Extended myectomy for hypertrophic obstructive cardiomyopathy patients with midventricular obstruction†

Yajie Tanga, Yunhu Songa,*, Fujian Duanb, Long Denga, Jun Rana, Ge Gaoa, Sheng Liuoa, Yun Liuc, Hao Wangb, Shihua Zaod and Shengshou Hua

a Department of Cardiovascular Surgery, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences, Peking Union Medical College, Beijing, People's Republic of China

b Department of Echocardiography, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences, Peking Union Medical College, Beijing, People's Republic of China

c Department of Cardiovascular Surgery, Ruijin Hospital, Shanghai, People's Republic of China

d Department of Magnetic Resonance Imaging, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences, Peking Union Medical College, Beijing, People's Republic of China

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Abstract

OBJECTIVES: Surgical strategies for patients with midventricular obstruction remain underappreciated. We sought to assess clinical and haemodynamic results, summarize the surgical technique of extended myectomy and provide reliable pre- and intraoperative methods of evaluating patients with midventricular obstruction.

METHODS: The preoperative evaluation process, intraoperative surgical strategy and early outcomes were thoroughly reviewed in 40 patients with midventricular obstruction.

RESULTS: Isolated transaortic myectomy was conducted in 38 (95.0%) patients, and 2 (5.0%) other patients with an apical aneurysm were treated with a combined transaortic and transapical myectomy. The median resection length of the removed muscle was 50 mm (45–55 mm), approximately 5 mm more than the obstruction length measured using preoperative transthoracic echocardiography. There were no early or late deaths, complete heart blocks or iatrogenic septal perforations in our study series with a median follow-up time of 19 months (13–54 months). Instantaneous pressure gradients at the subaortic level decreased from 70.5 mmHg (51–89.5 mmHg) preoperatively to 7.7 mmHg (6–11 mmHg) (∗P < 0.001) at the most recent evaluation and at the midventricular level from 61.0 mmHg (42.8–85.5 mmHg) to 8.5 mmHg (6.3–11.8 mmHg) (∗P < 0.001). In all patients, the New York Heart Association functional classifications improved, with a better haemodynamic status.

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CONCLUSIONS: Transaortic myectomy can be extended to the midventricular level, improving haemodynamic status and yielding satisfactory early outcomes in selected patients. Additional transapical myectomy should be considered in patients with a long obstruction, limited exposure of the midventricular area or a concomitant apical aneurysm.

Keywords: Midventricular obstruction • Cardiomyopathy • Hypertrophic • Transaortic myectomy

INTRODUCTION

In clinical practice, subaortic outflow tract obstruction (Subaortic) is the most common phenotype of hypertrophic obstructive cardiomyopathy (HOCM), which is characterized by disturbed flow at the subaortic level and is typically accompanied by the systolic anterior motion (SAM) phenomenon. Midventricular obstruction (MVO) occurs in approximately 10% of patients with hypertrophic cardiomyopathy (HCM) [1] and is characterized by impedence to flow at the midventricular level. Unrelated to SAM, MVO is thought to be caused by a combination of a hypertrophic septum and a hypertrophic anterior papillary muscle [2]. Though previous studies have demonstrated that MVO patients have an increased risk of HCM-related death and thromboembolic events [2–4], studies on the surgical treatment of MVO are limited.

In this study, preoperative transthoracic echocardiography (TTE) was used to thoroughly evaluate the morphology of the left ventricle. With the combination of preoperative TTE and specific surgical skills, the problems of limited visualization and resection extent could be solved via aortotomy for most patients in this study, and improvements in functional status and haemodynamic status were achieved. The objective of this study was to detail the surgical strategies and early outcomes in MVO patients who have undergone extended myectomy.

MATERIALS AND METHODS

Study population

Between September 2010 and December 2016, 415 consecutive patients with HOCM underwent an extended myectomy, which was performed by 1 surgeon (Y.S.) from our institution. Forty (9.6%) patients were considered to have an MVO and were enrolled in this study. The follow-up period extended from the time of surgery to the most recent evaluation (either in outpatient clinics or by telephone review). This study was approved by our institutional ethics committee.

