# Management of the mitral valve in thoracoscopic trans-mitral myectomy for hypertrophic obstructive cardiomyopathy

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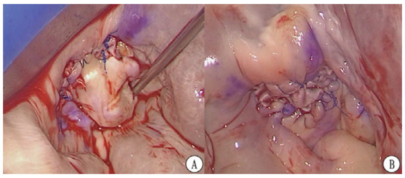
## ABSTRACT

**Objective:** This study aimed to compare clinical outcomes of different mitral valve (MV) management methods in thoracoscopic transmitral myectomy (TTM) and guide surgeons' decision making for hypertrophic obstructive cardiomyopathy (HOCM).

**Methods:** Seventy-three consecutive patients (41 females; mean age, 53.7 ± 13.6 years) with HOCM who underwent TTM between January 2019 and October 2022 were enrolled and divided into 3 groups according to MV surgical strategy. Clinical outcomes were analyzed and compared among the groups.

**Results:** None of the patients experienced postoperative residual left ventricular outflow tract obstruction. Percentages of patients with mitral regurgitation (MR) grade ≥3+ (57.5% vs 1.4%) and systolic anterior motion (95.9% vs 2.7%) were significantly decreased postoperatively ($P < .001$ for both). The preoperative anterior mitral leaflet length was longer in patients in the anterior mitral leaflet direct reattachment group (median, 2.9 cm [interquartile range (IQR), 2.7-3.3 cm] vs 2.7 [IQR, 2.4-2.9 cm]; $P = .018$), but the postoperative coaptation length was shorter (mean, 8.3 ± 2.1 mm vs 11.1 ± 3.8 mm; $P = .038$). After a median echocardiography follow-up of 11.8 months, the left ventricular outflow tract gradient (LVOTG) and mitral regurgitation grades remained significantly improved in all 3 groups ($P < .05$ for all).

**Conclusions:** Total TTM in selected patients is safe and effective, and all 3 MV management strategies can significantly reduce the LVOTG while improving MR. Mitral valvuloplasty is the preferred initial management strategy over valve replacement except in the scenario of irreparable intrinsic MV disease and valvuloplasty failure. (JTCVS Techniques 2023;22:39-48)


**Mitral valvuloplasty in thoracoscopic transmitral myectomy.**

### CENTRAL MESSAGE

Thoracoscopic transmitral myectomy performed by the experienced hypertrophic obstructive cardiomyopathy and thoracoscopic valve surgery team can safely and effectively relieve left ventricular outflow tract gradient with mitral regurgitation improvement.

### PERSPECTIVE

Minimal invasive surgery for hypertrophic obstructive cardiomyopathy requires accurate preoperative assessment of the mitral valve, subvalvular apparatus, and extent of resection. Patients with intrinsic mitral valve disease will benefit from concomitant mitral valve management; otherwise, direct reattachment of the mitral leaflet is preferred after precise septal myectomy.

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**Abbreviations and Acronyms**

| | |
|---|---|
| CPB | = cardiopulmonary bypass |
| HOCM | = hypertrophic obstructive cardiomyopathy |
| LVOTG | = left ventricular outflow tract gradient |
| MR | = mitral regurgitation |
| MV | = mitral valve |
| NYHA | = New York Heart Association |
| SAM | = systolic anterior motion |
| TTM | = thoracoscopic transmitral myectomy |

▶ Video clip is available online.

Extended septal myectomy is the preferred invasive treatment for hypertrophic obstructive cardiomyopathy (HOCM) and is most commonly performed via a transaortic approach. However, this has a restricted field of view via midline sternotomy and is susceptible to such complications as valve injury and vascular events by aortotomy.[1] Therefore, it is recommended that surgical myectomy be performed in experienced centers.[2] Total thoracoscopic transmitral myectomy (TTM), a novel surgical approach that overcomes the disadvantages of the classical transaortic myectomy procedure, has been reported less frequently.[3,4] Whether concomitant mitral valve (MV) interventions are necessary to address both systolic anterior motion (SAM) and mitral regurgitation (MR) remains controversial. One view, espoused by Hong and colleagues,[5,6] is to avoid MV interventions, as sufficient myectomy is able to eliminate MR in most cases. Other centers also have reported good outcomes with concomitant MV interventions for HOCM.[7-10] For TTM, the MV is detached from the annulus to expose the hypertrophic myocardium, and subsequent processing is required.

Which MV strategy is better remains unclear. In the present study, we compared the clinical outcomes of different MV management methods in TTM, with the aim of guiding surgeons' decision making for HOCM.

## MATERIALS AND METHODS

### Study Design and Subjects

This study was approved by the Institutional Review Board of Guangdong Provincial People's Hospital (Ethical Batch KY-Q-2022-164-03). Seventy-three consecutive patients (41 females; mean age, 53.7 ± 13.6 years) with HOCM who underwent total TTM alone between January 2019 and October 2022 were enrolled in this retrospective study. The study population was divided into 3 groups according to their final MV surgical strategy: anterior mitral leaflet direct reattachment (AMLDR) group (n = 23), anterior mitral leaflet extension (AMLE) group (n = 26), and MV replacement (MVR) group (n = 24), which included 5 patients who were converted to valve replacement because of failed intraoperative mitral valvuloplasty. The inclusion criteria were (1) a definite diagnosis of HOCM by preoperative transthoracic echocardiography or other imaging examination; (2) left ventricular outflow tract gradient (LVOTG) ≥50 mm Hg and persistent symptoms refractory to medical therapies; and (3) symptomatic HOCM with intrinsic MV disease necessitating surgical intervention. Exclusion criteria were (1) history of previous cardiac surgery; (2) cardiac thoracoscopy contraindications, such as unstable conditions, inability to tolerate unilateral collapse of the lung, flail chest, etc, or other thoracotomy surgical indications, such as ventricular aneurysm, coronary artery stenosis, and myocardial bridge; (3) unsuitabilty for TTM in terms of anatomy, including left atrial diameter ≤40 mm and apical HOCM; (4) other concomitant major surgical procedures, such as radiofrequency ablation; (5) life expectancy of <2 years due to other diseases, such as cancer; and (6) failure to consent to study participation.

