Long-term follow-up of posterior mitral leaflet extension for Type IIIb ischemic mitral regurgitation

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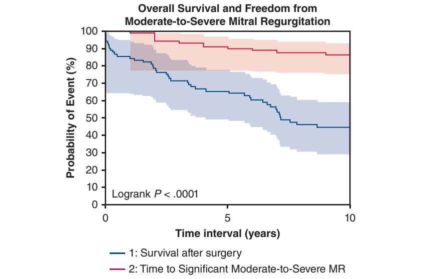
ABSTRACT

Objective: Ischemic mitral regurgitation (MR) is generally associated with very poor outcomes and disappointing results, despite a seemingly perfect initial repair and optimal revascularization. We previously published our intermediate-term results of posterior leaflet augmentation without follow-up extending beyond 4 years. Our objective is to assess long-term durability of the repair, survival, and the causes of late mortality.

Methods: Ninety-one patients with severe (4+) Carpentier Type IIIb ischemic MR underwent repair in a single center between 2003 and 2022 by method of posterior leaflet extension using a patch of bovine pericardium and a true-sized remodeling annuloplasty ring, with or without surgical revascularization. Serial echocardiography was performed over the years to ascertain valve competence and degree of ventricular remodeling, in addition to telephone follow-up and chart reviews.

Results: The average age of patients was 67 ± 9.6 years. Mean follow-up was 8 ± 5 years with some extending to almost 20 years. One-, 5-, and 10-year freedom from recurrent significant MR, characterized as moderate or severe MR, was 98.6%, 85.5%, and 71.3%, respectively. Thirty-day mortality was 6.5%. One-, 5-, and 10-year survival was 85.5%, 64.4%, and 43.3%, respectively. Of all the mortalities, only 17.5% were proven to be directly cardiac related.

Conclusions: The suggested repair technique offers satisfactory long-term outcomes with minimal residual regurgitation in surviving patients when used in context of ischemic MR. Despite durable repair, we have discovered that poor long-term survival is not directly related to cardiovascular causes. (JTCVS Open 2024;18:33-42)



Survival versus time to moderate or greater MR postrepair with posterior leaflet extension.

CENTRAL MESSAGE

A project 20 years in the making: Driven by the conviction that mitral repair techniques can still play a role in the ischemic setting and therefore, should not be abandoned.

PERSPECTIVE

Challenging what is now deemed standard practice, we believe that repair may yet be superior to replacement. The technique described for posterior leaflet extension should be easily reproducible and has consistently offered us positive results in the early and intermediate postoperative periods. We now share our long-term results, with hope that readers find it encouraging and thought-provoking.

▶ Video clip is available online.

To view the AATS Annual Meeting Webcast, see the URL next to the webcast thumbnail.

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Achieving the right mitral valve (MV) leaflet coaptation is dependent on the fine balance among the systolic closing forces produced by left ventricular (LV) contraction against the unimpaired opposing tethering forces of the subvalvular apparatus.[1] Ischemic mitral regurgitation (IMR) occurs when the valve is structurally normal yet rendered

Abbreviations and Acronyms

CSTN = Cardiothoracic Surgical Trials Network
IMR = ischemic mitral regurgitation
LV = left ventricle
MV = mitral valve

incompetent as a result of the disturbance of these forces. Induced by a localized or global infarct, this triggers ventricular remodeling and papillary muscles displacement, resulting in increased tethering of the chordae and subsequently, an incomplete leaflet coaptation.[2,3] A degree of MR is present in more than 50% of patients with reduced LV ejection fraction who undergo coronary artery bypass.[4] The key to a durable MV repair is the restoration of such leaflet coaptation, to which the placement of a conventional annuloplasty ring only partially achieves this objective by reducing annular size.[5] This practice tends to exacerbate posterior leaflet tethering and therefore impedes coaptation and decrease the desired mobility of the leaflets.[5] It is important to note that even a moderate residual regurgitant jet has been shown to stand as an independent factor of poor outcome.[5]

Our previous article, published in 2009[2] with the same title, advocated for the use of a bovine pericardial patch to augment the posterior leaflet. The goal of that study was to explore the long-term results of the technique first developed and described by Dobre and colleagues.[6] It has similarly been reported in the reconstruction of other mitral valve pathologies such as rheumatic disease and infective endocarditis.[6] Because our previous article[2] only offered a mean follow-up duration of 38 months, the authors recommended a longer follow-up to deduce whether or not the pliability and structural integrity of the bovine pericardial patch would stand the test of time. To our knowledge, no long-term study has been conducted to conclude survival beyond 4 years from a similar suggested repair of an IMR at the time of our study's conduction. The secondary goal of this analysis was to identify the late causes of mortality in patients surgically treated for IMR.

