Transmitral Septal Myectomy for Hypertrophic Obstructive Cardiomyopathy

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Background. **Intrinsic abnormalities of the mitral valve are common in patients with hypertrophic cardiomyopathy and may need to be addressed at operation.**

Methods. **Consecutive patients undergoing transmitral septal myectomy were retrospectively reviewed. The ventricular septum was exposed through a left atriotomy, and the anterior leaflet of the mitral valve was detached from its annulus. An extended myectomy was performed to the base of the papillary muscles. After myectomy, the anterior leaflet was reattached and concomitant mitral valve repair or replacement was performed. In some cases, we performed a modified anterolateral commissural closure suture, which served to reposition the lateral aspect of the anterior leaflet out of the left ventricular outflow tract ("curtain stitch").**

Results. **Twenty patients who underwent this procedure were identified (70% women; mean age 63 years). Mitral regurgitation was moderate in 55% and severe in 40%. Preoperative peak left ventricular outflow tract gradient was 92 ± 43 mm Hg. Mitral valve repair (n = 11) or replacement (n = 9) was performed. Predischarge transthoracic echocardiography demonstrated a left ventricular outflow tract gradient of 10 ± 5 mm Hg. There was no operative mortality. Follow-up was 100% complete and averaged 22 ± 25 months. No patient required reoperation, and there was no recurrence of left ventricular outflow tract obstruction or mitral regurgitation greater than mild.**

Conclusions. **Potential advantages of transmitral myectomy include a panoramic view of the septum and mitral subvalvular apparatus and the ability to simultaneously address mitral valve pathology. Consideration should be given to using the transmitral approach to septal myectomy as the preferred approach for the surgical treatment of hypertrophic cardiomyopathy.**

(Ann Thorac Surg 2018;■:■–■)

Morrow described transaortic septal myectomy (TASM) in 1968, and the operation has changed little since its original description [1, 2]. Conventional septal myectomy achieves reduction of left ventricular outflow tract (LVOT) gradients by calibrated resection of the interventricular muscular septum. The pathophysiology of LVOT obstruction in patients with hypertrophic cardiomyopathy (HCM) is complex but always results from interaction of two structures: the anterior leaflet of the mitral valve (MV) and the interventricular septum. Morphologic abnormalities of the MV are very common among patients with indications for operative treatment for HCM and LVOT obstruction, and in previous series 10% to 20% of patients undergoing septal myectomy have required concomitant procedures on the MV [3–6]. Transaortic septal myectomy has key limitations, including limited visibility of the ventricular septum (particularly the mid and apical ventricular septum), potential for damage to the aortic valve cusps, and limited access to the MV.

Transmitral septal myectomy (TMSM) for subaortic stenosis was first reported by Lillehei and Levy [7] in 1963. Recently, a number of case reports and small case series have reported use of TMSM to facilitate exposure of the ventricular septum and when addressing concomitant mitral pathology [8–13], whereas others have described TASM with a planned transatrial MV repair to address coexisting MV pathology [14, 15].

Benefits of the transmitral exposure include a wide view of the ventricular septum, absent risk of injury to the aortic valve cusps, and the opportunity to address concomitant abnormalities of the MV and subvalvular apparatus. In addition, there is an enhanced ability to teach trainees to perform septal myectomy (both trainee

Accepted for publication Oct 16, 2017.

Presented at the Fifty-third Annual Meeting of The Society of Thoracic Surgeons, Houston, TX, Jan 21–25, 2017.

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The Video can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2017.10.045] on http://www.annalsthoracicsurgery.org.

Published by Elsevier Inc.

0003-4975/$36.00
https://doi.org/10.1016/j.athoracsur.2017.10.045

and attending can see the procedure). We have applied TMSM to patients with HCM and LVOT obstruction and definite abnormalities of the MV complex and now report our experience.