Clinical and echocardiographic data were collected by 2 physicians unrelated to the surgical team. Color Doppler flow images of the standard long-axis view were acquired in at least 3 consecutive cardiac cycles to measure end-diastolic left ventricular wall thickness and identify the SAM and MR grade. The anterior mitral leaflet and coaptation lengths were measured using a 3-chamber view. Other values were collected as well, including LVOTG, ejection fraction, papillary anomalies, and internal diameter.

### Surgical Techniques

The TTM surgery for HOCM was performed as described in our previous study.[11,12] In brief, the surgical preparation and exposure are similar to that for total thoracoscopic MV surgery. Before myectomy, transesophageal echocardiography (TEE) and thoracoscopy were applied to identify any intrinsic MV disease (eg, rheumatic valve disease; Barlow disease; leaflet calcification, contracture, prolapse, or ruptured chordae with consequent flail leaflet; degenerative lesions). The anterior mitral leaflet was detached 2 mm from the mitral annulus and from the anterior commissure to the posterior commissure to expose the hypertrophic myocardium and to detect anomalies in the subvalvular apparatus. An extended myectomy was performed with minimally invasive instruments, beginning 5 mm below the right nadir of the right aortic sinus and then proceeding leftward to the anterior commissure and downward to the apex until the ventricular apex was observed. In complex cases, 3D modeling and printing technique was used to facilitate precise myocardial excision by comparing size and volume of the myocardium expected to be resected with that already resected.

Finally, different MV interventions were performed based on the preoperative imaging assessment and intraoperative findings: AMLDR, AMLE, and MVR. For AMLDR, the anterior mitral leaflet was reattached to the annulus with 5-0 Prolene suture to restore the original shape of the MV (Figure 1, *A*); the plicate technique[13] was added if the length of the anterior mitral leaflet was >30 mm or the leaflet extended over the coaptation point. For AMLE, an MV sizer of equal length as the fibrous triangle, usually 28#, was selected, and an autologous or bovine pericardial patch was cropped identical to the sizer with the side length no longer than the length of anterior mitral leaflet. A 5-0 Prolene suture was used for continuous suturing of the patch and the anterior mitral leaflet (Figure 1, *B* and Video 1). Other mitral valvuloplasty techniques were used as required. After cardioversion, TEE was used to evaluate the ventricular wall thickness, LVOTG, residual SAM, and MR degree. Cardiopulmonary bypass (CPB) was resumed and adapted to the surgical protocol if obstruction, SAM, or ≥3+ MR persisted.

### Statistical Analysis

According to a normal distribution, continuous variables are presented as mean ± standard deviation or median (interquartile range [IQR]) as appropriate. Categorical variables are presented as number (%). For comparison of continuous variables between 2 groups, either the Student *t* test or Mann-Whitney *U* test was used, and the paired-samples *t* test or independent-samples *t* test was used depending on group distribution.

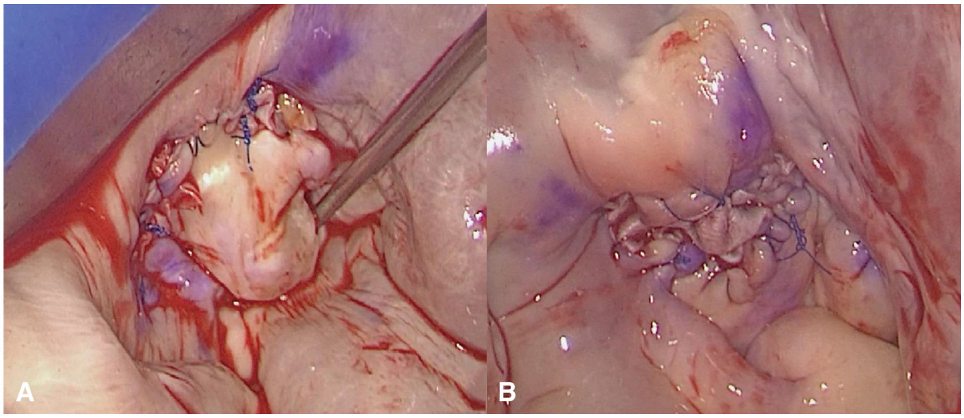


**FIGURE 1.** Mitral valvuloplasty for the anterior mitral leaflet in thoracoscopic trans-mitral myectomy surgery. A, Anterior mitral leaflet direct reattachment. B, Anterior mitral leaflet extension.

Differences among the 3 study groups were evaluated using the Kruskal-Wallis test. Comparisons of categoric variables were analyzed using the Pearson $\chi^2$ test or Fisher exact test. SPSS 26.0 for Mac (IBM) and Rstudio 4.0.2 (R Foundation for Statistical Computing) were used for statistical analysis and data visualization. A 2-sided $P$ value $< .05$ was considered to indicate statistical significance.