METHODS

Study Design

For this observational retrospective study, data were collected from scanned hospital medical records with institutional permission. Ninety-one adult patients with severe (4+) Carpentier Type IIIb IMR underwent MV repair using the technique of posterior leaflet extension from 2003 to 2022 at a single tertiary care cardiac center. Early perioperative mortality for this study is defined as death within 30 days from surgery or during the index admission. The remaining surviving patients, who were ultimately discharged from the hospital, were subsequently followed and evaluated by telephone interviews and serial transthoracic echocardiography. The study protocol was reviewed and approved by the McGill University Health Center Research Ethics Board on December 12, 2021, before the conduction of the study (alsh6006 / 2022-8468). Access to both paper and online medical records were granted.

Primary outcome is the durability of the repair, identified as detectable residual regurgitation deemed to at least be moderate in severity 3+. Freedom of such residual MR was evaluated using serial transthoracic echocardiography follow-ups, protocoled annually regardless of symptoms. We have investigated our Québec health records to extract every echocardiogram that was preformed between the desired follow-up durations, either due to symptoms or as part of pre-procedural workup, that image would be incorporated into the data gathered.

Secondary outcomes were focused on 10-year survival and causes of late mortality. Patients received warfarin for 3 months postoperatively, unless contraindicated by bleeding. At 3 months, warfarin was often discontinued unless an arrhythmia was detected.

Surgical Approach

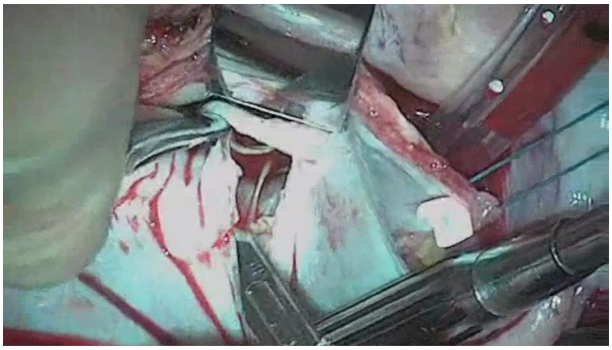
Intraoperative transesophageal echocardiography after induction of anesthesia confirmed the presence of severe Type IIIb MR with a combination of central and posterior-directed jet of regurgitation in all patients. Arterial and venous conduits were harvested if a concomitant coronary artery bypass was planned. All operations were performed under cardiopulmonary bypass with mild hypothermia (32-36 °C). The heart was arrested and myocardial protection was achieved with cold blood microplegia. The superior transseptal approach to the mitral apparatus was used for most cases. Direct visualization confirmed the normal morphologic appearance of the leaflets, with absence of annular calcifications. The posterior leaflet was detached from the middle of P2 to the posterior commissure. Posterior annuloplasty sutures (2–0 Ethibond Excel Polyester Suture) were placed from 1 commissure to the other. A bovine pericardial patch was rinsed, sized, and fashioned depending on the size of the defect. The patch was sutured in a running fashion first to the posterior annulus and then in an interlocked running fashion to the cut edge of the posterior leaflet (5–0 sutures were used). Once this was done, a true-sized complete annuloplasty ring (Carpentier-Edwards Physio I; Edwards Lifesciences) was chosen, with the most common size being 28, based on intraoperative measurement of anterior leaflet area and intercommissural distance (Video 1).

Statistical Analysis

Results are expressed as absolute values and percentages, continuous variables as the mean ± SD, and categorical variables as percentages. The Kaplan-Meier method was used to determine patient survival and freedom from significant moderate or severe MR. A competing risk regression analysis was used to supplement it with the competing risk being death. Software used by the Biostatistics Department at the McGill University Health Center was SAS version 9.2 (SAS Institute Inc).