Patients and Methods

Patient Selection

This study was approved by the University of Maryland School of Medicine Institutional Review Board. Between January 2007 and January 2017, 44 consecutive patients with symptomatic HCM unresponsive to medical therapy underwent septal myectomy for HCM. Among these, 20 patients underwent TMSM and repair or replacement of the MV. Decision to use the TMSM approach was made by an operating surgeon with extensive MV experience and was based on assessment of the patient's clinical status, LVOT gradient, and MV pathology. Pressure gradients across the LVOT were measured using preoperative and predischarge two-dimensional transthoracic echocardiography or transesophageal echocardiography, and peak gradients were reported. For each patient, four or five measurements were made of the LVOT gradient and three measurements of the interventricular septal thickness. From these values an average and standard deviation were generated for each patient before and after operation. Mitral regurgitation grade was based on preoperative two-dimensional transthoracic echocardiography or transesophageal echocardiography, using American Society of Echocardiography guidelines [16]. Follow-up echocardiograms were obtained from primary care physicians or referring cardiologists. Mitral regurgitation grade and LVOT gradient from the most recent follow-up echocardiogram were measured. Indication for MV repair or replacement included preoperative or intraoperative evidence of intrinsic MV pathology, such as leaflet prolapse, dense annular calcification, or ruptured chordae. Mitral valve morphology and pathology were characterized based on echocardiographic findings and intraoperative surgical inspection. Perioperative mortality was defined as death within 30 days after surgery or inhospital death. Patient morbidity was determined by interrogation of The Society of Thoracic Surgeons institutional database.

Operative Technique

Cardiopulmonary bypass was established with bicaval cannulation. A combination of antegrade and retrograde cardioplegia was used for myocardial protection. Exposure of the MV was enhanced using mobilization of the superior and inferior vena cavae, aggressive dissection of the interatrial groove, liberation of the left side of the pericardium, and a generous left atriotomy. After inspection and assessment of the MV, the anterior leaflet of the MV was sharply incised and detached at its base, with the incision extending anterior to the commissures and care taken to avoid disruption of the commissures (Video; Fig 1A). Inspection of the septum always revealed an opalescent, pearly white horizontal fibrous band on the septum, which corresponds to the contact point of the anterior leaflet with the septum. A stay stitch was placed at the level of this band, and septal traction was applied (Fig 1B).

The myectomy was performed with a 15 blade starting 3 mm to 4 mm above the horizontal fibrous band and including the entire band. The myectomy extended from the 12-o'clock position counterclockwise to the 8-o'clock or 9-o'clock position. The depth of the myectomy was adjusted based on the measured thickness of the septum on transesophageal echocardiography and was calculated to leave a residual septal thickness of 12 mm to 15 mm. The myectomy was extended to the level of the base of the papillary muscles (Fig 1C). After the initial resection, a sponge stick was used to press down on the anterior wall of the right ventricle to bring more distal septum into view, and a second-pass resection was performed. After myectomy, the anterior leaflet was reattached (Fig 1D), or in some cases, augmented with a patch of fresh autologous pericardium using running 4-0 monofilament suture when the anterior leaflet was foreshortened or not elongated.

The MV was then repaired or replaced. In some cases, a modified anterolateral commissural closure suture ("curtain stitch") served to reposition the lateral aspect of the anterior leaflet out of the LVOT (Fig 1D, 1E). This is a modification of a technique originally described by Hetzer, which involved a similar suture at both commissures [17]. We have used the curtain stitch successfully in the prevention and treatment of systolic anterior motion in MV repair operations. It is an important adjunct for repairing the MV in patients with HCM and obstruction. Adequacy of resection and repair were determined on postbypass transesophageal echocardiography. A successful repair is characterized by wide separation of the septum and the anterior leaflet throughout the cardiac cycle, absence of mitral regurgitation, a minimal LVOT gradient, no evidence of ventricular septal defect on color flow Doppler, or septal thickness less than 10 mm.