## RESULTS

### Baseline Characteristics

The baseline characteristics of the 3 study groups are listed in Table 1. There were significant differences among the 3 groups with respect to age. The MVR group was older than the AMLDR group and the AMLE group (mean, 59.6 ± 2.6 years vs 51.0 ± 3.4 years [$P = .028$] vs 50.8 ± 1.9 years [$P = .021$]). Moreover, the proportions of females and patients classified as New York Heart Association (NYHA) class ≥III were slightly higher in the MVR group, producing a relatively greater surgical risk (EuroSCORE II predicted mortality, median, 2.0% [IQR, 1.2-2.4%]). On echocardiography, the overall median septal thickness was 20 mm (IQR, 17-22 mm), with a mean LVOTG of 92.0 ± 30.1 mm Hg. Preoperative SAM was observed in 70 patients (95.9%), and 42 patients (57.5%) had an MR grade ≥3+. The anterior mitral leaflet was longer in the AMLDR group compared with AMLE group (median, 2.9 cm [IQR, 2.7-3.3 cm] vs 2.7 [IQR, 2.4-2.9 cm]; $P = .018$). The other preoperative characteristics were similar across the 3 groups.

### Surgical Outcomes

TTM was completed successfully in all patients using the different MV management strategies. Table 2 summarizes the surgical outcomes in the 3 groups. Five patients (3 patients initially treated with AMLDR and 2 initially treated with AMLE) underwent intraoperative valve replacement because of residual SAM or greater than moderate MR. There was 1 case of iatrogenic septal perforation in the MVR group, which was converted to thoracotomy. Therefore, the average aortic cross-clamp time and CPB time were significantly longer in the MVR group compared with the AMLDR group (aortic cross-clamp: 129.8 ± 52.0 minutes vs 100.8 ± 21.6 minutes, $P = .013$; CPB: 214 ± 82.2 minutes vs 155.1 ± 24.2 minutes, $P = .002$). The proportion of intrinsic MV disease was significantly higher in the MVR group compared with the AMLDR and AMLE groups (41.7% vs 13.0% [$P = .049$] vs 11.5% [$P = .024$]). Biological and mechanical prostheses were implanted in 14 and 10 patients, respectively. The mean postoperative hospital stay was 12.1 ± 9.1 days. Significant differences emerged in the length of intensive care unit (ICU) stay and the duration of mechanical ventilation across the 3 groups. This finding was confirmed by multiple additional comparisons. ICU stay was longer in the MVR group compared with the AMLDR and AMLE groups ($P = .003$ and .007, respectively), whereas ventilation time was shortest in the AMLDR group (vs AMLE, $P = .047$; vs MVR, $P = .007$). Two patients were resubmitted for thoracoscopic surgery because of postoperative bleeding, including 1 patient in the MVR group who died of low cardiac output syndrome.


**VIDEO 1.** The anterior mitral leaflet extension technique in thoracoscopic transmitral myectomy. Video available at: https://www.jtcvs.org/article/S2666-2507(23)00352-8/fulltext.

**TABLE 1. Perioperative characteristics of the 3 mitral valve management groups**

| Variable | AMLDR (N = 23) | AMLE (N = 26) | MVR (N = 24) | *P* value* |
|---|---|---|---|---|
| Age, y, mean ± SD | 51.0 ± 3.4 | 50.8 ± 1.9 | 59.6 ± 2.6 | .034 |
| Female sex, n (%) | 14 (60.9) | 12 (46.2) | 15 (62.5) | .437 |
| BMI, kg/m$^2$, mean ± SD | 24.1 ± 3.8 | 24.4 ± 2.7 | 24.1 ± 2.8 | .890 |
| NYHA class ≥III, n (%) | 13 (56.5) | 18 (69.2) | 20 (83.3) | .134 |
| EuroSCORE II, %, median (IQR) | 1.5 (1.0-2.1) | 1.4 (1.3-2.7) | 2.0 (1.2-2.4) | .334 |
| $P_{SCD}$, %, median (IQR) | 2.9 (2.0-3.8) | 2.9 (2.3-3.8) | 2.7 (2.1-4.1) | .976 |
| Family history of HCM, n (%) | 2 (8.7) | 3 (11.5) | 1 (4.2) | .770 |
| History of syncope, n (%) | 3 (13.0) | 3 (11.5) | 6 (25.0) | .488 |
| History of alcohol ablation, n (%) | 3 (13.0) | 1 (3.8) | 0 | .113 |
| Comorbidities, n (%) | | | | |
| Hypertension | 8 (34.8) | 6 (23.1) | 9 (37.5) | .539 |
| Coronary artery disease | 2 (8.7) | 1 (3.8) | 3 (12.5) | .507 |
| Diabetes | 3 (13.0) | 6 (23.1) | 5 (20.8) | .705 |
| Chronic pulmonary disease | 1 (4.3) | 3 (11.5) | 1 (4.2) | .610 |
| Creatinine, $\mu$mol/L, mean ± SD | 66.0 ± 16.7 | 75.2 ± 24.6 | 75.3 ± 15.1 | .196 |
| NT-proBNP, pg/mL, median (IQR) | 1039.0 (591.2-2361.0) | 1659.5 (563.4-2209.0) | 1552.0 (588.6-2752.0) | .610 |
| Arrhythmia, n (%) | | | | .710 |
| Atrial fibrillation | 1 (4.3) | 2 (7.7) | 1 (4.2) | |
| Left bundle branch block | 1 (4.3) | 3 (11.5) | 2 (8.3) | |
| Right bundle branch block | 3 (13.0) | 2 (7.7) | 1 (4.2) | |
| Atrioventricular/intraventricular conduction block | 1 (4.3) | 1 (3.8) | 1 (4.2) | |

*AMLDR*, Anterior mitral leaflet direct reattachment; *AMLE*, anterior mitral leaflet extension; *MVR*, mitral valve replacement; *BMI*, body mass index; *NYHA*, New York Heart Association; *EuroSCORE II*, European System for Cardiac Operative Risk Evaluation II; *IQR*, interquartile range; $P_{SCD}$, probability of sudden cardiac death in 5 years; *HCM*, hypertrophic cardiomyopathy; *SD*, standard deviation; *NT-proBNP*, N-terminal pro-brain natriuretic peptide. *$P < .05$ indicates a significant difference across the 3 groups.

