Lessons from reoperations for mitral stenosis after mitral valve repair

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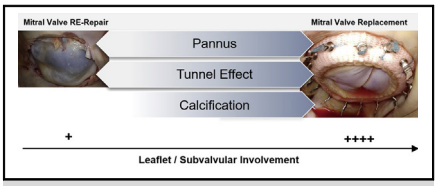
ABSTRACT

Background: The durability of mitral valve repair (MVr) is usually defined by the absence of recurrent significant mitral regurgitation. Postrepair mitral stenosis (MS) is a less frequent and less studied mode of failure of MVr. We analyzed our experience in patients who underwent reoperation for postrepair MS to characterize mechanisms resulting in MS and to summarize reoperative surgical strategies and mid-term outcomes.

Methods: Using a prospective database, we retrospectively analyzed data on 35 consecutive patients who underwent reoperation for symptomatic moderate to severe MS between January 1, 2011, and February 1, 2020.

Results: The mean patient age was 61.4 ± 11.4 years, and 69% were female. The median annuloplasty ring size used at the initial repair was 28 mm (interquartile range, 26-30 mm). Additional repair techniques at the initial operation included leaflet resection in 12 patients (34%) and commissuroplasty or edge-to-edge repair in 6 patients (18%). At reoperation, the most common mechanism of MS was pannus ingrowth in 20 patients (57%), leaflet calcification in 12 (34%), commissural fusion in 5 (14%), and tunnel effect (functional MS) in 3 (9%). Twenty-two patients (63%) underwent valve replacement, and 13 (37%) underwent valve re-repair. In patients who underwent re-repair, annuloplasty revision was performed in all patients, with 6 patients (46%) converted from complete ring to band, 4 (11%) converted from ring to pericardial annuloplasty, 2 (6%) converted to no annuloplasty, and 1 (8%) with annuloplasty ring upsizing. There were no in-hospital or 1-year mortalities. Survival at the 5-year follow-up was 93.9%.

Conclusions: MS causing late failure of MVr is frequently associated with smaller ring sizes and inflammatory or calcific changes in the valve. Highly selected patients may be good candidates for mitral valve re-repair. (J Thorac Cardiovasc Surg 2021;161:937-46)



Mechanisms of postrepair mitral stenosis and the impact each has on the ability to perform a re-repair versus replacement.

CENTRAL MESSAGE

Postrepair mitral stenosis is commonly related to small annuloplasty size. Pannus ingrowth, leaflet fibrosis, and/or leaflet calcification are also common findings.

PERSPECTIVE

Postrepair mitral stenosis (MS) may occur in the absence of significant mitral regurgitation causing late failure of repair. MS is most commonly related to small prosthesis size in association with leaflet fibrosis and calcification. Reoperations in the modern era can be performed with minimal morbidity and mortality, and re-repair is feasible in select patients.

See Commentary on page 947.

Mitral valve repair (MVr) remains the preferred therapy over mitral valve replacement (MVR) for most patients with mitral regurgitation, associated with better long-term outcomes and avoidance of prosthetic replacement complications.[1] With widespread adoption and standardization of mitral reconstructive techniques over the last few decades, guideline-driven indications for earlier surgery have expanded.[2] MVr durability following repair in the setting of mitral valve regurgitation is most commonly defined by the freedom from recurrent mitral regurgitation.[3] Postrepair mitral stenosis (MS) is an increasingly recognized but understudied mode of failure of MVr, with a lack of clarity regarding pathoanatomic findings as well as surgical management.

We retrospectively analyzed a consecutive series of patients who underwent reoperation for symptomatic postrepair MS at our Mitral Valve Reference Center. We focused our attention on intraoperative findings, as well as surgical strategies and mid-term outcomes.

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Abbreviations and Acronyms
BNP = B-type natriuretic peptide
IQR = interquartile range
MS = mitral stenosis
MVr = mitral valve repair
MVR = mitral valve replacement

METHODS

Study Population

Between January 1, 2011, and February 1, 2020, 263 consecutive patients were referred to our institution for mitral valve reoperation after previous failed MVr for mitral regurgitation. Of these, 35 patients (13.3%) underwent reoperation for symptomatic postrepair moderate-to-severe or severe MS. Patients with concomitant moderate or greater mitral regurgitation were not included in the cohort.

The diagnosis of MS was made using resting or stress echocardiography to confirm the diagnosis, according to echocardiographic definitions of MS by the European Association of Echocardiography/American Society of Echocardiography's recommendations for clinical practice.[4] Quantitative grading of MS was based on our own echocardiography lab according to current protocols set forth by the American College of Cardiology and American Heart Association.[5] In addition, invasive hemodynamic measurements via right heart catheterization were done in all patients to guide perioperative management. Operative data from the primary MVr surgery as well as from our reoperation were prospectively captured and reviewed retrospectively in all patients.

Surgical Technique

Reoperations were performed via midline sternotomy in all patients by a highly specialized team. Routine preoperative chest computed tomography scanning was done in all patients to determine the mediastinal anatomy and plan a cannulation strategy. Limited dissection of mediastinal adhesions was performed, to minimize operative time and bleeding. Central cannulation was achieved in all patients with vacuum-assisted venous drainage. Myocardial protection was achieved via cold and warm blood cardioplegia delivered in both antegrade and retrograde fashion. The mitral valve was accessed via either Sondergaard's groove or a transseptal approach, with the latter preferred in cases with small left atrium, a deep chest cavity, extensive adhesions, or in-situ aortic prosthesis. Once the mitral valve was exposed, systematic valve analysis was undertaken to confirm the mechanism(s) of stenosis.

