MORPHOLOGICAL CHARACTERISTICS OF HYPERTROPHIC CARDIOMYOPATHY ESTIMATED BY LEFT VENTRICULOGRAPHY

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To determine the common morphological characteristics of hypertrophic cardiomyopathy (HCM) by ventriculography from a right anterior oblique projection, diaphragmatic and free wall configurations were analyzed in 15 patients with obstructive HCM (HOCM), 32 patients with nonobstructive HCM (HNCM) and 17 controls. There was a convexity extending into the left ventricle in the right anterior oblique projection due to hypertrophy of the interventricular septum (IVS) in all patients with HCM. The peak convexity, where septal thickness was maximal (M point), was closer to the base in HOCM than in HNCM. Due to this convexity, the left ventricle showed a catenoid-shaped distortion at the M point. The distortion was severer in HOCM than in HNCM. Left ventricular free wall (LVFW) thickness was measured at the base and near the apex. LVFW thickness in HOCM decreased toward the apex, similar to that in controls, but in 17 of 32 HNCM (53%) LVFW thickness increased toward the apex. Cardiac index and stroke index in HCM were significantly smaller than those in controls. There was a significant correlation between the position of the M point and stroke index in HCM. These results indicate that a common morphological characteristic of HCM on the diaphragmatic side is the existence of a convexity extending into the left ventricle, and that cardiac performance in HCM is greatly influenced by the nature of the convexity. Myocardial abnormality seems to exist primarily at the base of the IVS in HOCM, and primarily in the lower part of the IVS and LVFW in HNCM.

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Since the first description of asymmetrical septal hypertrophy of the heart by Teare! several echocardiographic studies have been made regarding the left ventricular hypertrophic pattern in hypertrophic cardiomyopathy (HCM)2-3 There are great differences in the distribution of left ventricular hypertrophy among patients with HCM: Asymmetric septal hypertrophy is a very useful echocardiographic finding for the diagnosis of HCM, but it is also observed in other heart diseases4,5 and is not observed in some types of HCM6,7 Thus, common morphological characteristics of the left ventricle in

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Key words:
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HCM, as determined by echocardiographic methods, have not been established. Asymmetric septal hypertrophy has also been confirmed by biventriculographic cineangiography. As opposed to echocardiography, this angiographic method can provide complete information regarding left ventricular morphology in all subjects. Left ventriculogram from a left anterior oblique projection provides good information about left ventricular morphological characteristics. However, in the non-angled left anterior oblique projection, the apical and basal segments of interventricular septum (IVS) are either partially or completely superimposed. Therefore, to evaluate the left ventricle from a left anterior oblique view, cranial angulation must be added. A right anterior oblique projection can depict left ventricular configuration without distortion. Some characteristic shapes, such as "banana" shape and spade-like configuration have been found in the right anterior oblique view. However, common morphological configurations of HCM have still not been identified.

Therefore, the purpose of this study was to use left ventriculography in the right anterior oblique projection to determine whether or not the left ventricle in HCM exhibits common morphological characteristics and to examine whether distinct differences in left ventricular morphology exist between obstructive (HOCM) and nonobstructive (HNCM) types.

METHODS

Subjects

HCM group: This group consisted of 47 patients with HCM diagnosed according to the Manual for the Diagnosis of Idiopathic Cardiomyopathy in Japan. Patients with hypertension, significant coronary artery stenoses, valvular heart disease or other cardiac diseases were excluded from this study. Fifteen patients (14 men, 1 woman) were HOCM and 32 (27 men, 5 women) were HNCM. Four of 32 patients with HNCM showed apical hypertrophic cardiomyopathy. A diagnosis of HOCM was made when the patient had a pressure gradient greater than 20 mmHg in the left ventricular outflow tract without provocation. Asymmetric septal hypertrophy on echocardiogram was observed in 30 patients with HCM (64%). The mean age in HOCM was 50±8 years, and that in HNCM was 54±10 years.

Controls: Seventeen subjects (13 men, 4 women) served as controls. Six normotensive subjects and 11 hypertensive patients who experienced chest pain and had normal coronary arteries were included in this
Fig.2. Schematic representation of the measurements taken from left ventriculograms in normal control (A, A') and in hypertrophic cardiomyopathy (B, B').

Fig.3. Schematic representation of the measurement of the distortion index (θ). m1 and m2 are the midpoints of c-d and M-e, respectively.

The mean age was 54 ± 9 years. All subjects participated in the study only after they had given their informed consent.

Cardiac catheterization and left ventriculography
Routine cardiac catheterization and selective coronary cineangiography were performed using the Judkins technique. Left ventriculography at the 30 degree right anterior oblique position was performed in all subjects. To prevent extrasystole during left ventriculography, a 6F Cordis pigtail catheter was maintained so that the tip looped down and clockwise in the left ventricle. Thirty five ml of contrast medium were administered into the left ventricle at 12 to 15 ml per second. The recordings were made on 35 mm cine film exposed at 60 frames per second.