Preoperative echocardiographic evaluation

3 Echocardiographic evaluations were performed by 1 dedicated ultrasound doctor (F.D.) using TTE instruments (IE33 5000, Philips Medical Systems, NA, Bothell, WA, USA; Acuson Sequoia, Siemens Medical Solution USA Inc., Malvern, PA, USA). Subjects who were considered candidates for surgery were thoroughly appraised a second time. The left ventricular outflow tract gradient was quantified using the continuous-wave Doppler interrogation at rest or during physiological exercise. Patients were not necessarily required to undergo exercise provocation testing unless the gradient was less than 50 mmHg while severe symptoms were present. The mitral regurgitation (MR) severity was assessed using TTE were reviewed by a surgeon (Y.S.) and an echocardiographer (F.D.) to aid in selecting the appropriate surgical strategy.

Obstruction length. A distal region of disturbed flow under the apical 3-chamber view using Colour Doppler imaging was considered the location of obstruction (Fig. 1A). The distance between the disturbed flow and the aortic annulus under the apical long-axis window was defined as the obstruction length (OL), which was considered the minimal resection length of extended myectomy.

Morphological hypertrophic length. The morphological hypertrophic length (MHL) was defined as the distance between the aortic annulus and the distal region of hypertrophy under the apical long-axis view using 2-dimensional echocardiography in the diastolic phase, and this was considered the maximal resection length of myectomy (Fig. 1B).

Maximal septal thickness. The maximal septal thickness of the anterior septum was measured in the parasternal short-axis view from the mitral valve and papillary muscle levels using TTE, and the results were subsequently correlated with the cardiac magnetic resonance results to ensure accuracy (Supplementary Material, Fig. S1A3 and A4). The left ventricular morphological characteristics and preoperative haemodynamic functional status assessed using TTE were reviewed by a surgeon (Y.S.) and an echocardiographer (F.D.) to aid in selecting the appropriate surgical strategy.

Transoesophageal echocardiography was routinely performed to reconfirm the morphology of the ventricular septum and the intraoperative degrees of MR and to appraise the efficacy of surgery after weaning patients from cardiopulmonary bypass (CPB) while their systolic blood pressure was more than 100 mmHg.

Measurements of the aortic root and apical aneurysms.
(Supplementary Material, Methods) [5]

Surgical techniques. CPB was performed with the ascending aorta and 2-stage venous cannulation. (i) Transaortic extended myectomy: the general operative techniques for transaortic extended myectomy were described in our previous study [6]; additional details are supplemented as follows: a low oblique aortotomy that extended rightwards to the midpoint of the non-coronary aortic sinus was performed. Further exposure of subaortic structures was facilitated by a supine, left lateral, prone position with the head up (Fig. 1C) and the use of 2 prolate retractors (Video 1 and Supplementary Material, Fig. S1E). The en bloc resection was conducted using a 15th scalpel blade. The cutting edge of the 15th round blade was 1 cm in length, from which we determined that the resection length for every stab forward to the apex was equal to approximately 1 cm. The resection thickness at the basal and midventricular levels was based on the maximal septal thickness measured using preoperative TTE in different cross-sections of the short-axis view, which was approximately 40–50% of these measurements. When the resection area reached the level of the papillary muscle, the resected muscle bar...
was intentionally cut into 2 longitudinal pieces for the following reasons: (a) to better expose the midventricular level and (b) to appraise the resection thickness at that level to enable recalibration of the excision direction to increase or decrease the excision depth. Dragging the proximal resected septum as a means of counter-retraction facilitated further resection to the apex. The OL and MHL were regarded as the minimal and maximal resection lengths during surgery. However, because the OL was measured in the systolic phase, the actual OL may have been underestimated by several millimetres, and thus, we extended the excision by several millimetres apically (or it was extended to the distal end of the midseptal whitish subendocardial scar, when it was obviously visible, via aortotomy) to ensure a sufficient resection length. After completing the myectomy, all anomalous chordal structures and fibrous attachments from the mitral leaflets to the septum had to be divided, and the papillary muscles had to be fully mobilized by separating the fusions and adhesions to the septum or left ventricular wall. (ii) Transapical myectomy: transapical myectomy was exerted as an adjunct to the transaortic myectomy when the transaortic myectomy was considered ineffective at sufficient apical extension (Fig. 1D). A transapical incision was made at the avascular area of the apical aneurysm (AA). The length of this incision depended on the size of the AA. Myectomy was performed to remove the distal portion of the hypertrophic septum with scissors and a No. 15 round blade. Closure after a ventriculotomy involved 2 layers of sutures on 2 strips of Teflon felt. The length and width of the removed muscle specimen were measured during surgery (Fig. 2).