Statistical Analyses

Statistical software (JMP 8.0; SAS Institute, Cary, NC) was used for data analysis. Values are presented as mean ± SD or median with first and third quartiles (interquartile range). Median values were used when the data had skewed distributions. Preoperative and postoperative echocardiographic values were compared using a paired Student's t test. A p value less than 0.05 was considered statistically significant.

Results

Patient Characteristics

Preoperative patient characteristics are summarized in Table 1. The mean age was 64 ± 8.9 years and 70% (14 of 20) were women. Forty percent were in New York Heart Association functional class III or IV heart failure at the time of presentation, and 25% had a history of atrial fibrillation. Ten percent (2 of 20) had a permanent pacemaker preoperatively. No patients had undergone previous cardiac surgery. Ninety-five percent (19 of 20) of

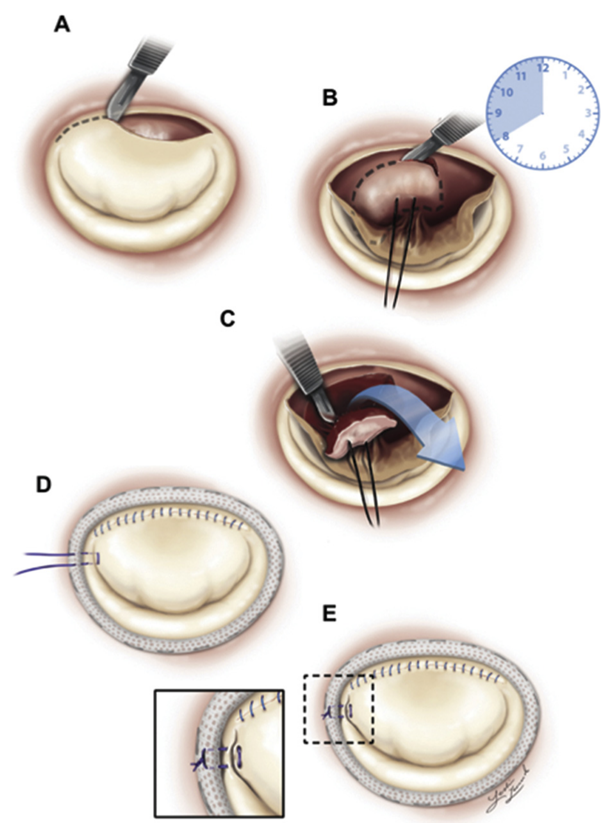

Fig 1. Operative technique for transmitral septal myectomy. (A) Sharp dissection of anterior mitral leaflet from its base provides wide exposure of the ventricular septum. (B, C) Septal resection extends in a counter-clockwise fashion from the 12-o'clock to the 8-o'clock position. (D) After myectomy, the anterior leaflet is reattached, and necessary mitral valve repair is performed, including ring annuloplasty. (E) In some cases, a curtain stitch is useful to reposition the lateral aspect of the anterior leaflet out of the left ventricular outflow tract. A horizontal mattress suture (with or without a pledget) is placed to join the coapting surfaces (not the free edges) of the anterior and posterior leaflets at the anterolateral commissure and brought through the annuloplasty ring.

patients had moderate or greater mitral regurgitation preoperatively (Fig 2). The mean left ventricular ejection fraction was normal (64% ± 6%). Preoperative septal wall thickness was 18 ± 4 mm (range, 13 to 27 mm). Preoperative gradient across the LVOT was 92 ± 43 mm Hg (range, 31 to 174 mm Hg).

Operative Characteristics

In all patients, surgical septal myectomy was performed through the MV after detachment of the anterior leaflet. There were no conversions to a transaortic or transapical approach. Concomitant surgery and other operative details are described in Table 2. An adequate muscular resection was achieved in each case.