### Early Outcomes

Table 3 summarizes the echocardiographic data of the 3 groups at baseline and before discharge. Overall, compared to before TMM, after TMM the interventricular septum thickness was significantly decreased (from 20.0 mm [IQR, 17.0-22.0 mm] vs 11.5 mm [IQR, 10.0-13.3 mm]; $P < .001$), with complete relief of obstruction and a significantly decreased LVOTG (87.0 mm Hg [IQR, 74.5-112.0 mm Hg] vs 7.0 mm Hg [IQR, 5.0-13.5 mm Hg]; $P < .001$) after TMM. There was significant improvement ($P < .001$) in median MR grade (Figure 2), decreasing from 3.0+ (IQR, 2.0-4.0) to 1.0+ (IQR, 0-1.0), and fewer patients had ≥3+ MR (57.5% vs 1.4%). The incidence of SAM decreased significantly (95.9% vs 2.7%; $P < .001$).

Comparison of the subgroup data revealed no differences in preoperative echocardiographic parameters among the 3 groups, and all 3 MV strategies significantly reduced septal thickness and LVOTG and improved SAM and MR (Table 3). The postoperative coaptation length was shorter in the AMLDR group compared with the AMLE group (mean, 8.3 ± 2.1 mm vs 11.1 ± 3.8 mm; $P = .038$).

Two patients in the AMLE group still had SAM before discharge, but both had MR grade 1+ and no outflow tract obstruction. One patient had an intraoperative TEE suggestive of 1+ MR, but the MR deteriorated to 4+ before discharge because of a tear in the root of the patch and valve leaflet. Patients in the AMLDR and MVR groups were free of residual SAM and ≥3+ MR before discharge.

### Follow-up Outcomes

All 72 surviving patients were followed up, with a median follow-up time of 11.8 months (IQR, 3.8-21.0 months). No patient died during the follow-up period. The left ventricular outflow tract gradients were similar in the AMLDR, AMLE, and MVR groups (median, 6.0 mm Hg [IQR, 4.0-8.0 mm Hg], 10.0 mm Hg [IQR, 6.0-16.0 mm Hg], and 6.0 mm Hg [IQR, 4.0-8.0 mm Hg], repsectively; $P = .080$). The median MR grades in the 3 groups were 1.0+ (IQR, 1.0-2.0), 1.0+ (IQR, 1.0-1.3), and 0 (IQR, 0-0), respectively. Compared with preoperative measurements, the LVOTG values and MR grades remained significantly improved in all 3 groups (all $P < .05$). Two patients in the AMLE group developed severe MR and subsequently

TABLE 2. Surgical outcomes in the 3 study groups

| Variable | AMLDR (N = 23) | AMLE (N = 26) | MVR (N = 24) | P value* |
|---|---|---|---|---|
| ACC time, min, mean ± SD | 100.8 ± 21.6 | 130.4 ± 37.2 | 129.8 ± 52.0† | .008 |
| CPB time, min, mean ± SD | 155.1 ± 24.2 | 196.3 ± 68.6 | 214 ± 82.2† | .015 |
| Concomitant valvuloplasty, n (%) | | | | - |
| Mitral annuloplasty | 2 (8.7) | 9 (34.6) | - | |
| Chordae reconstruction | 1 (4.3) | 3 (11.5) | - | |
| Edge-to-edge repair | 4 (17.4) | 1 (3.8) | - | |
| Myocardium removed, g, median (IQR) | 6.8 (5.3-9.0) | 5.9 (5.2-7.2) | 5.8 (4.3-10.3) | .541 |
| CPB resumed, n (%) | 0 | 0 | 7 (29.2) | - |
| Thoracotomy conversion, n (%) | 0 | 0 | 3 (12.5) | - |
| ICU stay, d, median (IQR) | 1.8 (0.9-3.8) | 2.7 (1.6-3.8) | 4.2 (2.7-9.3)† | .004 |
| Ventilation time, h, median (IQR) | 10.5 (5.0-19.3) | 19.2 (10.3-23.6)‡ | 19.2 (10.4-48.1)† | .019 |
| Ventilation time <24 h, n (%) | 20 (87.0) | 10 (38.5)‡ | 14 (58.3)† | .002 |
| Intrinsic MV disease, n (%) | 3 (13.0) | 3 (11.5) | 10 (41.7)†§ | .018 |
| Complications, n (%) | | | | |
| Septal perforation | 0 | 0 | 1 (4.2) | .644 |
| 30-d mortality | 0 | 0 | 1 (4.2) | .644 |
| New permanent pacemaker implantation | 0 | 1 (3.8) | 0 | 1 |
| 30-d reoperation | 0 | 2 (7.7) | 0 | .325 |

*AMLDR*, Anterior mitral leaflet direct reattachment; *AMLE*, anterior mitral leaflet extension; *MVR*, mitral valve replacement; *ACC*, aortic cross-clamp; *SD*, standard deviation; *IQR*, interquartile range; *CPB*, cardiopulmonary bypass; *ICU*, intensive care unit; *MV*, mitral valve. *$P < .05$ indicates a significant difference across the 3 groups. †$P < .05$, AMLDR versus MVR. ‡$P < .05$, AMLDR versus AMLE. §$P < .05$, AMLE versus MVR.

