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Research article

Transapical beating-heart septal myectomy for hypertrophic cardiomyopathy patients with midventricular obstruction

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ABSTRACT

Background: We developed a novel minimally invasive transapical beating-heart septal myectomy (TA-BSM) procedure for patients with midventricular obstruction (MVO), without the aid of cardiopulmonary bypass. This study aims to describe the TA-BSM procedure for the relief of MVO and to detail the clinical outcomes in these patients.
Methods: Sixty-one patients receiving TA-BSM for MVO were included: isolated MVO (n = 12) and combined MVO and subaortic obstruction (n = 49). We reviewed the electronic medical record to collect information on preoperative, intraoperative, and postoperative parameters.
Results: The intraventricular pressure gradient after the resection was largely attenuated. On the catheter measurement, the median resting and provoked gradient decreased by 29.0 and 71.0 mm Hg, respectively. Likewise, the resting intraventricular gradient was successfully reduced from 58.0 to 11.0 mm Hg, and the maximal intraventricular gradient was reduced from 88.0 to 20.0 mm Hg at 6 months follow-up. In addition, all patients showed significantly improved MR and 37 of 42 patients with preoperative MR grade ≥2+ showed MR grade ≤1+ after TA-BSM. During the follow-up, no death was observed and no one had HCM-related rehospitalization. All patients reported improvement in symptoms and the mean New York Heart Association class improved from 3.0 (IQR, 3.0–3.0) preoperatively to 1.0 (IQR, 1.0–1.0) at 6 months follow-up.
Conclusions: The TA-BSM procedure is a valuable therapy to relieve MVO, improving hemodynamics and providing satisfactory clinical outcomes. The procedure can also preserve favorable outcomes for patients with MVO and concomitant subaortic obstruction.

1. Introduction

Hypertrophic cardiomyopathy (HCM) is the most common inherited cardiovascular disease due to mutations in sarcomeric genes. Left ventricular (LV) outflow tract (LVOT) obstruction is observed in about 70 % of symptomatic HCM patients, predominantly due to systolic anterior motion (SAM) of the anterior mitral valve leaflet. Midventricular obstruction (MVO), characterized by the impedance to flow at the level of the papillary muscles, is less frequent and is estimated to occur in approximately 10 % of HCM patients [1]. Unrelated to SAM, MVO is mainly attributed to the apposition of marked septal hypertrophy and the hypercontractile left but non-hypertrophied LV-free wall, usually with the hypertrophied anterior papillary muscle [2]. Patients with MVO often have similar

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symptoms to those with LVOT obstruction, such as exertional dyspnea, palpitations, chest pain, and syncope. Further, it has been reported that MVO is associated with an increased risk of HCM-related death, formation of apical aneurysm, and lethal arrhythmias [3–5].

For patients with isolated MVO, transapical myectomy can provide excellent exposure to the hypertrophied midventricular septum and papillary muscles, and the concomitant apical aneurysm can be repaired [6]. Some patients present with both MVO and subaortic obstruction, in whom a combined transaortic and transapical approach has been reported to be the optimal strategy to achieve complete relief of the bilevel obstruction [7]. However, a combined approach complicates the surgical procedure and thereby makes the surgery more traumatic. Therefore, we have developed a minimally invasive transapical beating-heart septal myectomy (TA-BSM) procedure for managing HCM patients with MVO, enabled by an innovative beating-heart myectomy device (BMD) [8]. Visualization of the septal myectomy under a real-time echocardiographic cross-sectional view of the left ventricular geometry obviates the need for median sternotomy. Throughout the procedure, hemodynamic stability can be well maintained without the need for cardiopulmonary bypass (CPB). Of note, repeated resections were particularly useful in tailoring the extent of septal myectomy to achieve adequate relief of MVO. The objective of this study is to detail the TA-BSM procedure for the relief of MVO and to report the clinical outcomes in these patients.

2. Materials and methods

2.1. Study population

Between April 2022 and February 2023, we conducted a single-center, single-arm, first-in-man study on the TA-BSM procedure for patients with HCM, which was performed by a single surgeon at Tongji Hospital. All patients signed their informed consent to be included in the study. Among those patients in the prospective study, 61 undergoing a TA-BSM procedure for MVO were included in this study.

We reviewed the electronic medical record to collect information on preoperative, intraoperative, and postoperative variables. Patients were regularly followed up at 1, 3, and 6 months after surgery, and then every 6 months thereafter. Follow-up was performed in outpatient clinics or by telephone calls. No one was lost to follow-up in this study.