After muscular resection, the anterior leaflet was reattached primarily (n = 8), patched with autologous pericardium (n = 3), or resected before MV replacement (n = 9). Mitral valve morphology as noted by the surgeon is characterized in Table 3. All patients required a MV procedure based on intraoperative assessment of the operating surgeon (Table 4). Repair techniques varied, with most patients receiving a ring annuloplasty (6 of 11 patients undergoing repair). In 6 of the 11 patients undergoing repair, a curtain stitch was performed at the anterolateral commissure to reposition the anterior leaflet out of the LVOT (Fig 1E). Nine patients required valve replacement: rheumatic (n = 2), recurrent systolic anterior motion (n = 1), immobile leaflets (n = 3), or dense annular calcification not amenable to a repair (n = 3).

Effectiveness of Septal Myectomy

Based on comparison of transthoracic echocardiograms preoperatively and before dismissal, interventricular thickness decreased on average from 18 ± 4 mm to 12 ± 3 mm ($p < 0.0001$). Peak gradient across the LVOT decreased from 92 ± 43 to 10 ± 5 ($p < 0.0001$). Change in septal thickness and gradient is shown in Figure 3.

There was no incidence of iatrogenic ventricular septal defect. Three patients (15%) required a permanent pacemaker for third-degree heart block. Of these 3 patients, 1 had a MV replacement, 1 had concomitant cryomaze procedure, and 1 had a MV repair. Other complications included 1 patient with mediastinitis and 1 patient who required reexploration for bleeding (Table 5).

Clinical Outcomes

There was no operative mortality. Mean hospital length of stay was 10 ± 5 days (Table 4). No patients had greater than mild mitral regurgitation on predischarge echocardiography. Follow-up was complete for all 20 patients. At a mean follow-up time of 21.3 ± 25.5 months (range, 0.4 to 101.5), 19 of 20 patients were alive. One patient died of Alzheimer's dementia 4 years after the operation. No patient required reoperation. At last follow-up, the LVOT gradient averaged 8 ± 3 mm Hg, and no patient had worse than mild mitral regurgitation.

Comment

Lillehei and Levy [7] first described septal myectomy using a right thoracotomy, a left atriotomy, and incision through the base of the anterior leaflet to facilitate septal myectomy in 2 patients in 1963. Lillehei chose to perform TMSM because of previous suboptimal exposure through the aortic valve, and noted the feasibility of simultaneously repairing the MV through the same incision. Whereas the original understanding of the pathophysiology of LVOT obstruction in HCM was focused on septal muscular hypertrophy as the primary cause of obstruction, it has become clear that in most HCM patients the disease process is not confined to the cardiac muscle but includes structural abnormalities of the MV leaflets, chordae, and papillary muscle insertion [18]. The present experience demonstrates that TMSM is a safe and effective approach to septal myectomy that facilitates outstanding exposure of the septum from the septal shelf to the base of the papillary muscles and enables the

Table 1. Clinical Characteristics of 20 Patients Undergoing Transmitral Septal Myectomy

Preoperative Variables	Values
Female	14 (70)
Age, years	64 ± 8.9
Diabetes mellitus	6 (30)
Renal failure	1 (5)
Smoking history	6 (30)
Chronic obstructive pulmonary disease	2 (10)
Hypertension	14 (70)
Coronary artery disease	10 (50)
Atrial fibrillation	5 (25)
Permanent pacemaker	2 (10)
Prior MI	0 (0)
NYHA functional class	
I/II	12 (60)
III/IV	8 (40)
Previous cardiac operation	0 (0)
Left ventricular ejection fraction, %	64.2 ± 6.3
Interventricular septal wall thickness, mm	18.2 ± 3.8
Left ventricular end-systolic dimension, mm	24.5 ± 5.9
Left ventricular end-diastolic dimension, mm	42.8 ± 6.9
Left atrial dimension, mm	44.5 ± 8.2
Left ventricular outflow tract gradient, mm Hg	92.8 ± 42.9

Values are n (%) or mean ± SD.

MI = myocardial infarction; NYHA = New York Heart Association.

surgeon to perform concomitant intervention on the frequently abnormal MV.

