Diagnostic Usefulness of Carotid Pulse Tracing in Patients With Hypertrophic Obstructive Cardiomyopathy Due to Midventricular Obstruction*

A Comparison With Idiopathic Hypertrophic Subaortic Stenosis

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Study objectives: Of the hypertrophic obstructive cardiomyopathies, midventricular obstruction (MVO) often has been overlooked. In this study, hemodynamic parameters in patients with MVO were compared with patients with idiopathic hypertrophic subaortic stenosis (IHSS), following which the specific markers for diagnosis of MVO were examined.

Patients and design: Twenty healthy control subjects (mean ± SD age, 54 ± 8 years), 20 patients with MVO (mean age, 54 ± 13 years), and 12 patients with IHSS (mean age, 58 ± 12 years) participated in this study. Hemodynamic parameters associated with carotid pulse tracing (CPT) and echocardiography were examined.

Measurement and results: Left ventricular ejection time (LVET) and left ventricular pressure gradient (LVPG) were greater in patients with IHSS than in patients with MVO (p < 0.0001 for both). However, left ventricular dimensions and interventricular septal thickness did not vary between patients with MVO and those with IHSS. As specific markers for the diagnosis of patients with MVO, two specific CPT patterns, the “spike-and-dip pattern” and the “spike-and-half-dome pattern,” were identified, but no specific markers were observed echocardiographically. Among patients with MVO, both LVPG and LVET were greater in patients with the spike-and-half-dome pattern than in patients with the spike-and-dip pattern (113 ± 34 vs 57 ± 17 mm Hg, respectively [p < 0.0001]; 318 ± 19 vs 281 ± 27 ms, respectively [p = 0.0033]), but echocardiographic parameters revealed no significant differences between the two types of MVOs. The pattern of continuous-wave Doppler recordings of the left ventricle in patients with the spike-and-half-dome pattern was identical to that of patients with IHSS, but that of patients with the spike-and-dip pattern exhibited concavity from the onset of systole to the point of maximal velocity.

Conclusions: Two specific patterns for the diagnosis of patients with MVO were identified by CPT. These patterns may be strongly related to differences in ejection dynamics.

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Key words: carotid pulse tracing; echocardiography; hypertrophic cardiomyopathy; left ventricular pressure gradient; midventricular obstruction

Abbreviations: CPT = carotid pulse tracing; HCM = hypertrophic cardiomyopathy; HOCM = hypertrophic obstructive cardiomyopathy; IHSS = idiopathic hypertrophic subaortic stenosis; LVEDD = left ventricular end-diastolic dimension; LVESD = left ventricular end-systolic dimension; LVET = left ventricular ejection time; LVPG = left ventricular pressure gradient; MVO = midventricular obstruction; PEP = preejection period; SAM = systolic anterior motion of the mitral valve

It is well-known that there are two types of hypertrophic obstructive cardiomyopathy (HOCM). One is obstruction at the subaorta, which is called idiopathic hypertrophic subaortic stenosis (IHSS), and the other is the obstruction at mid left ventricle. A large number of studies concerning HOCM due to IHSS have been reported, but only a few studies have investigated HOCM due to midventricular obstruction (MVO), except in case reports. In the clinical setting, MVO may often be missed in patients. A “spike-and-dome pattern” seen on carotid pulse tracing (CPT) and systolic anterior motion of
the mitral valve (SAM)\textsuperscript{4} seen on an echocardiogram are known to be specific markers for IHSS. However, no specific markers for MVO have been reported.