Figure 1: Surgical approaches. (A) OL in the apical 3-chamber view (the systolic phase). (B) MHL in the diastolic phase. (C) Transaortic myectomy is facilitated by dragging the proximal section of the excised muscle bar cephalad to access the deeper portion of the septum. The inset at the top right corner shows the surgical position. (D) Additional transapical myectomy is recommended to excise the distal portion of the septum in the midventricle when the obstruction is too distal from the aortic annulus, especially for patients with an AA. AA: apical aneurysm; EM: excised muscle; LA: left atrium; MHL: morphological hypertrophic length; OL: obstruction length; PMs: papillary muscles.

Video 1: Operative procedures of a patient with midventricular obstruction.
Perioperative data were collected when patients were in the hospital, and follow-up data were obtained by telephone questionnaire and by echocardiographic examination in outpatient care. Normally distributed data are displayed as the mean ± standard deviation and were compared using the Student’s t-test; continuous variables with skewed distributions are expressed as the median (25th–75th percentile), and comparisons between groups were conducted using the Wilcoxon rank-sum test. Categorical data were compared using the χ² test, the Fisher’s exact test or the Kolmogorov–Smirnov test. Correlation between the resection length and the OL, MHL, body mass index and size of the aortic root were determined using Spearman correlation coefficients. All the statistical tests were 2-sided and P-values ≤0.05 were considered statistically significant. Bonferroni correction for multiple testing was performed. Statistical analyses were performed using IBM SPSS 19.0 statistical software (SPSS Inc., Chicago, IL, USA).

RESULTS

Patient characteristics

Forty MVO patients with extended septal myectomy were included in the study. As shown in Table 1, this was a predominantly male
population with a median age of 45.0 years (38.3–57.0 years). Five (12.5%) patients had concurrent AAs of 19.5 mm, 33.5 mm, 39.5 mm, 43.3 mm and 60.1 mm, and none of these subjects had a history of myocardial infarction. Although the OL ranged from 32 to 72 mm in this study, the OLs in most patients (n = 38, 95.0%) were <60 mm (Table 1); the other 2 (5.0%) patients with OLs >60 mm also had an AA. The 40 patients were divided into 2 groups: patients with both SubOTO and MVO (n = 32) and those with MVO alone (n = 8). Compared to patients with a concomitant SubOTO, subjects with MVO alone more frequently presented with non-sustained ventricular tachycardia and an AA and with longer MHL.

### Surgical data

The concomitant cardiac surgeries and abnormal subvalvular structures are shown in the Supplementary Material, Table S1.
The average duration of CPB was 77.5 min (69.0–109.0 min), and the cross-clamping time was 52.0 min (46.0–71.8 min).

Two (5%) patients required a second bypass. One patient (Patient 1 in Table 2) presented with residual obstruction at the midventricular level, with an instantaneous peak pressure gradient $\geq 50$ mmHg using transoesophageal echocardiography (OL = 72 mm, the initial resection length = 60 mm); he underwent a second cross-clamping for a transapical myectomy to remove another 2 cm of the distal septum region. Another patient presented with severe MR after weaning from CPB, and a mitral valvuloplasty was subsequently performed.

