Diagnostic Value of QRST Isointegral Maps in Detecting Myocardial Infarction Complicated by Bundle Branch Block

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The clinical usefulness of QRST isointegral maps (IQRST map) for detecting myocardial infarction that was complicated by intraventricular conduction disturbances was evaluated in patients with right bundle branch block (group RBBB, 64 patients) and left bundle branch block (group LBBB, 40 patients) by comparison with the normal mean IQRST map derived from 50 normal subjects. Myocardial infarction complicated the conduction disturbances in 24 of the 64 RBBB and in 18 of the 40 LBBB patients. A correlation coefficient was used for assessing the similarity of each map pattern with the normal mean IQRST map. The difference map was made by subtracting the average normal IQRST map from each abnormal IQRST map, and those differences that were less than 2 SD from the mean were retained as a significant area. The number of leads and their sum of differences were used to represent the size of the difference map. Correlation coefficients were significantly (p<0.001) smaller in patients with bundle branch block complicated by myocardial infarction than in patients with conduction disturbances not complicated by myocardial infarction. A significant area emerged in the difference map in all patients with myocardial infarction complicated by conduction disturbances. The emergence of a significant area revealed high diagnostic accuracy for detecting myocardial infarction in group RBBB (89.1%). The size of a significant area in a difference map was significantly larger in cases with complicated myocardial infarction than in cases with uncomplicated myocardial infarction in either group RBBB or group LBBB (p<0.001). The determination of the critical size of a significant area obtained by discriminant analysis improved the diagnostic accuracy of detecting complicated myocardial infarction to 98.4% and 87.5% for groups RBBB and LBBB, respectively. The IQRST map was highly useful for detecting myocardial infarction masked by intraventricular conduction disturbances. (Circulation 1989;80:542–550)

In patients with myocardial infarction complicated by bundle branch block or other intraventricular conduction disturbances, the diagnostic features for detecting myocardial infarction are often hidden in the wide QRS complex.1 Even though many investigators have attempted to diagnose myocardial infarction correctly in the presence of bundle branch block, correct diagnosis is still often difficult by standard 12-lead electrocardiogram (ECG).2–7 Also, one study has attempted to diagnose myocardial infarction by the direction and magnitude of the spatial ventricular gradient derived from the vectorcardiogram.8 However, the diagnostic accuracy of this method remains unsatisfactory.8

The present study examined the clinical usefulness of QRST isointegral maps (IQRST map9–12) based on Wilson’s concept of the ventricular gradient13 for diagnosing myocardial infarction complicated by bundle branch block.

Methods

Patients

Patients who had either complete right bundle branch block (RBBB) or complete left bundle branch block (LBBB) according to routine electrocardiograms and who visited our hospital between January 1983 and August 1987 were included in the present study if 1) a medical history was obtained satisfactorily and 2) except for myocardial infarction, there was no obvious underlying heart diseases such as congenital or valvular heart disease, hypertensive cardiovascular disease, and primary myocardial disease as

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assessed by routine examinations including echocardiography and Doppler cardiography.

Sixty-four patients had RBBB, and 40 had LBBB. Of the 64 patients with RBBB, 40 (26 men, 14 women; mean age, 45.1 years) were free from obvious underlying heart diseases (group RBBBn). The remaining 24 patients with RBBB (19 men, five women; mean age, 66.3 years) had the complication of an old myocardial infarction (group RBBBMH).

Of the 40 patients with LBBB, 22 (13 men, nine women; mean age 61.2 years) were without gross cardiovascular abnormalities (group LBBBn). The other 18 patients with LBBB (11 men, seven women; mean age, 70.4 years) had the complication of an old myocardial infarction (group LBBBMH).

Diagnosis of myocardial infarction was presumed by a history of prolonged chest pain accompanied by typical electrocardiographic changes and elevation of creatine phosphokinase (CPK), and myocardial infarction was confirmed either by the transmural perfusion defect in 201TI myocardial scintigraphy or wall motion abnormalities (akinesia or dyskinesis) in left ventriculography. The age of the myocardial infarctions ranged from 6 months to 8 years (mean, 4.3 years) in group RBBBMH, and it ranged from 2.5 years to 11 years (mean, 6.1 years) in group LBBBMH.

The locations of myocardial infarction determined by either left ventriculography or myocardial scintigraphy were anterolateral (12 patients), inferior (seven patients), anterior and inferior (four patients), and inferoposterior (one patient) in group RBBBMH and were anterior (12 patients) and inferior (six patients) in group LBBBMH.