Left ventricular pressure gradient (LVPG) is known to disturb ejection dynamics and is also known to have an impact on the prognosis of patients with hypertrophic cardiomyopathy (HCM).\textsuperscript{5} Several intervention therapies to attenuate LVPG have been performed successfully in patients with IHSS.\textsuperscript{6–10} However, the few intervention therapies such as myectomy and alcohol septal ablation may have limited effectiveness in attenuating LVPG in patients with MVO, because of an induction or deterioration of mitral regurgitation. Hintringer et al\textsuperscript{11} reported an 85-year-old woman with MVO whose LVPG and symptoms were alleviated by permanent dual-chamber atrioventricular pacing. However, one of two patients who were first reported by Falicov et al\textsuperscript{2} died suddenly shortly after undergoing an unsuccessful myectomy. In view of these findings, it is important to find specific markers for the diagnosis of patients with MVO and also to find appropriate therapies for patients with MVO.

In this study, therefore, we first examined the hemodynamic differences between patients with MVO and patients with IHSS, and subsequently searched for specific markers due to CPT and echocardiography for the diagnosis of patients with MVO.

**Study Subjects**

Twenty healthy control subjects and 32 patients with HOCM participated in this study after giving informed consent. Patients with HOCM were subdivided into two groups, one consisting of 20 patients with MVO, and the other of 12 patients with IHSS. A diagnosis of HCM was made based on the World Health Organization/International Society and Federation of Cardiology definition of cardiomyopathies.\textsuperscript{12} SAM was observed in all patients with IHSS but was not observed in patients with MVO. HOCM was diagnosed when an HCM patient had an LVPG of > 30 mm Hg without provocation. In this study, there was no patient with MVO associated with a pattern of apical infarction.\textsuperscript{11,14} All patients with MVO have some clinical symptoms including palpitation, angina, malaise, presyncope, and syncope. In patients with MVO, 10 patients had been treated with both β-blockers and calcium antagonists, 8 had been treated with β-blockers, and 2 had been treated with calcium antagonists. One patient had chronic atrial fibrillation, and two patients had transient atrial fibrillation, and had been treated with warfarin and digoxin.

**Study Protocol**

To elucidate the hemodynamic differences between patients with MVO and patients with IHSS, hemodynamic parameters determined by CPT and echocardiography were compared. Next, to find specific markers for patients with MVO, hemodynamic parameters from CPT and echocardiography were examined.

**M-Mode and Doppler Echocardiographic Studies**

Echocardiographic studies were carried out with an echocardiograph that had a 3.5-MHz transducer for two-dimensional and M-mode examinations and a 2.5-MHz transducer for continuous Doppler measurements (SSD-9000; ALOKA Inc; Tokyo, Japan). After the confirmation of cardiac anatomy using two-dimensional echocardiography, the following parameters were measured from M-mode echocardiographic recordings, according to the guidelines of both the American Society of Echocardiography\textsuperscript{15} and the Penn Convention\textsuperscript{16}: interventricular septal thickness; left ventricular posterior wall thickness; left ventricular end-diastolic dimension (LVEDD); left ventricular end-systolic dimension (LVESD); and fractional shortening. LVPG was measured from continuous-wave Doppler recordings at mid-ventricle and at the left ventricular outflow tract.\textsuperscript{17} In addition, patterns of continuous-wave Doppler recordings were examined in patients with MVO and IHSS. Peak A-wave and peak E-wave velocities and E-wave/A-wave ratios also were measured from transmitral Doppler flow recordings. M-mode echocardiogram and continuous-wave Doppler echocardiogram were recorded at a paper speed of 100 mm/s.

**Studies of CPTs**

CPT can detect disturbances of left ventricular ejection dynamics with high sensitivity. A “spike-and-dome pattern” on a CPT is a specific pattern in patients with IHSS, and the duration of left ventricular ejection time (LVET) is closely related to the severity of LVPG.\textsuperscript{15} However, to our knowledge, the examination of CPTs in patients with MVO has never been performed. In this study, we examined whether there were specific morphologic patterns on CPTs for the diagnosis of MVO. In addition to examining the pattern of CPTs, simultaneous recordings of ECGs, phonocardiograms, and CPTs were performed at a paper speed of 100 mm/s (Polygraph System; Nihon Kohden Co, Ltd; Tokyo, Japan) to measure electromechanical systole, LVET, and pre-ejection period (PEP) duration. Phonocardiograms and CPTs were recorded (TA-701T and TF-601T transducers; Nihon Kohden Co, Ltd) with a time constant of 3 ms. The recordings were performed with the patients in the left decubitus position and with their breathing at expiratory cessation, in accordance with a previously reported method\textsuperscript{19} and the systolic time intervals mentioned earlier were corrected for heart rate.\textsuperscript{20}