We started all mitral reoperations with removal of the previous annuloplasty prosthesis, by first incising the fibrous capsule around the prosthesis. The annuloplasty device was then carefully explanted using a combination of sharp and blunt dissection without injuring the underlying structures.

The decision to replace or re-repair the valve depended primarily on the intraoperative findings with regard to the availability, quality, and mobility of the remaining leaflet tissue, absence of mitral annular or leaflet calcification, and the status of the subvalvular apparatus. Other important factors included the primary etiology of mitral dysfunction, underlying ventricular function, patient age, and associated comorbidities.

Valve replacement, when necessary, was performed using chordal-sparing techniques, retaining all or most of the posterior leaflet with its chordal attachments to maintain ventriculoannular continuity. A nonevert-ing suture technique was used, locating the pledgets on the ventricular side to allow for supra-annular insertion of the prosthesis.

Mitral re-repair techniques included pannus debridement, leaflet peeling, primary and secondary chordal cutting to mobilize leaflets, and patch augmentation in cases of tissue deficiency. Annuloplasty strategies involved partial band annuloplasty, pericardial annuloplasty, and, rarely, upsized ring annuloplasty or nonannuloplasty repair.

After weaning from bypass and before decannulation, intraoperative transesophageal echocardiography was performed in all patients to assess prosthetic valve function in cases of MVR and to exclude residual MS and confirm valve competency in cases of valve re-repair.

Predischarge Echocardiography

Two-dimensional and Doppler transthoracic echocardiography examination was performed in all patients before discharge, using commercially

TABLE 1. Baseline characteristics (N = 35)

Characteristic	Value
Demographics	
Age at initial procedure, y, mean (SD)	55.1 (12.4)
Age at reoperation, y, mean (SD)	61.4 (11.4)
Time to reoperation, y, mean (SD)	6.8 (5.8)
Female sex, n (%)	24 (69)
Body mass index, kg/m^2, mean (SD)	32.3 (8.5)
Comorbidities, n (%)	
Hypertension	23 (66)
Pulmonary hypertension	32 (91)
Diabetes	7 (20)
Atrial fibrillation	21 (60)
Coronary artery disease	15 (43)
Chronic lung disease	7 (20)
Chronic kidney disease	9 (26)
Cerebrovascular disease	6 (17)
Previous endocarditis	3 (9)
Previous myocardial infarction	2 (8)
Medications, n (%)	
Beta-blockers	26 (74)
Diuretics	21 (60)
Anticoagulants	20 (57)
Antiarrhythmics	6 (17)
Cardiac function	
NYHA classification, n (%)	
I	0
II	12 (34)
III	20 (57)
IV	3 (9)
BNP, pg/mL, median (IQR)	160 (96.4-502.2)
Ejection fraction, %, mean (SD)	58.5 (9.3)
Normal RV function, n (%)	19 (54)
LAD, cm, mean (SD)	5 (0.8)
LVEDD, cm, mean (SD)	4.6 (0.7)
PASP by RHC at rest, mm Hg, mean (SD)	58.9 (17.5)
mPAP by RHC at rest, mm Hg, mean (SD)	37.4 (9.9)
mPAP at rest >40 mm Hg, n (%)	11 (35)
PCWP by RHC, mm Hg, mean (SD)	24.5 (6.3)

SD, Standard deviation; *NYHA*, New York Heart Association; *BNP*, B-type natriuretic peptide; *IQR*, interquartile range; *RV*, right ventricular; *LAD*, left anterior descending artery; *LVEDD*, left ventricular end-diastolic diameter; *PASP*, pulmonary artery systolic pressure; *RHC*, right heart catheterization; *mPAP*, mean pulmonary artery pressure ; *PWCP*, pulmonary capillary wedge pressure.

available 3.75-MHz transducers according to American Society of Echocardiography guideline protocols.[4]

Data Collection

All clinical variables were collected through retrospective review of prospectively collected data from patient electronic records. Long-term survival and echocardiographic follow-up were obtained by personal or telephone contact with the patient and referring cardiologist. The protocol was approved by our local Institutional Review Board and was compliant with the Health Insurance Portability and Accountability Act regulations and the ethical guidelines of the 1975 Declaration of Helsinki. The approval included a waiver of informed consent. Morbidities were defined according to the 2018 Society for Thoracic Surgeons Adult Cardiac Surgery Risk Models.

Statistical Analysis

Normally distributed continuous variables were represented as mean ± standard deviation. Nonparametric and categorical variables were represented as median and interquartile range (IQR) and as the number of patients as a percentage of the sample, respectively. Survival and follow-up for structural valve degeneration were analyzed using both standard and modified Kaplan–Meier survival curves to account for the instability in the right tail of the small-risk dataset.[6] Follow-up was available in all patients. The median duration of follow-up was 1.8 years (IQR, 6 months to 3.8 years). The statistical analyses were performed using SAS 9.4 statistical software (SAS Institute, Cary, NC).

Statement of Responsibility

All authors had full access to the data and take full responsibility for their integrity and accuracy. All authors have reviewed and agreed to the article as written.