Body surface maps were recorded by an HPM650014,15 (Chunichi Denshi, Japan) with 87 unipolar electrodes. IQRST maps (units, μV · sec) were made by minicomputer JEC980B (NihoDen-shi, Japan).

The PR segment on ECG was used as a baseline to calculate the area under the curve. Time instants of QRS onset and T offset were determined manually using lead V4 of the magnified ECG. The normal mean IQRST map was derived from 50 normal individuals (44 men, six women; mean age, 38.3 years), and each group’s IQRST map was compared with the normal mean IQRST map by a correlation coefficient according to previous methods of Abildskov et al.,16 Lux et al.,17 and Walker et al.18 In addition, pattern differences of IQRST maps from normal subjects and patients were compared to assist in discrimination.

When the isointegral value in each lead point in the IQRST map was less than the mean −2 SD, the reduction was considered statistically significant. The significant difference map of the IQRST map (IQRST difference map) was based on the area of significant reduction of IQRST values (significant area), and the following parameters were derived from the significant area to represent the size of the difference map: nDM, number of lead points in the difference map; ΣDM, sum of the value obtained by subtracting the normal mean IQRST value from the IQRST value of a given patient at each point in the difference map.

**Statistical Analysis**

The sensitivity [true-positive/(true-positive + false-negative)], specificity [true-negative/(true-negative + false-positive)], predictive value of a positive test [true-positive/(true-positive + false-positive)], predictive value of a negative test [true-negative/(true-negative + false-negative)], diagnostic accuracy [(true-positive + true-negative)/total group] were determined and expressed as a percentage.

Discriminant analysis was used to determine the diagnostic criteria for detecting complicated myocardial infarction by the parameters, nDM and ΣDM. Usual parametric, linear discriminant analysis was applied with nDM or ΣDM, which were the explanatory variables, and myocardial infarction complicated or uncomplicated, which were the discriminant items.

To increase the statistical validity, a procedure was performed in which two samples were chosen at random for each subgroup to calculate the jackknife estimates. To compare the difference of the mean values of nDM and ΣDM between groups, analysis of variance (one-way layout) and multiple comparisons were performed, and the null hypothesis was rejected when the p value was less than 0.05.

**Results**

**IQRST Maps in Normal Subjects**

In the normal mean IQRST map (Figure 1), the positive area covered most of the chest with the maximum located at V4 of the ECG and the minimum at the upper region of the sternum. The zero line in the chest ran from the right lateral chest toward the left shoulder, intersecting the V4 area.

**IQRST Map and IQRST Difference Map of Patients With Right Bundle Branch Block**

Group RBBBn. In group RBBBn patients, the locations of the maximum and minimum of the IQRST map were nearly the same as those locations for the normal mean IQRST map, resulting in very similar map patterns (Figure 2). The IQRST difference map was obtained in only seven of 40 patients (17.5%).

Group RBBBMH. In the IQRST map of RBBBMH patients with anterolateral myocardial infarction (Figure 3), the negative area was in the upper region of the left chest and back, and the minimum was in the upper region of V4. The positive area extended to the right chest and to the lower area of the left chest and back, and the maximum was at the lower region of V1. Significant area appeared in the left precordium, and V4 was at the center in IQRST difference map.

In patients with inferoposterior myocardial infarction (Figure 4), the negative area in the IQRST map was in the lower portion of the torso, and the
Normal Mean IQRST Map

Minimum was at the left lower chest. The positive area occupied most of the upper region of the chest, and the maximum was at the area above V2 and V3. The significant area appeared widely in the lower region of the torso in the IQRST difference map.

The significant area appeared in all patients in group RBBB_M, and its area was closely related to the location of infarction. The significant area appeared in the middle and left lateral region of the chest in patients with anterolateral infarction, in the lower region of the chest and back in patients with inferior infarction, and in the middle of the left back in patients with posterior infarction.

IQRST Map and IQRST Difference Map of Patients With Left Bundle Branch Block

Group LBBB_N. The distribution pattern of the positive and negative areas of the IQRST map of group LBBB_N was quite similar to that of the normal mean IQRST map. However, the negative value was large in the middle and lower regions of the right chest and back, resulting in the appearance

FIGURE 1. Normal mean IQRST (QRST time integral) map from 50 normal subjects. The rectangular frame represents the torso, of which the left half represents the chest and the right half the back. Thus, both the left and right margins represent the right axillary line. Six dots in the chest represent the positions of V1-V6 in standard 12-lead electrocardiogram. + and −, the maximum and minimum, respectively. Increments for the time integral line are 10 μV·sec. Average magnitudes of the maximum and minimum were 136 μVsec and −39 μVsec, respectively.

