Second crossclamp to perfect degenerative mitral valve repair: Decision-making algorithm, safety, and outcomes

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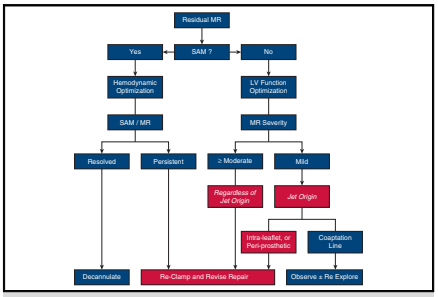
ABSTRACT

Objectives: Residual mitral regurgitation reduces the efficacy of mitral repair and is associated with worse outcomes. We adopted a policy using a second bypass run for patients with residual mitral regurgitation (>+1) and described our decision-making algorithm and outcomes.

Methods: From January 1, 2011, to December 31, 2016, 40 patients with degenerative disease underwent a second bypass run to address residual mitral regurgitation. The echocardiographic criteria for a second bypass run was the presence of moderate or greater mitral regurgitation or mild mitral regurgitation with unfavorable mechanism.

Results: A second bypass run was used in 40 patients. The mean age was 57.3 ± 13.5 years (21-79 years), and 14 patients (35%) were asymptomatic. Residual mitral regurgitation was mild in 25 patients, moderate in 9 patients, and moderate/severe in 6 patients. The cause of postbypass mitral regurgitation was technical or residual pathology in 35 patients and systolic anterior motion in 5 patients. Re-repair techniques were cleft closure in 22 patients, primary suture repair in 13 patients, and expanded polytetrafluoroethylene chordoplasty in 9 patients. After re-repair, 34 patients (85%) had no mitral regurgitation, 4 patients (10%) had trace mitral regurgitation, and 2 patients (5%) had mild mitral regurgitation. Median total cardiopulmonary bypass time was 208.5 minutes, first crossclamp time was 106 minutes, and second crossclamp time was 34 ± 12 minutes. Median intensive care stay was 2 days, and hospital stay was 8 days. On discharge, there was no mitral regurgitation in 13 patients (33%), trace in 23 patients (58%), and mild mitral regurgitation in 4 patients (10%). Freedom from moderate or greater mitral regurgitation at 5 years was 100%.

Conclusions: Residual mitral regurgitation can be effectively treated using a second bypass run with good long-term outcome and minimal incremental risk. (J Thorac Cardiovasc Surg 2020;160:1181-90)



Transesophageal echocardiographic algorithm for postbypass residual MR.

Central Message

A second bypass run to perfect mitral repair within a clinical algorithm is a critical procedure to perfect mitral repair with minimal incremental risk and potential for long-term benefits.

Perspective

Residual MR reduces the efficacy and durability of mitral valve repair and is associated with worse outcomes. A second bypass run to perfect mitral repair using a stepwise TEE-guided algorithm has minimal incremental perioperative risk and potential for long-term benefit.

See Commentaries on pages 1191, 1192, and 1193.

Mitral valve repair remains the gold standard therapy for patients with degenerative mitral regurgitation (MR). Both North American and European guidelines strongly recommend valve repair whenever possible with emphasis on a

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass
ePTFE = expanded polytetrafluoroethylene
FED = fibroelastic deficiency
IQR = interquartile range
MR = mitral regurgitation
SAM = systolic anterior motion
TEE = transesophageal echocardiography

high likelihood of a successful and durable repair without residual MR with expected low perioperative risk.[1,2] Both recurrent and residual MR have been associated with worse clinical outcomes and reduced late survival.[3,4] Therefore, a durable mitral repair starts with avoidance of postbypass residual MR to prevent the adverse downstream outcomes of suboptimal repair or unplanned direct valve replacement. However, some patients will have residual MR intraoperatively on weaning from cardiopulmonary bypass (CPB). This can be managed in various ways: acceptance, reinstitution of CPB for further mitral valve repair, and reinstitution of CPB for mitral valve replacement. Because of the critical importance of avoiding residual MR and the negative long-term prognostic effect of replacement over repair, we have had a zero tolerance policy for postbypass residual MR. We systematically use a second bypass run and further valve repair for patients with significant residual MR.

In this study we report on the echocardiographic patterns, hemodynamic interventions, re-repair strategies, and outcomes for patients undergoing degenerative mitral valve repair who underwent a second bypass run for residual MR.

MATERIALS AND METHODS

Study Population

From January 1, 2011, to December 31, 2016, we performed 1932 consecutive mitral valve repairs. A second bypass run was used in 73 patients. Of these, 18 had a second bypass run for reasons other than residual MR, and 15 patients had residual MR after repair for nondegenerative disease. This left a final cohort of 40 patients with degenerative mitral valve disease who required a second bypass run to address residual postbypass MR; this forms the population for this study (Figure 1).

For purposes of this study, we define residual MR as any regurgitation other than trivial that is persistent after weaning from CPB. Therefore, mild MR would be considered as residual MR. Grading of residual MR was done by a board certified anesthesiologist, using intraoperative transesophageal echocardiogram (TEE).

Patients' demographics, comorbidities, clinical characteristics, and preoperative echocardiographic parameters are summarized in Table 1. The mean patient age was 57.3 ± 13.5 years (range, 21-79). Seven patients (18%) were aged more than 70 years. A total of 14 patients (35%) were asymptomatic, and 5 patients (13%) received reoperations, of whom 4 (10%) had previous failed mitral repairs.