underwent reoperation, at 3 months and 3 years postoperatively. The MR grades at the latest follow-up are shown in Figure 2. The MVR group maintained predischarge surgical outcomes during the early follow-up period. Three patients in the AMLDR group and 5 patients in the AMLE group (including 2 who had an MV reoperation) had ≥3+ MR at the follow-up, but there was no significant difference ($P = .706$). Multiple regurgitation bundles from the incision (n = 3) were the most common reasons for MR deterioration in the AMLDR group, whereas patch tears (n = 3), leaflet perforation (n = 1), and SAM progression (n = 1) were common in the AMLE group. These patients were managed with reference to the SAM signs and MR with oral medication without heart failure or severe symptoms. There were no new-onset left ventricular outflow tract obstructions or permanent pacemaker implantations. Cardiac function was improved in all 3 groups, and no patient was rehospitalized for heart failure. The proportions of the latest NYHA class ≥III in the AMLDR, AMLE, and MVR groups were 22% (5 of 23), 19% (5 of 26), and 33% (8 of 24), respectively, which were significantly improved compared with the preoperative period ($P < .05$ for all).

## DISCUSSION

This study reports a novel surgical approach for HOCM and early- and mid-term results corresponding to 3 concomitant MV management strategies. The primary finding of our study is that TTM is a safe and reliable procedure for reducing septal thickness and eliminating left ventricular outflow tract obstruction, and that all 3 concomitant MV strategies are feasible for significantly improving MR.

The transmitral approach has unique strengths compared with the transaortic approach in the classical myectomy procedure. It combines the advantages of thoracoscopy to provide a larger and clearer surgical view and a more controlled operating space for the surgeon. Interventions for left midventricular obstruction, MV, and the subvalvular apparatus have become easier and more convenient. Such a minimally invasive approach also overcomes surgical contraindications, such as advanced age and high risk for HOCM. TTM successfully achieved surgical objectives by significantly decreasing the septal wall thickness and LVOTG while improving MR in this cohort ($P < .001$), demonstrating safety and efficacy similar to other studies on the transmitral approach for HOCM.[14,15] With the detailed imaging evaluation of selected patients, TTM is worth promoting in centers with experience in thoracoscopic valve surgery; however, the transmitral approach has its own limitations. As in other studies of the transmitral approach,[14,16] here the mitral leaflet was sacrificed at the beginning of the operation, leading to a time-consuming procedure for MV after myectomy. Except in cases of MV anomalies and a large extent of hypertrophic myocardium, patients should be selected carefully to balance the prolonged surgical time and the convenience of radical myectomy. The management strategy of MV is a more important

**TABLE 3. Perioperative echocardiography in the 3 study groups**

| Variable | AMLDR (N = 23) | AMLE (N = 26) | MVR (N = 24) | *P* value* |
|---|---|---|---|---|
| Septal thickness, mm, median (IQR) | | | | |
| Preop | 20.0 (17.0-25.0) | 18.0 (17.4-20.5) | 20.0 (17.4-20.5) | .165 |
| Postop | 11.0 (10.0-13.0)† | 12.0 (10.0-13.6)† | 11.0 (10.0-14.0)† | .780 |
| LVOTG, mm Hg, median (IQR) | | | | |
| Preop | 84.0 (74.0-100.0) | 89.5 (74.8-110.5) | 90.5 (75.0-120.0) | .173 |
| Postop | 6.0 (3.0-10.0)† | 11.6 (6.0-16.0)† | 7.0 (5.0-13.0)† | .049 |
| MR grading, median (IQR) | | | | |
| Preop | 4.0+ (2.0-4.0) | 3.0+ (2.0-4.0) | 4.0+ (2.0-4.0) | .641 |
| Postop | 1.0+ (1.0-2.0)† | 1.0+ (0-1.0)† | 0 (0-0)† | <.001 |
| MR grade ≥2+, n (%) | | | | |
| Preop | 20 (87.0) | 21 (80.8) | 22 (91.7) | .582 |
| Postop | 6 (13.0)† | 5 (19.2)† | 0† | .020 |
| SAM, n (%) | | | | |
| Preop | 21 (91.3) | 26 (100) | 23 (95.8) | .200 |
| Postop | 0† | 2 (7.7)† | 0† | - |
| LAD, mm, mean ± SD | | | | |
| Preop | 42.7 ± 6.5 | 44.1 ± 7.7 | 44.8 ± 4.1 | .517 |
| Postop | 37.8 ± 6.1† | 41.2 ± 6.2† | 39.9 ± 5.6† | .081 |
| LVEDD, mm, mean ± SD | | | | |
| Preop | 41.9 ± 4.5 | 44.2 ± 4.9 | 41.5 ± 4.6 | .085 |
| Postop | 45.1 ± 4.5† | 45.3 ± 6.1 | 43.6 ± 4.0 | .436 |
| LVEF, %, mean ± SD | | | | |
| Preop | 66.3 ± 3.7 | 68.2 ± 4.8 | 68.7 ± 3.7 | .114 |
| Postop | 61.7 ± 3.7† | 63.9 ± 6.6† | 64.1 ± 4.5† | .200 |

*Preop*, Preoperative; *Postop,* postoperative; *AMLDR*, anterior mitral leaflet direct reattachment; *AMLE*, anterior mitral leaflet extension; *MVR*, mitral valve replacement; *IQR*, interquartile range; *LVOTG*, left ventricular outflow tract gradient; *MR*, mitral regurgitation; *SAM*, systolic anterior motion; *LAD*, left atrial dimension; *SD*, standard deviation; *LVEDD*, left ventricular end-diastolic dimension; *LVEF*, left ventricular ejection fraction. *$P < .05$ indicates a significant difference across the 3 groups. †$P < .05$ indicates a significant difference in this parameter between the preoperative and postoperative periods.

issue, given that reinitiation of CPB further increases the operation time and the risk of adverse events.