FIGURE 2. IQRST and IQRST (QRST time integral) difference maps of complete right bundle branch block (CRBBB) without myocardial infarction (MI). No significantly reduced area appeared in the IQRST difference map. Numbers under the IQRST map are maximal and minimal values of the QRST time integral map.

FIGURE 3. IQRST and IQRST (QRST time integral) difference maps in a patient with complete right bundle branch block (CRBBB) complicated by anterolateral myocardial infarction (MI). Stippled area in the IQRST difference map is the significant area that was located in the left precordium. See text for details.
of a significant area in the same region in the IQRST difference map (Figure 5). The significant area was found in the above region in the IQRST difference map in 17 patients (77.3%).

**Group LBBBM**. The negative area covered the entire chest in the IQRST map in group LBBBM patients with anterior myocardial infarction (Figure 6). The minimum near V5 was remarkably smaller than normal, and the maximum was displaced toward the lower region of V
. The significant area covered a wide region in the left chest, and the center was at the V3-V5 area.

In patients with inferior infarction, the negative area in the IQRST map extended to the inferior region of the right chest and back (Figure 7). The significant area was in the inferior area of the torso.

The significant area was present in all patients in the LBBBM group and was closely related to the location of myocardial infarction. It appeared in the middle of the left chest in patients with anterior infarction and in the lower portion of the chest and back in patients with inferior infarction.

**Correlation Coefficient Between Normal Mean IQRST Map and IQRST Map of Each Group**

The correlation coefficient between the normal mean IQRST map and the IQRST map in group RBBBN was 0.85±0.10 (mean±SD), and 13 patients in whom the significant area appeared in the IQRST difference map had a map correlation coefficient of less than 0.83 (Figure 8).

The correlation coefficient for group RBBBM was 0.24±0.36, which was significantly lower than that for group RBBBN (p<0.001). The correlation coefficient for group LBBBN was 0.71±0.14, which was slightly lower than that for group RBBBN (NS). The significant area appeared in the IQRST difference map whenever the correlation coefficient was less than 0.84%.

The correlation coefficient for group LBBBM was 0.03±0.34, which was significantly lower than that for group LBBBN (p<0.001).

**Diagnostic Ability of an Emergence of a Significant Area in IQRST Difference Map to Identify Myocardial Infarction Complicated by Bundle Branch Block**

In all patients, the significant area emerged in the IQRST difference map when bundle branch block was combined with myocardial infarction irrespective of the site of block (Table 1).

The significant area emerged in fewer patients in group RBBBN than in group LBBBN, resulting in the higher specificity in the former (82.5% vs. 77.3%).

The negative predictive value was 100% in both groups; however, the positive predictive value was low, especially in group LBBB. The diagnostic accuracy was 89.1% and 57.5% in groups RBBBN and LBBBN, respectively.
Values for jackknife estimates were nearly equal to those obtained by the routine statistical procedures (Table 1).

**Comparison of nDM and ΣDM of the IQRST Difference Map in Each Group**

Both nDM and ΣDM were larger in the groups complicated by myocardial infarction (groups RBBB<sub>M</sub> and LBBB<sub>M</sub>) than in groups without infarction (groups RBBB<sub>N</sub> and LBBB<sub>N</sub>) (Figure 9). Both nDM and ΣDM were significantly larger in group LBBB<sub>N</sub> than in group RBBB<sub>N</sub>.

**Ability of nDM and ΣDM of IQRST Difference Map to Identify Myocardial Infarction Complicated by Bundle Branch Block**

Diagnostic ability for identifying complicated myocardial infarction with nDM and ΣDM values derived from the discriminant analysis was tested. In group

<table>
<thead>
<tr>
<th>Group</th>
<th>RBBB</th>
<th>LBBB</th>
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<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>100 (100)</td>
<td>100 (100)</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>82.5 (82.5)</td>
<td>77.3 (77.3)</td>
</tr>
<tr>
<td>Predictive value (+) (%)</td>
<td>77.4 (77.7)</td>
<td>51.4 (51.5)</td>
</tr>
<tr>
<td>Predictive value (-) (%)</td>
<td>100 (100)</td>
<td>100 (100)</td>
</tr>
<tr>
<td>Diagnostic accuracy</td>
<td>89.1 (89.1)</td>
<td>57.5 (57.5)</td>
</tr>
</tbody>
</table>

Values in parentheses are the jackknife estimates.

