BODY SURFACE MAPPING FOR THE ASSESSMENT OF LEFT VENTRICULAR HYPERTROPHY IN PATIENTS WITH ESSENTIAL HYPERTENSION

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To investigate the electrocardiographic abnormalities of left ventricular hypertrophy (LVH), body surface potential maps were acquired from 42 patients with essential hypertension. We adopted the time integral technique for analyzing body surface mapping data and used echocardiographic left ventricular muscle mass (LV mass) as the index of advance of LVH.

The QRS, ST-T and QRST isointegral maps in normal volunteers all demonstrated smooth bipolar surface distribution patterns, with positive values located over the precordium and negative values over the right upper chest and back.

In patients with essential hypertension, changes in the isointegral maps were observed as LVH advanced; A QRS increased on the upper left lateral chest and decreased (became more negative) on the right chest, A ST-T decreased on the lower left lateral chest and increased on the right upper chest, and areas of significant difference in A QRS and A ST-T were expanded as LVH advanced. A QRST decreased on the lower left lateral chest and increased on the right upper chest only in patients with severe LVH.

We conclude that the changes of QRS and ST-T isointegral maps depend on the degree of advance of LVH and the severe grade of LVH causes the alterations in intrinsic repolarization properties.

MANY investigators have studied electrocardiographic changes of left ventricular hypertrophy (LVH) by the standard 12-lead electrocardiogram or the vectorcardiogram. However, these methods offer little information on the back and the upper and lower chest, and are considered to be unsuitable for the detailed detection of electrocardiographic changes of LVH.

On the other hand, body surface potential mapping is constructed from a large amount of ECG data obtained from many lead points distributed over the entire thorax. Therefore, body surface potential mapping allows a more comprehensive and regionally discriminating analysis of electrocardiographic information than is possible with the standard 12-lead electrocardiogram. The enormous amount of data, however, is difficult to handle. Montague et al measured time integrals from each of the body surface ECG signals to reduce data efficiently.

The present study was performed to assess the relationship between electrocardiographic depolarization and repolarization abnormalities and LVH in patients with essential hypertension using maps analyzed by the time integral technique.

Key words:
Essential hypertension
Body surface map
Left ventricular hypertrophy

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TABLE I DATA RANGE OF TIME INTEGRALS IN 40 NORMAL VOLUNTEERS 
AND 42 PATIENTS WITH ESSENTIAL HYPERTENSION

<table>
<thead>
<tr>
<th></th>
<th>Normal volunteers</th>
<th>Group A (n = 10)</th>
<th>Group B (n = 15)</th>
<th>Group C (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\bar{A} QRST)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>41.5 ± 17.1</td>
<td>44.8 ± 18.7</td>
<td>61.9 ± 22.0*</td>
<td>68.4 ± 22.5*</td>
</tr>
<tr>
<td>Minimum</td>
<td>-42.6 ± 24.8</td>
<td>-44.9 ± 21.5</td>
<td>-55.7 ± 35.2</td>
<td>-59.9 ± 20.6</td>
</tr>
<tr>
<td>(\bar{A} ST-T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>148.3 ± 35.3</td>
<td>149.3 ± 42.5</td>
<td>172.3 ± 36.7</td>
<td>179.9 ± 69.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>-37.7 ± 11.5</td>
<td>-29.8 ± 5.5</td>
<td>-33.3 ± 12.3</td>
<td>-57.3 ± 48.2</td>
</tr>
<tr>
<td>(\bar{A} QRST)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>165.1 ± 36.7</td>
<td>159.0 ± 49.0</td>
<td>176.7 ± 50.1</td>
<td>166.2 ± 71.7</td>
</tr>
<tr>
<td>Minimum</td>
<td>-58.9 ± 16.3</td>
<td>-48.4 ± 12.8</td>
<td>-60.9 ± 22.7</td>
<td>-51.2 ± 20.1</td>
</tr>
</tbody>
</table>

Values are mean ± SD (µV·sec) 
*: p < 0.01 compared with corresponding value in normal volunteers.

![Fig.1. Superimposed Frank X, Y and Z leads locating the onset and offset of the QRS complex and T offset.](image)

**METHODS**

**Patients population**
Forty-two men with essential hypertension, ages 32–72 years (mean 49.0 years), were studied. Outpatient blood pressure determined by standard sphygmomanometric method exceeded 160 mmHg systolic and/or 95 mmHg diastolic in all cases. Patients with previous myocardial infarction, angina pectoris, intraventricular conduction disturbances, cardiac valvular disease, congenital heart disease or abnormalities of serum electrolyte such as Na, K, Cl or Ca were excluded.