Cineangiographic analysis
The cine film was viewed on a Tage Arno projector and the cardiac cycle for the measurements was selected. Care was taken to avoid a cycle which occurred during or immediately after an extrasystolic contraction. The measurements of left ventricular wall morphological indices were taken from the end-diastolic film. The correction for the measurements was determined using a film strip of a 1 cm² grid.

Measurements of morphological indices: Fig.1 shows the left ventriculograms from the right anterior oblique position in a normal control (A) and in patients with HCM (B, C, D and E). The configuration of the diaphragmatic side, which reflects hypertro-
TABLE I  ECHOCARDIOGRAPHIC FINDINGS IN HCM AND CONTROL

<table>
<thead>
<tr>
<th></th>
<th>Age (yrs.)</th>
<th>LVDd (mm)</th>
<th>LVDs (mm)</th>
<th>IVS (mm)</th>
<th>PW (mm)</th>
<th>LAD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>54±9</td>
<td>45.8±2.7</td>
<td>30.4±1.9</td>
<td>9.4±1.8</td>
<td>10.2±1.6</td>
<td>32.6±4.1</td>
</tr>
<tr>
<td>HCM</td>
<td>54±9</td>
<td>45.8±2.7</td>
<td>30.4±1.9</td>
<td>9.4±1.8</td>
<td>10.2±1.6</td>
<td>32.6±4.1</td>
</tr>
<tr>
<td>HNCM</td>
<td>54±10</td>
<td>46.5±4.7</td>
<td>28.7±5.7</td>
<td>18.2±4.4</td>
<td>11.7±2.7</td>
<td>38.1±6.5</td>
</tr>
<tr>
<td>HOCM</td>
<td>50±8</td>
<td>42.8±4.1#</td>
<td>24.9±5.7*#</td>
<td>18.5±5.4*</td>
<td>11.7±3.5</td>
<td>40.0±5.1*</td>
</tr>
</tbody>
</table>

Abbreviations: LVDd, left ventricular diastolic dimension; LVDs, left ventricular systolic dimension; IVS, interventricular septum; PW, posterior wall; LAD, left atrial dimension.
All values are mean±SD. **p<0.01, *p<0.05 vs Control, #p<0.05 vs HOCM.

TABLE II  MORPHOLOGICAL FINDINGS IN HCM AND CONTROL

<table>
<thead>
<tr>
<th>morphological measurements</th>
<th>cardiac performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>l₁ (cm) l₂ (cm) l₃ (cm) r (cm) Th₁ (mm) Th₂ (mm) PG (mmHg)</td>
<td>CI (l/min/m²) SI (mll/m²)</td>
</tr>
<tr>
<td>Control (n=17)</td>
<td></td>
</tr>
<tr>
<td>10.1 7.96</td>
<td>3.88</td>
</tr>
<tr>
<td>0.80 1.12</td>
<td>0.43</td>
</tr>
<tr>
<td>HCM (n=32)</td>
<td></td>
</tr>
<tr>
<td>10.3 8.18</td>
<td>3.04*</td>
</tr>
<tr>
<td>1.49 1.37 1.33 1.05 3.6 4.4</td>
<td>0.78</td>
</tr>
<tr>
<td>HNCM (n=28)</td>
<td></td>
</tr>
<tr>
<td>10.3 7.81 3.17# 5.93 17.0**</td>
<td>2.71**</td>
</tr>
<tr>
<td>HOCM (n=15)</td>
<td></td>
</tr>
<tr>
<td>1.23 1.13 0.69 0.89 5.0 4.4</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Abbreviations: PG, peak pressure gradient in left ventricle; CI, cardiac index; SI, stroke index.
All values are mean±SD. **p<0.01, *p<0.05 vs Control, #p<0.01, #p<0.05 vs HNCM.

Fig.4. Comparison of the l₁/l₂ ratio (left) and the distortion index (right) in HNCM and HOCM.

phy of the IVS, presents a gentle round shape in the control, while that in the HCM patients is convex extending into the left ventricle due to hypertrophy of the IVS, as shown by the arrows. This is the typical morphology of the diaphragmatic side of the left ventriculogram of HCM as assessed by left ventriculography from the right anterior oblique position. Therefore, we considered the top of the convexity (arrow), where the septal side thickness was maximum (M point), as one of the standards for morphological measurements of the left ventricle. Fig. 2 shows the method used to calculate the

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Fig. 5. Relationship between the $l_1/l_2$ ratio and the distortion index in HNMC (closed circle) and HOCM (opened circle). $y = 0.77 - 0.0067x$, $r = 0.62$, $p < 0.01$.