RESULTS

The preoperative characteristics of the study patients are shown Table 1. The average age of patients was



VIDEO 1. Posterior mitral leaflet extension technique for treatment of type IIIB ischemic mitral regurgitation. Video available at: https://www.jtcvs.org/article/S2666-2736(24)00008-1.

TABLE 1. Preoperative characteristics (N = 91)

Variable	Result
Sex, male/female	66/25
Mean age at operation (y)	67.5 ± 9.6
Preoperative NYHA functional class	
I	4 (4.3)
II	9 (9.8)
III	52 (57.1)
IV	26 (28.5)
Initial presentation	
Dyspnea	71 (78.0)
Angina	11 (12.0)
New-onset atrial fibrillation	4 (4.3)
Cardiac arrest	2 (2.1)
Redo surgery	11 (12.0)
Second redo surgery	3 (3.2)
Elective surgery	49 (53.8)
Urgent surgery	32 (35.1)
Emergency surgery	10 (10.9)
Average Parsonnet score	37.6 ± 13.9
Hypertension	65 (71.4)
Hyperlipidemia	43 (47.2)
Previous myocardial infarct	51 (56.0)
Chronic atrial fibrillation	32 (35.1)
Permanent pacemaker	13 (14.2)
Diabetes mellitus	34 (37.3)
Obesity (BMI >35)	6 (6.5)
Cerebrovascular accident	7 (7.6)
Peripheral vascular disease	8 (8.7)
Asthma/chronic obstructive pulmonary disease	18 (19.7)
Obstructive sleep apnea	5 (5.4)
History of smoking	21 (23.0)
Chronic kidney disease	13 (14.2)
Liver disease	3 (3.2)

Values are presented as n/n, mean ± SD, or n (%). *NYHA*, New York Heart Association; *BMI*, body mass index.

67 ± 9.6 years with mean preoperative LV ejection fraction of 37.3%. Mean patient follow up was 8 ± 5 years with 5 patients surviving almost 19 years. Operative data specifics are shown in Table 2, Table E1.

The rate of postoperative atrial fibrillation, renal failure, and cerebrovascular accidents was at 25 out of 91 (27%), 9 out of 91 (9.89%), and 3 out of 91 (3.29%), respectively. Other detailed secondary postoperative outcomes are listed in Table 3.

Table 4 exhibits detailed causes of early and late mortality. One-, 5-, and 10-year survival was 84.5%, 64.4%, and 43.3%, respectively (Figure 1, *A*). Perioperative mortality was at 6.5%, of which, half (3 out of 6) were identified as cardiovascular in nature, yet none had residual MR on their latest imaging. Of all the mortalities occurring in the 10 years following MV repair, only 17% were directly identified as related to cardiac causes. In the event the cause of death was unobtainable from the records, the death was labeled "unknown." Unidentifiable causes of mortality amounted to 10 out of 40 (25%) of all mortalities beyond

TABLE 2. Operative data (N = 91)

Variable	Result
Annuloplasty ring size	
26	17 (18.6)
28	32 (35.1)
30	24 (26.3)
32	10 (10.9)
34	6 (6.5)
36	1 (1.0)
40	1 (1.0)
Crossclamp time (min)	107 ± 33.8
Concomitant surgery	
Bypass	44 (48.3)
Average No. of grafts	1.6 ± 1.4
Tricuspid valve repair	22 (24.1)
Maze procedure	13 (14.2)
Aortic valve replacement	3 (3.2)
Bentall procedure	1 (1.0)
Left ventricular pseudoaneurysm repair	2 (2.1)
Aortic dissection	1 (1.0)
Pericardectomy	1 (1.0)
Intra-aortic balloon pump	13 (14.2)

Values are presented mean ± SD, or n (%).

TABLE 3. Postoperative outcomes (N = 91)

Variable	Result
30-d mortality	6 (6.5)
Mean follow-up (y)	8 ± 5 (1-19)*
Reoperation; bleeding/tamponade	3 (3.2)
Conversion to prosthesis	2 (2.1)
CVA	3 (3.2)
Atrial fibrillation	24 (26.3)
Permanent pacemaker	7 (7.6)
Renal injury	15 (16.4)
Dialysis	9 (9.8)
Liver failure	2 (2.1)
Respiratory complications	15 (16.4)
Wound infection	7 (7.6)

Values are presented mean ± SD, or n (%). *CVA*, Cerebrvascular accident. *Minimum to maximum.