**Statistical Analysis**

All values are expressed as the mean ± SD. Statistical comparisons for hemodynamic parameters among healthy control subjects, patients with IHSS, and patients with MVO were carried out by one-way analysis of variance with subsequent Scheffe multiple range test. A value of p < 0.05 was considered to be significant.
We analyzed the patterns on CPT in all subjects. Figure 2 shows the representative patterns of a healthy control subject (A), a patient with HOCM (C), and patients with MVO (middle left, B) and patients with IHSS (middle right, D). In contrast to the pattern of healthy control subjects and patients with MVO, the dip-type pattern was observed in 8 patients with IHSS. Midsystolic decline and flat pattern and a half-dome type were observed in 8 patients with MVO. A half-dome type was observed in 4 patients with IHSS. Those patterns of CPTs in each type of HOCM were depicted to overlap the diagram in Figure 3. In contrast to the pattern of healthy control subjects, all patients with HOCM showed a very rapid upstroke. In addition, all patients with MVO and those in patients with IHSS showed a spike-and-dome pattern of CPTs in each type (Fig 2, middle left, B). A patient with IHSS showed a very rapid upstroke. In addition, all patients with MVO, the dip-type pattern was observed in 12 patients with IHSS, except for left ventricular posterior wall thickness.

Both LVET and LVET index showed no significant differences between healthy control subjects and patients with MVO and IHSS, but those in patients with MVO and IHSS were much longer than those in the other two groups. Both PEP and PEP index also showed no significant differences between healthy control subjects and patients with MVO and IHSS. LVPG at rest was markedly greater in patients with IHSS than in patients with MVO and IHSS. Fractional shortening, interventricular septal thickness, and left ventricular posterior wall thickness were smaller and thinner in patients with MVO and IHSS than in patients with IHSS and MVO. Other echocardiographically determined parameters among hemodynamic parameters among healthy control subjects and patients with MVO and IHSS were greater in healthy control subjects than in patients with MVO and IHSS. Both LVEDD and LVESD were greater in healthy control subjects than in patients with MVO and IHSS. Fractional shortening, interventricular septal thickness, and left ventricular posterior wall thickness were smaller and thinner in patients with MVO and IHSS than in patients with IHSS and MVO. Other echocardiographically determined parameters among healthy control subjects and patients with MVO and IHSS were greater in healthy control subjects than in patients with MVO and IHSS.

### Table 1—Comparisons of Hemodynamic Parameters Among Healthy Control Subjects, Patients With HOCM due to MVO, and Patients With IHSS*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Age, yr</th>
<th>HR, beats/min</th>
<th>LVPG, mm Hg</th>
<th>LVEDD, mm</th>
<th>LVESD, mm</th>
<th>FS, %</th>
<th>IVST, mm</th>
<th>LVPWT, mm</th>
<th>LVET, ms</th>
<th>LVET Index, ms</th>
<th>PEP, ms</th>
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<td>HCS (n = 20)</td>
<td>54 ± 8</td>
<td>61 ± 7</td>
<td>47.5 ± 2.7</td>
<td>3.06 ± 3.5</td>
<td>35.7 ± 5.3</td>
<td>7.6 ± 0.9</td>
<td>7.8 ± 0.8</td>
<td>284 ± 11</td>
<td>386 ± 10</td>
<td>118 ± 8</td>
<td>157 ± 10</td>
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<tr>
<td>MVO patients (n = 20)</td>
<td>54 ± 13</td>
<td>57 ± 8</td>
<td>41.4 ± 4.4</td>
<td>20.5 ± 4.5</td>
<td>50.8 ± 7.8</td>
<td>20.9 ± 3.2</td>
<td>14.1 ± 2.7</td>
<td>296 ± 30</td>
<td>390 ± 27</td>
<td>114 ± 13</td>
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<tr>
<td>IHSS patients (n = 12)</td>
<td>58 ± 12</td>
<td>59 ± 7</td>
<td>158 ± 54</td>
<td>39.9 ± 5.8</td>
<td>20.5 ± 4.3</td>
<td>49.0 ± 6.9</td>
<td>21.8 ± 4.1</td>
<td>162 ± 28</td>
<td>357 ± 45</td>
<td>453 ± 44</td>
<td>101 ± 16</td>
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*p Values:
- HCS vs MVO patients: 0.4986, 0.3011
- HCS vs IHSS patients: 0.0796, 0.3592
- MVO vs IHSS patients: 0.2891, 0.9270

