Objectives. The aim of this study was to examine the value of dynamic three-dimensional (3D) transesophageal echocardiography (TEE) for the postoperative evaluation after extended myectomy and surgical reconstruction of the subvalvular mitral valve apparatus in patients with hypertrophic obstructive cardiomyopathy (HOCM).

Background. Two-dimensional imaging techniques such as echocardiography, computed tomography and magnetic resonance imaging have not been able to precisely quantify the effects of surgical therapy on the morphology of the left ventricular outflow tract (LVOT).

Methods. Multiplane TEE with 3D reconstruction was performed in 11 patients before and after the operation and in 16 normal control subjects for comparison. The preoperative maximal systolic pressure gradient in the LVOT was 69 ± 59 mm Hg. The following variables were measured within the dynamic 3D data set: depth, width, length and cross-sectional area (CSA) gain caused by the myectomy trough, minimal CSA of the LVOT at each time point and its cyclic changes and maximal mitral leaflet deviation during systole.

Results. Functional class improved from 3.0 ± 0.2 before the operation to 1.5 ± 0.6 after it. The maximal systolic pressure gradient in the outflow tract decreased to 26 ± 21 mm Hg postoperatively (p < 0.001). Minimal CSA of the outflow tract increased from 1.1 ± 1.2 to 3.8 ± 1.9 cm² postoperatively (p < 0.001), similar to the value of the control group (4.2 ± 1.5 cm², p = NS). The area gain due to the myectomy trough was 1.3 ± 1.0 cm², corresponding to 48 ± 12% of the total operative area difference. Maximal systolic depth of the myectomy was 7 ± 2 mm, maximal width was 20 ± 8 mm and length was 28 ± 7 mm. Maximal deviation of the mitral leaflets fell from 15 ± 7 to 6 ± 7 mm postoperatively (p < 0.01). In five patients mass measurements of the intracavitary portion of the papillary muscle (PM) revealed an increase from 7.3 ± 1.0 to 12.1 ± 2.5 g due to surgical mobilization of PMs (p < 0.01).

Conclusions. 3D TEE quantifies the differences in outflow tract morphology before and after surgery for HOCM. This technique may have an impact on the planning of operative interventions and allow for the evaluation of its results.

Dynamic obstruction of the left ventricular outflow tract (LVOT) in hypertrophic cardiomyopathy (HOCM) is a complex phenomenon based on a combination of left ventricular (LV) morphologic abnormalities and hemodynamic alterations. There is general agreement that asymmetric hypertrophy of the basal septum and reduced cavity dimensions represent the major determinants of the disease (1–3). Other factors contributing to LVOT obstruction include mitral valve malformations (4,5) and malpositioning of the subvalvular apparatus due to hypertrophied papillary muscles (PMs) (6,7). The relative importance of each of these factors for the occurrence of LVOT obstruction is still not fully understood. Echocardiography is the noninvasive method of choice for the evaluation of morphologic and functional abnormalities in HOCM (8,9). Two-dimensional (2D) and Doppler studies allow only limited quantitative evaluation with regard to the degree of local septal thickness, distribution of hypertrophy (8,9) and extension and size of the LVOT (10).

In symptomatic patients with severe outflow tract obstruction at rest or during provocation despite adequate medical therapy, surgical interventions are indicated (11). Different operative techniques have been used to abolish outflow obstruction (12–19). The standard technique is still transaortic septal myotomy-myectomy (11,15,17).

Recently, a more comprehensive approach with extended
myectomy and reconstruction of the subvalvular mitral apparatus has been reported with excellent early hemodynamic and long-term clinical results (20,21). Because of the lack of an adequate animal model to analyze the effects of a new surgical technique, echocardiography is of paramount importance for the evaluation of alterations brought on by surgically repairing the complex morphology of HOCM. Until now, 2D echocardiography allowed for the qualitative evaluation of postoperative results (enlargement of LVOT and LV cavity, relief of systolic anterior motion [SAM] and outflow tract obstruction) (14,18), based on standardized cross-sectional image planes, and correlated well with clinical outcome (21). However, quantitative analysis is limited owing to the difficulties in describing the complex three-dimensional (3D) appearance of the LVOT, the subvalvular structures and their rapid dynamic changes.