RESULTS

Patients' demographics, comorbidities, and preoperative echocardiographic and invasive hemodynamic parameters are described in Tables 1 and 2. The mean age at the time of reoperation was 61.4 ± 11.4 years. The median interval from primary repair to reoperation was 4.5 years (IQR, 1.8-11.8 years), and 24 of the patients (69%) were female. The most common comorbidities were pulmonary hypertension, in 32 patients (91%), and atrial fibrillation, in 21

TABLE 2. Mitral valve characteristics (N = 35)

Characteristic	Value
Initial pathology	
Disease etiology, n (%)	
Degenerative	11 (31)
Functional	10 (29)
Rheumatic	6 (17)
MAC	3 (9)
Radiation	2 (6)
Endocarditis	2 (6)
Congenital	1 (3)
Dysfunction, n (%)	
MR	31 (89)
Mixed MR/MS	4 (11)
Initial mitral repair procedure	
Annuloplasty (N = 35)	
Complete ring (N = 29), n (%)	29 (83)
All size, median (IQR)	28 (26-30)
Duran ring	4 (11)
Partial band (N = 6)	6 (17)
Repair technique, n (%)	
Leaflet resection	12 (34)
NeoChord	7 (20)
Commissuroplasty or edge-to-edge	6 (18)
Cleft closure	4 (11)
Approach, n (%)	
Sternotomy	31 (89)
Right thoracotomy	4 (11)
MS echocardiographic parameters	
MS grade, n (%)	
Moderate-severe	3 (9)
Severe	32 (91)
MV mean gradient at rest, mm Hg, mean (SD)	11.2 (2.9)
MV mean gradient stress, mm Hg, mean (SD)	19.8 (7.1)
MVA, cm^2, median (IQR)	1.4 (1.1-1.8)

MAC, Mitral annular calcification; *MR*, mitral regurgitation; *MS*, mitral stenosis; *MV*, mitral valve; *MVA*, mitral valve area; *IQR*, interquartile range.

TABLE 3. Operative characteristics (N = 35)

Characteristic	Value
Reoperative mitral procedure	
MS etiology, n (%)	
Organic	34 (97)
Pannus ingrowth	20 (57)
Leaflet calcification	12 (34)
Commissural fusion	5 (14)
Leaflet scarring	4 (11)
MAC	4 (11)
Subvalvular stenosis	2 (6)
Functional (tunnel effect)	3 (9)
Replace (N = 22), n (%)	22 (63)
Size, median (IQR)	25 (25-25)
Re-repair (N = 13), n (%)	13 (37)
Annuloplasty	
Ring to oversized ring	1 (8)
Ring to band	6 (46)
Ring to pericardial annuloplasty	4 (11)
No annuloplasty	2 (6)
Repair technique	
Pannus debridement	10 (77)
Commissurotomy	1 (8)
Chord cutting	4 (31)
Leaflet peel	2 (15)
Patch augmentation	2 (15)
Papillary myotomy	1 (8)
NeoChord	1 (8)
Concomitant procedures, n (%)	
CryoMaze	15 (43)
Left atrial appendage exclusion	4 (11)
TV repair	22 (63)
CPB time, min, mean (SD)	138.6 (32.9)
Cross-clamp time, min, mean (SD)	107.2 (28.4)

MS, Mitral stenosis; *MAC*, mitral annular calcification; *IQR*, interquartile range; *TV*, tricupsid valve; *CPB*, cardiopulmonary bypass; *SD*, standard deviation.

(60%). The mitral valve etiology was degenerative in 11 patients (31%), functional in 10 patients (29%), rheumatic in 6 patients (17%), and other (radiation valvopathy, endocarditis, or congenital) in the remaining 8 patients (23%). Patients presented with a mean mitral valve gradient at rest of 11.2 ± 2.9 mm Hg and a median mitral valve area of 1.4 cm^2 (IQR, 1.1-1.8 cm^2). MS grade was moderate-severe in 3 patients (9%) and severe in 32 (91%). All patients who presented were symptomatic on medical therapy (66% in New York Heart Association functional class ≥III), with elevated B-type natriuretic peptide (BNP; median, 160 pg/mL; range 96.4-502.2 pg/mL).

Repair data from the primary operation are described in Table 3. A complete ring annuloplasty was performed in 29 patients (83%) with a median ring size of 28 mm (IQR, 26-30 mm). The most common repair techniques used during the initial repair were leaflet resection in 12 patients (34%), commissuroplasty or edge-to-edge repair in 6 patients (18%), and cleft closure in 4 patients (11%). Among the 12 patients who underwent leaflet resection, 9 (75%) underwent quadrangular resection.

All reoperations were done via sternotomy. Three patients had 3 reoperations and 1 patient had 4 reoperation. Following valve analysis, the most common causes of postrepair MS were pannus ingrowth (20 patients; 57%) and leaflet calcification (12 patients; 34%). The "tunnel effect," defined as functional MS with small annuloplasty ring in relation to residual length of the anterior leaflet, was observed in 3 patients (9%).

MVR was performed in 22 patients (63%), using a bioprosthesis in all cases. Mitral valve re-repair was performed in 13 patients (37%), all of who underwent revision of the previous mitral annuloplasty. Other re-repair techniques included pannus debridement in 10 patients (77%) and chordal cutting in 4 (31%). Characteristics of the reoperation procedure are presented in Table 3.

TABLE 4. Perioperative outcomes

Outcome	Value
Intensive care unit LOS, d, median (IQR)	3 (1-7)
Hospital LOS, d, median (IQR)	10 (7-15)
Time to extubation, h, median (IQR)	12 (7-31)
Low cardiac output state, n (%)	8 (23)
Epinephrine dose leaving OR, ng/kg/min, mean (SD)	48 (46.2)
Norepinephrine dose leaving OR, ng/kg/min, mean (SD)	33 (44.5)
Milrinone dose leaving OR, median (IQR)	0.25 (0.125-0.25)
Inhaled nitric oxide, n (%)	6 (27)
Perioperative blood product administration, n (%)	14 (40)
Deep sternal wound infection, n (%)	1 (3)
Tracheostomy, n (%)	1 (3)
Intra-aortic balloon pump, n (%)	0 (0)
Acute kidney injury, n (%)	0 (0)
Mortality, n (%)	0 (0)
Predischarge MV mean gradient rest, mm Hg, mean (SD) (re-repair only, N = 13)	3.9 (1.0)
MVA, cm^2, median (IQR) (re-repair only, N = 13)	2.2 (1.8-2.6)

LOS, Length of stay; *IQR*, interquartile range; *SD*, standard deviation; *OR*, operating room; *MVA*, mitral valve area.