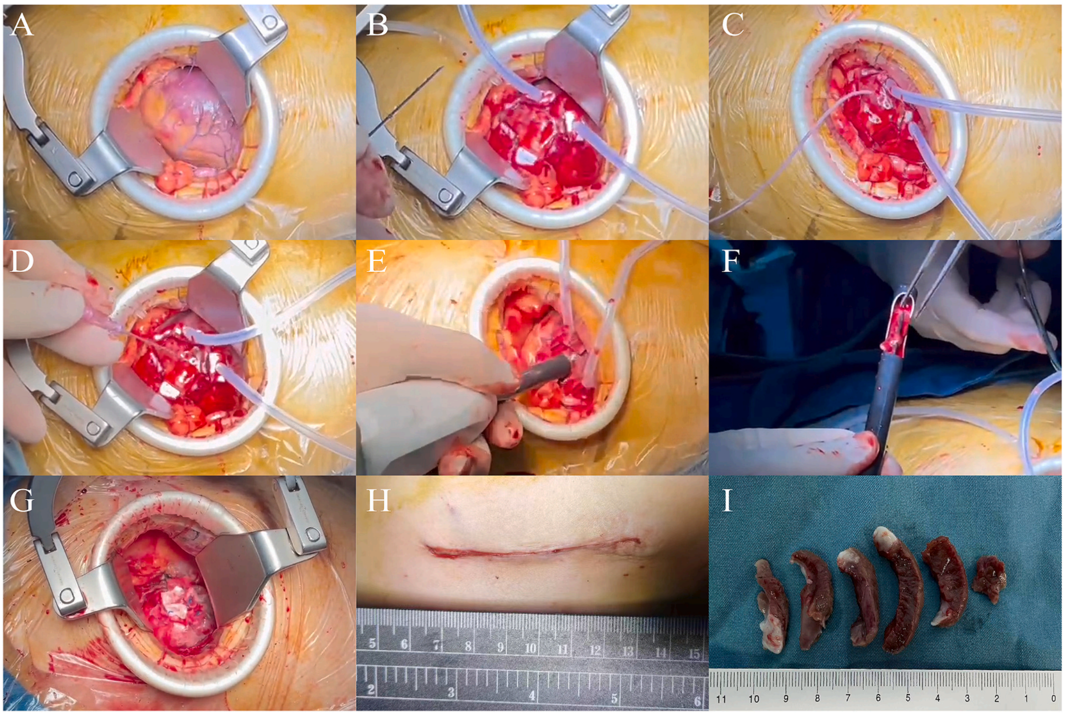

Fig. 1. Intraoperative photographs show the transapical beating-heart septal myectomy (TA-BSM) procedure. (A) The surgery is performed through the left fifth intercostal incision without the assistance of cardiopulmonary bypass. (B and C) Two sets of purse string sutures with Teflon felt pledgets are performed in the avascular area of the cardiac apex and a manometric catheter is inserted into the LV apex through the purse. (D and E) After puncturing and dilating the apex inside the purse, BMD is introduced into the LV cavity under the guidance of transoesophageal echocardiography. (F) The resected muscle from the thickened septum can be visualized in the BMD. (G) The apical incision is then closed using the purse strings. (H and I) The surgical specimen of excised tissue and the length of the surgical incision are shown. BMD, beating-heart myectomy device; LV, left ventricular.

2.2. Definition

The diagnosis of HCM was based on the presence of left ventricular maximum wall thickness ≥15 mm in the absence of diseases associated with this degree of hypertrophy. Isolated MVO was defined by the detection of the hypertrophied midventricular septum (≥15 mm) and systolic obstruction of the mid-left ventricle with a peak gradient exceeding 30 mm Hg and without SAM of the mitral apparatus producing subaortic obstruction (Supplemental Fig. 1) [7]. Patients needed to receive exercise provocation testing if the gradient was less than 30 mm Hg.

During the surgery, the intraventricular gradient was routinely reassessed before and after the resections by the direct needle puncture and manometric catheter [9]. Owing to the patient's physical position and the effect of anesthesia during the procedure, the directly measured gradient of MVO may vary compared with the gradient measured on Doppler echocardiography in the conscious state. During the resections, the diagnosis of MVO was further validated through inspecting the resected myocardium of the mid-ventricular septum. Similar to the contact lesion on the endocardial surface in the subaortic area produced by SAM, a whitish endocardial thickening on the midportion of the septum delineates the area of contact and MVO (Supplementary Fig. 3).

Combined subaortic obstruction was diagnosed according to the septal morphology and hemodynamics assessed on preoperative transthoracic echocardiography (TTE) or cardiac magnetic resonance imaging (CMR) (Supplemental Fig. 2). Typically, the maximum basal septum thickness was greater than 15 mm with a peak LVOT gradient ≥30 mmHg. The magnitude of LVOT obstruction (LVOTO) was remeasured as well by the manometric catheter intraoperatively. Of note, we did not designate patients as having coexistent LVOTO if only a basal septal bulge was observed without detectable subaortic obstruction.

The mitral regurgitation (MR) severity was classified as none (0), mild (1+), moderate (2+), moderate to severe (3+), and severe (4+). Complete left bundle branch block is frequent in patients undergoing septal myectomy, thus, the implantation of a temporary pacemaker was performed in patients with preoperative complete right bundle branch block before surgery.

2.3. Transapical beating-heart septal myectomy procedure

The details of the surgical procedures for TA-BSM have been previously published (Fig. 1) [9]. Briefly, after the left intercostal incision without the assistance of cardiopulmonary bypass (CPB), purse string sutures with Teflon felt pledgets are performed in the

Table 1
Baseline patients characteristics.