TABLE 4. Early & late causes of mortality using the posterior mitral leaflet extension technique

Early mortality	6
Cardiac mortality	3 (50)
Postoperative myocardial infarction	1 (16.6)
Cardiogenic Shock	2 (33.3)
Noncardiac mortality	3 (50)
Respiratory failure	2 (33.3)
Mesenteric ischemia	1 (16.6)
Late mortality	40
Cardiac mortality	7 (17.5)
Pericardial tamponade	1 (2.5)
Congestive heart failure	2 (5)
Severe aortic stenosis	2 (5)
Cardiac arrest	2 (5)
Noncardiac mortality	23 (57.5)
Cerebrovascular accident	6 (15)
Pulmonary embolism	3 (7.5)
Pneumonia	3 (7.5)
Respiratory failure	1 (2.5)
Renal failure	3 (7.5)
Sepsis	1 (2.5)
Multiorgan failure	1 (2.5)
Neoplasm	4 (10)
Trauma	1 (2.5)
Unknown	10 (25)

Values are presented as N or n (%).

30 days. The burden of cardiovascular versus noncardiovascular deaths is shown in Figure 1, *D*.

One-, 5-, and 10-year freedom from recurrent moderate or severe MR in the survivor's group was 98.6%, 85.5%, and 71.3%, respectively (see Figure 1, *B*). Notably, 34 out of 40 (85%) of patients had no significant MR before their death, as deemed by their imaging. Reoperation necessitating MV replacement was performed in 2 patients, 1 and 5 years after their initial repair. Figure 1, *B*, was stratified by the LV end-diastolic diameter, grouped as either <60 mm or ≥60 mm, to generate Figure 1, *C*.

Figure 2 reflects the significance of MR in the surviving patient cohort on an annual basis. The fluctuation could be secondary to acute decompensation because some of those echocardiograms were performed during ongoing hospitalizations. We also conducted a competing risk regression model conducted to analyze the risk for recurrence of moderate-to-severe MR (see Figure 3).

We noted the stabilization of LV ejection fraction at 45%, combined with continuous minimal improvement of remaining parameters in surviving patients at 8 years, with LV end-systolic diameter and LV end-diastolic diameter at 39 mm and 52 mm, respectively (Table 5). The follow-up rate was concluded to be 84.6% at 5 years and 73.6% at 8 years (Figure 4).

DISCUSSION

Posterior Leaflet Augmentation

The preservation of the native MV apparatus allows us to restore a more natural physiologic configuration and help prevent further progression of LV dilation.[7-9] By combining the traditional annuloplasty with leaflet augmentation, it increases the coaptation surface in the region where the leaflet is most susceptible to tethering from the posteromedial papillary muscle.[10,11] It extends the height of the posterior leaflet by 1 cm in P3 as well as the medial half of P2, which provides a larger safety margin of tissue for the foreseeable event that LV remodeling persists after surgery.

True-Sized Annuloplasty Ring

Although implanting a downsized MV annuloplasty ring was initially theorized to reduce dilatation of the annulus and improve coaptation of the leaflets, studies based on the Cardiothoracic Surgical Trials Network (CSTN) randomized trial have reported a recurrence rate of moderate to severe MR at 58% in 2 years following deployment of undersized annuloplasty rings.[12-14] The excessive posterior leaflet tethering, particularly when the ischemic papillary muscles remain laterally and apically displaced in relation to the annulus, can lead to subsequent recurrent MR and poor durability.[15]

LV End-Systolic Diameter/Ring Ratio

An adjunct to an appropriately sized annular correction would be the surgical reduction of LV end-systolic diameter.[16,17] A means of reducing LV end-systolic diameter would have the opposite effect of annular overcorrection because it would bring the papillary muscle closer to the mitral annulus and thus decrease leaflet tethering forces.[18] A ratio of LV end-systolic diameter-to-ring size >2 has been highlighted as a predictor of risk of recurrent MR following annuloplasty repair alone.[15] Our average LV end-systolic diameter/ring ratio size was 1.44 ± 0.37 (based on 70 patients with existing preoperative LV end systolic diameter). Of those 70 patients, only 10 had a ratio ranging between 2.0 and 2.2 and none >2.2. This did not correlate with the early perioperative mortalities.