Moderate to severe or greater mitral regurgitation has been reported in as many as 60% of patients with HCM and LVOT obstruction and results from distraction of the anterior leaflet toward the septum during systole and failure of coaptation or other intrinsic abnormalities of the MV (prolapse, chordal rupture, and so forth) [3]. A

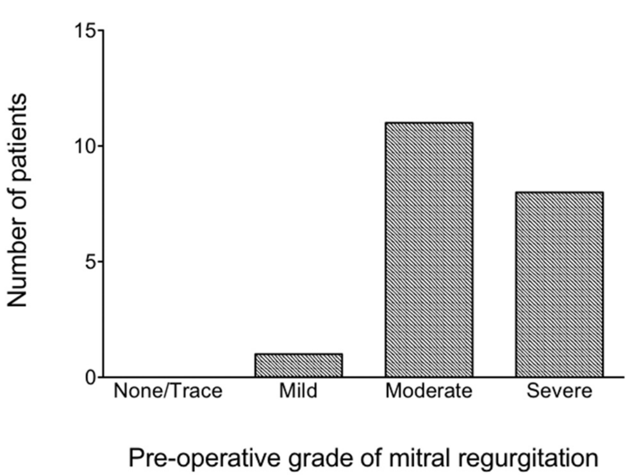

Fig 2. Preoperative grade of mitral regurgitation by transthoracic echocardiogram.

Table 2. Summary of Operative Details

Operative Details	Values
Cross-clamp time, minutes	106 ± 30.2
Septal myectomy	20 (100)
Mitral valve operation	
Repair	11 (55)
Replacement	9 (45)
Concomitant procedures	
Coronary artery bypass grafting	2 (10)
Cryomaze	5 (25)
Atrial septal defect repair	2 (10)

Values are mean ± SD or n (%).

number of large series have shown that 10% to 20% of HCM patients undergoing TASM will require a MV operation in addition to septal myectomy [3, 4]. Hong and colleagues [3] report returning to cardiopulmonary bypass to address MV abnormalities after initial TASM in 58 of 174 patients (33%) who required a concomitant MV operation. In another experience, 115 of 851 patients (13.5%) required MV repair or replacement performed in conjunction with a TASM [4].

Structural and morphologic abnormalities of the MV in HCM patients have been well described [19, 20]. Klues and associates [19] studied resected MV from 65 patients undergoing MV replacement for HCM and reported increased mitral leaflet area in the HCM valves as compared with control patients (12.9 cm^2 versus 8.7 cm^2). The increase in area was largely attributable to an increase in anterior leaflet length (2.2 cm for HCM versus 1.8 cm for control patients). Maron and colleagues [21] studied 172 HCM patients and 172 controls using cardiac magnetic resonance imaging and found that anterior and posterior MV leaflets were significantly longer in HCM patients. Mitral valve leaflet elongation was found to be independent of left ventricular wall thickness; however, a ratio of anterior mitral leaflet length to LVOT diameter of more than 2.0 was associated with mitral anterior leaflet systolic anterior motion–based subaortic obstruction. The researchers concluded that mitral leaflet elongation was

Table 3. Intraoperative Findings of Mitral Valve Morphology

Morphology	n (%)
Rheumatic	2 (10)
Dense mitral annular calcification	4 (20)
Degenerative	4 (20)
Barlow	2
Severe posterior leaflet prolapse	1
Ruptured chordae tendinae	1
Other	9 (45)
Elongated anterior leaflet	6
Fibrotic/foreshortened anterior leaflet	3
No pathology	1 (5)
Total	20 (100)

Table 4. Operative Techniques for Mitral Valve Repair or Replacement

Technique	n (%)
Replacement	9 (45)
Bioprosthetic	3
Mechanical	6
Attempted repair first?	4
Reasons for going straight to replacement:	5
Immobile leaflets	2
Dense calcification	3
Repair	11 (55)
Ring annuloplasty	6
Neochords	4
Reefing/imbrication stitch	2
Closure of leaflet cleft	5
Curtain stitch	6
Patch of anterior leaflet (autologous pericardium)	3
Anterior leaflet fenestration	1