The proposed MV strategy selection algorithm is shown in Figure 3. AMLDR is the optimal and preferred strategy in TTM because it is simple to perform and has the shortest operative time. Moreover, there was a significant reduction in the number of ≥3+ MRs at follow-up compared with the preoperative period (65.2% vs 13.0%; $P = .001$), with no recurrence of SAM or reoperation. The excellent results for AMLDR are related to the fact that most HOCM patients have MR originating from SAM.[5,17,18] Although complex, the mechanism of SAM has often been shown to be closely related to the structural factors of septal hypertrophy in patients with HOCM.

The key to improving MR is to ensure sufficient myectomy from the septal level toward the apex that can be evaluated by direct inspection or palpation[19]; even in the case of CPB resumption, extended myectomy should be prioritized over MV interventions.[5] In our study, a precise extended myectomy was performed via thoracoscopy, and none of the patients required additional septal myectomy. In cases with complex anatomy, we applied 3-dimensional modeling and printing technology to assess the extent and volume of resection preoperatively. Based on computed tomography data, a hypertrophic or bulging septum will be marked using Materialise Mimics software and the marked volume calculated automatically. Comparison of the excised myocardium with marked myocardium ultimately enables the visualization of intracardiac structures and precise resection.[20] Thus, the primary purpose of AMLDR during TTM is to restore the complete anatomy of the MV, which also decreases the risk of new-onset SAM by mitral valvuloplasty. Notably, the presence of an incision between the anterior mitral leaflet and annulus and good myocardial contractility in HOCM usually leads to trace to mild residual MR after surgery.

To ensure the long-term effect of AMLDR and avoid long-term reoperation, it is necessary to ensure that the needle spacing is not too wide during suturing; otherwise, excessive incision tension and valve leaflet deformation may generate multiple regurgitation bundles. Leaflet structural abnormalities in HOCM patients are most commonly

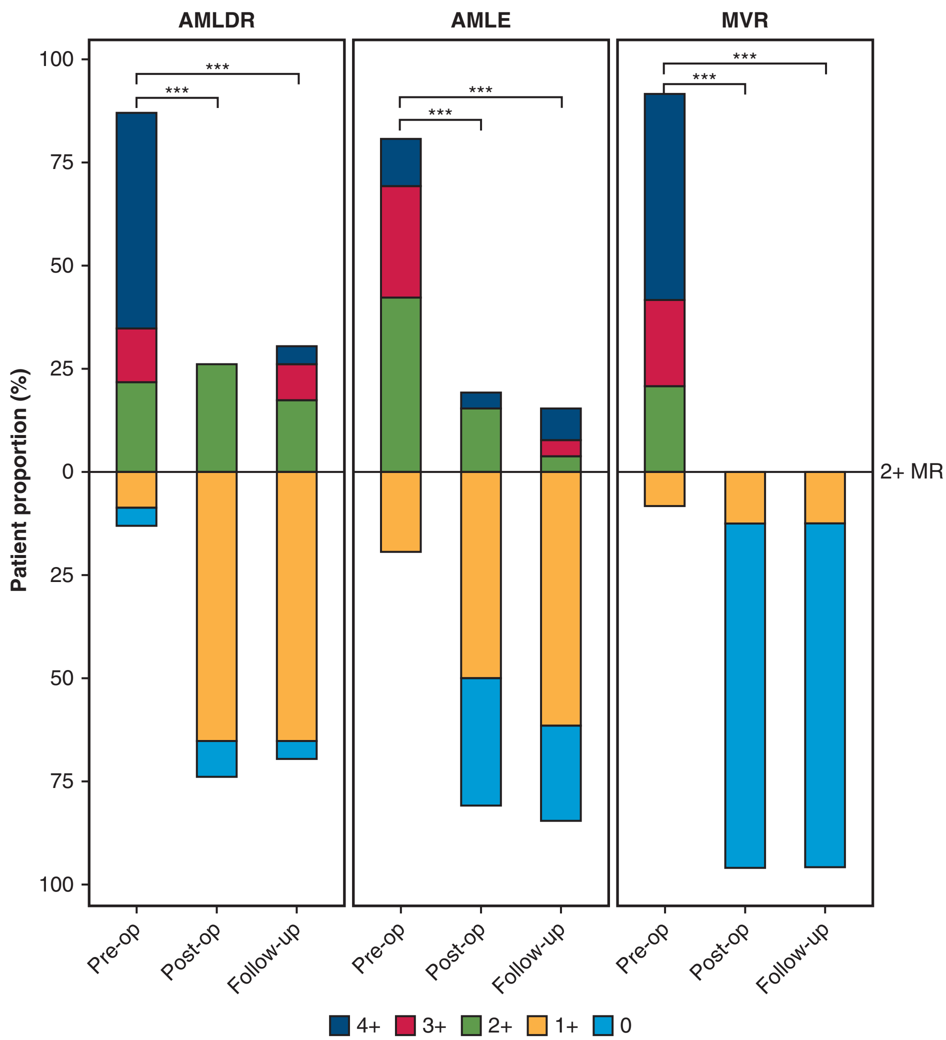


**FIGURE 2.** Mitral regurgitation grades during surgery and at the latest follow-up. *AMLDR*, Anterior mitral leaflet direct reattachment; *AMLE*, anterior mitral leaflet extension; *MVR*, mitral valve replacement. ***$P < .05$.

characterized by lengthy anterior mitral leaflets, which may be a major phenotypic expression of HCM with a genetic basis.[21-23] Balaram and colleagues[24] concluded that the anterior mitral leaflet should be plicated when >30 mm, thereby shortening as well as increasing the stiffness of the leaflet. This procedure was confirmed to be effective after medium- to long-term follow-up, with a 10-year survival rate of 92%, and residual SAM in only 3.8% of patients after surgery.[13,24] Similarly, a plication effect can be achieved in TTM by suturing the leaflets into multiple layers and reducing the length of the anterior leaflet to 30 mm. The addition of a plication technique to the AMLDR strategy not only prevents postoperative SAM, but also enhances the suture to reduce the risk of severe postoperative MR. This is more appropriate for patients with extremely long anterior mitral leaflets or with residual leaflets longer than the coaptation point.