Repair Versus Replacement

Comparing the effectiveness of valve repair versus replacement in patients with severe IMR is an ongoing debate.[19] In the CSTN trial, 251 patients with severe IMR were randomized to undergo either repair with a restrictive annuloplasty versus a chord-sparing replacement.

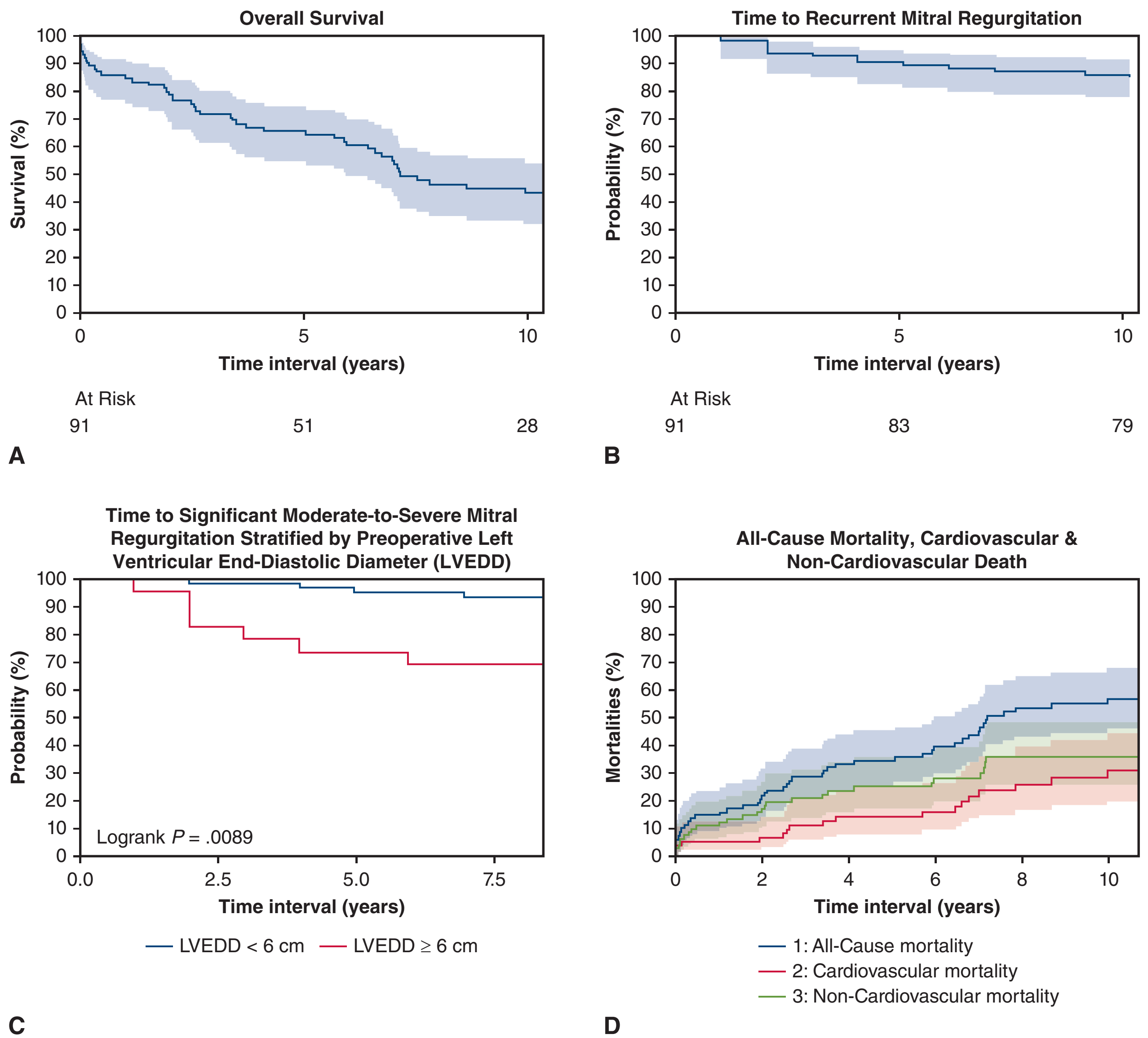


FIGURE 1. A, Kaplan-Meier survival curve for patients with ischemic mitral regurgitation (IMR) after repair with posterior leaflet extension. B, Kaplan-Meier curve for time to recurrent significant MR (moderate or greater) after repair with posterior leaflet extension. C, Time to moderate-to-severe MR stratified by left ventricular end-diastolic diameter (LVEDD), grouped as either <60 mm or ≥60 mm. D, All-cause mortality, both depicted separately as cardiovascular causes in *red* (includes the unknowns accounting for 25% of mortalities) and noncardiovascular causes in *green*.