Table 1 shows the comparisons of hemodynamic parameters among healthy control subjects, patients with MVO, and patients with IHSS.

*Values given as mean ± SD, unless otherwise indicated. HR = heart rate; FS = fractional shortening; IVST = interventricular septal thickness; LVPWT = left ventricular posterior wall thickness; HCS = healthy control subjects.
structed by a fast rise immediately followed by a fast fall of the CPT. In the dip type of MVO, a systolic bulge disappeared after the spike occurred. In patients with the half-dome type of MVO, systolic bulge after the spike was seen, but a “cleft,” which had been observed in IHSS patients, was not observed.

Figure 4 shows the patterns of continuous-wave Doppler recordings in a patient with IHSS (left, A), in a patient with dip-type MVO (middle, B), and a patient with half-dome type MVO (right, C). The pattern in the patient with the half-dome type MVO was almost identical to that in a patient with IHSS. In these patients, the flow speed changed clearly at the early systolic to midsystolic phase. Thus, in these patients a point of inflection existed between the early systolic and midsystolic phase, as indicated by the arrow. On the other hand, the pattern in patients with dip-type MVO remained concave from the onset of systole almost to the point

**Figure 1.** Relationship between LVPG and LVET in patients with IHSS (A [○]) and patients with MVO (B [○]).

**Figure 2.** Representative patterns of CPTs in a healthy control subject (left, A), a patient with IHSS (middle left, B), a patient with an MVO of the spike-and-dip type (middle right, C), and a patient with an MVO of the spike-and-half-dome type (right, D). a = dome pattern; b = dip pattern; c = half-dome pattern; PCG = phonocardiogram; ACG = apex cardiogram.
of maximal velocity. Thus, in this type of MVO, a point of inflection did not exist. In addition, the pattern of continuous-wave Doppler recording in the dip-type MVO shown in Figure 4 continued over the second heart sound. Figure 5 shows the change in the continuous-wave Doppler pattern before the oral administration of 200 mg cibenzoline (top, A) and 2 h after oral administration of 200 mg cibenzoline (bottom, B). After the administration of cibenzoline, the LVPG was markedly attenuated, and the continuous-wave Doppler pattern was separated. The first Doppler recording was finished before the second heart sound occurred.

Comparisons of Hemodynamic Parameters Between the Two Types of MVO

Table 2 shows the hemodynamic parameters due to CPT and echocardiogram in patients with the two types of MVOs. Both LVET and LVET index were longer in the half-dome type of MVO than in the dip type, and PEP and PEP index were both shorter in the half-dome type of MVO than in the dip type. LVPG was markedly greater in the half-dome type of MVO than in the dip type. Other echocardiographically determined parameters showed no significant differences between the two types of MVOs. Figure 6 shows the comparison of the site of intracavity obliteration between the dip-type MVO and the half-dome type. The images in Figure 6, top, A, are the four-chamber echocardiographic views of patients with dip-type MVO, and those in Figure 6, bottom, B, are those of patients with the half-dome type of MVO. In each panel, interval a is the distance between the mitral valve and the apex, and interval b is the distance between the mitral valve and the site of intracavity obliteration at end-diastole. As ob-
served in Figure 6, the site of intracavity obliteration was much closer to the base in patients with the half-dome type of MVO than in those with the dip type.