Of the 5 (12.5%) patients with an AA, a combination of the transaortic and transapical approaches was performed in 2 (5%) patients (Table 2). Details of Patient 1 are as described above. The additional transapical myectomy for Patient 2 was performed as planned before surgery for the coexistence of a small-sized aortic annulus (18.83 mm) and a left ventricular AA (33.5 mm).

The median resection length of the removed specimens was 50 mm (45–55 mm) (ranging from 28 to 80 mm), which was 5 mm (3–9.8 mm) longer than the OL. For most patients, the length of the removed specimen was longer than the corresponding OL ($n = 38$) and shorter than the MHL ($n = 39$) (Fig. 3A). In 36 patients with a successful transaortic myectomy, there was a positive correlation between resection length and the OL, the MHL and the diameter or the aortic annulus ($P < 0.001$, $P = 0.007$ and $P = 0.007$, respectively; $r = 0.626$, $r = 0.440$ and $r = 0.440$, respectively), supported by simple correlation analysis (Supplementary Material, Table S2), and these results remained significant after Bonferroni correction for multiple testing.

**Haemodynamic and clinical benefits**

The median follow-up time was 19 months (13–54 months) (≥6 months for all patients). There were no instances of iatrogenic septal perforation or complete atrioventricular block, and no patient had recurrent syncope or died during the follow-up period. Four (10.0%) patients were rehospitalized for atrial fibrillation. The instantaneous pressure gradients at the subaortic level decreased from 70.5 mmHg (51–89.5 mmHg) preoperatively to 7.7 mmHg (6–11 mmHg) ($P < 0.001$) at the most recent evaluation and from 61.0 mmHg (42.8–85.5 mmHg) to 8.5 mmHg (6.3–11.8 mmHg) ($P < 0.001$) (Fig. 3B). Thirty-two (80.0%) patients with preoperative SAM showed significantly improved MR and no SAM. Furthermore, no traction-related aortic regurgitation was detected postoperatively. Thirty-six (90.0%) patients were classified as the New York Heart Association (NYHA) III/IV before surgery, and none were classified as such during the follow-up time ($P < 0.001$) (Table 3).

**Residual midventricular obstruction.** Two (5.0%) patients had residual MVO, and their peak pressure gradients remained at >30 mmHg during follow-up (Table 4). The resection lengths for both patients were not long enough to reach the OL. They experienced recurrent mild shortness of breath during ordinary activity (NYHA II).

**DISCUSSION**

Surgical treatment of MVO has been reported infrequently. In a study from the Mayo Clinic [7], a total of 56 MVO patients had undergone extended myectomy (including patients with both SubOTO and MVO), 5 of whom underwent a transaortic approach, 32 a transapical approach and 19 combined approaches. Furthermore, in a recent study from the Mayo Clinic, the combination of transaortic and transapical approaches effectively prevented residual MVO and allowed the myectomy to augment diastolic filling [8]. Although the aforementioned studies demonstrated that the 3 surgical strategies (transaortic myectomy, transapical myectomy and combined transaortic and transapical myectomy) were effective for removing the hypertrophic septum...
in the midventricular region, thus relieving MVO, the recommended surgical approach for patients with MVO remains unclear. Therefore, this study concludes that a thorough preoperative evaluation and a judicious decision-making process are needed for choosing the appropriate surgical approach.

### Transaortic myectomy

Although extended myectomy has been the main surgical procedure for HOCM patients since it was first proposed by Dr Messmer in 1994 [9], data on the efficacy of this approach for patients with MVO are limited [1]. The midventricular area is generally considered accessible by transaortic myectomy for patients with HOCM; however, the lower level of obstruction in patients with MVO is generally considered out of reach via aortotomy and may increase the risk of residual obstruction and recurrent symptoms after surgery [10], especially for those with a small aorta, a small aortic valve annulus, a deep chest, obesity or a long obstruction [11]. As documented in this clinical review, isolated transaortic myectomy was conducted in 38 (95.0%) patients and resulted in satisfactory symptomatic and haemodynamic improvements in 36 (90.0%) patients, which could be primarily attributed to surgical skills and a thorough preoperative evaluation. The surgical experiences of this study are summarized as follows: (i) the integrated muscle bar serves as a counter-retractor to help us gain access to the midventricular septum transaortically, working similarly to a sharp triple-hook retractor noted by Dr Messmer [9]; (ii) the smaller-sized blade and slim scalpel handle occupy less space in the midventricle and (iii) 2 prolate retractors can reach deeper to help adjust the direction of the aortic orifice, thus maximally exposing the midventricular area via aortotomy.