Perioperative Outcomes

Perioperative outcomes are shown in Table 4. Low cardiac output state was defined as any patient requiring >100 ng/kg/min of epinephrine leaving the operating room. Notably, patients left the operating room receiving mean doses of 48 ± 46.2 ng/kg/min of epinephrine and 33 ± 44.5 ng/kg/min of norepinephrine. Mechanical circulatory support was not required in any patient. One patient with previous chest radiation therapy sequelae required sternal wound reconstruction and prolonged ventilatory support. The median intensive care unit length of stay was 3 days (IQR, 1-7 days), and the median postoperative

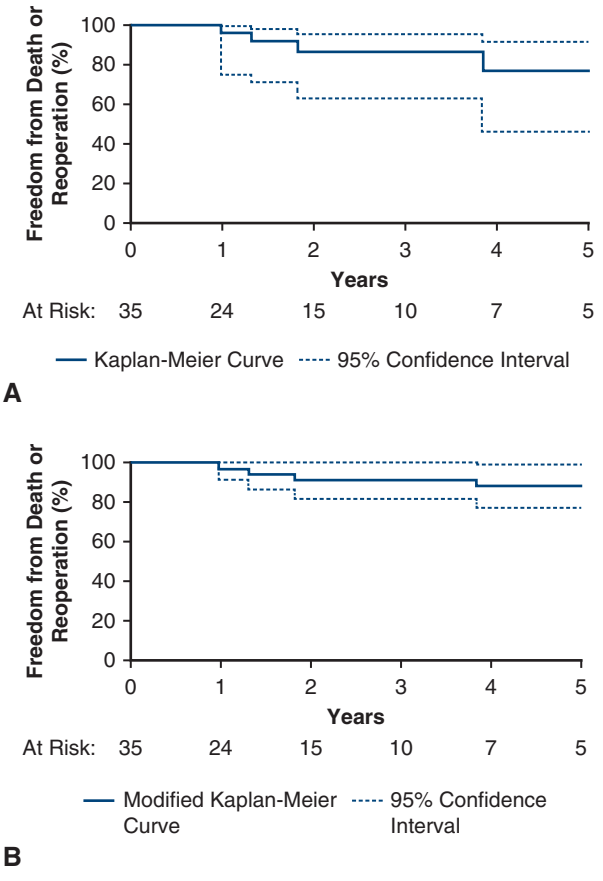

FIGURE 1. A, Modified and B, standard Kaplan–Meier curve illustrating freedom from death or reoperation over 5 years of follow-up.

hospital length of stay was 10 days (IQR, 7-15 days). There were no in-hospital or 1-year mortalities.

Mid-Term Outcomes

Freedom from death or reintervention is shown in Figure 1. Survival at a 5-year follow-up was 93.9% (95% confidence interval, 100%-85.8%). There were 2 late mortalities. The first was a 50-year-old patient who died of respiratory failure at 16 months after surgery due to radiation-induced lung disease. The other was a 68-year-old patient who underwent a third redo MVR and died 4 years later of congestive heart failure. Two of the re-repair patients underwent reoperative MVR at 14 and 22 months after surgery, respectively, due to recurrent MS. There were no reinterventions during the follow-up period for patients who underwent replacement.

DISCUSSION

Key Findings

"The true work of art is but a shadow of the divine perfection" —Michelangelo Buonarroti.[7]

A mitral valve reconstructive procedure should aim to eliminate mitral regurgitation while minimizing the potential for MS. For more than 3 decades, reconstructive techniques have been well described, including repair at the leaflet, annular, and subannular levels, typically with the use of annular stabilization of an otherwise dynamic, saddle-shaped native annulus to enhance the durability of repair.[8,9] It is intuitive that some degree of narrowing of the native valve orifice is inevitable in many repairs; however, for years, outcome research has focused primarily on recurrent mitral regurgitation as the index of long-term effectiveness of MVr.[2,10] Postrepair MS remains underreported in the literature, with uncertainty regarding its hemodynamic and clinical consequences, as well as its prognostic implications.[11-13]

As a national MVr reference center, we are referred many patients with failed MVr, including those with predominantly MS. The key findings of this study are that postrepair MS causing late failure of repair was mostly related to complications of annuloplasty technique with leaflet

