ELECTROCARDIOGRAPHIC DIAGNOSIS OF LEFT VENTRICULAR HYPERTROPHY IMPROVED BY CONSIDERING BOTH QRS VOLTAGE AND ST-T CRITERIA

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We evaluated the usefulness of a combination of QRS voltage and the pattern of ST-T abnormality in the electrocardiographic diagnosis of left ventricular hypertrophy (LVH) in 100 middle-aged men: 32 normals, 59 with hypertension (HT), and 9 with hypertrophic cardiomyopathy (HCM) with evidence of LVH (RV5 or RV6≥2.6 mV, SV1+RV5 or SV1+RV6≥3.5 mV). The subjects were classified into three groups based on ST-T pattern: normal (group N), early strain (group ES), and strain (group S). Echocardiographic evidence of LVH was present in 52.0% (52/100) of the subjects: 72.8% (43/59) of the patients with HT, all 9 patients with HCM, and none of the 32 normals. Echocardiographic evidence of LVH was present in 31.3% (20/64) of group N, 73.3% (11/15) of group ES, and all 21 subjects of group S. In patients with HT, the incidence of echocardiographic LVH was higher in group S (100%) than in both group ES (78.6%) and group N (60.6%).

QRS voltage (RV5,RV6,RV5+SV1, and RV6+SV1) was significantly correlated with interventricular septal thickness (IVST), IVST+LVPWT/2, and LV mass, as determined by echocardiography, in patients with LVH (IVST or left ventricular posterior wall thickness (LVPWT) of ≥12 mm) (r=0.55 to r=0.75, p<0.05), but not in patients without LVH (IVST and LVPWT<12 mm). There were significant correlations between QRS voltage indices (RV5, RV6, RV5+SV1, and RV6+SV1) and IVST, IVST+LVPWT/2, and LV mass in group S (r=0.68 to r=0.86, p<0.05), but not in group N. Values for IVST and LV mass were significantly greater in group S than in groups ES or N. The combination of QRS criteria and ST-T findings reflected the echocardiographic assessment of LVH, especially in patients with HT. The electrocardiographic diagnosis of LVH thus appeared to be improved by evaluating both the QRS voltage and ST-T abnormality pattern. (Jpn Circ J 1994; 58: 698–706)

Left ventricular hypertrophy (LVH), which is associated with diastolic left ventricular dysfunction, is a major indicator of the risk of cardiovascular disease. It may also be a prognostic factor in patients with such disease. Electrocardiography (ECG), which is inexpensive, noninvasive, rapid and convenient, is widely used in screening for LVH in large populations. Several criteria have been proposed for ECG diagnosis of LVH. While an increase in

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QRS voltage and the strain type of ST-T are important indicators, they are not specific for LVH. Their diagnostic accuracy is questionable\(^{23-28}\) and their use is associated with a high rate of false-positive and false-negative results. Repolarization wave abnormalities are related to an increase in left ventricular (LV) mass, hemodynamic overload of the left ventricle, presence of coronary artery disease, and subendocardial ischemia. Although the value of the QRS voltage and ST-T wave change has been described, the groups studied were heterogeneous\(^{23-28}\) so that results may not accurately reflect the relationships between the type of ST-T strain and the increase in the mass or thickness of the ventricle which leads to LVH.

We hypothesized that the relationships between QRS voltage and criteria for ST-T wave abnormality, LV mass, and underlying heart disease may affect the accuracy of the electrocardiographic diagnosis of LVH. Accordingly, we evaluated the diagnostic usefulness of a combination of the QRS voltage criteria and the ST-T abnormality pattern vs QRS voltage criteria alone in middle-aged Japanese men with electrocardiographic findings of LVH, but without coronary artery disease or valve disease.

**METHODS**

**Subjects**

We studied 100 men (aged 40—88 years; mean 56.1 years) who satisfied voltage criteria for LVH. They included 32 men without heart disease, 59 patients with hypertension (HT), and 9 patients with hypertrophic cardiomyopathy (HCM). Hypertension was diagnosed according to the WHO criteria (\(\geq 160/95\) mmHg). Patients with complete bundle branch block. Wolff-
TABLE I  CORRELATIONS BETWEEN ELECTROCARDIOGRAPHIC AND ECHOCARDIOGRAPHIC INDICES