### Table 3: Symptomatic and haemodynamic improvements

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre</th>
<th>Post (&gt;6 months)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echocardiographic data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAD (mm), mean ± SD</td>
<td>44.0 ± 6.9</td>
<td>39.2 ± 7.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVEDD (mm), mean ± SD</td>
<td>38.0 ± 5.2</td>
<td>42.0 ± 3.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EF (%), mean ± SD</td>
<td>72.9 ± 6.9</td>
<td>66.0 ± 5.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVOTPG (mmHg), mean (range)</td>
<td>70.5 (51.0–89.5)</td>
<td>7.7 (6.0–11.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MPG (mmHg), mean (range)</td>
<td>61.0 (42.8–85.5)</td>
<td>8.5 (6.3–11.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mitral regurgitation (%)</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>None</td>
<td>0 (0)</td>
<td>11 (32.3)</td>
<td></td>
</tr>
<tr>
<td>Trace</td>
<td>4 (12.9)</td>
<td>13 (41.9)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>10 (32.3)</td>
<td>7 (22.6)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>17 (54.8)</td>
<td>1 (3.2)</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>1 (2.5)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Aortic regurgitation (%)</td>
<td></td>
<td></td>
<td>0.488</td>
</tr>
<tr>
<td>None</td>
<td>38 (95.0)</td>
<td>36 (85.0)</td>
<td></td>
</tr>
<tr>
<td>Trace</td>
<td>2 (5.0)</td>
<td>3 (12.5)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>0 (0)</td>
<td>1 (2.5)</td>
<td></td>
</tr>
<tr>
<td>NYHA (%)</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>I</td>
<td>0 (0)</td>
<td>31 (77.5)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>4 (10.0)</td>
<td>9 (22.5)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>31 (77.5)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>5 (12.5)</td>
<td>0 (0)</td>
<td></td>
</tr>
</tbody>
</table>

*Echocardiographic data of 32 patients with subaortic obstruction and systolic anterior motion phenomenon.

EF: ejection fraction; LAD: left atrial dimension; LVEDD: left ventricular end-diastolic dimension; LVOTPG: left ventricular outflow tract pressure gradient; MPG: midventricular pressure gradient; NYHA: New York Heart Association; Post: the most recent evaluation; Pre: preoperative evaluation; SD: standard deviation.

### Table 4: Functional status and haemodynamic status of 2 patients with residual MVO

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Follow-up time (months)</th>
<th>NYHA</th>
<th>DAA (mm)</th>
<th>OL (mm)</th>
<th>RL (mm)</th>
<th>MPG/SPG (mmHg)</th>
<th>Sub-IVST</th>
<th>Mid-IVST</th>
<th>Echocardiographic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>42</td>
<td>III</td>
<td>II</td>
<td>24</td>
<td>46</td>
<td>40</td>
<td>66/33</td>
<td>51/10</td>
<td>Insufficient resection length and extremely hypertrophic APM (20 mm)</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>III</td>
<td>II</td>
<td>20</td>
<td>35</td>
<td>28</td>
<td>107/76</td>
<td>32/7</td>
<td>Insufficient resection length, width and thickness at the midventricular level</td>
</tr>
</tbody>
</table>

*The pressure gradient under the provocative condition was 76 mmHg (the gradient in the resting condition was 32 mmHg).