RBBB, right bundle branch block; LBBB, left bundle branch block.
FIGURE 9. Comparison of nDM and ΣDM in IQRST difference map for each group.

RBBB, the diagnostic accuracy was 98.4% by either nDM≥13 or ΣDM≥816, and the discriminant probability was 87.9% and 93.9%, respectively (Table 2).

In group LBBB, the diagnostic accuracy was 77.5% by nDM≥21 and 87.5% by ΣDM≥1,350, and the discriminant probability was 80.9% and 85.4%, respectively. ΣDM≥816 and ΣDM≥1,350 resulted in greater diagnostic accuracy in detecting infarction complicated by right and left bundle branch block, respectively.

Values for jackknife estimates were nearly equal to those obtained by the routine statistical procedures (Table 2).

Discussion

It is not unusual to encounter patients with myocardial infarction complicating bundle branch block that is difficult to diagnose correctly by ECG despite many attempts at defining diagnostic criteria.2-6 Many reports have shown that body surface mapping is useful for clinically diagnosing myocardial infarction in various locations that are hard to detect by ECG.16-27 Musso et al.2 recently developed a procedure using body surface maps with a preliminary learning set of maps to allow classification of LBBB with and without infarction. Whether or not body surface mapping is useful for these cases has not yet been sufficiently studied.

In recent years, ECG isointegral maps have been clinically applied to diagnose various cardiac diseases11,28-31 based on Wilson’s concept of ventricular gradient13 verified through experimental studies,11,32-34 theoretical consideration,35 and clinical observations.30

The present study was carried out to determine the clinical usefulness of IQRST maps to correctly diagnose myocardial infarction complicated by bundle branch block. IQRST maps of the normal mean and of group RBBB were similar to each other. These were predominantly characterized by a smooth bipolar body surface distribution pattern12 with a high correlation coefficient between these two maps, which indicates that the ventricular gradient was unaffected by the abnormal ventricular activation sequence or the consistency of ventricular gradient.35 On the other hand, the IQRST map of group LBBB was slightly different from that of the normal mean in the distribution of the negative area, suggesting the possibility that the ventricular gradient is somewhat affected by the ventricular activation sequence. Left bundle branch block is often associated with a variety of cardiac abnormalities,36,37 especially in elderly patients such as those in the present study. We cannot exclude the possibility that group LBBB included patients with a cardiac disease that resulted in a IQRST map pattern somewhat different from the normal mean. The IQRST map pattern was quite different from the normal mean map pattern in the presence of myocardial infarction, which was shown by a low correlation coefficient in the present study as Abildskov showed experimentally.38,39

The area of significant reduction of integral values (i.e., significant area) in the IQRST difference map

<table>
<thead>
<tr>
<th>Group</th>
<th>RBBB</th>
<th></th>
<th></th>
<th>LBBB</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nDM≥13</td>
<td>ΣDM≥816</td>
<td>nDM≥21</td>
<td>ΣDM≥1,350</td>
<td></td>
</tr>
<tr>
<td>Sensitivity (%)</td>
<td>95.8</td>
<td>95.8</td>
<td>77.8</td>
<td>77.8</td>
<td></td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>100</td>
<td>100</td>
<td>77.3</td>
<td>95.5</td>
<td></td>
</tr>
<tr>
<td>Predictive Value (+) (%)</td>
<td>100</td>
<td>100</td>
<td>73.7</td>
<td>93.3</td>
<td></td>
</tr>
<tr>
<td>Predictive Value (-) (%)</td>
<td>97.6</td>
<td>97.6</td>
<td>81.0</td>
<td>84.3</td>
<td></td>
</tr>
<tr>
<td>Diagnostic Accuracy (%)</td>
<td>98.4</td>
<td>98.4</td>
<td>77.5</td>
<td>87.5</td>
<td></td>
</tr>
<tr>
<td>Discriminant Probability (%)</td>
<td>87.9*</td>
<td>93.9†</td>
<td>80.9‡</td>
<td>85.4§</td>
<td></td>
</tr>
</tbody>
</table>

Values in parentheses are jackknife estimates.

RBBB, right bundle branch block; LBBB, left bundle branch block.