<table>
<thead>
<tr>
<th>Echocardiographic indices</th>
<th>Echocardiographic indices</th>
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<tbody>
<tr>
<td>IVST</td>
<td>RV&lt;sub&gt;s&lt;/sub&gt;</td>
</tr>
<tr>
<td>LVH (+)</td>
<td>0.652*</td>
</tr>
<tr>
<td>LVH (-)</td>
<td>0.070</td>
</tr>
<tr>
<td>LVPWT</td>
<td>RV&lt;sub&gt;s&lt;/sub&gt;</td>
</tr>
<tr>
<td>LVH (+)</td>
<td>0.016</td>
</tr>
<tr>
<td>LVH (-)</td>
<td>0.122</td>
</tr>
<tr>
<td>IVST + LNPWT/2</td>
<td>SV&lt;sub&gt;1&lt;/sub&gt; + RV&lt;sub&gt;5&lt;/sub&gt;</td>
</tr>
<tr>
<td>LVH (+)</td>
<td>0.569*</td>
</tr>
<tr>
<td>LVH (-)</td>
<td>0.027</td>
</tr>
<tr>
<td>LV mass</td>
<td>SV&lt;sub&gt;1&lt;/sub&gt; + RV&lt;sub&gt;6&lt;/sub&gt;</td>
</tr>
<tr>
<td>LVH (+)</td>
<td>0.531*</td>
</tr>
<tr>
<td>LVH (-)</td>
<td>0.075</td>
</tr>
</tbody>
</table>

LVH (+): IVST or LVPWT ≥12 mm, LVH (-): IVST and LVPWT <12 mm
*: p<0.05

Fig.2. IVST and LV mass in ST-T groups.
S: strain ST-T, ES: early strain ST-T, N: normal ST-T. IVST and LV mass were significantly greater in group S than in either group ES or group N. Neither IVST nor LV mass differed between groups N and ES.

Parkinson-White syndrome, left ventricular dilation, right ventricular hypertrophy, electrolyte imbalance, chest pain, wall motion asynchrony in echocardiography, coronary artery disease by cardiac catheterization, history of ischemic heart disease, history of cerebrovascular accident, myocardial infarction, and those receiving digitalis, were excluded from the study. Such factors would may interfere with the detection of LVH<sup>29,30</sup>

ECG Data

We recorded twelve-lead ECGs and used the voltage criteria of Sokolow and Lyon (RV<sub>s</sub> or RV<sub>6</sub> ≥2.6 mV, SV<sub>1</sub> + RV<sub>5</sub> or SV<sub>1</sub> + RV<sub>6</sub> ≥3.5 mV). Subjects were classified into three groups according to ST-T patterns as follows (Fig. 1): Normal ST-T (group N); normal ST-T in twelve leads; Early strain ST-T (group ES): ST depression, flat T (T/R<1/10), or diphasic T in V<sub>5</sub> or V<sub>6</sub> (ST-T abnormality not satisfying strain ST-T), and strain ST-T (group S): >0.05 mV ST de-
There was a significant positive correlation between IVST and LV mass in patients with strain ST-T. The correlation equation was estimated as:

$$y = 2.6x + 2.8$$

with a slope of 2.6, an intercept of 2.8, a correlation coefficient of 0.85, and a p-value of <0.01. This indicates a strong association between IVST and LV mass in patients with strain ST-T.

### TABLE II CORRELATIONS BETWEEN ELECTROCARDIOGRAPHIC AND ELECTROCARDIOGRAPHIC INDICIES IN ST-T GROUPS

<table>
<thead>
<tr>
<th>Echocardiographic indices</th>
<th>Electrocardiographic indices</th>
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</thead>
<tbody>
<tr>
<td><strong>ST-T group</strong></td>
<td><strong>RV₂</strong></td>
</tr>
<tr>
<td>IVST</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>ES</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>LVPWT</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>ES</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>IVST+LVPWT/2</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>ES</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>LV mass</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>ES</td>
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<td></td>
<td>S</td>
</tr>
</tbody>
</table>

*: p<0.05

Left ventricular mass was estimated according to Devereux's method using the following equation: LV mass = 1.04 [(LVDd + LVPWT + IVS)³ - (LVDd)³] - 14. We defined echocardiographic evidence of LVH as an IVST or LVPWT of ≥12 mm.

### Statistical Analysis

Values are expressed as mean±SD. Data were analyzed by an analysis of variance (ANOVA) with Scheffe's test used for multiple comparisons. A p value <0.05 was considered significant.