APM: anterior papillary muscle; DAA: diameter of the aortic annulus; Mid-IVST: midventricular interventricular septal thickness; MPG: midventricular pressure gradient; MVO: midventricular obstruction; NYHA: New York Heart Association; OL: obstruction length; Post: the most recent evaluation; Pre: preoperative evaluation; RL: resection length; SPG: subaortic pressure gradient.
Relief of MVO by isolated transaortic myectomy for patients without an AA would make the surgery less traumatic by avoiding an apical incision. Additionally, the described methodology (i.e. sufficient apical excision via aortotomy) is also applicable to HOCM patients (especially those with hypertrophic midventricular septum) with SAM-related MR and can help redirect flow away from the mitral valve and reduce drag forces on mitral leaflets [12, 13], thereby minimizing the need for a concomitant mitral repair or replacement to eliminate postoperative MR [6, 14]. Therefore, isolated transaortic myectomy is recommended for patients with an accessible midventricular hypertrophic septum and without AA.

Transapical myectomy

Despite the finding that the resection length is significantly positively correlated with the OL, the problem of obtaining a clear visual field beyond the midventricular level became apparent when the resection length reached 70 mm (seen in a patient with an OL = 65 mm and a corresponding resection length = 72 mm), indicating that it may be difficult to apically elongate the resection length sufficiently by transaortic myectomy for patients with a long OL or longitudinally lengthened left ventricle. According to our surgical experience, an additional transapical myectomy is recommended for patients with a long OL (>60 mm) or whenever the resection length will not reach or surpass the OL via aortotomy during surgery (e.g. failure to sufficiently expose the midventricular area or maintain the en bloc resection). In addition, although we did not perform transatrial myectomy [15], this method, as opposed to transapical myectomy, is still considered another effective surgical alternative for patients with a long OL, especially for those without an AA, to avoid an additional apical incision and thereby make the surgery less traumatic.

The presence of an AA is also an indication to lower the threshold for a transapical myectomy. As documented in other reports, an HCM-related AA occurs in approximately 25% of patients with MVO [1] and 4.8% with HCM [5], indicating that the AA is not rare in MVO patients. In this study, 5 (12.5%) patients had concurrent AAs, and 2 underwent an additional transapical myectomy, whereas the other 3 patients did not. Although the MVOs of these 3 patients were successfully relieved, a combined transaortic and transapical myectomy is still considered reasonable for patients with an AA (especially medium- or large-sized AAs) to reduce the pull on the aortic annulus and obtain a wide-open surgical field in the midventricle.

Clinical benefits

All patients showed improvement in symptoms, and none had undergone rehospitalization for syncope or ventricular arrhythmia at the most recent evaluation. The survival benefits and improvements in both functional status and haemodynamic status in the early follow-up results indicate that extended myectomy is a feasible therapeutic alternative for patients with MVO.

Limitations

This is a retrospective single-centre study with the surgical experience of 1 surgeon in cooperation with 1 dedicated echocardiographer. Although we found that findings from the preoperative evaluation matched those found intraoperatively, this surgical experience needs to be investigated in further detail to have general applicability. The morphological characteristics of patients with MVO vary widely [5]; however, this study only included patients with MVO who had a concurrent hypertrophied basal septum. Therefore, we cannot report on the surgical experience of patients without a thickened septum at the subaortic level. Our goal of proving the validity of extended myectomy for MVO was not fully achieved due to the limited number of samples in the study. The follow-up time of our study was not long enough to reveal the long-term effects of transaortic extended septal myectomy for MVO patients with regard to the complications of ventricular arrhythmia and cardiac function. Nonetheless, these findings indicate that further studies should be conducted to analyse and identify specific imaging characteristics of HOCM patients with MVO to provide additional data in guiding the treatment of these patients.

CONCLUSIONS

Transaortic myectomy can be extended to the midventricular level, improving haemodynamic status and yielding satisfactory early outcomes in selected patients. Additional transapical myectomy should be considered in patients with a long obstruction, limited exposure of the midventricular area or a concomitant AA.

SUPPLEMENTARY MATERIAL

Supplementary material is available at EJCTS online.

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Conflict of interest: none declared.

REFERENCES


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