Degenerative mitral valve pathology was defined on the basis of echocardiographic assessment and surgical exploration. Mitral valve pathoanatomy was classified into 1 of 3 morphologic categories based on our previously described etiologic classification of degenerative mitral disease as Barlow's disease, forme fruste Barlow's, and fibroelastic deficiency (FED).[5] Reoperations for failed previous mitral repair were considered a separate morphologic entity due to altered valve anatomy from the first surgery.

FED was found in 13 patients, forme fruste Barlow's disease was found in 12 patients, and Barlow's disease was found in 11 patients. The remaining 4 patients presented for mitral valve re-repair. A total of 24 patients (60%) had isolated posterior leaflet prolapse, and 16 patients (40%) had bileaflet prolapse (Table 1).

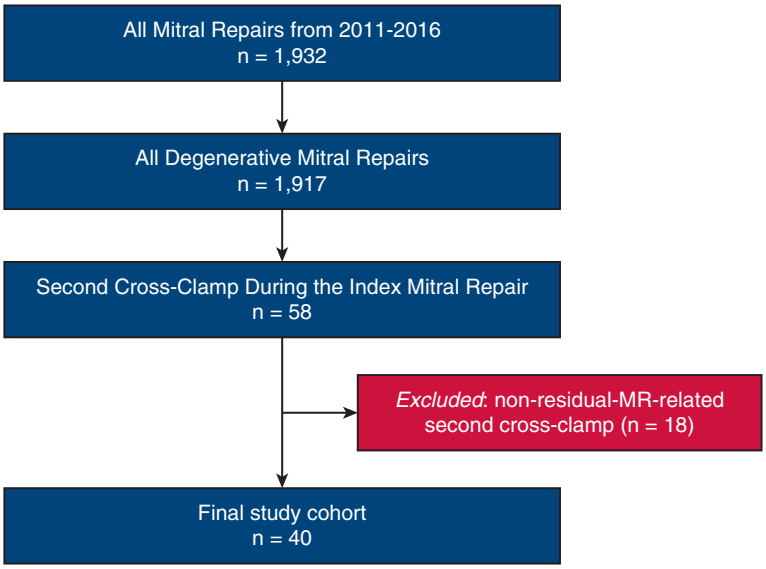

FIGURE 1. Cohort selection diagram. *MR*, Mitral regurgitation.

TABLE 1. Baseline patient demographics and clinical characteristics (n = 40)

Demographics	N (%)
Age, y, mean (SD)	57.3 (13.5)
Female	16 (40%)
Body mass index, kg/m^2, mean (SD)	24.6 (3.9)
Comorbidities	
Hypertension	21 (53%)
Pulmonary hypertension	8 (20%)
Diabetes mellitus	1 (3%)
Atrial fibrillation	8 (20%)
Coronary artery disease	15 (38%)
Chronic lung disease	2 (5%)
Chronic kidney disease	2 (5%)
Cerebrovascular disease	2 (5%)
Prior endocarditis	3 (8%)
Prior myocardial infarction	3 (8%)
Previous sternotomy	5 (13%)
Prior mitral valve surgery	4 (10%)
Preoperative cardiac characteristics	
NYHA classification	
Asymptomatic	14 (35%)
II-IV	26 (65%)
Valve pathology*	
FED	13 (33%)
Forme fruste Barlow's	12 (30%)
Barlow's disease	11 (28%)
Leaflet involvement	
Isolated posterior	24 (60%)
Isolated anterior	0 (0%)
Bileaflet	16 (40%)
Cardiac function	
Ejection fraction, %, mean (SD)	58.1 (6.4)
LA diameter, mm, mean (SD)	45.4 (8.0)
LVEDD, mm, mean (SD)	53.8 (7.4)
LVESD, mm, mean (SD)	35.7 (6.5)
Normal RV function	40 (100%)
Normal LV systolic function	37 (93%)

SD, Standard deviation; *NHYA*, New York Heart Association; *FED*, fibroelastic deficiency; *LA*, left atrial; *LVEDD*, left ventricular end-diastolic diameter; *LVESD*, left ventricular end-systolic diameter; *RV*, right ventricular; *LV*, left ventricular. *Four patients presented for mitral valve re-repair.

Surgical Technique

In our mitral reference center, all operations were performed by a single group of surgeons. All operations were performed using a median sternotomy, typically done through a limited lower midline skin incision.[6] Standard CPB techniques with central aortic and bicaval cannulation, with direct aortic clamping, were used. Myocardial protection was achieved via cold blood cardioplegia given in an antegrade and retrograde fashion. The mitral valve was accessed via Sondergaard's groove. Systematic valve analysis was undertaken to identify all lesions producing valve dysfunction(s).

Valve repairs were performed by means of standard reconstructive techniques, blending resection, and nonresection techniques as dictated by the valve lesions/dysfunction. Flexible or semi-rigid bands or rings were used interchangeably depending on the valve anatomy, ventricular function and dimensions, and the risk of systolic anterior motion (SAM). After completion of the repair, we assess adequacy of repair using saline and ink testing. We aim for a symmetric and posteriorly displaced closure line with at least 9 to 10 mm of coaptation depth.