3D transesophageal echocardiography (TEE), as an evolving diagnostic tool, has the potential to overcome these limitations using a complete 3D data set and offers the opportunity for exact quantitative analysis. The aim of this study was to examine the value of dynamic 3D TEE for the quantitative assessment of preoperative and postoperative morphology of the LVOT and the subvalvular mitral apparatus.

**Methods**

**Selection of patients.** The study group consisted of 11 patients undergoing surgical treatment for HOCM at the University Hospital Aachen between 1994 and 1996. Diagnosis of HOCM was based on the presence of a hypertrophied nondilated LV in the absence of other cardiac or systemic diseases capable of producing the magnitude of hypertrophy present in these patients. In addition, each patient had characteristic clinical symptoms of severe HOCM, such as syncope, angina or dyspnea of at least New York Heart Association functional class III, combined with a significant outflow obstruction as assessed by Doppler or invasive measurements with a peak gradient >40 mm Hg at rest or after provocation despite medical therapy (Table 1).

Basal septal thickness measured from a transthoracic echocardiogram according to the recommendations of the American Society of Echocardiography (22) and calculated from the formula:

\[ s = \frac{B - C}{2} \]

where \( s \) is the basal septal thickness, \( B \) is the width of the basal septal region and \( C \) is the width of the left ventricular cavity. In the plane of the mitral annulus, the thickness of the interventricular septum and the anterior mitral leaflet were measured and averaged to get the basal septal thickness.

**Table 1. Clinical, Echocardiographic and Hemodynamic Characteristics of the Patient Group**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Gender</th>
<th>Age (years)</th>
<th>NYHA Functional Class</th>
<th>Preoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>44</td>
<td>III</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>68</td>
<td>III</td>
<td>26</td>
<td>8</td>
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<tr>
<td>3</td>
<td>M</td>
<td>60</td>
<td>IV</td>
<td>30</td>
<td>10</td>
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<tr>
<td>4</td>
<td>F</td>
<td>69</td>
<td>III</td>
<td>30</td>
<td>10</td>
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<td>5</td>
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<td>60</td>
<td>III</td>
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<td>65</td>
<td>III</td>
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<td>M</td>
<td>57</td>
<td>III</td>
<td>20</td>
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<td>M</td>
<td>60</td>
<td>III</td>
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<td>9</td>
<td>M</td>
<td>64</td>
<td>III</td>
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<td>10</td>
<td>M</td>
<td>46</td>
<td>III</td>
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<td>F</td>
<td>32</td>
<td>III</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>56 ± 14</td>
<td>3.2 ± 0.2</td>
<td>66 ± 9</td>
<td>141 ± 70</td>
</tr>
</tbody>
</table>

*According to Seller et al. (23). LVEDP = left ventricular end-diastolic pressure; LVOT = left ventricular outflow tract; NYHA = New York Heart Association.
can Society of Echocardiography (22) ranged from 15 to 32 mm (mean ± SD 24 ± 6). All patients were in sinus rhythm. Systolic pressure gradients within the LVOT were evaluated preoperatively and postoperatively using continuous wave Doppler flow measurements from the apical transthoracic echocardiographic window. In addition, each patient underwent invasive hemodynamic assessment and coronary angiography within 2 months of the operation, including direct measurement of the intraventricular gradient and LV end-diastolic and pulmonary pressures. Significant coronary artery disease and aortic valvular disease were excluded in all patients, and the degree of concomitant mitral regurgitation was classified according to the classification of Seller et al. (23). Complete preoperative and postoperative patient characteristics are given in Table 1.