The patients were separated into 3 groups based on echocardiographic left ventricular muscle mass (LV mass). Group A included 10 patients (mean 46.6 years) with LV mass of less than 215 g (mean ± SD 187.5 ± 19.7 g). Group B included 15 patients (mean 49.6 years) with LV mass of 215–300 g (247.1 ± 19.4 g). Group C included 17 patients (mean 50.0 years) with LV mass of more than 300 g (373.2 ± 59.3 g).

**Normal volunteers**
Forty normal volunteers, all men, ages 22–55 years (mean 33.2 years), underwent body surface mapping to evaluate the normal magnitude and body surface distribution of time integral values. None of the volunteers had a history of cardiac disorders or systemic arterial hypertension, and all had normal physical and ECG findings.

**Body surface mapping**
Body surface mapping was performed with the use of the HPM-5100 system (Chunichi Denshi Company, Nagoya). Eighty-seven electrodes were placed over the torso, 59 leads were placed on the anterior chest, and 28 were placed on the back. The localization of the lead points and procedure used for the data sampling and processing have been described in detail elsewhere. Data were recorded in digital format, using Wilson’s central terminal as a reference, at a rate of 250 samples/sec. Data sampling was always done at the resting expiratory level in the supine position. Frank lead vectorcardiograms were recorded simultaneously with the body surface maps.

Three time integrals were evaluated: QRS, ST-T and QRST segments. The time instants of QRS onset, offset and T offset were determined from edited Frank X, Y and Z leads! The QRS
Fig. 2. Mean QRS, ST-T and QRST isointegral maps constructed from 40 normal volunteers. The left half and right half represent the precordial and back, respectively. The dotted area represents the positive time integrals. + and - indicate a maximal and minimal time integral, respectively. Each map demonstrated smooth bipolar distribution patterns, with positive values located over precordium and negative values over the right upper chest and back. The maximal A QRS, A ST-T and A QRST located on the left chest, and the minimal A QRS on the middle anterior chest and the minimal A ST-T and A QRST on the right upper chest.

Fig. 3a. The QRS, ST-T and QRST isointegral maps of a 41-year old patient in group A, whose LV mass was 188 g. Distribution pattern of each isointegral map was very similar to that in normal volunteers.

lines on each map.

Echocardiographic data

M-mode echocardiograms were recorded using standard techniques with 2.0 MHz transducers interfaced to a Hitachi EUB-10 echograph. Simultaneous visualization of interventricular septal thickness (IVS), left ventricular internal dimension (LVID) and posterior wall thickness (PWT) was sought, at or just below the tips of the mitral leaflets. End-diastolic measurements were made by the standard convention according to the recommendations of the American Society of Echocardiography. LV mass was calculated from these measurements by the following formula reported by Devereux et al.

\[
\text{LV mass} = 1.04 \left[ (\text{LVID} + \text{PWT} + \text{IVS})^3 - (\text{LVID})^3 \right] - 13.6 \text{ (g)}
\]

Statistical analysis

Statistical analysis was performed using

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Fig. 3b. Mean QRS, ST-T and QRST isointegral maps constructed from 10 patients in group A. Distribution patterns of the QRS and QRST maps were similar to those in normal volunteers. On the other hand, the location of the minimal A ST-T was moved to the upper back compared with that in normal volunteers.

Normal volunteers
Normal volunteers had a marked consistency in the spatial distribution for each of A QRS, A ST-T and A QRST. Mean QRS, ST-T and QRST isointegral maps constructed from 40 normal volunteers are illustrated in Fig. 2. These demonstrated smooth bipolar surface distribution patterns, with positive values located over the precordium and negative values over the right upper chest and back. The maximal A QRS, A ST-T and A QRST located on the left chest, and the minimal A QRS on the middle anterior chest and the minimal A ST-T and A QRST on the right upper chest.

Essential hypertension
1) Group A
The QRS, ST-T and QRST isointegral maps of a patient in group A are shown in Fig. 3a. Distribution pattern of each isointegral map was very similar to that in normal volunteers. All

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patients of group A showed a consistent distribution pattern as shown in this case.

Mean QRS, ST-T and QRST isointegral maps constructed from 10 patients of group A are illustrated in Fig. 3b. Each isointegral map showed smooth bipolar surface distribution patterns like those in normal volunteers. The locations of the maximal A QRS, A ST-T and A QRST were similar to those in normal volunteers. On the other hand, the minimal A ST-T was located on the upper back, although in normal volunteers the minimal A ST-T was located on the right upper chest.

The comparison of A QRS, A ST-T and A QRST at each lead point between group A and normal volunteers is shown in Fig. 3c. There was no significant difference in A QRS between 2 groups. A ST-T at lead points on the right upper chest were significantly higher and A ST-T on the left lateral chest were significantly lower in group A than those in normal volunteers. There was no significant difference in A QRST between 2 groups.