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TABLE III  ECHOCARDIOGRAPHIC EVIDENCE OF LEFT VENTRICULAR HYPERTROPHY IN SUBJECTS CLASSIFIED BY HEART DISEASE

<table>
<thead>
<tr>
<th>Group</th>
<th>ST-T type</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Early Strain</td>
<td>Strain</td>
<td>Total</td>
</tr>
<tr>
<td>Normal</td>
<td>0/31 (0)</td>
<td>0/1 (0)</td>
<td>12/12 (100)</td>
<td>0/32 (0)</td>
</tr>
<tr>
<td>HT</td>
<td>20/33 (60.6)</td>
<td>11/14 (78.6)</td>
<td>9/9 (100)</td>
<td>43/59 (72.8)</td>
</tr>
<tr>
<td>HCM</td>
<td>20/64 (31.3)</td>
<td>11/15 (73.3)</td>
<td>21/21 (100)</td>
<td>52/100 (52.0)</td>
</tr>
</tbody>
</table>

HT: hypertension, HCM: hypertrophic cardiomyopathy. (%)

TABLE IV  ECHOCARDIOGRAPHIC INDICES IN THE SAME ST-T CATEGORY IN PATIENTS WITH DIFFERENT HEART DISEASE

<table>
<thead>
<tr>
<th>Echocardiographic indices</th>
<th>Strain ST-T</th>
<th>Normal ST-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVST(mm)</td>
<td>14.5±3.6</td>
<td>11.3±1.7</td>
</tr>
<tr>
<td>LVPWT(mm)</td>
<td>12.0±2.4</td>
<td>16.6±3.8*</td>
</tr>
<tr>
<td>IVST+LVPWT/2(mm)</td>
<td>287.1±64.0</td>
<td>394.1±139.5*</td>
</tr>
<tr>
<td>LV mass(g)</td>
<td>9.8±1.1</td>
<td>200.1±40.6</td>
</tr>
</tbody>
</table>

HT: hypertension, HCM: hypertrophic cardiomyopathy. *, p<0.05 HT vs HCM, †: p<0.05 Normal vs HT

RESULTS

Relationship Between QRS Voltage and Left Ventricular Mass or Left Ventricular Thickness

LVH was identified by echocardiography in 32/100 (52.0%) of the subjects. IVST, IVST+LVPWT/2 and LV mass were correlated with RV5, RV6, SV1+RV5 and SV1+RV6 in the subjects with LVH (LVH (+)) (Table I). LVPWT did not correlate with any QRS voltage criteria. There were no correlations between QRS voltage criteria and echocardiographic indices in subjects without LVH (LVH (-)). No significant differences were observed in QRS voltage criteria or echocardiographic indices between the younger subjects (40 to 59 years) and the older subjects (60 to 88 years).

Relationship Between QRS Voltage and Left Ventricular Mass or Left Ventricular Thickness According to ST-T Classification

LVH was identified by echocardiography in all 21 (100%) of the subjects in group S, 11/15 (73.3%) subjects in group ES, and in 20/64 subjects (31.3%) in group N. Group S subjects exhibited significantly higher IVST and LV mass values than those in either group ES or group N. There were no significant differences in IVST or LV mass between groups N and ES (Fig. 2), and no significant differences in LVPWT between the three groups. The correlation between QRS voltage criteria and IVST, IVST+LVPWT/2 and LV mass was higher in group S than in subjects with LVH (LVH (+)) (Fig. 3, Table II). In group ES, only RV6 was correlated with IVST, LVPWT, IVST+LVPWT/2 and LV mass. There were no correlations between QRS voltage criteria and echocardiographic indices in group N (Table II).
Relationship Between QRS Voltage and Left Ventricular Mass or Left Ventricular Thickness According to Heart Disease Classification

Echocardiographic evidence of LVH was present in 43/59 subjects with HT (72.8%). The frequency of LVH determined by echocardiography was higher in group S (100%) than in either group ES (78.6%) or in group N (60.6%). The ST-T pattern of all of the subjects with HCM was strain ST-T, all of whom had LVH on echocardiographic examination. No evidence of LVH was found in any of the normal subjects (Table III). In group S, IVST, IVST+LVPWT/2 and LV mass were significantly higher in subjects with HCM than in those with HT, whereas there was no significant difference in QRS voltage criteria between these two groups. In group N, IVST, LVPWT, IVST+LVPWT/2 and LV mass were significantly higher in subjects with HT than in normal subjects. There was no significant difference in QRS voltage criteria between these two groups (Table IV).