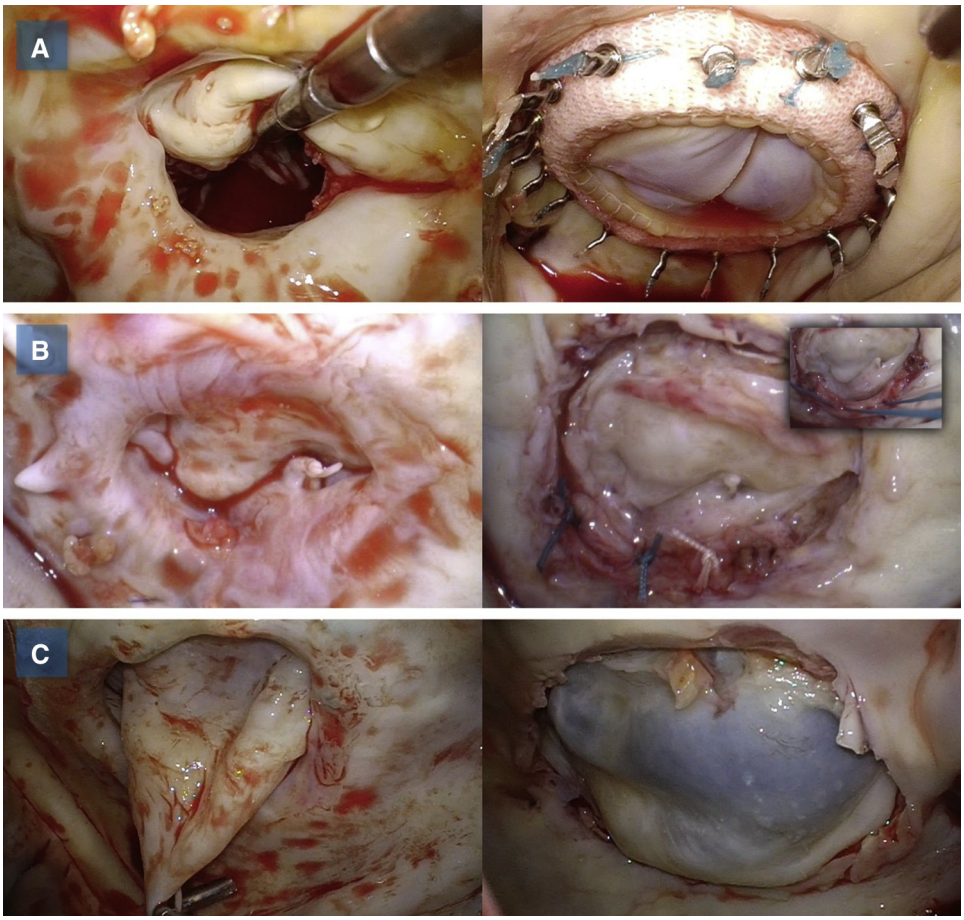

FIGURE 2. Intraoperative image findings during reoperation. A, Extensive fibrocalcification encroaching the mitral annulus and leaflets, necessitating valve replacement. B, Predominant pannus ingrowth is seen encasing the circumference of the previous mitral annuloplasty ring, successfully repaired with pannus debridement and autologous pericardial annuloplasty. C, Mitral leaflet-to-annulus size mismatch leading to a "tunnel effect" was successfully repaired using a no annuloplasty approach (see text for details).

calcification (Figure 2, *A*), and that pannus ingrowth (Figure 2, *B*) in association with a small prosthesis size (median ring size, 28 mm) were the most common pathoanatomic findings in patients with postrepair MS. This combination of undersizing at original repair with redundant tissue have contributed to turbulence and abnormal flow dynamics, leading to the development of early MS.[14-16] Furthermore, it is notable that 9 of 12 patients who underwent leaflet resection underwent a quadrangular resection, which may have contributed to the reduction in annuloplasty size to optimize the length of coaptation with deficiency of leaflet tissue.

MVR was the most common surgical strategy for dealing with postrepair MS; however, valve preservation with mitral valve re-repair was feasible in carefully selected patients (Figure 3). We were able to perform all reoperations with minimal perioperative morbidity and no in-hospital or 1-year mortality.

All of our patients had experienced varying degrees of congestive heart failure with elevated biomarkers (BNP), and a majority of patients had pulmonary hypertension, tricuspid regurgitation, and new-onset atrial fibrillation. Those adverse clinical and hemodynamic consequences have been confirmed by several other studies in both degenerative and nondegenerative cohorts with post-repair MS.[12,13,17,18] The high rate of concomitant tricuspid repair (63%) reflects our aggressive approach toward concomitant tricuspid repair in patients with risk factors for disease progression, such as in reoperations, atrial fibrillation, and pulmonary hypertension.[19]