Discriminant function: *Z=2.978–0.225 nDM; †Z=5.114–0.00627 ΣDM; ‡Z=3.390–0.164 nDM; §Z=3.923–0.0029 ΣDM.
suggested the location of infarction in patients with complicated myocardial infarction as Flowers et al20-24,40 reported.

When diagnostic ability of a significant area in the IQRST difference map was examined to identify infarction, sensitivity and negative predictive value was 100% in groups RBBB and LBBB. Diagnostic accuracy was satisfactory in group RBBB only by using the parameter of presence or absence of a significant area, but accuracy was not high enough for clinical use in group LBBB.

Because a significant area appeared in the IQRST difference map in some patients in groups RBBB\textsubscript{N} and LBBB\textsubscript{N}, we examined whether or not the determination of the critical size of a significant area obtained by the discriminant analysis would improve diagnostic power. In group RBBB, diagnostic accuracy was 98.4% by nDM\textgreater{}13 and by \(\Sigma D\text{DM}\textgreater{}816\), which showed a much higher diagnostic accuracy than by the emergence of a significant area only.

The discriminant probability obtained when using these parameters was high enough for a clinical use. Diagnostic accuracy of nDM\textgreater{}21 and \(\Sigma D\text{DM}\textgreater{}350\) in group LBBB was also improved compared with the diagnostic accuracy by the emergence of a significant area only, and it was high enough for a clinical use.

Because LBBB is frequently complicated by a variety of cardiac pathologic changes\textsuperscript{36,37} that are clinically obscure, values of nDM and \(\Sigma D\text{DM}\) for the diagnostic criteria in group LBBB to detect coexisting myocardial infarction were larger than those in group RBBB. Parameters nDM and \(\Sigma D\text{DM}\) proved to be very useful for detecting infarction in groups RBBB and LBBB, and the emergence of a significant area only was also practically useful in diagnosing an infarction in group RBBB because of its simplicity as a parameter.

The present study showed that by using IQRST maps and the variables derived from the maps (nDM and \(\Sigma D\text{DM}\)), patients with myocardial infarction complicated by bundle branch block could also be diagnosed satisfactorily, although they could not be diagnosed by the QRS isointegral map.\textsuperscript{41,42}

Limitations

The diverse conditions associated with LBBB suggest that a nonspecific pathologic process may also be common to most etiologic factors. Patients in group LBBB\textsubscript{N} were quite elderly, and pathologic process due primarily to aging in these patients may mimic myocardial infarction, resulting in the appearance of significant areas in the IQRST difference map. In addition, the alteration of depolarization sequence may be greater in left bundle branch block than in right bundle branch block, and this may have a greater influence on the ventricular gradient.\textsuperscript{43,44}

The age of myocardial infarction and bundle branch block was variable in the present study groups, and this could influence the result because it has been shown experimentally to affect ventricular repolarization properties.\textsuperscript{43}

Because IQRST difference maps depend greatly on the normal mean IQRST map, the appropriate selection of normal subjects to make the latter map is important. Standard maps derived from a large number of normal subjects of different age groups, sex, and body structure\textsuperscript{45} will be needed also for a more reasonable comparison to patient populations.

The correlation coefficient is independent of the potential magnitudes of the two maps and only gives an indication of the similarities in potential distributions. More precise study regarding the similarities of absolute values of maps including surface potentials may be required.

The values of nDM and \(\Sigma D\text{DM}\) derived from the present retrospective study need to be tested in a prospective study on a larger scale to confirm their validity in screening or diagnostic tests. As an alternative method, a jackknife procedure was used to increase the statistical validity of this study with a limited number of patients. The values for the jackknife estimate were almost equal to those obtained by routine statistical procedures, and statistical values shown in Tables 1 and 2 were considered to be reasonable.

Clinical Implications

When the ventricular gradient is used to detect myocardial infarction complicated by conduction disturbances, sensitivity and specificity are often unreliable because the normal range for ventricular gradient is wide\textsuperscript{46} and because diagnosis of the location of myocardial infarction is difficult by this parameter. There are also occasional false-negative findings by this method.\textsuperscript{47}

The IQRST difference map has advantages in detecting myocardial infarctions complicated by bundle branch block through its ability to detect the primary differences between normal and abnormal repolarization properties. This suggests that diagnosis of these cases could be more accurately performed if the diagnostic criteria are further refined through the prospective study on a larger scale by using a sex-matched normal control group.

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**KEY WORDS** • ST-T changes • body surface mapping • QRST time integral map • myocardial infarction
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