At 1 and 2 years, the repair cohort was associated with a significantly higher incidence of moderate or greater recurrent MR (at 58.8% with repair vs 3.8% with replacement; $P < .001$), with no difference between the 2 cohorts in the degree of LV reverse remodeling, LV ejection fraction, survival, hospitalization, or major adverse cardiac and cerebrovascular events.[20] Despite the excellent contribution of the articles originating from this trial, the study was underpowered to demonstrate accurate survival differences. The randomized study design cannot compensate for potential flaws: the repair types across the 22 participating CTSN centers were not coordinated and the exact method of repair was not always disclosed.[15]

LV Dimensions

Remaining parameters were discussed in greater detail in our previous article[2] with reported improvement in LV ejection fraction, LV end-systolic diameter, and LV end-diastolic diameter in up to 3 years, and thus were not the primary highlight of the article. The lack of uniform reporting of specific echocardiogram parameters have made it challenging to retrospectively extract valuable information over the span of that many years.

It is possible that the reduced mean LV end-diastolic diameter compared with CTSNet data is a contributing factor to the improved outcome. It could represent improvement of outcomes in the subgroup of patients in whom

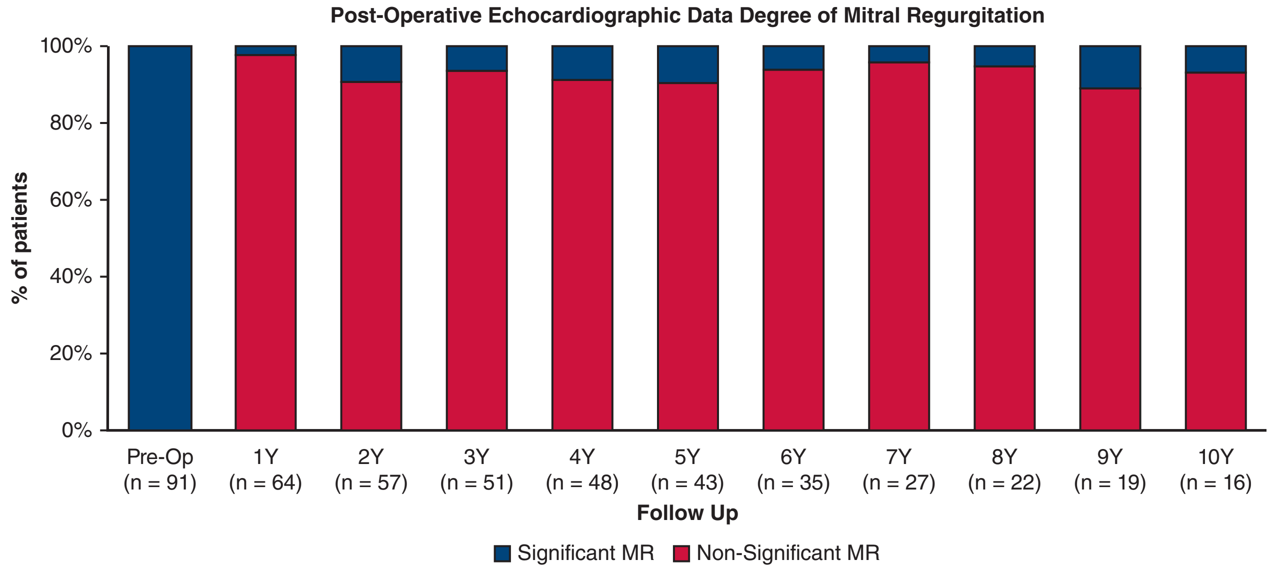


FIGURE 2. Postoperative echocardiographic data reflecting the degree of moderate-to-severe mitral regurgitation (*MR*) in the surviving patient cohort on an annual basis.

MR was addressed sooner, before any further deterioration in ventricular function or remodeling. This merely reflects the targeted patient population by our institution. No patient with advanced dilation of the LV end-diastolic diameter was excluded.