morphological indices from the right anterior oblique left ventriculogram (A, $A' =$ normal control, B, $B' =$ HCM). To estimate the hypertrophy of the diaphragmatic side of the IVS, the following indices were measured: (1) $l_1$ (long axis) = the line from the midpoint of the aortic sinuses (a, b) to the apex (f), (2) $r$ (short axis) = the line perpendicular to $l_1$ which passes through the posterosuperior process ($c$), (3) $l_2$ = the line from the intersection of $l_1$ and $r$ to the apex, (4) $l_3$ = the line from the intersection of $l_1$ and the line M-e, which is the line parallel to $l_1$ which passes through the M point, (5) the $l_3/l_2$ ratio was measured to verify the position of the M point from the base of the IVS, (6) the distortion index ($\theta$): the distortion index was the angle between the line $m_1-m_2$ and the line $m_2-f$, where $m_1$ and $m_2$ are the midpoints of $r$ and the line M-e, respectively (Fig. 3).

In addition, to estimate hypertrophy in the left ventricular free wall, the wall thickness was measured at two points: $Th_1 =$ wall thickness at two-fifths of $l_1$ from the base, $Th_2 =$ wall thickness at one-fifth of $l_1$ from the apex (Fig. 2). The $Th_2/Th_1$ ratio was also calculated.

**Measurement of cardiac output**

Cardiac output (CO) and stroke volume (SV) were measured by the dye-dilution method using a cuvette densitometer according to the method of Stewart-Hamilton in 40 patients with HCM and 17 controls. Cardiac index (CI) and stroke index (SI) were calculated as $CI = CO/body$ surface area, $SI = CI/heart$ rate.

**Echocardiography**

The wall thickness and left ventricular end-diastolic dimension were measured with an ultrasound beam passing through the left ventricle just caudal to the tips of the mitral leaflets at the R wave of a simultaneously recorded electrocardiogram. The left ventricular end-systolic dimension was also measured at the initial component of the second heart sound according to the Penn method.

**Statistical analysis**

All values are presented as the mean±SD. Differences between subgroups were assessed by an analysis of variance, and subsequent comparisons were made using Scheffe's F test. The unpaired t test was used to compare two groups. Linear regression analysis was used to determine whether re-

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lationships existed between variables. Differences with P values of 0.05 were considered significant.

RESULTS

Patient profiles and data in each group are summarized in Tables I and II.

LVDDd and LVDs in HOCM were significantly smaller than those in HNCM. LAD in both HOCM and HNCM was significantly larger than that in the control (Table I). CI and SI in both HNCM and HOCM were smaller than those in the control group (Table II).

There were no significant differences in l1 (long axis), l2 or r (short axis) between the three groups. However, there was a significant difference in l3, which reflects the position of the M point, between HOCM and HNCM. Thus, as shown in Fig. 4 (left), the l3/l2 ratio was significantly greater in HNCM than in HOCM. The l3/l2 ratio in almost all of the patients with HOCM was less than 0.5. Distortion index (θ) of HOCM was significantly greater than that of HNCM (Fig. 4, right). Fig. 5 shows the relation between the l3/l2 ratio and the distortion index (r=0.62, p<0.01). The four patients without distortion represent apical hypertrophic cardiomyopathy.

Fig. 6 shows representative patterns of the left ventricular free wall. A, B and C were taken in patients with pressure gradient in the outflow tract, midventricular obstruction and no pressure gradient, respectively. Wall thickness in A decreased gradually toward the apex, but those in B and C increased toward the apex. Fig. 7 shows the Th2/Th1 ratio in each group. The Th2/Th1 ratio in HOCM was identical to that in the control group, but that in HNCM was larger than those in HOCM and the control group. The Th2/Th1 ratios in the control group and HOCM were less than 1.0 in almost all cases, but in 17 of 32 HNCM (53%) the Th2/Th1 ratio was more than 1.0.

CI and SI in both HNCM and HOCM were smaller than those in the control group (Table II). In addition, SI in HOCM was smaller than that in HNCM. Fig. 8 shows the relation between SI and the l3/l2 ratio in HCM (r=0.50, p<0.01).

DISCUSSION

On the diaphragmatic side of the left ventriculogram, protrusion of the IVS toward the left ventricle due to myocardial hypertrophy was found to be a common morphological characteristic of HCM. In addition, due to protrusion of the IVS, left ventricular configuration is distorted at the M point. There is also difference between the patterns of myocardial hypertrophy of the LVFW in HOCM and HNCM. The thickness of the LVFW in HOCM decreased toward the apex, as in the control group, while in 53% of HNCM, LVFW thickness increased.