The indications for AMLE in the extended septal myectomy procedure remain unclear. Previous reports have suggested that they depend on the area of the anterior mitral leaflet, including patients with fibrosis and contracture of the anterior leaflet, commonly seen in advanced age and in HOCM patients after alcohol ablation,[8] and in patients with an anterior leaflet area >12 $cm^2$.[25] In the long term, the patch does not increase the length of the anterior leaflet; instead, it increases the leaflet area along the horizontal direction so that its bending point is stiffened. Consequently, the coaptation length and the distance between the coaptation point and the septum are increased. These characteristics of concomitant AMLE prevent postoperative SAM and provide good durability.[18,25,26]

Our early exploration of patch extension strategies in TTM found that the application of a patch showed promising early results.[12] However, at follow-up, we found a

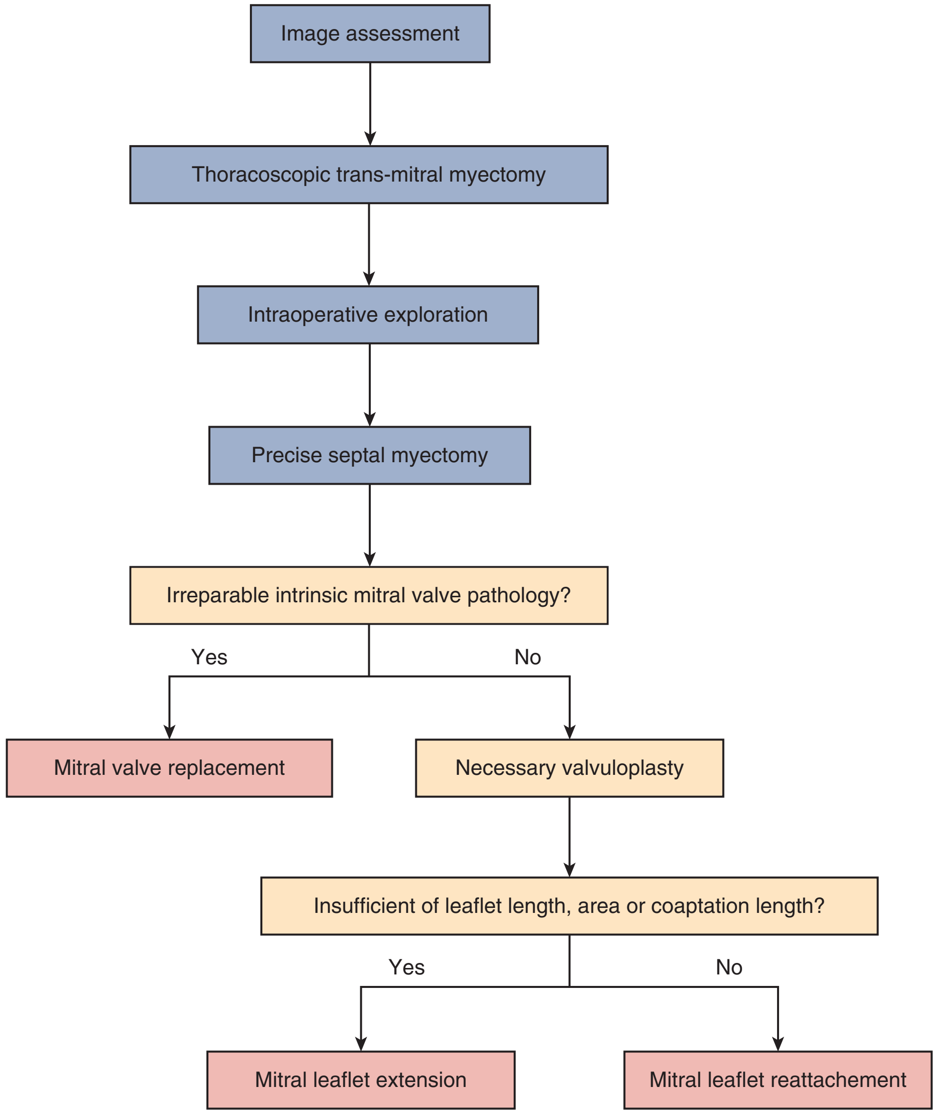


**FIGURE 3.** Algorithm for selection of mitral valve intervention strategy in thoracoscopic transmitral myectomy.

higher reoperation rate in AMLE than in AMLDR, although the difference was not statistically significant (7.7% vs 0%; $P = .491$). Suturing the patch to the annulus and anterior leaflet and maintaining a flat stretched state are more difficult with this technique than with the AMLDR technique. When the patch is cropped too small or the tension on both sides of the incision is high, a tear tends to form, especially at the commissures, which can easily cause severe MR. Therefore, we performed patch extension at a later stage while reinforcing with interrupted sutures with spacers at the anterior and posterior commissures to prevent tearing. In addition, the postoperative coaptation length was longer than AMLDR after patch extension, but patch extension is not only a technique to prevent SAM but also to create an initial SAM. When the patch is too large, it would create a redundant leaflet exceeding the coaptation point, which is a risk factor for recurrence of SAM and the need for reoperation.[27] Given the good results in the direct suture group and the risks of tearing, calcification, and reoperation in the long term, we suggest that in the transmitral approach, the routine use of patch extension is unnecessary as long as precise and sufficient septal resection is achieved by accurate preoperative imaging assessment, unless the anterior mitral leaflet length, area, or coaptation length is insufficient.