Variable	Total (n = 61)	Isolated MVO (n = 12)	MVO + LVOTO (n = 49)	P value
Age, years	47.0 (32.5–57.5)	47.0 (39.3–57.8)	47.0 (32.0–57.5)	0.820
Male	45 (73.8 %)	8 (66.7 %)	37 (75.5 %)	0.796
Body mass index, kg/m^2	25.2 (22.2–27.7)	24.0 (21.0–27.7)	25.3 (22.4–27.6)	0.637
NYHA class III/IV	50 (82.0 %)	10 (83.3 %)	40 (81.6 %)	0.967
Clinical presentation				
Chest pain	30 (49.2 %)	5 (41.7 %)	25 (51.0 %)	0.561
Dyspnea	40 (65.6 %)	9 (75.0 %)	31 (63.3 %)	0.669
Syncope	11 (18.0 %)	3 (25.0 %)	8 (16.3 %)	0.778
Amaurosis	15 (24.6 %)	4 (33.3 %)	11 (22.4 %)	0.681
Palpitation	35 (57.4 %)	6 (50.0 %)	29 (59.2 %)	0.564
Comorbidities				
Hypertension	19 (31.1 %)	2 (16.7 %)	17 (34.7 %)	0.389
Diabetes mellitus	10 (16.4 %)	1 (8.3 %)	9 (18.4 %)	0.684
Coronary artery atherosclerosis	19 (31.1 %)	3 (25.0 %)	16 (32.7 %)	0.869
Atrial fibrillation	8 (13.1 %)	3 (25.0 %)	5 (10.2 %)	0.377
NSVT	23 (37.7 %)	7 (58.3 %)	16 (32.7 %)	0.100
Medical history	19 (31.1 %)	4 (33.3 %)	15 (3.6 %)	>0.999
Family history of sudden cardiac death	1 (1.6 %)	0	1 (2.0 %)	>0.999
Family history of HCM	7 (11.5 %)	2 (16.7 %)	5 (10.2 %)	0.901
History of septal reduction therapy	2 (3.3 %)	0	2 (4.1 %)	>0.999
Permanent pacemaker	3 (4.9 %)	1 (8.3 %)	2 (4.1 %)	0.488
Medical therapy				
Beta-blockers	42 (68.9 %)	9 (75.0 %)	33 (67.3 %)	0.869
Calcium-channel blockers	20 (32.8 %)	4 (33.3 %)	16 (32.7 %)	>0.999
NT-proBNP, pg	1492.0 (449.8–2744.8)	1396.0 (465.5–2162.3)	1523.5 (447.5–2790.0)	0.637
Echocardiography				
Maximum septal thickness ≥30 mm	19 (31.1 %)	4 (33.3 %)	15 (30.6 %)	>0.999
Basal septum thickness, mm	22.0 (19.4–26.0)	20.1 (16.1–22.0)	23.0 (20.0–28.0)	0.009
Midventricular wall thickness, mm	26.0 (19.0–30.9)	26.5 (23.5–30.9)	25.0 (18.4–30.5)	0.404
Resting intraventricular gradient, mmHg	58.0 (37.5–76.1)	40.5 (28.0–60.4)	63.0 (42.5–83.0)	0.035
Maximal intraventricular gradient, mmHg	88.0 (71.0–100.2)	76.5 (60.7–96.3)	88.0 (74.5–101.5)	0.127
Systolic anterior motion	49 (80.3 %)	0	49 (100 %)	<0.001
Mitral regurgitation ≥ grade 2+	42 (68.9 %)	6 (50.0 %)	36 (73.5 %)	0.116

Note: Values are presented as numbers (percentages), or median (interquartile range) when appropriate.
Abbreviations: HCM, hypertrophic myocardiopathy; NT-pro BNP, N-terminal pro-brain natriuretic peptide; NYHA, New York Heart Association.

avascular area of the cardiac apex to provide an entrance for the beating-heart myectomy device (BMD) [8]. Intraoperatively, the intracavitary pressure gradients are measured by a manometric catheter inserted into the LV apex. Peak-to-peak gradients are calculated by subtracting the peak systolic peripheral arterial pressure from the peak systolic apical pressure.

After puncturing and dilating inside the purse string, BMD is introduced into the LV cavity under the guidance of transoesophageal echocardiography (TEE). We remove the excess muscle from the thickened septum under the surveillance of three-dimensionally intraoperative TEE. Notably, we would evaluate intraventricular gradient, remaining septal thickness, and MR grade after each resection to determine the next resection strategy. In addition, markedly hypertrophied papillary muscles are shaved to prevent midventricular narrowing. Finally, the apical incision is closed using the purse strings. After completing the myectomy, an isoproterenol provocation test is performed to determine whether additional resections were necessary. Relief of obstruction (a provoked intraventricular gradient <30 mmHg) is confirmed by direct measurement of a manometric catheter and TEE. A repeat procedure is immediately performed in the presence of residual obstruction.

Unlike conventional surgical myectomy, TA-BSM can also be performed in patients with combined MVO and subaortic obstruction through the isolated apical approach. In these patients, we usually first remove the hypertrophied basal septum, and muscle resection is then extended to the mid-ventricle. Similarly, a provocation maneuver will be performed to detect the presence of residual obstruction after the excision is completed.

2.4. Statistical analysis

Continuous variables are displayed as the median and interquartile range (IQR), and comparisons between two groups were conducted using the Wilcoxon rank-sum test. Categorical variables, expressed as frequency and percentages, were compared using the χ^2 test or Fisher's exact test. Survival probability was estimated using the Kaplan-Meier method and the log-rank test was used to compare survival curves between groups. A two-sided p-value of <0.05 was considered statistically significant. Statistical analyses were performed using the SPSS software (version 26.0).

3. Results

3.1. Patient characteristics

Sixty-one patients undergoing TA-BSM for MVO were included in the study. Their baseline characteristics are summarized in Table 1. There was a predominantly male population (45 patients, 73.8 %) with a median age of 47.0 years (IQR, 32.5–57.5 years). At baseline, 50 patients (82.0 %) were in New York Heart Association Functional Classification III or IV. The most frequent symptoms were dyspnea with exertion in 40 patients (65.6 %) and palpitation in 35 (57.4 %). Patients with hypertension, diabetes mellitus, and coronary artery atherosclerosis constituted 31.3 % (n = 19), 16.4 % (n = 8), and 31.3 % (n = 19) of the total population, respectively.