TEE after weaning from CPB, but before decannulation, was performed for all patients to control for the quality of the repair. For patients with residual MR greater than trace (1+), the algorithm outlined in Figure 2 was followed to determine the next steps in management. For patients with SAM, hemodynamic parameters were optimized using gentle maneuvers, including discontinuation of inotropic support, volume loading, maintaining atrioventricular synchrony, and increasing afterload using vasopressors (preferably vasopressin to achieve a mean arterial pressure of 80-100 mm Hg) and beta-blockade (typically using esmolol to achieve a heart rate <80 beats/min). If SAM persisted, the decision was made to put the patient back on CPB and re-repair the mitral valve via further displacement of the posterior leaflet using expanded polytetrafluoroethylene (ePTFE) chordoplasty, free edge remodeling, or annuloplasty revision, usually by taking out the trigonal sutures from the annuloplasty band to open up the left ventricular outflow. A detailed management of SAM was previously described by our group.[7]

If SAM was not the cause of residual MR, myocardial systolic and diastolic functions were optimized via reperfusion on CPB, initiation of inotropic, or inodilator drugs such as milrinone, as well as restoration of atrioventricular synchrony before reassessing valve function. If MR persisted, a second bypass run was instituted for moderate or greater MR or mild MR with unfavorable mechanisms such as an eccentric, periprosthetic, paracommissural jet, or jet through the body of the leaflet. Additional valve re-repair techniques were used to perfect the repair. If, after a careful analysis, a cause for the residual regurgitation cannot be found or the surgeon thinks the regurgitation cannot be eliminated in a predictable or durable fashion, then valve replacement should be considered. In our practice, however, such a scenario did not emerge, and we found that with systematic echocardiographic and surgical analysis the residual regurgitation was always fixable. If there was persistent ventricular dysfunction, we would continue cardiac reperfusion and reinstitute bypass only if we were satisfied that the heart could tolerate a second ischemic period.

For patients with residual mild MR within the closure line especially with postbypass left ventricular dysfunction, a second bypass run was not typically used, because in our experience this is a stable lesion that would often manifest as trivial or no regurgitation on subsequent transthoracic echocardiography.

A discussion between the mitral surgeon and an echocardiographer with expertise in intraoperative TEE including 3-dimensional TEE is crucial for implementation of the algorithm.

Predischarge Echocardiography

Two-dimensional and Doppler transthoracic echocardiographic examinations were performed in all patients before discharge. All echocardiographic studies were performed by using commercially available 3.75-MHz transducers and echocardiographic systems. Quantitative data promptly stored in the institutional server were not altered throughout the study. The presence of MR was prospectively assessed, and its severity was evaluated semiquantitatively by using color Doppler regurgitant color jet area as previously validated.[8] The grade of regurgitation was classified as none (0, no detected jet), trivial (1+, jet area/left atrial area < 5%), mild (2+, jet area/left atrial area 5%-20%), moderate (3+, jet area/left atrial area 20%-40%), and severe (4+, jet area/left atrial area > 40%).

Data Collection

Clinical variables were identified through retrospective review of the electronic medical record. Data were prospectively collected. Information regarding long-term survival and echocardiographic follow-up were obtained by personal or telephone contact with the patient and referring

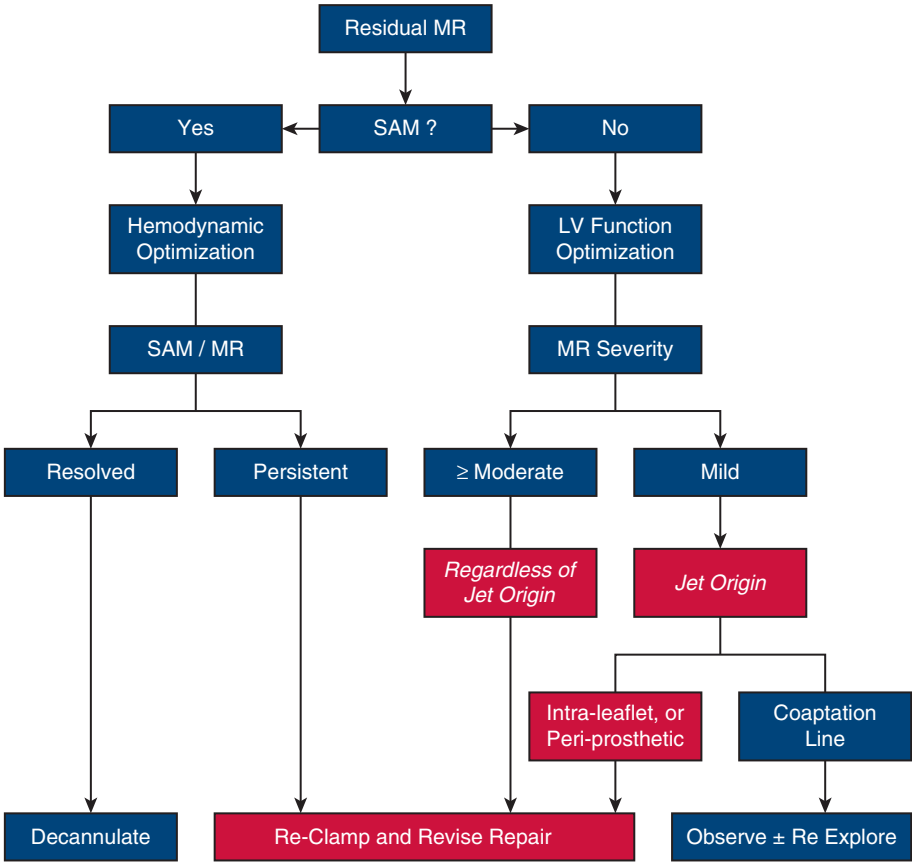

FIGURE 2. Transesophageal echocardiographic decision-making algorithm for postbypass residual MR. *MR*, Mitral regurgitation; *SAM*, systolic anterior motion; *LV*, left ventricle.