Control subjects. For comparison, TEE studies including 3D reconstruction were performed in 16 subjects serving as the control group. There was no evidence of LV disease (i.e., no valvular abnormalities, no signs of hypertrophy with a basal septal thickness between 9 and 12 mm [mean ± SD 10 ± 2] and no congenital malformations). Indications for the TEE studies in control subjects included the search for cardiac sources of emboli (n = 12) and for infective endocarditis (n = 4). Baseline demographic characteristics of the control group did not differ significantly from those of the patient group (Table 2).

3D TEE. After each patient gave written informed consent, a TEE study was performed under mild sedation (2.5 to 5 mg of midazolam intravenously). Methods and technical equipment for dynamic 3D reconstruction of 2D echocardiographic images have been described in detail elsewhere (24–27). In brief, 3D TEE was performed using a slightly modified multiplane 5-MHz TEE probe (Hewlett Packard) controlled by a 3D image acquisition system (Echoscan, TomTec GmbH, München, Germany). This system rotates the image plane in 2° increments from 0° to 180° (90 different planes) under electrocardiographic (ECG) and respiratory gating. The choice of 2° increments was a compromise between an acceptable acquisition time (increased using smaller increments) and a high spatial resolution (reduced using larger increments), which has been used in several previous studies (24,25,27).

The acquired echocardiographic sequences were stored, reconstructed and analyzed quantitatively on the computer off-line in any desired transsecting plane (“any plane slicing”), as described subsequently (Fig. 1 and 2).

Each patient underwent a TEE study 6 to 8 weeks before and 2 to 8 weeks after the operation, with 3D acquisitions both from the TEE window for evaluation of the LVOT and of the total LV mass and from the transgastric echocardiographic window for analysis of the intracavitary mass of the PM. For transesophageal acquisition, the probe was placed in the mid esophageal position, where an adequate four-chamber view could be obtained. The transgastric window with a basal gastric position of the probe allows for improved delineation of endocardial and epicardial borders of the LV and the subvalvular apparatus depending on axial rather than lateral resolution. The acquisition protocol was identical for every patient. Care was taken to achieve a similar probe position for the follow-up examination, which guaranteed that the shape of the whole LV was included in the sector scan of all image planes during rotation of the transducer.

Quantitative analysis of 3D TEE data sets. The following variables were measured in the 3D data set in each patient with HOCM (Fig. 3) and in all normal control subjects (except for postoperative measurements of the myectomy trough): 1) Minimal cross-sectional area (CSA) of LVOT and its cyclic changes during systole: The LVOT by definition is limited by

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Table 2. Comparison of Baseline Characteristics Between Patients With Hypertrophic Obstructive Cardiomyopathy and Control Subjects

<table>
<thead>
<tr>
<th>Patient Group (n = 11)</th>
<th>Control Group (n = 16)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>55 ± 17</td>
<td>53 ± 12</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>6/5</td>
<td>10/6</td>
</tr>
<tr>
<td>Septal thickness (mm)</td>
<td>24 ± 6</td>
<td>10 ± 2</td>
</tr>
</tbody>
</table>

Data are presented as mean value ± SD or number of patients or control subjects. F = female; M = male.
the interventricular septum, the aortic annulus and the ante-
rior mitral leaflet (AML). Its apical limit to the LV is the tip of
the AML (10). To use the complete temporal information of
the acquired dynamic data set, the CSA of the LVOT was
analyzed at each time point throughout the whole systole
(every 40 ms, five to eight stop frames per patient). Within the
3D data set, a short-axis image plane of the aortic annulus,
which included its complete circumference, was selected as a
reference plane to which all other short-axis cross sections
were parallel. The smallest unobstructed CSA in every stop
frame data set (temporal minimum) was selected by shifting
the reconstructed cross-sectional image plane parallel to the
reference plane. The minimum of all systolic time points was
defined as the minimal systolic CSA of the LVOT. These
measurements were repeated for the postoperative analysis.
Preoperative and postoperative locations of the minimal sys-
tolic LVOT area were not necessarily identical.

