of initial anterior forces, and c) maximal QRS magnitude.

**Data Evaluation**

If an ECG or VCG criterion did not indicate AMI when applied to a member of the normal criteria subgroups (A and B), a true negative result was recorded. If an ECG or VCG criterion indicated anterior infarction when applied to a member of the infarct criteria subgroups (C or D), a true positive result was recorded.

Optimal criteria for the diagnosis of AMI were identified by determining the value of each parameter which yielded a maximum of true positive results with at least 95% true negative results in both normal subgroups A and B. It was felt that this high degree of specificity was important in order to try to minimize the recognized specificity problems with AMI criteria encountered in the presence of other forms of heart disease. For example, figure 1 shows that when the criterion of less than 15 msec duration of initial anterior forces is applied to the criteria group, 99% and 96% true negative results are obtained in subgroups A and B, respectively, while there are 72% true positive results in subgroup C and 86% in subgroup D. The best criterion for VCG diagnosis of AMI was developed on subgroups A-D using this method of analysis and then tested on subgroups A'-D'.

The performance of the proposed VCG criterion also was compared to established VCG criteria for anterior infarction using the test group. For this analysis the criterion of Hugenholtz, Forkner and Levine\(^{9}\) was used because of its wide acceptance,\(^{10}\)\(^{12}\) i.e., posterior displacement of the initial 0.02 sec vector in the transverse plane. This criterion will be referred to hereafter as the Hugenholtz criterion.

In addition, the performance of the proposed VCG criterion was compared to commonly used ECG criteria for anteroseptal and anterior myocardial infarction as follows:

**Definite**

1) QS in leads V_{1}, V_{2} and V_{3};
2) QS in V_{1} with QR in V_{2} and V_{3};
3) QR in V_{1}, V_{2} and V_{4} (Q of .04 sec and 25% of following R);
4) Initial R in V_{4}, with Q in V_{2} through V_{4};
5) Decreasing amplitude of initial R on going from V_{1} to V_{4}.

**Possible**

1) QR in V_{1}, V_{2} and V_{4} (Q of .02 to .04 sec and 10% of following R);
2) RS in V_{1} with QR in V_{2} through V_{4}.

\(^{1}\)CPK-MB is a myocardial specific creatine phosphokinase isoenzyme and LDH, (lactic dehydrogenase) greater than LDH is a finding consistent with acute myocardial infarction.
All of the above are modified from the criteria of McConahay et al. In addition, the following was added to the possible criteria:

3) QS in V₁ and V₂.

Statistical analysis of the comparison of the criteria detailed above was performed using McNemar's test for equality of correlated proportions. When any two criteria are evaluated this test can be used to compare the number of occasions when each is exclusively in error, and to determine the statistical significance of this comparison. To estimate these classification errors, "two by two" frequency tables were constructed for both the normal test subgroups A' and B' and the infarct test subgroups C' and D'.

Figure 1 Determination of the value for anterior duration which yields the largest number of true positives while maintaining at least 95% true negatives in both subgroups A and B (dotted line). The abscissa shows the value of anterior duration used as a criterion for AMI to obtain the incidence of correct results shown on the ordinate, i.e., true negatives for subgroups A and B (upper graph) and true positives for subgroups C and D (lower graph). Fifteen msec was found to be the best value using this approach as explained in the text.

Figure 2 Determination of the best value for amplitude of initial anterior forces alone. Five mV was found to be the best value as explained in the text.

Results

Criteria Group

The analysis of the transverse plane VCG measurements is shown in figures 1–3. Figure 1 shows the effect of varying durations of initial anterior forces as a criterion for diagnosis of AMI. When less than 15 msec is used, 99% of subgroup A and 96% of subgroup B are truly negative while 72% of subgroup C and 86% of subgroup D are truly positive. When 20 msec is used, true positive results in subgroups C and D are improved to 80 and 90%, respectively, but there is an unacceptable decrease in true negatives (less than 95%) in subgroup B. Thus, using anterior duration alone, less than 15 msec appeared to be the optimal criterion.