**Discussion**

The present study demonstrated for the first time that CPTs could delineate two specific patterns (i.e., the spike-and-dip pattern and the spike-and-half-dome pattern) for patients with HOCM due to MVO, but echocardiography could not find specific patterns for patients with MVO. The dip-type MVO in patients with MVO was characterized by a lower LVPG and a shorter LVET, and the half-dome type of MVO was characterized by a higher LVPG and a longer LVET. In view of these findings, we can diagnose HOCM with ease by using CPTs, especially in patients with MVO.

**Diagnosis of Patients With MVO**

It is not difficult to diagnose IHSS when a patient with HCM has a loud systolic murmur, a SAM seen on echocardiogram, and a spike-and-dome pattern seen on CPTs. However, MVO often may be overlooked in patients in the clinical setting. This may be because systolic murmurs in patients with MVO are usually not loud, such that SAM is not found in these patients. This may be one of the main reasons for there being many fewer studies of patients with MVO than of patients with IHSS. Two patients with MVO were first reported in 1976 by Falicov et al.\(^2\)

One of these two patients died suddenly after undergoing an unsuccessful myectomy. In view of this finding, the prognosis of patients with MVO may be severe. In the present study, two specific types of CPTs were observed in patients with MVO. Thus, we were able to diagnose MVO easily in these patients by using CPTs.

**Hemodynamic Differences Between Patients With MVO and Patients With IHSS**

In the present study, we compared for the first time the hemodynamic parameters between patients with IHSS and patients with MVO. LVPG was greater in most patients with IHSS than in patients with MVO. In echocardiographic studies, there were no significant differences in LVEDD, LVESD, and interventricular septal thickness between the two groups, except for thicker left ventricular posterior wall thickness in patients with IHSS. On the other hand, both LVET and LVET index were longer in patients with IHSS than in patients with MVO, and PEP index was shorter in patients with IHSS than in patients with MVO. There is a well-known good correlation between LVET and LVPG in patients with IHSS.\(^16\) In the present study, we also confirmed the good correlation between LVET and LVPG both in patients with IHSS and in patients with MVO. Thus, the longer LVET and LVET index in patients with IHSS than in patients with MVO may be mainly responsible for the higher LVPG in the former patients than in the latter.

Differences in LVPG and LVET between patients with IHSS and patients with MVO may be due to the sites of obstruction. Systolic obstruction in patients with IHSS is produced by systolic apposition of the mitral leaflet against the septum, and in patients with MVO is produced by muscular apposition in the midventricular area. Thus, a left ventricular distal chamber with high pressure may be larger in patients with IHSS than in patients with MVO.\(^13\) A larger distal chamber may generate larger left ventricular systolic pressure and longer LVET. This may be the main reason why LVET is longer in patients with IHSS than in patients with MVO.

**Two Specific Patterns on CPT in Patients With MVO**

All patients with HOCM showed a very rapid upstroke. This may be closely related to the low
value of wall stress in patients with HOCM. In this study, we show for the first time the great usefulness of CPTs for the diagnosis of MVO. Two specific patterns on CPTs for patients with MVO were found. One is the dip type, and the other is the half-dome type. To our knowledge, there has been no study describing the relationship between CPTs and HOCM due to MVO. In a textbook of cardiovascular medicine, Willerson described three different patterns of CPTs in patients with IHSS. In this text-book, as a phonocardiogram is not described together with CPTs, a dicrotic notch cannot be confirmed. We wonder whether the position of the dicrotic notch in the first example in the textbook by Willerson is accurate. If the dicrotic notch occurs earlier in the case of the patient shown in that book, the example is identical to that of the CPT of the patient seen in Figure 2, right middle, C, in our study.