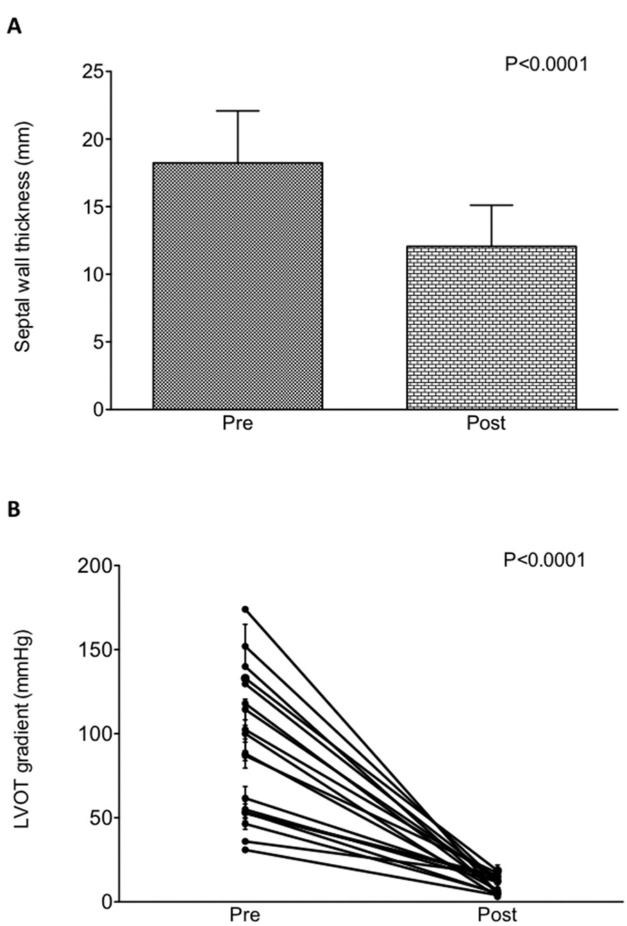

Fig 3. Preoperative (Pre) and postoperative (Post) reduction in (A) width of basal interventricular septum (18.2 ± 3.8 mm versus 12.1 ± 3.0 mm, p < 0.0001) and (B) left ventricular outflow tract (LVOT) gradient (92.8 ± 42.9 mm Hg versus 10.9 ± 5.1 mm Hg, p < 0.0001) after transmitral septal myectomy.

Table 5. Postoperative Outcomes

Postoperative Data	Values
Survival	
To discharge	20 (100)
Last follow-up	19 (95)
Hospital length of stay, days	10 ± 5
Stroke	0 (0)
Renal failure	0 (0)
Complete heart block	3 (15)
New onset atrial fibrillation	4 (20)
Reoperation for bleeding	1 (5)
Mediastinitis	1 (5)
Mitral regurgitation ≥2, at last follow-up	0 (0)
Left ventricular ejection fraction, %	61 ± 7.9
Left ventricular outflow gradient, mm Hg	10.9 ± 5.1
Septal wall thickness, mm	12.1 ± 3.0

Values are n (%) or mean ± SD.

an independent phenotypic expression of HCM and that the combination of a small outflow tract and an elongated anterior mitral leaflet was responsible for LVOT obstruction in HCM. Finally, in a subset of HCM patients with mild hypertrophy (less than 16 mm), isolated septal myectomy is unlikely to resolve LVOT obstruction and increases the risk for iatrogenic ventricular septal defect if an aggressive resection is performed [22]. In this group of patients (3 of 20 in our series), a shallow muscular resection and MV repair or replacement with a low profile prosthesis is mandatory.