The total 61 patients were divided into 2 groups: patients with isolated MVO (n = 12) and those with combined MVO and LVOTO (n = 49). Patients in both groups had the same demographic, symptomatic, and medical history characteristics. Compared to patients with a concomitant LVOTO, those with isolated MVO had less hypertrophied basal septum (23.0 mm vs. 20.1 mm, P = 0.009) and lower resting intraventricular gradient (63.0 vs. 40.5 mm Hg, P = 0.035) However, there are no differences in midventricular wall thickness, intraventricular gradient and MR grade between two groups.

3.2. Perioperative parameters

Table 2 summarizes TA-BSM procedure-associated perioperative data. The median weight of the resected myocardium was 7.2 g (IQR 5.3–11.0 g). The median ventilation time after surgery was 3.7 h (2.6–4.9 h) and there was no prolonged ventilation (>24 h). Only two patients (3.3 %) with MVO and LVOTO received red blood cell transfusion, one for concomitant mitral valve replacement,

Table 2
Transapical beating-heart septal myectomy procedure-associated perioperative variables.

Variable	Total (n = 61)	Isolated MVO (n = 12)	MVO + LVOTO (n = 49)	P value
Weight of resected myocardium, g	7.2 (5.3–11.0)	6.4 (5.7–12.8)	7.6 (5.0–10.8)	0.637
Duration of surgery, h	2.6 (2.1–3.3)	2.5 (2.1–2.7)	2.7 (2.3–3.6)	0.078
Duration of ventilation, h	3.7 (2.6–4.9)	2.8 (2.2–3.9)	3.8 (2.9–5.0)	0.171
Intensive care unit stay, h	24.0 (20.2–42.2)	25.3 (18.3–45.2)	23.3 (20.6–34.5)	0.779
Red blood cell transfusion	2 (3.3 %)	0	2 (4.1 %)	>0.999
Use of cardiopulmonary bypass	1 (1.6 %)	0	1 (2.0 %)	>0.999
New onset left bundle branch block	33 (54.1 %)	4 (33.3 %)	29 (59.2 %)	0.198
New-onset atrial fibrillation	2 (3.3 %)	0	2 (4.1 %)	>0.999
Major adverse events				
Permanent pacemaker implantation	2 (3.3 %)	0	2 (4.1 %)	>0.999
Iatrogenic valvular injury	1 (1.6 %)	0	1 (2.0 %)	>0.999
Median sternotomy conversion	1 (1.6 %)	0	1 (2.0 %)	>0.999
In-hospital/30-d death	0	0	0	>0.999

Note: Values are presented as numbers (percentages) or median (interquartile range).

and the other for prolonged operation time (5.5 h) due to extremely hypertrophied septum (48 mm).

There was no in-hospital or 30-d death in this study. Two patients with preoperative complete right bundle branch block developed a complete atrioventricular block and were implanted with a permanent pacemaker. One patient was converted to median sternotomy due to mitral valve injury during the procedure and received concomitant mechanical mitral valve replacement with the use of CPB. This patient recovered uneventfully and discharged. There were no iatrogenic septal perforations and reoperations for bleeding. In addition, no one had postoperative embolization, thrombosis, or any stroke.

3.3. Hemodynamic changes and clinical benefits

The median follow-up time was 7.8 months (IQR, 6.8–11.6 months). The intraventricular pressure gradient after the resection was largely attenuated (Fig. 2). On the catheter measurement, there was a 29.0 mm Hg decrease in the resting gradient and a 71.0 mm Hg decrease in the provoked gradient (Table 3). Likewise, comparing the intraventricular gradient measured at baseline and at 6 months follow-up, the results were in keeping with the findings of the catheter measurement; the resting intraventricular gradient was successfully reduced by 47.0 mm Hg (58.0 mm Hg vs 11.0 mm Hg, $P < 0.001$) and maximal intraventricular gradient reduced by 68.0 mm Hg (88.0 mm Hg vs 20.0 mm Hg, $P < 0.001$) (Fig. 3A). Furthermore, the median basal septum thickness and midventricular wall thickness were successfully reduced by 8 and 9 mm, respectively (Fig. 3B). The median left atrial diameter was significantly decreased (36.0 vs. 41.0 mm, $P < 0.001$). In addition, all patients showed significantly improved MR, and 37 of 42 patients with preoperative MR grade ≥2+ showed MR grade ≤1+ after TA-BSM (Fig. 3C).

During the follow-up period, no death was observed and no one had HCM-related rehospitalization. All 61 patients reported improvement in symptoms and the mean New York Heart Association class improved from 3.0 (IQR, 3.0–3.0) preoperatively to 1.0 (IQR, 1.0–1.0) at 6 months follow-up ($P < 0.001$; Fig. 3D).

3.4. Residual obstruction

There was no residual MVO, but two (3.3 %) patients had residual LVOTO with resting pressure gradients ≥30 mmHg and provoked gradients ≥50 mmHg at 6 months follow-up (Table 3). The resection of basal septum in these two patients was not deep enough to reach the complete relief of LVOTO. However, they had no symptoms during daily activity (NYHA I).