There was a clear difference in the pattern seen on CPTs between dip-type and half-dome-type MVOs. In the dip-type MVO, a positive bulge during mid-systole to end-systole on CPTs was not observed, and the CPT pattern during this period became flat, reflecting less blood flow during this period. In the half-dome type MVO, a bulge during mid-systole to end-systole on CPTs was observed. However, in contrast to the pattern in patients with IHSS, the cleft between the spike and bulge was very shallow or not observed. Thus, we named this pattern half-dome type. The LVPG at rest was higher in the patient with the half-dome type of MVO than in the dip type. In echocardiographic parameters, there was no significant difference between the two types of MVOs. However, there were marked differences in systolic time intervals between the two types. Both LVET and LVET index were shorter in the dip-type MVO than in the half-dome type, and both PEP and PEP index were longer in the dip-type MVO than in the half-dome type. The longer LVET in the half-dome type MVO may be due to the higher LVPG.

Differences in CPT patterns between the two types of MVOs may depend mainly on the position of the obstruction in the left ventricle, as shown in Figure 6. The position of the obstruction in patients with the dip type of MVO may be close to the apex, while the obstruction in patients with the half-dome type of MVO may be due to the higher LVPG.

### Table 2—Mechanocardiographic and Echocardiographic Parameters in Patients With MVOs*

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<tr>
<th>Patient No.</th>
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<th>SBP, mm Hg</th>
<th>DBP, mm Hg</th>
<th>Q-II, ms</th>
<th>LVET, ms</th>
<th>PEP, ms</th>
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*SBP = systolic BP; DBP = diastolic BP; Q-II = electromechanical systole; NS = not significant; E Vel = E-wave velocity; A Vel = A-wave velocity. See Table 1 for abbreviations not used in the text.
and therefore the distal chamber size may be small. The small distal chamber size may be related to the relatively lower LVPG and the shorter LVET. In contrast, the position of the obstruction in the patient with the half-dome type of MVO may be close to the base, and therefore the distal chamber size in the patient with the half-dome type of MVO may be larger than in the patient with the dip-type MVO. Thus, LVPG is higher and LVET is longer in patients with the half-dome type of MVO than in those with the dip type, and thus, the pattern of CPTs in the half-dome type is close to that in patients with IHSS.

Continuous-Wave Doppler Patterns in Patients With MVO

Patterns of continuous-wave Doppler recordings in patients with mitral regurgitation and aortic stenosis are usually symmetric, but those in almost all patients with HOCM are not. In addition, the present study elucidated a marked difference in continuous-wave Doppler recording patterns between patients with half-dome-type MVOs and patients with dip-type MVOs. As mentioned before, the continuous-wave Doppler pattern in a patient with the half-dome type of MVO was almost identical to that in a patient with IHSS. Thus, the patterns on CPTs in patients with the half-dome type of MVO was close to that in patients with IHSS. On the other hand, the pattern of continuous-wave Doppler recordings in patients with dip-type MVOs showed concavity from the onset of systole to the point of maximal velocity. The exact mechanism underlying this observation remains to be determined. In view of the findings that CPT at the mid-to-late systolic phase is flat and that LVET is short in patients with dip-type MVOs, a very small volume of ejection blood in the distal chamber may be related to the concave pattern seen in continuous-wave Doppler recordings. In addition, as shown in Figure 4, middle, B, the continuous-wave Doppler flow recording in patients with dip-type MVOs continued over the second heart sound. However, this continuous-wave Doppler flow recording was markedly changed after the patient received treatment with the antiarrhythmic drug cibenzoline. As shown in Figure 5, in addition to the marked attenuation of LVPG, the Doppler flow pattern was separated at the point of the second heart sound. Thus, the continuous-wave Doppler flow pattern in patients with dip-type MVOs may include, in part, a paradoxical diastolic flow.

References

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