Limitations of conventional TASM include limited visualization of the septum, particularly in the mid cavity of the left ventricle and the possibility and risk of incomplete myectomy and inadequate relief of LVOT obstruction. Visualization of the septum through the aortic valve is limited to the operating surgeon, compromising the ability to teach septal myectomy. Myectomy is a procedure that is often limited to centers of excellence [23] as a result of lack of surgeon experience and comfort with TASM. In contrast, TMSM is performed using standard MV exposure and anterior leaflet incision routinely used in MV replacement. The exposure afforded after the anterior leaflet is incised and retracted is panoramic and extends from the septal “shelf” under the aortic valve to the base of the papillary muscles.

The rate of MV replacement in the present study was 45% (9 of 20 patients) and is consistent with results in previous large series of patients, ranging from 24% to 42% [3, 4]. Our approach is to repair the valve whenever possible. In our experience with HCM patients, the mitral leaflets were not infrequently found to be diffusely thickened and fibrotic. Similar observations were noted by Kaple and colleagues [4], who cataloged morphologic changes of the MV in 115 HCM patients undergoing concomitant MV surgery and found that 70% of patients with MV dysfunction had thickened and restricted leaflets. In that series, half the patients underwent repair and half required replacement. Similarly, we also encountered a relatively high percentage of patients with dense mitral annular calcification, which in some cases precluded repair. The mechanism of valve thickening and calcification is unknown, but the trauma of repetitive septal contact may play a role.

One drawback of the transmitral approach could be an increased risk of injury to the conduction system. We found 3 of 20 patients had heart block requiring permanent pacemaker. Although that is higher than the incidence of heart block with transaortic myectomy, it may be related to concomitant operations that were performed (eg, cryomaze) [24]. Therefore it is not clear whether the incidence of heart block in this study was related to our approach to the septum or to a complication of one of the concomitant procedures. We have also modified the location of the myectomy: early in the series, resection was started at the 1-o'clock position and carried in a counterclockwise direction. In an effort to avoid the conduction system, we now initiate the myectomy at the 12-o'clock position. Finally, we have now implemented the use of cardiac magnetic resonance imaging as part of the preoperative evaluation of these patients, and that may aid in assessment of intrinsic MV pathology [25].

This study was limited by the retrospective collection of data and the relatively small sample size. In addition, the operations were performed over a 10-year period by a single surgeon with a large referral MV surgery practice. Moreover, the echocardiograms were not initially read in a core laboratory. Acknowledging this limitation, a single cardiologist re-reviewed each patient's preoperative and predismissal echocardiograms to measure the septal thickness and LVOT gradient and to assess the degree of mitral regurgitation.

In conclusion, the present study reports a large experience with TMSM. Key findings of this experience include clearly evident superior visualization of the ventricular septum through the detached MV, effective immediate and midterm relief of LVOT obstruction, and improvement in symptoms. Concomitant abnormalities of the MV were addressed using a variety of techniques, including an anterolateral curtain stitch that was an effective adjunct to displace the anterior MV leaflet out of the LVOT. Although TASM and TMSM are both highly effective at relieving LVOT obstruction, TMSM has the advantage of allowing unfettered access to the entire MV complex and septum. Recognizing the pivotal contribution of the MV to LVOT obstruction in HCM, it is conceivable that future innovative percutaneous and small-incision beating heart techniques will be developed that are effective at relieving the LVOT obstruction by altering the structure of the MV without concomitant myectomy. Inceptive efforts to treat obstruction with percutaneous leaflet plication are sure to be followed by more sophisticated techniques [26, 27].

Transmitral septal myectomy is clearly applicable to patients with LVOT obstruction who present with concomitant MV pathology and those with minimal septal hypertrophy. As our experience has grown with this approach and the benefits have become clear, we now favor the transmitral approach as the preferred operative approach for myectomy in our institution and it deserves broader adoption, especially in patients where significant MV abnormalities contribute to LVOT obstruction.

Funding for this study was provided by internal funding from the Division of Cardiac Surgery at the University of Maryland School of Medicine.

Audio Discussion: Audio of the discussion that followed the presentation of this paper at the STS Annual Meeting can be accessed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2017.10.045] on http://www.annalsthoracicsurgery.org.

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