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. Low cardiac output state was defined as any patient requiring more than 100 ng/kg/min of epinephrine leaving the operating room.

Statistical Analysis

Normally distributed continuous variables were represented as mean ± standard deviation. Nonparametric and categoric variables were represented as median and interquartile range (IQR) or as the number of patients as a percentage of the sample, respectively. Repair durability was obtained by echocardiography when follow-up took place and analyzed by using both standard Kaplan–Meier survival curves and modified Kaplan–Meier survival curves to account for the instability in the right-tail of small-risk dataset.[9] Follow-up was available in all patients. Median length of follow-up time was 3.4 year (IQR, 1 month to 5.3 years). The statistical analyses were performed using SAS 9.4 statistical software (SAS Institute, Inc, 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

Mitral valve repair was achieved in 100% of the patients, and no patients received a mitral valve replacement for degenerative MR within the study period. The details of surgical reconstructive techniques during the first bypass run are shown in Table 2. Initial mitral valve repair was achieved via blending resection and nonresection techniques, with posterior leaflet resection in 32 patients and ePTFE chordoplasty in 22 patients. An annuloplasty device was used in all patients but 1 because of high risk for SAM in the patient who needed concomitant septal myectomy for a 20-mm basal septal hypertrophy. We used complete ring annuloplasty in 27 patients and band annuloplasty in 12 patients.

A complexity scoring scale previously described by our group was applied.[10] Valve repairs were categorized into 11 simple, 7 intermediate, and 22 complex repairs.

After the initial repair, 25 patients had mild residual MR, 9 patients had moderate MR, and 6 patients had moderate to severe MR (Figure 3). Mechanisms of residual MR were stratified into 3 possible subgroups: technical in 31 patients, SAM in 5 patients, and residual pathology (eg, prolapse or clefts) in 4 patients. We defined the technical cause of

TABLE 2. Initial reconstructive techniques and operative details (n = 40)

Valve complexity score	N (%)
Simple	11 (28%)
Intermediate	7 (18%)
Complex	22 (55%)
Initial repair technique	
PL resection	
Triangular resection	16 (40%)
Quadrangular resection, sliding plasty	16 (40%)
ePTFE chordoplasty	
AL	10 (25%)
PL	16 (40%)
Commissuroplasty	
Anterolateral	5 (13%)
Posteromedial	15 (38%)
Cleft closure	17 (43%)
Chordal transfer	2 (5%)
Annular decalcification	2 (5%)
Leaflet free-edge remodeling	2 (5%)
Patch augmentation	1 (3%)
Haircut technique	1 (3%)
Annuloplasty	
Ring	27 (68%)
Band	12 (30%)
Concomitant procedures	
TV annuloplasty	30 (75%)
LA appendage exclusion	11 (28%)
Cryo-Maze ablation	8 (20%)
Coronary artery bypass graft	5 (13%)
PFO closure	3 (8%)
Septal myectomy	1 (3%)

PL, Posterior leaflet; *ePTFE*, expanded polytetrafluoroethylene; *AL*, anterior leaflet; *TV*, tricuspid valve; *LA*, left atrial; *PFO*, patent foramen ovale.

residual MR as ''MR occurring as direct consequence of repair procedures such as suture line gaps, suture dehiscence, iatrogenic leaflet perforation and excessive leaflet resection.''

Re-repair techniques included cleft closure in 15 patients, primary repair of a suture line defect in 12 patients, magic suture placement in 10 patients, and ePTFE chordoplasty in 9 patients. A total of 21 patients required a single re-repair technique, and 34 patients required 2 or more re-repair techniques to completely eliminate residual regurgitation. At the conclusion of surgery, 34 patients had no regurgitation, 4 patients had trace MR, and 2 patients had mild MR (Figure 3).

Median first crossclamp time was 106 minutes (IQR, 81-140 minutes), second crossclamp time was 34 minutes (IQR, 29-38 minutes), and total CPB time was 208.5 minutes (IQR, 187-224 minutes) (Table 3). Three patients required a third bypass run. The first patient was a 58-year-old with FED requiring P2 triangular resection and band annuloplasty during the first bypass run. However, because of mild residual MR, a second bypass run for 32 minutes was needed to close a posterior leaflet cleft. Another intraleaflet MR jet was found on weaning from the second bypass run, requiring a third bypass run for 36 minutes to repair a suture line tear using a pericardial pledgeted suture because of poor tissue quality. The second patient was a 63-year-old who underwent an urgent mitral repair for acute endocarditis complicating Barlow's mitral disease with bileaflet prolapse treated with P2 quadrangular resection with extended sliding plasty and ePTFE chordoplasty to both anterior and posterior leaflets. A second CPB run for 20 minutes was needed for residual mild to moderate MR to remove a restrictive ePTFE chord from the anterior leaflet. TEE after the second CPB run showed residual mild regurgitation. A third bypass run for 25 minutes was needed to remove an ePTFE chord tethering the P2 segment, as well as to repair a leaflet perforation, and perform an anterior commissuroplasty ''magic stitch'' to securely eliminate MR.

The third patient required a third bypass run for 18 minutes to address superior vena cava stenosis requiring revision of the left atriotomy suture line.