2) Group B

The QRS, ST-T and QRST isointegral maps of a representative example are shown in Fig. 4a. When compared with normal volunteers, A QRS were higher and A ST-T were lower at lead points on the left lateral chest. On the other hand, the distribution pattern of A QRST was similar to that in normal volunteers.

Mean QRS, ST-T and QRST isointegral maps constructed from 15 patients of group B are illustrated in Fig. 4b. As in normal volunteers, each isointegral map showed smooth bipolar surface distribution patterns. The locations of the maximal A QRS, A ST-T and A QRST were similar to those in normal volunteers. On the other hand, the minimal A ST-T was located on the upper back as in group A, which differed

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from that in normal volunteers.

The comparison of A QRS, A ST-T and A QRST at each lead point between group B and normal volunteers is shown in Fig. 4c. A QRS at lead points on the upper left lateral chest were significantly higher and A QRST on the right chest were significantly lower in group B than those in normal volunteers. A ST-T at lead points on the right upper anterior chest were significantly higher and A ST-T on the lower left lateral chest were significantly lower in group B than those in normal volunteers. The changes in A QRS at lead points on the left lateral chest were observed mainly on upper, while the changes in A ST-T on the left lateral chest were observed mainly on lower. However, there was no significant difference in A QRST between 2 groups.

3) Group C

The QRS, ST-T and QRST isointegral maps from one member of this group are shown in Fig. 5a. Although the maximal A QRS was more positive and the minimal A QRS was more negative compared with those in normal volunteers, body surface distribution pattern was similar to that in normal volunteers. Body surface distribution pattern of A ST-T, with positive values located over the right chest and right back and negative values over the left lateral chest, was completely different from that in normal volun-
Fig. 5b. Mean QRS, ST-T and QRST isointegral maps constructed from 17 patients in group C. The ST-T isointegral map showed different distribution pattern, with negative values spread out the left lateral chest, and minimum located on the upper back, from that in normal volunteers. The maximal A QRST (lead F5) was shifted to the right and upward compared with that in normal volunteers (lead G4).

Fig. 5c. The comparison of A QRS, A ST-T and A QRST at each lead point between group C and normal volunteers. There were significant different in A QRS and A ST-T between 2 groups just as between group B and normal volunteers, but area of significant difference was larger than that between group B and normal volunteers. While, A QRST at lead points on the upper right chest were significantly higher and A QRST on the lower left lateral chest were significantly lower in group C than those in normal volunteers, differed from those in group A and B.

QRS, ST-T and QRST isointegral maps constructed from 17 patients of group C are illustrated in Fig. 5b. Although body surface distribution pattern of the QRS isointegral map was similar to that in normal volunteers, the ST-T isointegral map showed different distribution pattern, with negative values spread out on the left lateral chest and the minimum located on the upper back, from that in normal volunteers. The maximal A QRST (lead F5) was shifted to the right and upward compared with that in normal volunteers (lead G4).

The comparison of A QRS, A ST-T and A QRST at each lead point between group C and normal volunteers differed greatly. The A QRS at lead points on the left lateral chest were lower compared with those in normal volunteers and isointegral lines in this area were pushed out to the right, and positive values were shifted to the right chest. Such distribution pattern of the QRST isointegral map, completely different from normal volunteers, was observed in 7 patients in this group. LV mass of these 7 patients with abnormal distribution pattern (400.3 ± 71.7 g) tended to be larger than that of the other 10 patients in this group (354.3 ± 43.1 g). The maximal A QRS of these 7 patients (75.6 ± 25.3 μV·sec) tended to be higher than that of the other patients (63.4 ± 20.1 μV·sec). And the minimal A ST-T of 7 patients (−96.4 ± 55.1 μV·sec) was significantly lower than that of the other patients (−29.9 ± 8.7 μV·sec, p < 0.01).

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normal volunteers is shown in Fig. 5c. There was a significant difference in \( \text{A QRS} \) and \( \text{A ST-T} \) between 2 groups just as between group B and normal volunteers, but area of significant difference was larger. \( \text{A QRS} \) at lead points on the upper right chest were significantly higher and \( \text{A QRS} \) on the lower left lateral chest were significantly lower in group C than those in normal volunteers.

**DISCUSSION**

In recent years, the time integral analysis technique of body surface mapping was reported.\(^{1-5}\) This technique was considered to be an effective and convenient method to reduce data efficiently.

We have adopted this technique to assess the relation between electrocardiographic abnormalities and the advance of LVH in patients with essential hypertension. We used LV mass as the index of advance of LVH.\(^{10}\)

**Normal volunteers**

The QRS, ST-T and QRST isointegral maps demonstrated smooth bipolar surface distribution patterns. And distribution patterns were consistent in all normal volunteers. Our results were almost the same as those reported by Montague et al.\(^1\) in distribution patterns and locations and integral values of the maximum and minimum.