4. Discussion

MVO is less common than subaortic obstruction in patients with HCM; the intraventricular gradient arises from the interventricular septum coming into contact with the anterolateral papillary muscle during systole. Surgical strategies for relief of MVO have been reported to be effective for removing the hypertrophied midventricular septum and thus relieving MVO, mainly including transaortic myectomy, transapical myectomy, and combined transaortic and transapical myectomy [7,10,11]. Specifically, transapical myectomy is performed for patients with isolated MVO; transaortic myectomy and combined transaortic and transapical myectomy are suitable for patients with concomitant LVOTO. However, all these surgical treatments are performed through median sternotomy with CPB, and the combined transaortic and transapical myectomy may complicate the procedure causing more trauma. Therefore, this study reports a novel procedure—transapical beating-heart septal myectomy (TA-BSM), which is performed through a minimally invasive intercostal incision and without CPB. As detailed in our study, TA-BSM can be performed safely and is efficient to abolish MVO and

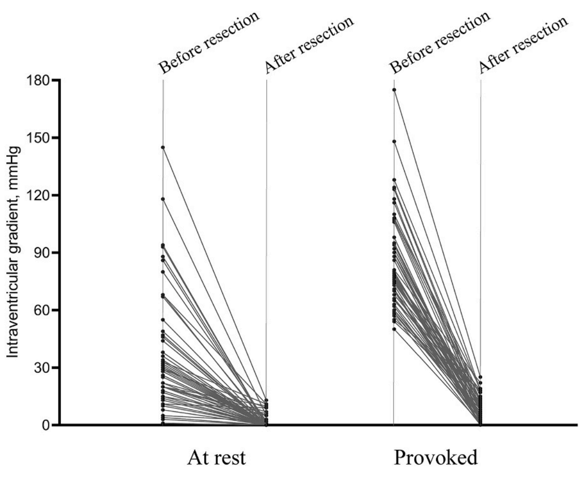

Fig. 2. Intraventricular gradient measured by the catheter during the surgery.The intraventricular pressure gradient after resection was largely attenuated; the resting intraventricular gradient was reduced from 29.0 mm Hg (IQR, 17.5–46.5) to 0.0 (IQR, 0.0–2.0) mm Hg and the maximal intraventricular gradient was decreased from 78.0 (IQR, 69.0–95.0) mm Hg to 7.0 (IQR, 3.0–12.5) mm Hg.

Table 3
Preoperative, intraoperative and postoperative hemodynamic parameters.

Variable	Before resection	After resection	P value
Intraventricular gradient measured by the catheter, mmHg			
Resting	29.0 (17.5–46.5)	0.0 (0.0–2.0)	<0.001
Provoked	78.0 (69.0–95.0)	7.0 (3.0–12.5)	<0.001
	Baseline	6 months follow-up	
Echocardiographic findings			
Left atrium diameter, mm	41.0 (37.0–45.5)	36.0 (33.0–42.0)	<0.001
Left ventricular end-diastolic dimension, mm	44.0 (40.5–46.5)	49.0 (45.5–52.0)	<0.001
Left ventricular ejection fraction, %	70 (65.0–73.5)	61.0 (57.5–65.0)	<0.001
Maximum basal septum thickness, mm	22.0 (19.4–26.0)	14.0 (13.0–18.0)	<0.001
Maximum midventricular wall thickness, mm	26.0 (19.0–30.9)	17.0 (13.5–20.0)	<0.001
Resting intraventricular gradient, mmHg	58.0 (37.5–76.1)	11.0 (7.5–15.0)	<0.001
Resting intraventricular gradient ≥30 mmHg	49 (80.3 %)	2 (3.3 %)	<0.001
Maximal intraventricular gradient, mmHg	88.0 (71.0–100.2)	20.0 (16.0–23.5)	<0.001
Maximal intraventricular gradient≥50 mmHg	61 (100 %)	2 (3.3 %)	<0.001
Mitral regurgitation grade			<0.001
0	0	34 (55.7 %)	
1+	19 (31.1 %)	22 (36.1 %)	
2+	16 (26.2 %)	5 (8.2 %)	
3+	21 (34.4 %)	0	
4+	5 (8.2 %)	0	
New York Heart Association class			<0.001
I	0	54 (88.5 %)	
II	11 (18.0 %)	7 (11.5 %)	
III	44 (72.1 %)	0	
IV	6 (9.8 %)	0	

Note: Values are presented as numbers (percentages), or median (interquartile range) when appropriate.

concomitant subaortic obstruction.

4.1. Natural history of MVO

The present report differed from a previous study [2] with more prevalence of New York Heart Association class III or IV (82 % vs. 4 %), probably because we were a tertiary referral hospital receiving more patients with severe symptoms and we included patients with both subaortic and midventricular obstruction in this study. In addition, we found bursts of NSVT in over a third of MVO patients, which has been reported as an independent determinant of sudden cardiac death (SCD) in patients with HCM [12]. In a study of 490 HCM patients with a follow-up over 10 years, Minami et al. [2] reported that patients with MVO had a significantly greater likelihood of SCD and potentially lethal arrhythmic events compared with patients without MVO.

In this study, two patients underwent previous septal reduction therapy for MVO but had residual or recurrent symptoms. One had failed alcohol septal ablation for the inconsistency of the septal artery blood supply and hypertrophic obstruction in the ablation target zone. The other received percutaneous intramyocardial septal radiofrequency ablation and had residual obstruction for insufficient infarcted area and inadequate depth of infarction.

4.2. Transaortic myectomy

The midventricular septum is considered accessible by a standard transaortic myectomy. However, extensive instrumentation through the aortic annulus risks injury to the aortic valve cusps. In addition, transaortic myectomy may increase the risk of incomplete resection and residual obstruction for patients with small aorta, small aortic valve annulus, deep chest, or long distance from the aortic valve to the obstructed region [13]. A recent study reported that transaortic myectomy was performed in 38 of 40 MVO patients with satisfactory clinical outcomes [11]. In three patients with significant residual gradients after transaortic myectomy, only one was identified and corrected intraoperatively with concomitant transapical myectomy, indicating the difficulty in the exposure of the midventricular septum. And one patient received a combination of the transaortic and transapical myectomy for the existence of apical aneurysm.