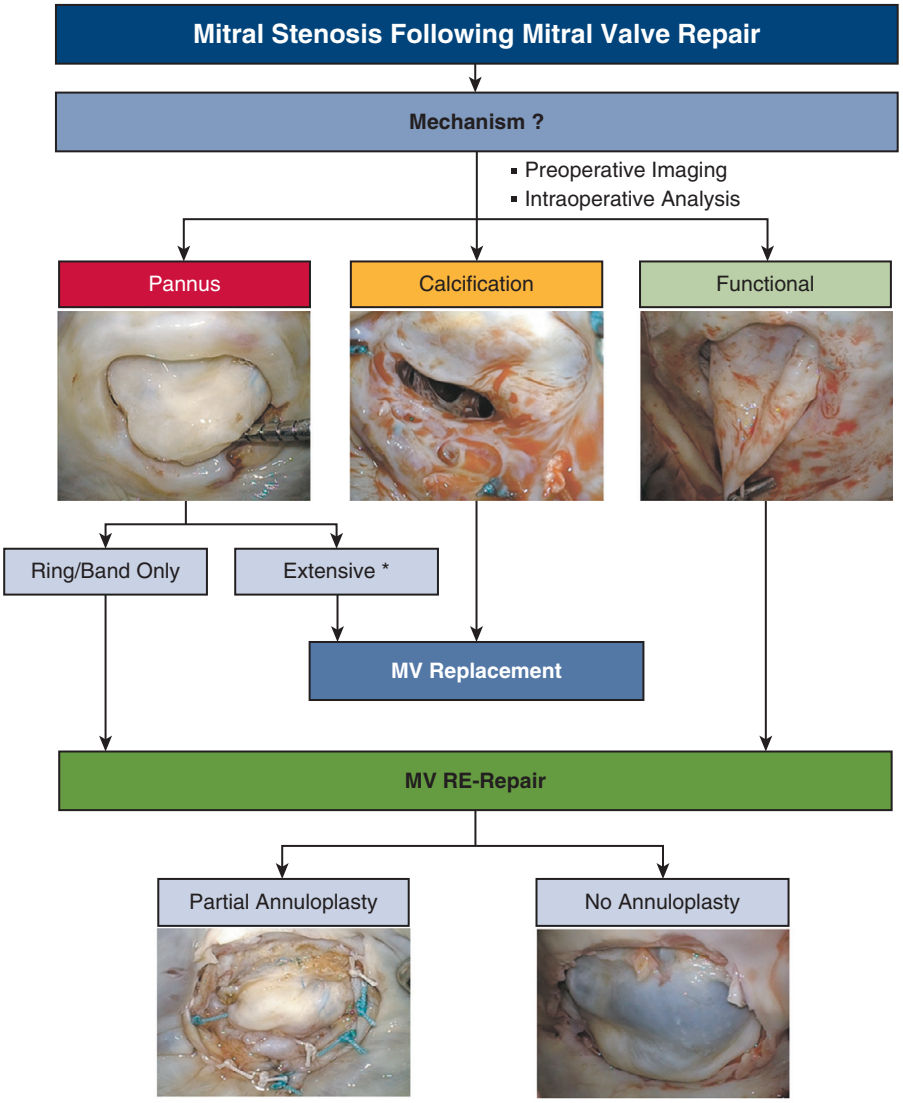

FIGURE 3. Mitral inflow stenosis following previous valve reconstruction and annuloplasty is caused by fibrocalcific degeneration and/or annuloplasty size–leaflet tissue mismatch. The extend of pathology and residual leaflet mobility will influence the feasibility of re-repair and reoperative strategy. *MV*, Mitral valve.

Several other authors have described the risk factors and mechanisms for postrepair MS, including several case descriptions of the association between MS and the use of Duran rings (Medtronic, Minneapolis, Minn) due to pannus ingrowth.[20,21]

In our series, the majority of patients had a complete ring annuloplasty as opposed to partial bands (29 of 35 patients; 83%). Duran rings were used in only 4 patients. Pannus ingrowth and leaflet calcification were the major MS mechanisms in the majority of patients irrespective of the annuloplasty device used. Thus, an association between pannus ingrowth and use of a particular ring or annuloplasty technique could not be identified in this cohort, which is also consistent with other studies that identified complete ring annuloplasty and aggressive undersizing as the main etiology of MS regardless of the device shape or brand.[17,22] Implantation technique can also influence postrepair MS. In one patient, for example, the first surgeon used multiple pledgeted annuloplasty sutures to implant a size 28 flexible ring in a degenerative repair, and during the reoperation, the ring was found to be completely encased in everted atrial tissues as well as pannus ingrowth, indicating a likely causal relationship (Figure 4).

The majority of patients were found to have an underlying organic cause of MS (pannus ingrowth and or calcification), which is consistent with the longer mean interval from primary surgery until reoperation (6.8 years). The use of a small annuloplasty ring at the primary operation, with resultant inflow turbulence, might have contributed to the development of fibrosis/calcification process; however, further larger studies are needed to understand the risk factors for pannus formation. Interestingly, we also found a few patients with functional MS due to a marked discrepancy between the residual leaflet tissue and annuloplasty ring size, with long leaflets below the annuloplasty device creating a subvalvular tunnel (the "tunnel effect") (Figure 2, *C*).

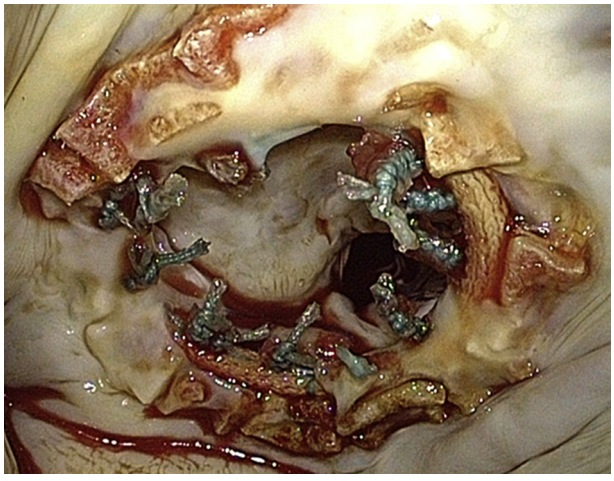

FIGURE 4. Case example of a previous mitral repair using multiple pledgeted annuloplasty sutures to implant a flexible annuloplasty ring, leading to pannus formation and mitral stenosis.

More than two-thirds of our patients underwent MVR on reoperation (Figure 2, *A*). This is an important observation indicating that patients who develop postrepair MS are at a much greater risk of MVR, even in a repair reference center. We were able to re-repair 13 valves (37%) owing to the absence of leaflet calcification or subvalvular restriction. Revision of the annuloplasty was required in all re-repairs, mostly conversion from small rings to open bands or no annuloplasty. Other periprocedural keys to good outcomes include preoperative optimization of pulmonary hypertension and fluid status, routine preoperative computed tomography scanning to plan for sternal reentry and cannulation strategy, limited surgical dissection, meticulous myocardial protection, optimization of valve exposure using a transseptal approach when indicated, and aggressive concomitant tricuspid repair.[23] The recurrence of MS that we observed in 2 patients with radiation valvopathy reflects the progressive nature of radiation disease. We learned these patients would be better served with MVR in the future.

CONCLUSIONS

Postrepair MS typically occurs in the absence of significant mitral regurgitation causing late failure of repair. It is most commonly related to pannus ingrowth and calcification in association with small prosthesis size. Reoperations can be done with minimal morbidity and mortality, and re-repair is feasible in a select group of patients.