2) SAM of mitral valve leaflet: The maximal systolic devi-
ation of the AML during SAM was measured in the cross
section showing the minimal systolic LVOT area (Fig. 1). The
deprivation was defined as the maximal distance between the
point of coaptation of both mitral leaflets and the tip of
the AML (Fig. 2).

3) Measurements of myectomy trough (width, depth, length
and maximal area gain): Postoperatively, the myectomy trough
created by the surgeon could easily be visualized in short-axis
cross sections of the LVOT in all patients. Maximal depth and
width of the myectomy trough were determined in LVOT
short-axis cross sections in a similar way, as described for the
minimal LVOT area (Fig. 3).

The maximal CSA gain caused by the myectomy trough was
traced manually and measured at the same mid-systolic time
point as the minimal systolic LVOT area (Fig. 1). The relation
between the maximal myectomy area gain and the total
operative area gain (difference between postoperative and
preoperative minimal systolic LVOT area) was calculated as
relative myectomy area gain (percent total area gain). To
measure the length of the myectomy, a long-axis slice of the
LVOT was reconstructed orthogonally to the reference plane,
in which the myectomy could be clearly delineated and mea-
sured (Fig. 1).

4) LV and PM mass: The 3D data sets acquired from the
TEE window were used to determine the total LV mass and
the transgastric data sets to determine the mass of the intra-
cavitary part of both PMs. The method and validation of
myocardial mass calculation using multiplane TEE with 3D
reconstruction and the summation of slices method have been
described previously (28). In brief, using diastolic stop frame
images, endocardial and epicardial borders were traced man-
ually in parallel short-axis slices of the LV. The PM was
defined as intracavitary if less than one-third of the PM’s
circumference in the selected short-axis slice was contiguous
to the LV wall (Fig. 4).

Surgical technique. Details of the surgical procedure, es-
pecially the differences from previous techniques, have been
described recently (29). The surgical approach to the LV was
exclusively transaortic, exposing the extent of hypertrophy.
After inserting a sharp triple-hook retractor to the deepest
point of the hypertrophied basal septum, this muscle mass was
pulled anteriorly to allow better visualization. A deep myectomy was created by cutting into the direction of the prongs of the retractor. This technique allows removal of more tissue from deeper parts of the basal septum than does conventional myotomy and myectomy. In addition, creation of a large and deep LVOT trough improves access to the deeper structures of the LV, so that both PMs can then be mobilized down to the apex and all hypertrophied portions and muscular trabeculae can be resected.

Statistical analysis. All data are expressed as the mean value ± SD. Comparison between groups was performed using 1) paired and unpaired t tests; 2) Pearson's linear correlation and analysis of nonlinear inverse relation for continuous variables; and 3) chi-square or Spearman's rank-sum test for categoric variables, as appropriate. A p value ≤0.05 was considered significant.

For determination of interobserver variability, the minimal LVOT area was independently measured by two examiners in all patients according to the method of Altman and Bland (30). For determination of intraobserver variability, one observer repeated both measurements in a random fashion. It was defined as the difference between one observer's consecutive measurements expressed as the percentage of the first value and the standard deviation of the measurement of one observer.

Results

Clinical findings. Perioperative and postoperative mortality in the study group was 0%, and no major intraoperative or perioperative complications occurred. One patient had postoperative pneumonia with respiratory insufficiency 3 days after the operation but recovered without residual deficits within the next 3 weeks. Two other patients had intermittent rapid atrial fibrillation, which was successfully treated medically. Another patient developed an asymptomatic coronary LV fistula due to a transsected septal branch of the left anterior descending coronary artery draining into the LVOT. Preoperatively, one patient was in functional class IV and the remaining 10 patients were in class III. Functional class improved to class I or II in 10 of 11 patients (Table 1). One of the patients in functional class III before the operation (the patient with postoperative pneumonia) had no improvement at the time of 3D TEE (4 weeks after the operation).