4.3. Transapical myectomy

The midventricular septum is more easily exposed through a transapical approach, and septal myectomy is guided by uniformly present endocardial scar [10]. Sun et al. [7] reported that transapical myectomy was performed in 63 of 80 isolated MVO patients with significant relief of obstruction; the median resting and provoked gradient reduced by 41 and 31 mm Hg, respectively. Further, the transapical myectomy permits apical aneurysm repair and scar resection, reducing the risk of SCD [14]. For those with concomitant LVOTO, Hang and colleagues [15] reported that combined transaortic and transapical myectomy was safe with an overall 30-day survival of 95.5 % and was effective in relieving subaortic and midventricular gradients. In addition, symptom relief was

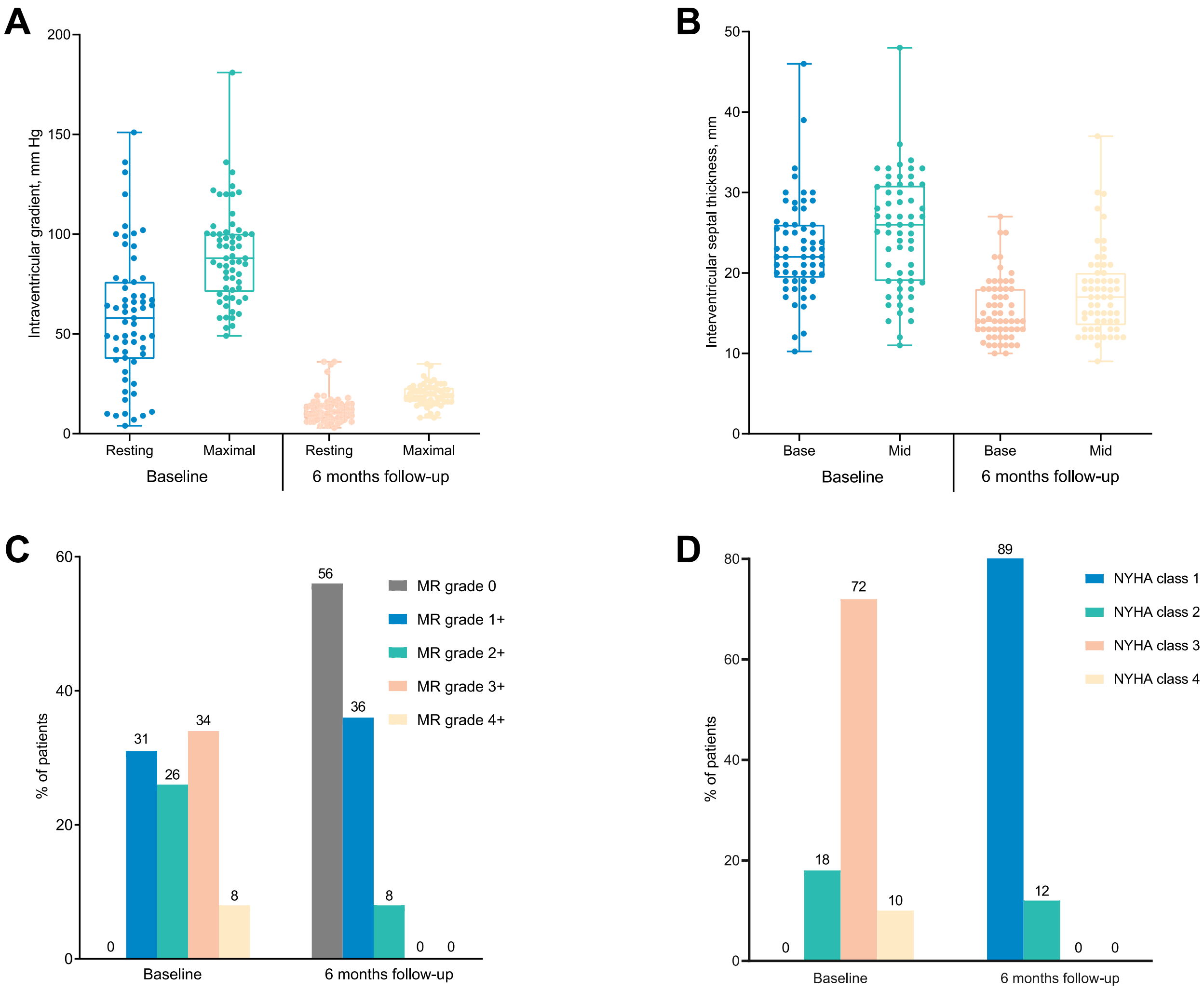

Fig. 3. Clinical parameters of patients preoperatively and at 6 months follow-up. (A) Resting and maximal intraventricular gradient. (B) Maximum basal septum thickness and midventricular wall thickness. (C) Mitral regurgitation severity, % of patients. (D) New York Heart Association class, % of patients.

satisfactory with functional improvement in 41 (97.6 %) of 42 patients with less than New York Heart Association class III.