Perioperative outcomes are reported in Table 4. No patients required placement of an intra-aortic balloon pump or inhaled nitric oxide. Intraoperative blood products were required in 16 patients. Patients left the operating room on a mean of 50 ± 39 ng/kg/min of epinephrine and 43 ± 47 ng/kg/min of norepinephrine (Table 4). There were no in-hospital or 30-day deaths. Median time to extubation was 11 hours (IQR, 8-14.5), and 2 patients required mechanical ventilation for more than 24 hours. One patient had a deep sternal wound infection requiring surgical debridement and chest wall reconstruction. One patient had a stroke. No patients needed renal replacement therapy. Median intensive care unit length of stay was 2 days (IQR, 1-3), and hospital length of stay was 8 days (IQR, 6-9).

On predischarge transthoracic echocardiogram, MR was absent in 13 patients, trace in 23 patients, and mild in 4 patients (Figure 3). Mean ejection fraction was 52.4% ± 9.4%.

Freedom from moderate or greater MR at 5 years was 100% (Figure 4). Two patients experienced moderate MR at any point during follow-up. No patients underwent reintervention on the mitral valve during follow-up. One patient developed severe aortic insufficiency requiring surgical aortic valve replacement 8 years postoperatively. Another patient underwent transcatheter aortic valve implantation 4 years postoperatively for treatment of severe aortic stenosis. All patients were alive at latest follow-up.

DISCUSSION

Key Findings

The present study achieved a 100% repair rate without residual MR in all our patients with degenerative disease

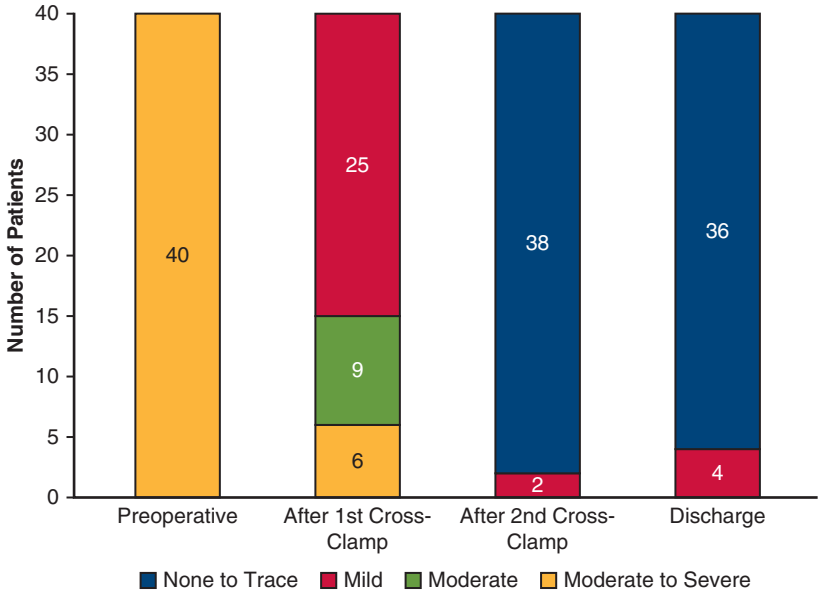

FIGURE 3. MR grades preoperatively, after first crossclamp, after second crossclamp, and at discharge.

who underwent a second bypass run for residual MR. This included a range of valve complexity and baseline patient risk profile. We had no early mortality or major complications that we could attribute to the second bypass run. The long-term echocardiographic and clinical outcomes have been excellent. This cohort included a combination of low-risk asymptomatic patients in approximately one-third of cases with pressure for excellent outcomes, as well as complex and high-risk patients including reoperations, mitral re-repairs, and concomitant procedures (34/40 patients).

Few have reported the incidence of intraoperative repair revision for residual MR. De Bonis and colleagues[11] reported a second crossclamp incidence of 4% in 94 of 2318 patients with degenerative disease.

Ma and colleagues[12] reported an incidence of 5% second bypass run for revision of the repair in a series of 815 patients. In a cohort of 40 patients, they reported a re-repair rate of 57.5% (23 patients), with the remaining 17 patients undergoing valve replacement.[12] Goldstone and colleagues[13] reported repair revision in 26 patients of 525 repairs (5.0%), half of which were performed via minithoracotomy.

In our cohort, the mitral valve pathoanatomy was evenly distributed among FED, Barlow's disease, and forme fruste cases. Mitral repair was achieved via blending resection and nonresection techniques as described in the "Materials and Methods" section. All patients had perfect saline testing at the conclusion of the initial repair. This emphasizes the role of the cardiac anesthesiologist with expertise in perioperative 3-dimensional TEE to detect residual MR and its mechanism, and to guide the management as explained in the algorithm.

The main mechanism for residual MR in our series was technical (suture line–related MR) as opposed to residual pathology or SAM. Technical causes are usually easily fixable as reflected by our median second crossclamp time of only 34 minutes (IQR, 29-38 minutes). Repair was usually achieved using a single shot of antegrade cardioplegia with simple re-repair technique(s), such as cleft closure, repair of leaflet perforation, magic stitch, or ePTFE chordoplasty. Annuloplasty revision was a rare event (only 3 patients) and was reserved for patients with refractory SAM in whom the trigonal sutures of a flexible band were removed to open up the outflow tract. We prefer to use conventional repair techniques such as suturing of defects, release of restrictive chordae, and correction of residual prolapse or SAM with neochordae to enable re-repair, with the hope that this would best maintain long-term valve functionality. The edge-to-edge technique, which we applied in 1 patient, is a useful bailout approach and can be applied to larger valves (without perceived risk of stenosis) where the cause of regurgitation is unclear or cannot be easily resolved by other means.