Figure 2 shows the results of using different amplitudes of initial anterior forces as criteria for AMI. When .05 mV is used, true negative results in both subgroups A and B exceed
95%; however, true positives are only 64% in subgroup C and 76% in subgroup D. Although use of .10 mV increases the incidence of true positive results in both subgroups C and D to about 90%, there is a decrease in true negatives in subgroup B to 91%, an unacceptable result. Thus using anterior amplitude alone, .05 mV appears to be the optimal criterion.

Figure 3 shows the results of combining duration and amplitude requirements. In this graph, the amplitude is held constant at ≤0.10 mV and the anterior duration is varied along the abscissa. The data clearly show that when this amplitude requirement is used, the duration requirement can be increased from less than 15 msec to less than 25 msec with improvement of true positives in both subgroups C and D to over 90% while maintaining the incidence of true negative results in both normal subgroups at 95% or more. A similar analysis holding anterior duration constant while varying maximal anterior amplitude did not result in identification of a better criterion. The best criterion for the diagnosis of AMI was found to be: in the absence of right or left ventricular hypertrophy or bundle branch block, initial anterior QRS forces must not exceed 0.1 mV in maximal anterior amplitude and also must not exceed 24 msec in duration. Note that if the transverse plane loop comes anterior again after first being posterior, this additional anterior force does not contribute to these measurements. Also the criterion does not include a requirement for direction of rotation of initial transverse plane forces.

Test Group

This proposed criterion was then tested using the test group and the results are shown in the left column of table 1. Note that once again the incidence of true negatives is greater than 95% in both normal subgroups A' and B'. The results of applying the Hugenholtz criterion to the test group is shown in the right column of table 1. The comparison of the performances of these criteria can be analyzed further as shown in figure 4. In 4A, the normal subgroups A' and B' are analyzed in a two-by-two frequency table which shows how each individual VCG was classified by the Hugenholtz and by the proposed criteria. Cell a shows the number classified as positive by both methods while cell d shows the number classified as negative by both methods. Cell b shows those classified as positive by the proposed criterion and negative by the Hugenholtz criterion and thus are exclusive errors made by the proposed criterion. Cell c shows those classified as positive by the Hugenholtz criterion and negative by the proposed criterion (exclusive Hugenholtz error). Using this approach, only the exclusive errors (cells b and c) are important in determining the difference in performance of the two methods and the statistical significance of this difference can be determined by the McNemar test. As shown in figure 4A, the results using the two criteria are not significantly different in defining the normal subgroups.

In figure 4B, the infarct subgroups C' and D' are analyzed by the same method. However, since the patients in these subgroups have had infarcts, a negative classification by a criterion for AMI is an error. Thus, cell b now shows exclusive Hugenholtz errors while cell c shows exclusive errors made by the proposed criterion. Again there is no significant difference between the diagnoses determined by each criterion and thus no statistical difference in sensitivity between the criteria. It should be noted, however, that no exclusive error (cell c) is made by the proposed criterion while four exclusive errors (cell b) are made by the Hugenholtz criterion.

Table 1. Performance of VCG Criteria for AMI Using Test Group

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>N</th>
<th>Proposed criterion</th>
<th>Hugenholtz criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A' NI Volunteer</td>
<td>100</td>
<td>100 (100%)</td>
<td>98 (98%)</td>
</tr>
<tr>
<td>B' NI Cath</td>
<td>76</td>
<td>75 (99%)</td>
<td>75 (99%)</td>
</tr>
<tr>
<td>C' Acute AMI</td>
<td>25</td>
<td>25 (100%)</td>
<td>23 (92%)</td>
</tr>
<tr>
<td>D' Abnl Cath</td>
<td>21</td>
<td>20 (95%)</td>
<td>19 (90%)</td>
</tr>
</tbody>
</table>

The percentages indicate incidence of true negative results for the normal subgroups (A' and B') and true positive results for the infarct subgroups (C' and D').
In figure 4C, all four subgroups are combined, and positive and negative are replaced by correct and error, where correct refers to true positive or true negative and error refers to false positive or false negative. Cell b shows exclusive Hugenholtz errors while cell c shows exclusive errors made by the proposed criterion. Analyzing overall performance in this manner there is a significant difference (P < 0.05) between the performance of the proposed criterion and the Hugenholtz criterion. Furthermore, since seven of the eight exclusive errors (cell b + cell c) are Hugenholtz errors (cell b), the performance of the proposed criterion is significantly better than the Hugenholtz criterion.