4.4. *Transapical beating-heart septal myectomy*

Despite the benefits mentioned above, two major inadequacies of conventional septal myectomy are limited exposure and lack of real-time evaluation. On the contrary, the echocardiographic cross-sectional view during the TA-BSM procedure provided a comprehensive and greatly enhanced visualization of LV geometry. Both hemodynamic and morphological characteristics can be carefully re-evaluated after each resection, providing revolutionary advantages over conventional septal myectomy. The target septal myocardium was precisely localized and repeated resections were safely performed to tailor the extent of myectomy for sufficient abolishment of MVO and MR, avoiding any CPB-induced injury. With real-time echocardiographic monitoring, iatrogenic injury to intracardiac structures was largely prevented, maximally preserving myocardial function. In addition, conventional septal myectomy seems traumatic through median sternotomy. Further, the combined transaortic and transapical myectomy procedure is complicated with increasing surgical risk and may be challenging for surgeons without extensive experience. The TA-BSM procedure was performed through the left intercostal incision without the assistance of CPB, thus reducing the surgical trauma and blood loss. In this study, only one patient (1.6 %) was converted to median sternotomy and a majority of patients (96.7 %) were free from red blood cell transfusion. In addition, median ventilation hours (3.7 [IQR 2.6, 4.9]) and intensive care unit hours (24.0 [IQR 20.2, 42.2]) were relatively short.

4.5. Alcohol septal ablation

Alcohol septal ablation (ASA) for patients with LVOTO has clinical outcomes similar to surgery in terms of gradient reduction, symptom improvement, and exercise capacity in experienced centers [16], and ASA has become the primary septal reduction therapy modality in many centers [17]. However, limited experience, mostly from small cohort studies [18] and case reports [19–21], suggests that mid-ventricular obstruction can be relieved by ASA with good short-term outcomes. In a study of 22 patients receiving ASA for MVO, complete atrioventricular block occurred in 7 patients (31.8 %), while atrioventricular conduction was restored in all of these patients before discharge and no new permanent pacemaker dependency occurred [18]. Yang et al. [18] reported that ASA substantially reduced pressure gradient from 79.7 $\pm$ 21.2 mm Hg to 43.7 $\pm$ 28.9 mm Hg, but 4 of 22 patients (18.2 %) had recurrent severe symptoms with New York Heart Association class III/IV dyspnea during the follow-up. The recurrent symptoms may be due to the unsuccessful ASA after ablating the first or third septal perforator artery alone, as the first or third septal perforator artery does not cover the whole obstructive septal area or the obstructive septal segments was supplied by two or more vessels [22].

4.5.1. Clinical benefits

As documented in this clinical study, there was no in-hospital or late death during the follow-up period. In addition, this procedure resulted in satisfactory morphologic and hemodynamic improvements. There was an 8 mm decrease in median basal septum thickness and a 9 mm decrease in median midventricular wall thickness; the resting and maximal intraventricular gradient was successfully reduced to 11 mm Hg and 19 mm Hg, respectively. In addition, symptom relief was recorded in all patients; fifty (82 %) patients classified as the NYHA class III/IV before surgery were divided into I/II during the follow-up. The survival benefits and improvements in hemodynamics and functional status indicate that TA-BSM is a safe and effective therapy for patients with MVO.

4.6. Limitations

The current study has some limitations. This is a single-center study from a tertiary referral hospital. Because TA-BSM is a novel procedure for the treatment of MVO and is not used in other centers, this study result needs to be validated in further detail by comparable cohorts. Owing to the short application time of the TA-BSM procedure, the focus of the present study was on perioperative and short-term clinical outcomes. The validity of TA-BSM for patients with MVO may be not fully achieved due to the limited number of samples in the study. Therefore, further research with longer follow-up time and larger population samples is required.

5. Conclusions

In our experience, the TA-BSM procedure is a valuable therapy to relieve MVO, improving hemodynamics and functional status, and providing satisfactory outcomes. The procedure can also preserve favorable outcomes for patients with MVO and concomitant subaortic obstruction. This method can also provide a real-time echocardiographic view, making the myectomy more precise.

Ethics declarations

This study was reviewed and approved by the Ethics Committee of the Tongji Medical College, Huazhong University of Science and Technology, with the approval numbers: 2022-S013, 2022-S013-1, 2022-S013-2, 2022-S013-3, 2022-S013-4. All patients provided informed consent to participate in the study.

Consent for publication

Not applicable.

Data availability statement

Data will be made available on request.

Sources of funding

None.

CRediT authorship contribution statement

Jiangtao Li: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Xiang Wei:** Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31492.