The peak Doppler echocardiographic pressure gradient within the LVOT decreased significantly from 69 ± 59 mm Hg before the operation to 26 ± 21 mm Hg after it (p < 0.001)
(Table 3). No patient had a residual maximal Doppler gradient >60 mm Hg; five patients had a positive SAM phenomenon at the postoperative control study.

3D TEE findings before and after the operation. Image acquisition was repeated two to four times to optimize image quality, resulting in 36 rotational scans in 11 patients. The mean acquisition time per scan was 2.6 ± 1.3 min, and off-line postprocessing required an additional 10 to 20 min depending on the spatial depth of the 3D data set. Further quantitative analysis required between 40 and 95 min.

1) Minimal CSA of LVOT and its cyclic changes during systole: Complete data are given in Tables 3 and 4. Minimal systolic CSA of the LVOT increased from 1.1 ± 1.2 cm² preoperatively to 3.8 ± 1.9 cm² postoperatively (p < 0.001). The difference of 2.6 ± 1.6 cm² corresponds to an increase of 235%. Postoperative minimal systolic LVOT area in the patients with HOCM was not significantly different from that in the control subjects (4.2 ± 1.5 cm²) (Table 4).

Analysis of the temporal changes of the smallest unobstructed LVOT CSA (A_temp in Fig. 5) in the preoperative patients with HOCM revealed a small CSA at the beginning of systole (3.2 ± 1.6 cm²), with a further decrease to a mid-systolic minimum (1.1 ± 1.2 cm², 43 ± 30% of area at beginning of systole) and a slight increase at end-systole (2.1 ± 1.1 cm²) (Fig. 5). Postoperatively, the temporal minimal area at the beginning of systole was significantly larger (5.0 ± 2.4 cm², p < 0.001 vs. preoperatively) and decreased slightly to a mid-systolic minimum (3.8 ± 1.9 cm², 74 ± 36% of initial area), with a mild increase at end-systole (4.0 ± 2.0 cm², 82 ± 40% of initial area). In contrast, there was a continuous decrease in the control group, from a large area at the beginning of systole (5.8 ± 1.7 cm²) to an end-systolic minimum (4.0 ± 1.0 cm², 69 ± 17% of initial value). There were no significant differences in the temporal minimal LVOT area between postoperative patients and normal control subjects at each time point, even though a mid-systolic decrease occurred in all patients with HOCM due to a residual SAM phenomenon.

Linear regression analysis between the minimal systolic LVOT area and the maximal Doppler gradient before the operation revealed a moderate but significant correlation (r = −0.61, p < 0.05). Analysis of a nonlinear correlation between these two variables showed an inverse relation with a slightly higher correlation coefficient of 0.85 (p < 0.05; Doppler gradient = 30 + 16/minimal LVOT area). There was no statistically significant correlation between minimal area or total preoperative/postoperative area difference and the change in LVOT gradient or functional class.

2) SAM of mitral valve leaflet: The maximal systolic deviation of the AML decreased from 15 ± 7 mm preoperatively to 6 ± 7 mm postoperatively (p < 0.01), indicating the reduction of SAM phenomenon with a slight to moderate residual SAM in 5 of 11 patients.

3) Measurements of myectomy trough (width, depth, and maximal area gain): Enlargement of the outflow tract as a result of the operation becomes obvious when comparing two corresponding short-axis cross sections of the LVOT before and after myectomy (Fig. 3). The average maximal depth and width of the myectomy were 7 ± 2 and 20 ± 8 mm, respectively. The systolic length of the myectomy, measured in an adapted long-axis slice of the LVOT, was 28 ± 7 mm. The area gain of the LVOT, due to the channel of myectomy, was 1.3 ± 1.0 cm² or 48 ± 14% of the total difference between the minimal area before and after the operation. Maximal systolic deviation of the AML and the dimensions of the myectomy trough were compared with the LVOT gradient and its change and with functional class and its change. All variables revealed no statistically relevant linear or nonlinear relation.