**Patients**

QRS isointegral map

Distribution pattern of each group was similar to that in normal volunteers. In group A, we considered mild stage of LVH, there was no significant difference in \( \text{A QRS} \) at each lead point, and the maximal and minimal \( \text{A QRS} \) were similar, compared with those in normal volunteers. But Safar et al.\(^{11}\) reported that in patients with borderline hypertension the thickness of the interventricular septum was significantly increased, whereas the posterior wall thickness remained within normal range. Our investigation\(^{12}\) using isopotential analysis technique showed that the potentials on the middle anterior chest at 20 msec from QRS onset were significantly higher in patients with borderline hypertension than those in normal volunteers, reflecting hypertrophy of IVS. Montague et al.\(^1\) suggested that isointegral analysis would not be expected to be as sensitive as the isopotential method in detecting abnormalities in segments, such as the QRS complex, in which potential change was great and occurred rapidly. It was considered that the change in the potentials on the middle anterior chest was negated by using the time integral analysis technique in this study.

In group B, moderate stage, and C, severe stage, significant difference in \( \text{A QRS} \) was observed at lead points on the right chest and upper left lateral chest, and the maximal \( \text{A QRS} \) was significantly higher, compared with those in normal volunteers. And area of significant difference in \( \text{A QRS} \) was expanded as LVH advanced. It was considered that the lead points on slightly rightside of \( V_1 \) and slightly upper than \( V_{4.5.6} \), were also important for the detection of QRS change due to LVH.

ST-T isointegral map

In group A, significant difference in \( \text{A ST-T} \) was observed at several lead points on the upper right chest and left lateral chest, compared with those in normal volunteers. The location of the minimal \( \text{A ST-T} \) was moved to the upper back compared with that in normal volunteers. Libretti et al.\(^{13}\) reported that in patients with hypertension the angle between the spatial QRS and T vector increased and the direction of the T vector was shifted to anterior at early phase. Devereux et al.\(^{14}\) reported that in patients not receiving digitalis with LV mass within the range 100-200g, LV "strain" was observed in frequency of approximately 10%. Therefore, not only QRS but also ST-T change was important for the detection of early phase of LVH.

In groups B and C, significant difference in \( \text{A ST-T} \) was observed at lead points on the right upper chest and lower left lateral chest and location of the minimal \( \text{A ST-T} \) was moved to the upper back, compared with those in normal volunteers. An area of significant difference in \( \text{A ST-T} \) was expanded as LVH advanced. ST-T change progressed in a manner that the area of negative values invaded the lower left lateral chest. The lead points on slightly rightside of \( V_1 \) and lower than \( V_{4.5.6} \), were also important for the detection of ST-T change due to LVH, and the ST-T isointegral map was useful to assess the degree of advance of LVH.

QRS isointegral map

In 1934, Wilson et al.\(^{15}\) hypothesized that the algebraic sum of the QRST area (ventricular gradient) reflected intrinsic repolarization properties, which are independent of ventricular activation.
sequence. The QRST area can be utilized as an applicable tool for differentiating the altered ventricular repolarization from the normal repolarization. Conventionally, the ventricular gradient was measured with the orthogonal scalar ECG, but the determined direction and magnitude showed wide variations, and were not suitable for the detection of the small change. The QRST isointegral map has advantages that included not only the locations and magnitude of the maximum but also the change in the distribution pattern can be assessed. This method was more useful for the early detection of change in intrinsic repolarization properties than the conventional methods.

In groups A and B, the distribution pattern of the A QRST was very similar and there was no significant difference in A QRST at each lead point, compared with those in normal volunteers. It was considered that, in groups A and B, the ventricular gradient almost remained in the normal ranges and the ST-T change was secondary to the QRS change.

In group C, significant difference in A QRST was observed at lead points on the upper right chest and lower left lateral chest compared with those in normal volunteers. The distribution pattern, completely different from normal volunteers, was observed in 7 patients in this group. LV mass of these 7 patients tended to be larger than that of other 10 patients in this group. And the minimum A ST-T of 7 patients was significantly lower than that of other patients. We considered that, as LV mass increased, the degeneration and fibrosis of myocardium appeared15 and therefore, changes in intrinsic repolarization properties, which altered the distribution pattern of A QRST, took place. It was suggested that the primary ST-T change was included in group C.

We conclude from this study that the QRS and ST-T isointegral maps are very useful to assess the degree of advance of LVH and the severe grade of LVH causes the alterations in intrinsic repolarization properties.

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