Valve Competency

The incidence of significant recurrent MR, characterized as at least moderate in severity, was low. We believe these results to be due to the restoration of annular shape, preservation of the subvalvular apparatus, and increasing the coaptation surface between the 2 leaflets to a degree that would compensate for continued remodeling. Overall, there was significant observed reverse remodeling in the LV with slight improvements in the mean LV ejection fraction from 37% ± 14% to 41% ± 15%.

Two patients required conversion to prosthesis due to recurrence of significant MR. One patient had a displaced coaptation point toward the apex resulting in grade III/IV central MR at 1-year follow-up. We suspected an element of dilated cardiomyopathy juxtaposed to his ischemic problem. Intraoperative echocardiogram showed no dehiscence of the mitral annulus, with good mobility of the 2 leaflets of the MV, except of the posterior mitral leaflet restriction. The patch appeared intact, but we confirmed the increase in posterior MV leaflet restriction attributed to the increase in dilation of the LV. The patient had a size 29 mm St Jude mechanical prosthesis implanted with total preservation of the subvalvular apparatus. Another patient required a redo after 5 years, with new symptomatic severe aortic stenosis and an occluded vein graft.

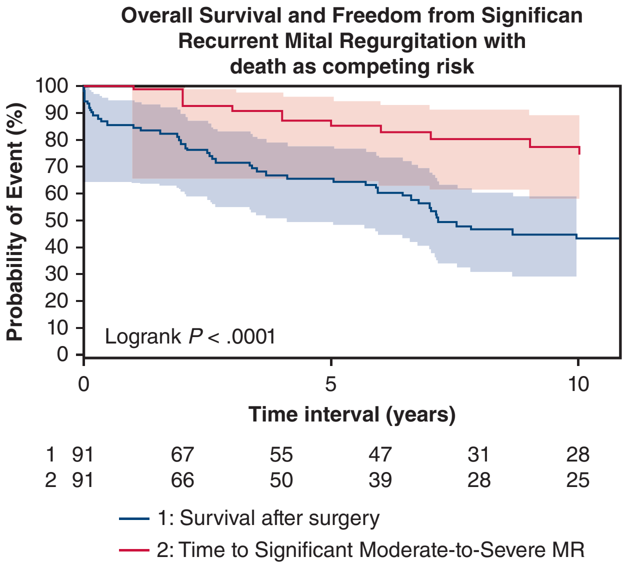


FIGURE 3. A competing risk regression model conducted to analyze the risk for recurrence of moderate-to-severe mitral regurgitation (*MR*), with the competing risk being death.

Mortality

Comparing our results with the CTSN, mean ages were similar. Our 1-year mortality is consistent with their result for repair at 14.3% (vs 17.6% for the replacement cohort). When compared with the more recent Cleveland Clinic numbers from 2019, their in-hospital mortality was reported at 8.3%, overall 10-year survival at 45.9%, and freedom from moderate to severe MR at 53%, when repaired predominantly using the classic Carpentier-Edwards ring.[21]

Our reassuring echocardiogram parameters and the absence of significant MR before patients' death does not

TABLE 5. Left ventricular ejection fraction (LVEF), LV end-systolic diameter (LVESD), and LV end-diastolic diameter (LVEDD)

	Preoperative		At 5 y		At 8 y	
	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
LVEF (%)	91	37.3 ± 14.6	43	43.4 ± 15.2	22	45 ± 15.2
LVESD (mm)	70	42.4 ± 10.7	34	40.8 ± 12.9	21	39.8 ± 11.8
LVEDD (mm)	91	54.9 ± 8.99	43	54.7 ± 12.7	22	52.5 ± 8.7

LVEF, Left ventricular ejection fraction; *LVESD*, LV end-systolic diameter; *LVEDD*, LV end-diastolic diameter.

appear to correlate with the persistently poor survival graph. Perhaps other variables need to be taken into consideration that may not relate directly to the repair's durability itself. Our article[2] from 2009 has eluded into the reality that IMR is often a single element amongst many determining the final clinical outcome of these patients and that remodeling often continues despite the surgical reconstruction of the MV.