DISCUSSION

ECG Diagnosis of Echocardiographically Determined LVH

The combination of QRS voltage criteria and ST-T classification, according to our definition of ST-T pattern, provided greater accuracy in diagnosing LVH than QRS voltage alone. Kimura et al reported that LVH was present in 47.9% of postmortem examinations. However, when the voltage criteria (SV1 + RV5 > 3.5 mV) were combined with strain ST-T, echocardiographic LVH was detected in 67.3% of the subjects, as compared with 41.4% using non-specific ST-T findings. The findings of Kimura et al., as well as those of the present study, suggest that strain-type ST-T changes can be highly accurate in diagnosing LVH. The higher incidence of echocardiographic LVH in our study than in that of Kimura et al may be attributed to differences in methodology. For example, we studied 100 men with normal hearts, HT or HCM, whereas they studied 78 men and 61 women (mean age 76.3 years) who had hypertension, coronary sclerosis, myocardial infarction, valvular disease, or cardiomyopathy. Nonspecific ST-T findings of LVH are difficult to distinguish from those of coronary artery disease and may affect the accuracy in diagnosing LVH echocardiographically. We cannot exclude the possibility that differences in study populations influenced the results of both studies. In addition, our study involved subjects with LVH on ECG in the clinical setting, whereas those authors evaluated hearts at postmortem.

We found that all of the patients with HT and strain-type ST-T changes showed echocardiographically determined LVH, whereas those with HT and normal ST-T, or early strain ST-T, showed a lower incidence of LVH (78.6% and 60.6%, respectively) which suggests that the combination of QRS voltage and ST-T abnormality pattern criteria is useful in identifying patients with LVH, especially those with HT. No evidence of LVH was found in subjects without disease. Among subjects with strain ST-T, IVST, IVST+LVPWT/2 and LV mass were significantly higher in those with HCM than in those with HT. Among subjects with normal ST-T, these values were significantly higher in those with HT than in normal subjects. These results indicate that it is important to analyze the relationship between the blood pressure level and voltage and ST-T abnormality criteria in diagnosing LVH using electrocardiography.

Correlation Between ECG Indices and Echocardiographic Indices

Significant correlations were found between QRS voltage and IVST, IVST+LVPWT/2 and LV mass in the subjects with LVH, but not in those without LVH. This is consistent with the findings of Carter and Estes who reported that a correlation between ECG voltage and postmortem heart weight in the presence of LVH, but not in its absence.

There was no correlation between QRS voltage and either IVST, LVPWT or LV mass in group N. Only RV5 was correlated with IVST, IVST+LVPWT/2 and LV mass in group ES. In group S, IVST and LV mass were significantly higher than those in groups ES and N, and were significantly correlated with QRS voltage. These results suggest that the combination of QRS voltage and ST-T abnormality pattern criteria reflect
the degree of LV mass and LV thickness. However, previous studies have indicated that ECG criteria have a relatively poor sensitivity for LVH, and that there is a poor correlation between the voltage criteria of Sokolow and Lyon and the LV mass\textsuperscript{35–38}. The differences between these earlier reports and our present report may be related to differences in the characteristics or the classification of study populations. In the present study, exclusion of the patients with clinical or angiographic evidence of coronary artery disease and hemodynamic overloading of the left ventricle had no effect on the relationships between the combination of QRS voltage and ST-T abnormality pattern criteria and LV mass and or LV thickness. The mechanism which underlies the usefulness of the ST-T classification in the relationship between QRS voltage and LVH remains to be determined.

Burger and van Milaan\textsuperscript{39} suggested that the relationship between voltage on body surface ECG (V) and cardiac electromotive force (H) can be represented as $V = \frac{1}{H}$ (lead vector)-H. Lead vector is based on body build, electric ratio, the position of the heart and parapet, lung effect, anisotropy of the tissues surrounding the heart, and the distance of the exploring electrode from the center of the heart\textsuperscript{39–42}. In view of our present results, we cannot exclude the possibility that the lead vector influenced the body surface ECG. The relationship between L and H may influence the differences between the groups with respect to the correlation between the QRS voltage and echocardiographic indices.

**Clinical Implications**

The observed relationship between QRS voltage and either LV mass or IVST was specifically related to ST-T wave abnormality criteria on ECG. The combination of QRS voltage and ST-T wave abnormality criteria were more reliable in diagnosing LVH echocardiographically than QRS voltage alone, especially in hypertensive patients. Therefore, we suggest that the echocardiographic diagnosis of left ventricular hypertrophy was improved by considering both QRS voltage and ST-T abnormality pattern criteria, and may be more useful in screening for LVH, taking into consideration the patient's blood pressure or underlying heart disease. Multivariate statistical techniques may be required in mass screening of a larger number of patients in the present study.

**Acknowledgment**

The authors thank Professor Nobuo Nakashima for his assistance.

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