Of note, De Bonis and colleagues[11] reported residual prolapse was the most common cause for MR, identified in 41 of 94 patients (43.5%) with edge-to-edge suture used to rescue these valves in 35 of 41 patients (85.3%) with a median second crossclamp time of 23 minutes (range, 17-34 minutes).[11]

TABLE 3. Causes of residual regurgitation and re-repair techniques (n = 40)

Mechanism of residual regurgitation	N (%)
Suture line related	31 (78%)
SAM	5 (13%)
Residual pathology	4 (10%)
Re-repair technique	
ePTFE chordoplasty	
AL	3 (8%)
PL	7 (18%)
Commissuroplasty	
Anterolateral	4 (10%)
Posteromedial	6 (15%)
Cleft closure	15 (38%)
Leaflet free-edge remodeling	6 (15%)
Primary suture repair	12 (30%)
Annuloplasty device revision	3 (8%)
Edge-to-edge repair	1 (3%)
Septal myectomy	1 (3%)
Total re-repair techniques used per patient	
1	21 (53%)
2	13 (33%)
3+	6 (15%)
Crossclamp and CPB times	
First crossclamp time, min, median (IQR)	106.0 (81-140)
Second crossclamp time, min, median (IQR)	34.0 (29-38)
Total crossclamp time, min, median (IQR)	145.0 (120-169)
Total CPB time, min, median (IQR)	208.5 (187-224)

SAM, Systolic anterior motion; *ePTFE*, expanded polytetrafluoroethylene; *AL*, anterior leaflet; *PL*, posterior leaflet; *CPB*, cardiopulmonary bypass; *IQR*, interquartile range.

TABLE 4. Perioperative outcomes (n = 40)

Variable	N (%)
Mortality	0 (0%)
Epinephrine dose and duration, ng/kg/min, mean (SD); h, mean (SD)	49.5 (39.4); 28.7 (17.0)
Norepinephrine dose and duration, ng/kg/min, mean (SD); h, mean (SD)	42.5 (47.6); 16.7 (11.4)
Low cardiac output state	8 (20%)
IABP	0 (0%)
Inhaled NO	0 (0%)
Time to extubation, h, median (IQR)	11 (8.0-14.5)
ICU length of stay, d, median (IQR)	2 (1-3)
Hospital length of stay, d, median (IQR)	8 (6-9)
Mechanical ventilation >24 h	2 (5%)
Length of stay >14 d	2 (5%)
Permanent stroke	1 (3%)
Myocardial infarct	0 (0%)
Renal failure	0 (0%)
Intraoperative or postoperative blood or blood product transfusion	16 (40%)
Sepsis	1 (3%)
Deep sternal wound infection	1 (3%)
Moderate-severe MR	0 (0%)
Reoperation	0 (0%)

SD, Standard deviation; *IABP*, intra-aortic balloon pump; *NO*, nitric oxide; *IQR*, interquartile range; *ICU*, intensive care unit; *MR*, mitral regurgitation.

Thus, under the pressure of the second bypass run, the mitral surgeon should not hesitate to pursue further re-repair before any consideration of direct valve replacement without an attempt for re-repair because that can be usually achieved using a simple surgical technique without taking down the original repair. Indeed, we postulate that mitral valve replacement would likely have taken longer than further repair in most of our patients (with also likely worse early and late outcomes).

The median total CPB time was 208.6 minutes (IQR, 187-224 minutes), which was comparable to other studies that pursued further repair.[13] However, this was also an all-comer series with patients requiring complex mitral re-pairs, reoperations including mitral re-repair, concomitant procedures (85%), and few patients requiring a third bypass run. A secondary benefit of reexploration is that while the patient is on the second crossclamp, surgeons can also can take the opportunity to also optimize any subtle abnormalities detected on TEE, such as correction of tendency to SAM or achieving a deeper coaptation line to perfect the repair (which explains the occasional use of multiple surgical techniques in a few patients, even if only 1 mechanism for the residual MR was suspected). A full sternotomy approach may have facilitated our ability to implement our algorithm for all patients regardless of complexity.

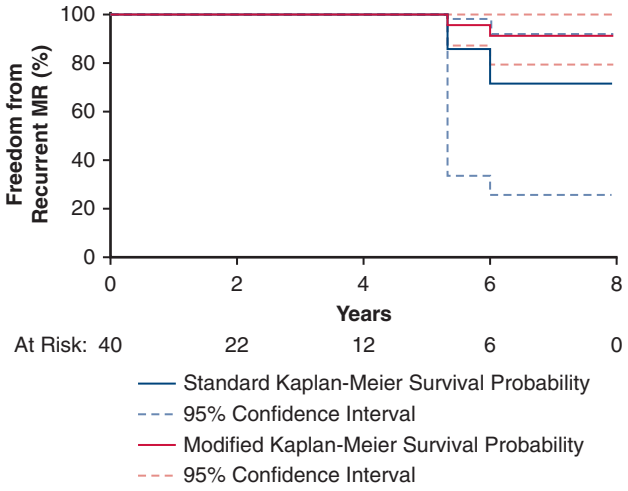

FIGURE 4. Time-to-event analysis for freedom from moderate or greater MR using standard Kaplan–Meier curve and modified Kaplan–Meier curve. *MR*, Mitral regurgitation.