References

[1] G.K. Efthimiadis, E.D. Pagourelias, D. Parcharidou, T. Gossios, V. Kamperidis, E.K. Theofilogiannakos, et al., Clinical characteristics and natural history of hypertrophic cardiomyopathy with midventricular obstruction, Circ. J. 77 (9) (2013) 2366–2374.
[2] Y. Minami, K. Kajimoto, Y. Terajima, B. Yashiro, D. Okayama, S. Haruki, et al., Clinical implications of midventricular obstruction in patients with hypertrophic cardiomyopathy, J. Am. Coll. Cardiol. 57 (23) (2011) 2346–2355.
[3] L. Deng, H. Zuo, A. Li, C. Yang, X. Huang, Numerical simulation study on the mechanism of formation of apical aneurysm in hypertrophic cardiomyopathy with midventricular obstruction, Front. Physiol. 12 (2021) 717717.
[4] R. Maeda, Y. Minami, S. Haruki, K. Kanbayashi, R. Itani, A. Suzuki, et al., Implantable cardioverter defibrillator therapy and sudden death risk stratification in hypertrophic cardiomyopathy patients with midventricular obstruction: a single-center experience, Int. J. Cardiol. 214 (2016) 419–422.
[5] C. Cai, F.J. Duan, Y.J. Yang, X.Y. Guo, Y.L. Liu, Y.Q. Liu, et al., Comparison of the prevalence, clinical features, and long-term outcomes of midventricular hypertrophy vs apical phenotype in patients with hypertrophic cardiomyopathy, Can. J. Cardiol. 30 (4) (2014) 441–447.
[6] K.C. Ong, J.B. Geske, H.V. Schaff, R.A. Nishimura, Transapical myectomy for severe mid-ventricular obstructive hypertrophic cardiomyopathy, Eur. Heart J. 35 (39) (2014) 2713.
[7] D. Sun, H.V. Schaff, R.A. Nishimura, J.B. Geske, J.A. Dearani, S.R. Ommen, Transapical septal myectomy for hypertrophic cardiomyopathy with midventricular obstruction, Ann. Thorac. Surg. 111 (3) (2021) 836–844.
[8] J. Fang, R. Wang, H. Liu, Y. Su, J. Chen, X. Han, et al., Transapical septal myectomy in the beating heart via a minimally invasive approach: a feasibility study in swine, Interact. Cardiovasc. Thorac. Surg. 30 (2) (2020) 303–311.
[9] J. Fang, Y. Liu, Y. Zhu, R. Li, R. Wang, D.W. Wang, et al., First-in-Human transapical beating-heart septal myectomy in patients with hypertrophic obstructive cardiomyopathy, J. Am. Coll. Cardiol. 82 (7) (2023) 575–586.
[10] M.R. Kunkala, H.V. Schaff, R.A. Nishimura, M.D. Abel, P. Sorajja, J.A. Dearani, et al., Transapical approach to myectomy for midventricular obstruction in hypertrophic cardiomyopathy, Ann. Thorac. Surg. 96 (2) (2013) 564–570.
[11] Y. Tang, Y. Song, F. Duan, L. Deng, J. Ran, G. Gao, et al., Extended myectomy for hypertrophic obstructive cardiomyopathy patients with midventricular obstruction, Eur. J. Cardio. Thorac. Surg. 54 (5) (2018) 875–883.
[12] m Authors/Task Force, P.M. Elliott, A. Anastasakis, M.A. Borger, M. Borggrefe, F. Cecchi, et al., ESC guidelines on diagnosis and management of hypertrophic cardiomyopathy: the task force for the diagnosis and management of hypertrophic cardiomyopathy of the European society of cardiology (ESC), Eur. Heart J. 35 (39) (2014) 2733–2779, 2014.
[13] E. Quintana, H.V. Schaff, J.A. Dearani, Transapical myectomy for septal hypertrophy not accessible through the aortic root, World J. Pediatr. Congenit. Heart Surg. 6 (3) (2015) 455–457.
[14] A. Nguyen, H.V. Schaff, Electrical storms in patients with apical aneurysms and hypertrophic cardiomyopathy with midventricular obstruction: a case series, J. Thorac. Cardiovasc. Surg. 154 (6) (2017) e101–e103.
[15] D. Hang, H.V. Schaff, S.R. Ommen, J.A. Dearani, R.A. Nishimura, Combined transaortic and transapical approach to septal myectomy in patients with complex hypertrophic cardiomyopathy, J. Thorac. Cardiovasc. Surg. 155 (5) (2018) 2096–2102.
[16] M. Liebregts, L. Faber, M.K. Jensen, P.A. Vriesendorp, J. Januska, J. Krejci, et al., Outcomes of alcohol septal ablation in younger patients with obstructive hypertrophic cardiomyopathy, JACC Cardiovasc. Interv. 10 (11) (2017) 1134–1143.
[17] E. Arbelo, A. Protonotarios, J.R. Gimeno, E. Arbustini, R. Barriales-Villa, C. Basso, et al., ESC Guidelines for the management of cardiomyopathies, Eur. Heart J. 44 (37) (2023) 3503–3626, 2023.
[18] Y.J. Yang, C.M. Fan, J.Q. Yuan, S.Y. Wang, Y.H. Song, S.B. Qiao, et al., Effectiveness of alcohol septal ablation versus transaortic extended myectomy in hypertrophic cardiomyopathy with midventricular obstruction, J Interv Cardiol 29 (6) (2016) 619–627.
[19] K. Suwa, R. Sato, K. Iguchi, Y. Maekawa, Four-dimensional flow cardiac MRI for hemodynamic assessment of alcohol septal ablation for hypertrophic obstructive cardiomyopathy with multiple obstructions, Radiol Cardiothorac Imaging 5 (5) (2023) e230074.
[20] H. Seggewiss, L. Faber, Percutaneous septal ablation for hypertrophic cardiomyopathy and mid-ventricular obstruction, Eur. J. Echocardiogr. 1 (4) (2000) 277–280.
[21] I. Tengiz, E. Ercan, E. Alioglu, U.O. Turk, Percutaneous septal ablation for left mid-ventricular obstructive hypertrophic cardiomyopathy: a case report, BMC Cardiovasc. Disord. 6 (2006) 15.
[22] S.F. Nagueh, J.M. Buergler, M.A. Quinones, W.H. Spencer 3rd, G.M. Lawrie, Outcome of surgical myectomy after unsuccessful alcohol septal ablation for the treatment of patients with hypertrophic obstructive cardiomyopathy, J. Am. Coll. Cardiol. 50 (8) (2007) 795–798.