In table 2, a comparison of the proposed VCG criterion and ECG criteria is shown. There is no significant difference in true negative results (subgroups A' and B') but there is a highly significant difference in true positives (subgroups C' and D') (P < 0.01) both using ECG definite and possible criteria when analyzed by the McNemar method shown above. In addition, the overall performance is significantly different.

**Discussion**

The ideal method for selection of criteria for diagnosis or exclusion of AMI would include tissue confirmation. However, this is not practical since multiple infarcts have usually occurred prior to the death due to coronary artery disease. Therefore it was necessary to select subgroups with both acute and static clinical descriptors of AMI. A subgroup with evolution of specific (V1,2) ST and T wave changes in the presence of isoenzyme patterns diagnostic of acute myocardial damage allows identification of acute AMI. Localized anterior wall dyskinesia or akinesia associated with at least 70% occlusion of the left anterior descending coronary artery has been shown to be a reliable indicator of significant myocardial fibrosis in the anterior wall at autopsy.

The purpose of this study was to identify improved criteria for VCG diagnosis of AMI in patients without other cardiac abnormality. Therefore, patients were eliminated from both the criteria and test groups if they showed VCG evidence of left or right ventricular hypertrophy by the criteria specified in the Methods section. In addition, patients were eliminated if they showed VCG or ventriculographic evidence of posterior myocardial infarction because this involvement would tend to mask VCG changes of anterior infarction. Patients with evidence of inferior infarction were also excluded since this location of infarction is often associated with posterior involvement as well. The criterion identified appears to be more reliable than the widely used Hugenholtz criterion.

The superior sensitivity of quantitative VCG criteria (including the Hugenholtz criterion) over traditional ECG criteria has been shown in previous studies. The data from this study suggest that the presence of a QS in only V1 and V2 should be a reliable criterion for AMI. However, more quantitative criteria for R wave duration and amplitude in V1 and V2 would seem to be unjustified due to variation in precordial electrode placement that commonly occurs in clinical electrocardiography.

Several investigators have recognized the problem of false positive diagnosis of AMI in the setting of left ventricular hypertrophy. Another study from our institution has shown that the incidence of false positive diagnosis of AMI by either the proposed criterion or the Hugenholtz criterion exceeds 30% in patients with significant aortic valve disease but normal coronary arteriograms and no ventricular contraction abnormalities. The number of false positives can be significantly reduced in this patient population, however, by

| Table 2. Comparison of Proposed VCG Criteria and ECG Criteria for AMI |
|------------------------|----------------|-----------------|-----------------|
| Subgroup              | Proposed VCG  | Definite ECG   | Definite or     |
|                       | criteria      |                 | possible ECG    |
| A' Ni Vol             | 100           | 100 (100%)     | 100 (100%)      |
| B' Ni Cath            | 76            | 75 (99%)       | 76 (100%)       |
| C' Acute AMI          | 25            | 25 (100%)      | 15 (60%)        |
| D' Abn Cath           | 21            | 20 (95%)       | 9 (45%)         |

The percentages indicate incidence of true negative results for the normal subgroups (A' and B') and true positive results for the infarct subgroups (C' and D').
interpreting the proposed criterion as diagnostic of AMI only when the maximal transverse plane magnitude is less than 1.8 mV. 18

There is also a significant increase in false positive diagnoses of AMI in patients with chronic obstructive lung disease and cor pulmonale. 2, 18 We have also found that there is about a 15% incidence of VCG diagnosis of AMI using both the proposed criterion and the Hugenholtz criterion in patients with significant chronic obstructive lung disease and no history of chest pain or infarction. Most of the patients who meet these criteria show VCG changes of type C right ventricular hypertrophy, 19 and all of them show severe changes on their pulmonary function studies.

In summary, the proposed criterion appears to be very reliable for the diagnosis of AMI. As reported previously, similarly reliable criteria have been developed for inferior myocardial infarction. 8 Since both of these criteria were developed using patients without evidence of right or left ventricular hypertrophy (by the criteria detailed under Methods) or bundle branch block, they must currently be used with caution in these settings.

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