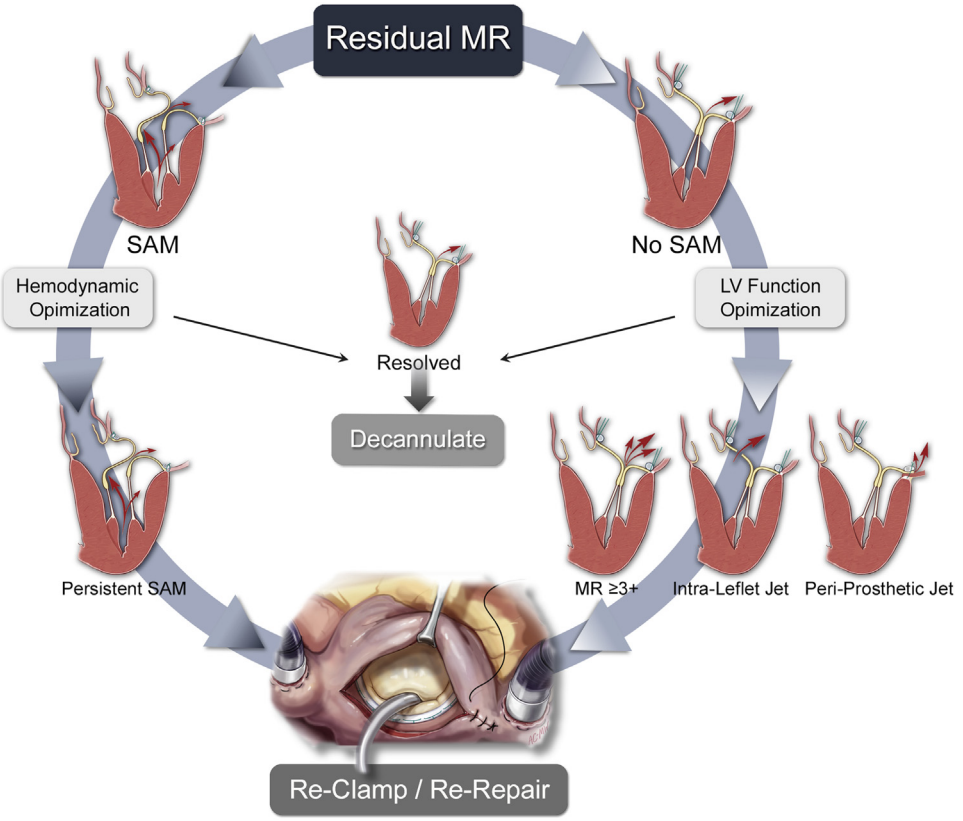

FIGURE 5. When residual MR is due to SAM, an attempt is made to optimize left ventricular afterload and heart rate/rhythm before reexploration. If SAM is not the cause, the first step is to improve myocardial contractility. The repair should then be revised when periprosthetic or intraleaflet regurgitant jet is seen on color Doppler or with moderate or greater regurgitation (see text for details). *MR*, Mitral regurgitation; *SAM*, systolic anterior motion; *LV*, left ventricle.

Transfusion of blood or blood products was needed in 40% of the patients, mostly to deal with postbypass coagulopathy possibly due to prolonged bypass run. However, for patients with SAM, optimization of the hematocrit was necessary as part of hemodynamic optimization. There were no reoperations for bleeding.

Overall, despite the relatively prolonged operative and bypass times, a second bypass run did not appear to negatively affect major perioperative morbidity with excellent midterm outcomes. This has been consistent with other series studying this unique patient population.[11,13]

Implications for Practice

With the use of this TEE-guided clinical algorithm (Figure 5), postbypass residual MR can be safely and effectively eliminated in selected patients with a second bypass run with minimal incremental risk and potential for better outcomes.

We believe that surgeons should have a low threshold for a second CPB run to eliminate residual MR, particularly in those patients undergoing surgery for prognostic benefit (eg, asymptomatic patients) and those expected to have a long life expectancy. In young patients with low operative risk, a more aggressive approach is preferred for better long-term outcomes, in contrast to elderly and high-risk patients or patients with postbypass left or right ventricular dysfunction when the increased perioperative morbidity of a second bypass run and additional myocardial ischemia should be carefully balanced against the potential benefits.

Study Limitations

This study has several limitations that may influence the interpretation and reproducibility of the results. Our study is a retrospective review and is therefore subject to all the attendant limitations related to this model of analysis. Our sample size for analysis was limited given that residual regurgitation is a relatively infrequent clinical occurrence. Because reexploration was our trigger for study inclusion, we did not obtain data on the few patients who may have had residual MR but were not re-explored. Finally, implementation of the protocol and interpretations of those outcomes have been achieved within a single comprehensive valve center of excellence (level I center of excellence) with an experienced team, and our results may not be generalizable to nonreference centers.

CONCLUSIONS

This study presents a comprehensive management strategy for patients with postbypass residual MR in degenerative mitral repair through the use of a detailed stepwise TEE-guided algorithm allowing elimination of residual MR with minimal perioperative adverse outcomes while maintaining excellent repair stability on follow-up. A low threshold to revise suboptimal mitral repairs is a safe and feasible practice in mitral reference centers.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/19%20AM/Sunday_May5/1.%20PLENARY/1.%20PLENARY/16h%20-%2018h/P3_4.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's involvement in the development of 2 mitral valve repair rings and 1 tricuspid valve repair ring. Dr Adams is the National Co-Principal Investigator of the CoreValve United States Pivotal Trial, which is supported by Medtronic. Dr Bhatt is a clinical consultant for Neochord, LLC. All other authors have nothing to disclose with regard to commercial support.