Implications for Practice

The quality and durability of MVr should not be evaluated based on residual or recurrent mitral regurgitation alone, but also should include surveillance for postrepair MS due to its adverse major hemodynamic and clinical consequences leading to the need for reoperations.

Refinement in surgical techniques, including the avoidance of undersized complete ring annuloplasty, mismatch of tissue height to annuloplasty circumference, and aggressive commissuroplasty, might help avoid postrepair MS.

Limitations

Our study is a retrospective review of a patient cohort and thus is subject to all the attendant limitations related to this model of analysis. The retrospective nature of this study prevented us from identifying an adequate control group for comparison. Given the rarity of this clinical condition, our sample size was small and limited the ability to apply more rigorous statistical methodology in assessing risk factors for development of postrepair MS. The outcomes that we achieved in our reference MVr center might not be generalizable to nonreference centers. Regardless, given the paucity of clinical reports about postrepair MS requiring reoperation, our systematic approach to reoperations and

the rigorous prospective data collection in our study are unique and allowed for detailed analysis of repair failure due to MS and its management. We believe that this strength outweighs the limitations.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/20AM/Presentations/Observations%20from%20Reoperations%20for%20M.mp4.

Conflict of Interest Statement

The Icahn School of Medicine at Mount Sinai receives royalty payments from Edwards Lifesciences and Medtronic for intellectual property related to Dr Adams' involvement in the development of 3 mitral valve repair rings and a tricuspid valve repair ring. All other 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: mitral valve repair, mitral valve replacement, mitral valve stenosis, mitral valve regurgitation

Discussion

Presenter: Dr Ahmed El-Eshmawi

Dr Y. Joseph Woo *(Stanford, Calif)*. Ahmed, thank you for an outstanding presentation. It is a privilege to discuss this paper. I congratulate you, David Adams, and the entire team for yet another impactful, scholarly investigation of a highly specific aspect of your exceptional clinical skills and experience. Your research will guide both technical

considerations during the primary repair operations and the evaluation of postrepair mitral stenosis patients.

I have 4 lines of inquiry within which are embedded discussion topics and questions. Let's cover these one by one. My first line of inquiry is on the influence of the primary operation on the subsequent development of mitral stenosis. Are there specific characteristics of that operation, such as the way in which the abundance of existing leaflet tissue is treated, via resection or preservation, band versus ring, ring size, ring types, such as a Physio II, which has a greater AP diameter, versus say, Profile 3D, which has a narrower AP diameter? Also, coaptation length, which potentially could contribute to your funnel effect, and finally, mean gradient postop—do any of these factors, in your opinion. Contribute more or less to the propensity for developing mitral stenosis?

Dr Ahmed El-Eshmawi *(New York NY)*. Thanks, Joseph. I should say that we based our analysis of the initial mitral repair details primarily on the available surgical notes. If there were any missing parameters not mentioned in the surgical notes, like exactly how much resection done or how much tissue left, and postrepair gradients, we could not correlate that to our findings at reoperation.

However, I should say we had a very detailed description of the annuloplasty device type and size used during the primary repair. As you know, most of these patients—over 80%—had complete ring annuloplasty, with a median size of 28. We also looked at the type of rings. Basically, we were looking specifically to see if Duran rings were used. As you know, based on Dr Tirone David's previous report on the possible association of Duran rings and post repair mitral stenosis; however, I could not find such an association giving the small number of patients. Also, those were a mix of different types of rings and bands, ranging from classical Carpentier's ring, flexible bands, rigid rings, 3D rings, etc. So I don't think the ring type was a predominant factor in those patient groups. However, the use of a small complete ring annuloplasty might have been be a contributing factor.

Dr Woo. The next line of inquiry relates to findings during reoperation. Are there specific features that you believe are more conducive to the ability to re-repair, and is there a distinct difference between those patients who had primary regurgitation or secondary regurgitation at the time of their initial operation?

Dr El-Eshmawi. As regards the first part of the question, and because of the small number of patients, it is hard to make clear specifications. But you know that in our Mitral Center of Excellence, we are very interested in mitral re-repair. So our bias is to re-repair valves that have potential for durability, as in case of good quality of leaflet tissue, in the absence of calcification, good subvalvular apparatus, especially in young patients with degenerative valves who still have plenty of tissue, as opposed to elderly patients who have annular calcification or left ventricular dysfunction.

As for the second part of the question, yes, patients who had previous mitral repair due to functional mitral regurgitation and developed mitral stenosis due to aggressive undersizing or leaflet restriction, our bias is to replace those valves due to underlying ventricular disease as opposed to patients with primary regurgitation.

Dr Woo. Next is a technical question. We have all learned from the Mitral Conclave that when we are attempting a mitral re-repair that we really should take down everything and thoroughly examine the valve and then start anew. And that typically begins with the removal of the prior annuloplasty. When you do that, you often have a deep groove that is left over, and I saw you in the video debriding some of that groove material. Can you give us some advice on how to use or treat that area of tissue for the subsequent re-repair? Do you inlay the new ring inside that groove? Do you close and overlay? Or do you try to peel and debride all of it and start anew?

Dr El-Eshmawi. We start our reoperations by careful removal of the annuloplasty device and all suture materials, taking care to not injure the underlying leaflet tissue before formal valve analysis. Regarding the trough or the deep groove left behind after ring or band removal, we completely ignore it, because sometimes the device was implanted on the leaflet or the left atrium as opposed to the actual annulus. We never close the trough, because this might create leaflet restriction, which would be counterproductive and exacerbate mitral stenosis. We place the new annuloplasty sutures on the anatomic annulus, which might be the same trough or nearby.