4) LV and PM mass: In five patients complete visualization and quantification of the intracavitary portion of the PM were possible using 3D data sets acquired from the transgastric window. In the remaining six patients no sufficient transgastric image quality or stable transducer position during the acquisition could be achieved. In each patient the portion of the anterior PM that was contiguous to the LV wall was larger, whereas its intracavitary portion was smaller than that of the posterior PM. After patients had the operation for HOCM, the intracavitary mass increased from 2.4 to 5.0 g (p < 0.001) for the anterolateral PM and from 4.5 to 6.5 g for the posteromedial PM (p < 0.01) (Table 3), without significant differences compared with control subjects (Table 4).

Mean biases of interobserver variability were −0.06 ± 0.30 cm² (95% confidence interval −0.64 to 0.44) for the minimal LVOT area measurements and −0.8 ± 2.3 mm (95% confidence interval −5.4 to 3.8) for the distance measurements such as width, depth and length of the myectomy and the maximal deviation of the AML. Intraobserver variabilities were 7 ± 5% for the minimal LVOT area and 6 ± 2% for the distance measurements.

Discussion

Previous echocardiographic studies of HOCM and its surgical therapy. Echocardiographic studies have had a significant impact on the understanding of the morphology and
pathophysiology of HOCM. Initial echocardiographic studies performed with the M-mode technique demonstrated SAM of the AML as a typical sign of HOCM (31). 2D echocardiography allowed description of several patterns of LV hypertrophy (2,8,9) and revealed the frequency and importance of mitral valve abnormalities (4,5,31). Malpositioning of the PM as a part of the subvalvular mitral apparatus has also been observed (6), and its relevance in producing SAM was demonstrated recently in an animal model (7). However, its hemodynamic relevance has not been proven, possibly because of limitations of 2D imaging techniques in the evaluation of complex 3D structures and their quantitative evaluation (22). Several echocardiographic findings were of significant importance for the development of new surgical techniques. Conventional 2D and Doppler echocardiography have been able to demonstrate the effects of surgical procedures and have been used to compare preoperative and postoperative morphology qualitatively (15,21). However, precise quantitative assessment of important variables such as minimal CSA of the LVOT, which is a determinant of systolic LVOT obstruction, and its temporal changes, was not possible.

Transthoracic 3D reconstruction of the LVOT demonstrated the significantly smaller mid-systolic minimal CSA of the LVOT in patients with unoperated HOCM as compared with normal control subjects (32,33). The transesophageal approach for acquisition of 3D data sets used in the present study is less comfortable than transthoracic echocardiography and involves a minimal risk for the patient. However, it provides a significantly better image quality, which is especially necessary if small morphologic changes have to be analyzed quantitatively.

**Quantitative analysis of 3D data set.** To our knowledge this is the first study to demonstrate the effects of surgical therapy on LVOT morphology in patients with HOCM using 3D TEE. Comparison of preoperative and postoperative data showed a more than threefold increase in the minimal systolic CSA of the LVOT resulting in the relief of LVOT obstruction. Comparison of the postoperative minimal systolic LVOT area between patients with HOCM and control subjects revealed no significant differences, demonstrating the beneficial effect of the procedure. The decrease in the maximal systolic deviation of the AML shown in this study is another sign of reduced LVOT obstruction. It quantitatively proves earlier qualitative 2D echocardiographic findings that demonstrated a decrease in SAM after different surgical procedures (34).

Measurements of the width, length and depth of the myectomy in the beating heart is only possible in a 3D data set, where the complete spatial information can be evaluated. To our knowledge the present study is the first to describe in a quantitative manner the total CSA gain of the LVOT (difference between preoperative and postoperative minimal systolic LVOT area), as well as the area gain obtained by myectomy alone, calculated in relation to the total area gain. The myectomy contributed 48 ± 12% to the total area gain, indicating that it is not only the trough that causes relief of LVOT obstruction. Whether the remaining 52% of total area gain is due to the effect of subvalvular mitral reconstruction and mobilization of both PMs or whether it is partly an indirect result of the myectomy remains to be determined.