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Key Words: degenerative mitral disease, mitral regurgitation, mitral repair, residual mitral regurgitation

Discussion

Dr Patrick M. McCarthy *(Chicago, Ill)*. Congratulations to Dr El-Eshmawi, Dr Adams, and the entire Mount Sinai team on another useful contribution for practicing surgeons. Mount Sinai is leading the way with educational endeavors for mitral surgery. Also, congratulations on outstanding clinical results with the need for a second crossclamp in only a small number of these patients.

At Northwestern, we follow a similar protocol to yours, and our experience with residual mild MR was presented earlier by Dr Imielski. Not mentioned in our Northwestern presentation is that we have used a second crossclamp in 20 patients. We always re-crossclamp if a patient has greater than mild MR. We only tolerate mild MR for patients with an irregular area at the coaptation line, so these are different patients than this report from Mt Sinai.

I have some brief questions, and some are a bit longer. First, the series began in 2011, but Dr Adams has been there longer than that. Why did you choose to begin the series at that point?

Dr Ahmed El-Eshmawi *(New York, NY)*. It coincided with the introduction of electronic medical records in our center, so that's when we actually could have electronically tracked patients who had a second bypass run.

Dr McCarthy. The second is a more important practical point: How do you test the valve at the end of the repair? That is a really important test. At that point you have placed your chords or done your resection and placed the ring. We have a methodical

way that we test the valve. If you do that well, then you shouldn't have significant residual jets, which is why there is a low risk for a second crossclamp.

Dr El-Eshmawi. I want to clarify that all of our patients undergo meticulous saline testing after repair, and if there is any leak identified we correct it with additional maneuvers before weaning from CPB at the time of the first clamp. In terms of our protocol, we inject the ventricle with saline until it is full. We also make sure that the aortic root is distended. Sometimes we even give antegrade cardioplegia and distort the aortic valve intentionally to fill the ventricle while holding the mitral leaflets shut to create tension on the chords.

We also do the ink test on all of our valve repairs. By marking the closure line with the ventricle distended, we can control the depth of leaflet coaptation and identify clefts within the closure line, which we often close. But again, no static testing is 100% reliable, so that's why we still see some cases with residual MR after the initial bypass run.

Dr McCarthy. I would like to stress the use of the ink test. If you see a small jet when the ventricle is pressurized, take the ink and mark that small spot. Then when you decompress the ventricle you may see a small cleft or some other abnormality. All it takes is a small irregularity at the level of coaptation, and it may cause a small jet. If you have marked the spot with a dot of ink, then you can easily see the abnormality and repair it.

Your algorithm ends with a group of patients who don't have SAM, MR is mild, and it is along the closure line. How many of those patients did you have? You didn't reclamp those, and those are the patients who we reviewed in our Northwestern article.

Dr El-Eshmawi. We did not have the information regarding this group of patients. But it has been our experience with mild MR within the closure line that it remains stable or resolves on predischarge transthoracic echo. The patients we are more concerned about are those who have any of the unfavorable echo criteria I described, including, intraleaflet, periprosthetic, paracommissural, or eccentric jets.

Dr McCarthy. My last question has to do with that exact point, and it's a practical aspect for practicing surgeons. If you identify a small tear in the leaflet before you have closed the left atrium or when you re-crossclamp, how do you repair that?

Dr El-Eshmawi. First, we try not to have that problem, particularly in patients with FED. We are also meticulous in placing annuloplasty sutures, and if we see a tear that is close to the annuloplasty device, we usually remove those sutures to gain more access at the base of the leaflet. We also have to be careful reconstructing leaflets because the tissues are often fragile. When repairing a leaflet tear, we also use a pericardial reinforced pledgeted suture, as I showed in the video.

Dr Soon J. Park *(Rochester, Minn).* A great discussion. I have a question about those patients who had SAM; you medically optimized them and they got better. Do you know how many patients and how they did long term?

Dr El-Eshmawi. No. That happens every day, I can tell you, in the operating room. We see a lot of SAM cases. It's one of the most common complications that we encounter. I wouldn't even call it a complication. But if we can't reverse the SAM hemodynamically by raising the afterload, filling the heart, slowing the heart rate down, we usually use esmolol in these cases. And you can get the closure line but still leaves out any left ventricular outflow tract gradient without MR. We can guarantee that almost 100% of these patients will remain stable. But again, if you can't actually do this anatomic correction of SAM with gentle hemodynamic measures, then it's always the question of whether to go back on bypass and do something for the valve.

Dr Park. So you know how they respond intraoperatively when you medically optimize, but do you have data on how they might do in more vigorous lifestyle situations?

Dr El-Eshmawi. No, we don't have the data on that particular study.

Dr Park. My concern based on my experience and some published literature from Mayo is that despite successful amelioration of SAM intraoperatively, some of these people may end up requiring redo surgery. Especially when you perform mitral valve repair in young and healthy people who want to get back to normal and vigorous activity, they may develop significant symptoms from hemodynamic compromise due to dynamic SAM.

I may propose an alternative approach; would it be rather prudent to actually try to simulate a strenuous hemodynamic situation by challenging these people with Isuprel or rapid atrial pacing in the operating room to see whether their SAM gets worse? If it worsens, would it be a good time to address it proactively? I understand your proposal that by medically optimizing SAM in the operating room they would do okay, but I am not sure that's really the case.

Dr El-Eshmawi. I think you raise an interesting point, but it has not been my experience to see exercise-induced systolic motion in our practice if the predischarge echo confirms a good repair in a patient who initially had SAM that resolved with simple intraoperative maneuvers.

Dr Park. I'm not sure it's that rare. I ask you to think about that.