After we take down the repair, we reassess the tissues left, and then make a decision as to whether we're happy with the amount and quality of the leaflet tissue. If so, then we go ahead with the re-repair if you have good experience with valve re-repair. But if there is any doubt about the durability of re-repair, then we proceed with a valve replacement. Particularly, as you know, lots of those patients have calcification, radiation disease, etc, as I mentioned earlier and in detail in the paper.

Dr Woo. A complementary question related to the technical aspects involves the leaflets themselves. If there is fibrosis or pannus growing down onto the leaflets or impingement of the hinge point, have you ever found the ability to peel this material away and preserve the tissue you need?

Dr El-Eshmawi. Yes, we have had a few cases where we could peel the leaflet. But again, this is a very meticulous technique and unless you can see a transparent leaflet after you do the peeling without injuring the leaflet, it would be very difficult to trust that valve on the long term. But to answer the question, yes, leaflet peel as well as pannus debridement are the first steps in trying to mobilize the leaflet to attempt a valve re-repair. We also do aggressive

chordal cutting of restrictive secondary and sometimes even primary chords and use Gore-Tex NeoChord to further mobilize leaflets.

Dr Woo. My last line of inquiry is related to the fact that we are going to see more and more of these patients as time goes along. Everyone is trying to repair patients with mitral regurgitation. What would be your advice to less experienced surgeons and centers facing this scenario? Would you advise that they send all these patients to a center of excellence? Would you advise them against simply reoperating and replacing all these patients? Or is there some more nuanced approach where you could guide less experienced groups on finding ways to discern those patients who might be re-repairable and should be referred versus those who should simply undergo a redo replacement?

Dr El-Eshmawi. Thank you Jo for your excellent question. As you know, this is very difficult to answer, however, there are a few observations that I found important. First, those patients are often sick, with baseline heart failure symptoms, pulmonary hypertension, and atrial fibrillation. Also, those reoperations are challenging, valve exposure is often difficult, so we tend to expose the valve via a transseptal approach in complex reoperations. As I mentioned in the paper, there is also quite often extensive fibrosis and a small valve orifice, which might be challenging to oversize the prosthesis. So those are not just redo mitral replacements but tend to be a more technically challenging reoperation and are better be done by a surgeon with expertise with this field, since complications of valve replacement are not forgiving.

Regarding repair or replacement, I think this is less of an issue as in general, valve re-repair is only done in centers with expertise in valve re-repair, so I, think valve replacement is not an unreasonable option in many situations, as I discussed earlier.

However, I would also encourage low-volume surgeons who see young patients with a failed degenerative repair to consider re-repair owing to the overall survival advantage in repair patients even if this involves transfer to a valve reference center, as we saw in this study population. The decision has to be individualized, based on available local expertise and access to valve reference centers, as well as patient-related factors and wishes.

Finally, there's no right or wrong answer. Mitral stenosis is such a bad disease and the long-term outcomes are worse. I guess the main focus should be on how we can prevent iatrogenic post repair mitral stenosis from happening at the beginning. And also, if we can identify specific techniques that we should avoid to prevent leaving a culprit lesion or a substrate for the development of mitral stenosis, such as using small ring annuloplasty in combination with aggressive leaflet resection or edge-to-edge repairs. I would be happy to hear from the panel, as well. Thank you.

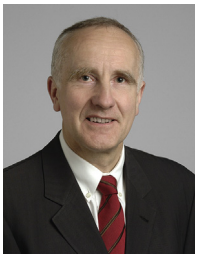
Dr Woo. Thank you. I commend you again on the clinical expertise and the impact of your research.

Dr El-Eshmawi. Thank you.

Dr Patrick McCarthy *(Chicago, Ill).* I have a brief comment. Ahmed, another great presentation, a year after I discussed your previous AATS presentation. You show great results in this interesting and underreported difficult patient group. I'm especially interested in the pannus ingrowth. I doubt that it is related to the size of the ring, the type of the ring, or the anatomy. I'll tell a brief story. I had a patient who developed stenosis over a year out after repair. She needed a replacement. Later we found out that she had a silicone allergy, and of course there is silicone in the repair rings. We don't ever check these patients for a physiologic cause of the pannus. Now I test a patient with pannus ingrowth for an allergy to the ring components. Perhaps that group of patients has sensitivity to the implantable that we put there. Have you ever seen or recognized something like that?

Dr El-Eshmawi. Thanks, Dr McCarthy, We suspected it in maybe 1 patient in 10 years, but you know a lot of the pathology studies on the explanted valve pannus, showed that this is a nonimmune granulomatous inflammatory reaction, basically a foreign body reaction to the annuloplasty device. However, this must be also multifactorial, since pannus dose not happen in every patient even when small rings are used, so there might be other factors that could explain this, as you mentioned in your patient. I would definitely consider the allergic history of patients undergoing valve repair or even replacement. I remember a patient who had a history of a porcine skin graft rejection and needed a valve replacement, so we used a bovine pericardial valve for him. Those are very rare situations, but an excellent observation.

Dr McCarthy. I think there must be something physiologic that we don't recognize yet. This patient had a 36-mm ring, so it wasn't due to a small ring.



Dr Gosta B. Pettersson *(Cleveland, Ohio).* Congratulations on bringing this problem up. Pat is correct: this is the tip of an iceberg. We don't know the denominator. I see a fair number of patients and agree that in most of these patients, you have to replace the valve. It requires a very careful debridement to open that annulus up so that you can get a good size valve in. A group of patients to be very cautious about putting rings in are those with radiation heart disease. I've seen patients develop stenosis very soon after ring repairs—fibrous reaction with scar tissue that doesn't fully mature, but sort of fleshy and edematous. Again, congratulations on bringing this difficult topic up.

Dr El-Eshmawi. Thank you.