In the present study, there was only a moderate correlation between the minimal systolic LVOT area and the maximal Doppler gradient before the operation, whereas all other 3D-derived variables such as area gain, myectomy dimensions and systolic deviation of the AML revealed no statistically significant relation to the LVOT gradient or functional class and their changes. This lack of correlation may partly be caused by the small number of patients examined, by the fact that Doppler or invasive measurements of the LVOT gradient and 3D acquisition were not performed simultaneously and by the spontaneous variation of the dynamic LVOT obstruction. Earlier studies comparing simultaneous and nonsimultaneous recordings of Doppler and catheterization measurements have demonstrated a relevant spontaneous variation of LVOT obstruction, which was mainly responsible for measurement discrepancies (35). The area gain due to the myectomy contributed <50% to the total LVOT area gain. Thus, it may not be surprising that it did not show a correlation to gradient and functional class. Furthermore, functional classification may be too subjective and inaccurate to be correlated with quantitative 3D measurements, particularly because it depends not only on the degree of obstruction but also on the presence of diastolic LV dysfunction.

Analysis of PM mass and its changes after surgical reconstruction of the subvalvular apparatus has not been possible until now using 2D echocardiography owing to the 3D complexity of the structures (22). In the present study the measurements in a subgroup of patients revealed an increase in the intracavitary portion of the PMs. Preoperatively, the anterolateral PM was significantly more contiguous to the LV wall. As a consequence, it had to be mobilized more intensively during the operation compared with the posteromedial PM. This explains the higher increase in intracavitary muscle mass for the anterior compared with the posterior PM.

**Alternative imaging techniques.** Other imaging techniques have been used for the evaluation of preoperative and postoperative findings in patients with HOCM, such as computed tomography and magnetic resonance imaging (36,37). The presence of SAM phenomenon and the flow disturbance ratio between LVOT and the descending aorta before and after conventional myotomy and myectomy were compared semiquantitatively by use of cine magnetic resonance imaging. A reasonable correlation between Doppler echocardiographic measurements and the LVOT gradient was found. To our knowledge, until now no studies have been published on the possible value of magnetic resonance imaging to visualize or quantify changes in the LVOT after the operation.

**Study limitations.** At present, quantitative analysis of 3D echocardiography requires time-consuming manual contour tracing in reconstructed 2D slices, limiting its use for clinical practice. Another limitation of the present study is the lack of an independent reference method for the analysis of minimal LVOT area, owing to the fact that no other method has been...
shown to accurately delineate the minimal LVOT area and its cyclic changes. The feasibility of performing adequate 3D reconstruction of the subvalvular apparatus, including the PM, may be limited if a stable transgastric echocardiographic window with sufficient image quality is difficult to obtain. Furthermore, the selection of adequate LVOT long-axis and short-axis slices for the measurement of the minimal LVOT area may be a source of error, because it remains examiner-dependent despite its precise definition. However, analysis of interobserver and intraobserver variability for the minimal systolic LVOT area demonstrated acceptable accuracy and reproducibility.

Conclusions. Dynamic 3D TEE for the first time allows a comprehensive quantitative evaluation of the results after extended myectomy and reconstruction of the subvalvular mitral apparatus. A quantitative comparison of the postoperative results of patients with HOCM with the preoperative morphology, as well as with the morphology of normal subjects, became possible. The main effect of the evaluated operative technique was the relief of LVOT obstruction due to the myectomy trough and the extensive PM mobilization. Postoperative minimal systolic LVOT areas in patients with HOCM were not different from those of normal control subjects. Thus, 3D echocardiography has the potential to be an accurate imaging tool for the assessment of procedural results after operation for complex spatial pathomorphology. It may have an impact on the planning of operative interventions and, in case of availability of faster equipment, may even be used for intraoperative monitoring.

We thank Dr. Rainer Hoffmann for his valuable contributions to the preparation of this report.

References