However, owing to our small sample size and the potential long-term complications of patch extension, we did not identify a cutoff value for distinguishing AMLE from AMLDR. In our experience, we suggest the AMLDR strategy when the anterior mitral leaflet is longer than normal (25 mm) and suggest a combined replicate technique when it is >30 mm. Conversely, an AMLE strategy should be used to restore the MV morphology when the leaflet is <25 mm. Thresholds regarding leaflet length or other parameters corresponding to different MV management strategies need to be further validated in prospective, large-sample, and long-term follow-up studies.

MVR is a simpler and more straightforward strategy than mitral valvuloplasty to ensure MR improvement in all MV intervention strategies. Concurrent MVR is the sole treatment option for patients with HOCM and irreparable intrinsic MV disease. The mitral leaflet(s) will be removed at the beginning to obtain a clear view exposure and avoid an aortic incision. In our MVR cohort, patients with intrinsic MV disease were mostly elderly women with combined rheumatic heart disease, mitral stenosis, or leaflet perforation, and the organic pathology was independent of HOCM and SAM. Although MVR strategy via the transmitral approach has shown a comparable survival rate,[28] multiple studies have demonstrated the superiority of concomitant mitral valvuloplasty over MVR in patients with HOCM.[5,8,29] The difference in long-term survival between the 2 strategies is attributed mainly to the higher rates of device or cardiac complications associated with MVR, such as postoperative embolism, bleeding, and reoperation. Therefore, we strongly recommend that TTM and MVR strategies be considered for HOCM patients who have intrinsic MV diseases that are irreparable or have failed valvuloplasty.

The mechanism of SAM involves one or more structural, dynamic, and geometric factors. To address the concerns of surgeons, more than moderate grade residual SAM and/or MR remained after the cross-clamp was removed. In our experience, preoperative echocardiography is essential for identifying intrinsic MV diseases and evaluating whether MR is independent of SAM. Although 43% of intrinsic MV diseases are recognized intraoperatively,[5] some markedly intrinsic features, such as chordae tendineae rupture, are common and easy to be distinguished. For example, posterior MV prolapse has an alternative anteromedial bundle of regurgitation instead of the posterolateral MR caused by SAM. TEE has a greater spatial resolution; thus, prebypass TEE should be performed routinely to identify intrinsic MV diseases. A detailed assessment of MV anatomy, function, and abnormalities using 3-dimensional printing or multimodality imaging is helpful for surgical strategy selection.[30] Necessary mitral valvuloplasty should be performed as long as possible after extended myectomy, to eliminate other risk factors associated with SAM, such as secondary chordae tendineae and thickening of papillary muscles. Mitral valvuloplasty itself also can affect the degree of postoperative MR and also trigger new SAM.[31,32] Thus, before removing the aortic cross-clamp, leaflet motion should be checked to determine whether the prosthetic ring is too small, whether the length of the anterior leaflet of the MV is too long (beyond the coaptation point) or too large in proportion to the posterior leaflet, and whether the left ventricular volume is sufficient. If CPB resumption is required, the second MV strategy should be individualized by assessing the thickness of the septal wall, the LVOTG, and the source of MR via TEE.

Poor efficacy or failure of valvuloplasty was the main reason for a second intervention. One patient in the AMLE group had an intraoperative MR >3+ and underwent edge-to-edge repair to control the MR to 1+. Edge-to-edge repair is a functional prosthetic valve technique that effectively eliminates MR and SAM.[33] This technique is characterized by the absence of reblocking of the aorta, a simple but effective operation, and is a preferred technique for dealing with unsatisfactory MR improvement.

This study has several limitations. First, as a retrospective study, and considering the fact that decisions about the approach to HOCM depend to some extent on operator experience and the existence of a learning curve for the procedures described herein, only patients with HOCM who were surgically treated by a single-arm, single-surgical team were included. Consequently, owing to the relatively small sample size and low incidence of adverse events, further detailed classification and screening of risk factors was not possible. Larger, prospective studies are needed to verify our present results.

Second, surgical expertise is one factor in the decision of whether to spare the MV. Although we favor MV repair more than MVR, in this study we included the early cases of selected MVR without intrinsic MV disease, which might have led to the relatively higher rate of MVR in this small sample size. Third, the surgical results may be biased by the differing experience of the physicians on the surgical team. Finally, this study only revealed good early follow-up results, which does not mean that patients can continue to be protected from adverse events such as severe MR, reoperation, or even death. Evaluating the clinical effects of TTM requires continued long-term, detailed follow-up.

## CONCLUSIONS

TTM in selected patients is safe and effective, and all 3 MV management strategies significantly reduced the LVOTG while improving MR. Mitral valvuloplasty is the preferred initial management strategy over valve replacement, except in the scenario of intrinsic MV disease and valvuloplasty failure. Direct reattachment of the mitral leaflet is recommended as the preferred strategy, as it is a simple procedure with a low reoperation rate. Leaflet extension is favored in the HOCM subset with short mitral leaflet and coaptation lengths. Further studies using long-term data are needed.

### Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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**Key Words:** hypertrophic cardiomyopathy, mitral valve, minimal invasive surgery, systolic anterior motion