The difference in the position of the M point, which is the peak point of the protrusion, was the most conspicuous difference between HOCM and HNCM. A high M point (i.e., further from the apex) is necessary for a pressure gradient in the left ventri-
The high M point in HOCM produces a marked hypertrophy of the IVS near the base of the left ventricle. The leaflets of the mitral valve in patients with a high M point contact the IVS, which generates a pressure gradient. Thus, a high M point is necessary to generate a pressure gradient. Hutchins and co-workers\textsuperscript{3,14} have reported that patients with idiopathic hypertrophic subaortic stenosis have catenoid-shaped IVS due to marked myocardial hypertrophy. Based on biventricular cineangiographic data, Redwood et al\textsuperscript{8} reported that the left ventricular endocardial surface of the septum in patients with HCM was straight or bulged into the left ventricular chamber, and that septal width increased significantly inferiorly. Our results confirmed and extended the finding of Hutchins and co-workers. IVS protrusion into the left ventricle, i.e., a catenoid shape, was also observed in left ventriculograms from the right anterior oblique projection. In addition, the catenoid shape was observed in both HOCM and HNCM. The exact nature of the catenoid shape depends upon the position of the M point, as shown in Fig. 1. In patients with higher M points, the catenoid shapes are more pronounced. In most HOCM patients, the configuration of the entire diaphragmatic side shows a catenoid shape, as shown in Fig. 1. In addition, the left ventricle is distorted at the M point by the protrusion. The distortion of the left ventricle increases in patients with higher M points. In other words, the distortion is severer in HOCM than in HNCM. This abnormal morphology on the diaphragmatic side may influence the systolic function in patients with HCM. Hutchins and Bulkley\textsuperscript{14} suggested that the dynamics of the IVS observed in idiopathic hypertrophic subaortic stenosis (IHSS) was due to isometric contraction associated with its catenoid shape. Regional function in HCM, as measured by echocardiography, is not uniform, with the IVS being hypodynamic\textsuperscript{15,16}. In the present study, the IVS in all of the patients with HCM was catenoid-shaped. As shown in Fig. 1, in cases B and C, where the M point (arrow) is close to the base, the convexity extends over almost the entire IVS. On the other hand, in D and E, where the M point is close to the apex, the convexity is confined to the apex, and the IVS is concave from the middle to the base, as in the control (A). In other words, the range of the convexity of the IVS depends upon the position of the M point, as expressed by the I\textsubscript{1}/I\textsubscript{3} ratio. Thus, our finding that a catenoid shape exists in almost all of the HCM patients adequately explains the hypodynamic function of the IVS.

Fig. 8 suggests that cardiac performance is considerably influenced by the position of the M point. As shown in Fig. 1, left ventricular volume is usually less in patients with higher M points than in patients with lower M points. Therefore, the decrease in left ventricular volume associated with the protrusion due to myocardial hypertrophy may be responsible for the low CI and SI in patients with HCM. In this regard, it is reasonable that CI and SI in HOCM were smaller than those in HNCM. In addition, the distortion may impede ejection from the distal chamber of the left ventricle.

The left ventricular free wall thickness in most patients with HOCM decreased toward the apex, as in the control group. However, in 17 of 32 HNCM patients (53%), LVFW thickness increased toward the apex. In many patients, it is difficult to determine LVFW thickness at the apex by left ventriculogram from the right anterior oblique projection due to halation. If free wall thickness is measured at the apex rather than at one-fifth of I\textsubscript{1} from the apex, where LVFW was measured in this study, then the TH\textsubscript{2}/TH\textsubscript{1} ratio should decrease further in patients with HOCM, and increase further in patients with HNCM (Fig. 7). This finding may suggest that there is a qualitative difference between myocardial hypertrophy in the free wall in HOCM and HNCM. Considering that the LVFW pattern in HOCM is the same as that in the control group, the increase in LVFW thickness observed in HOCM may be due primarily to secondary myocardial hypertrophy to compensate for the hypomovement of the IVS. On the other hand, the increase in free wall thickness, especially near the apex, in patients with HNCM may be strongly related to primary myocardial hypertrophy. Maron and co-workers\textsuperscript{17,18} reported that cellular abnormalities in HOCM were limited to the IVS, while HNCM showed abnormalities in the IVS and the LVFW. This agrees with our findings using left ven-

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triculography from the right anterior oblique projection.

In conclusion, myocardial abnormalities exist mainly near the base of the IVS in HOCM, and mainly in the lower part of the IVS and LVFW in HNCM. Cardiac performance in HCM is considerably influenced by the extent of the cationoid shape on the diaphragmatic side.

REFERENCES

1. TEARE D: Asymmetrical hypertrophy of the heart in young adults. Br Heart J 1958; 20: 1—8
7. LOUIE EK, MARON BJ: Hypertrophic cardiomyopathy with extreme increase in left ventricular wall thickness: functional and morphologic features and clinical significance. J Am Coll Cardiol 1986; 8: 57—65