Limitations

This was a single-center prospectively designed study, certainly not free from limitations. Patient selection was

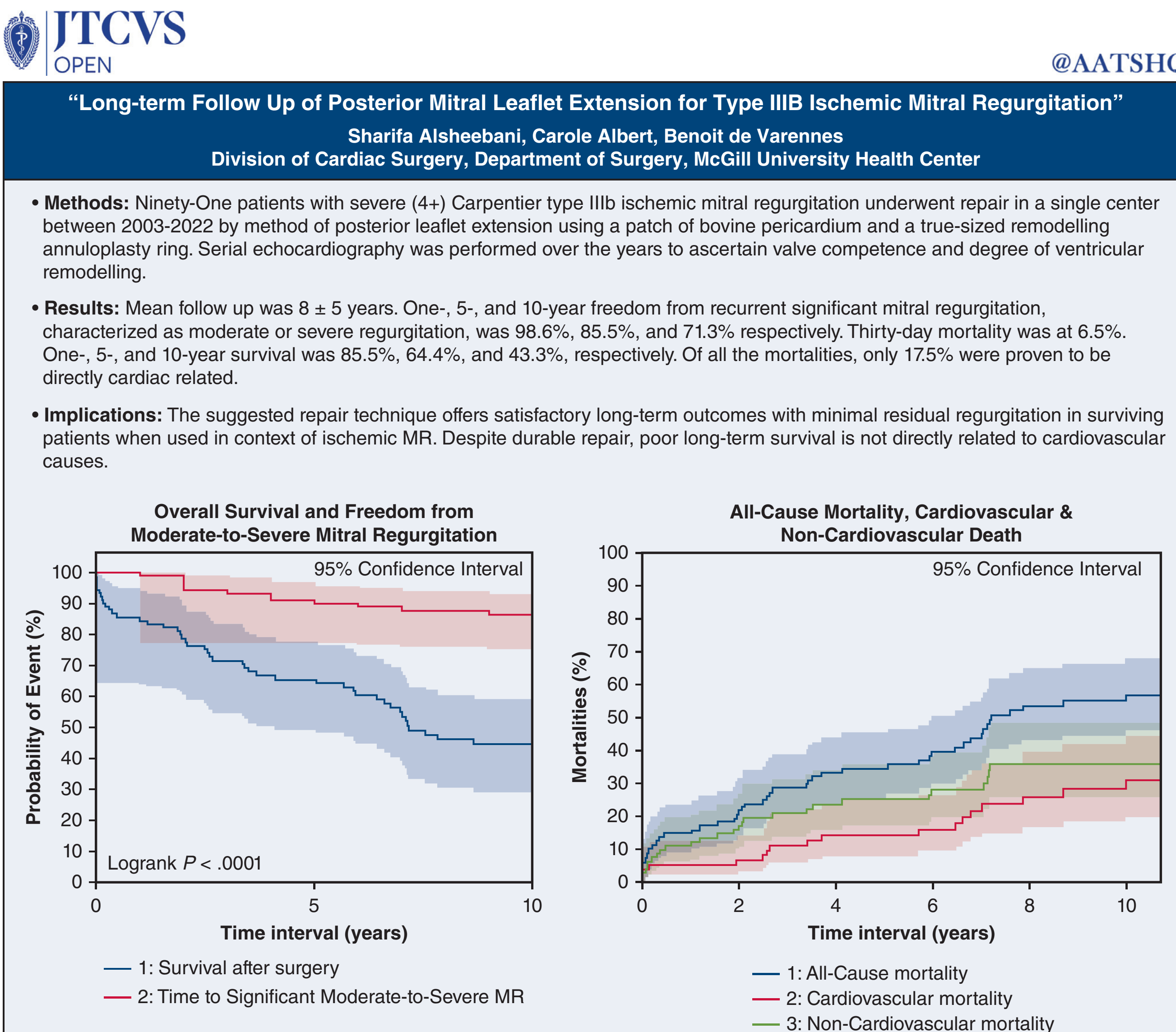


FIGURE 4. Graphical abstract. *MR*, Mitral regurgitation.

at the discretion of the surgeon with many of those repairs done on an emergency basis. Because some of the data obtained were from early 2000s, several patients were naturally lost to follow-up who could potentially be harboring severe MR. Official records with a clear primary cause of death of were not always available nor investigated, especially if the death occurred at home due to "natural" causes. And unsurprisingly, autopsy reports were few. Nonetheless, it is clear that even when combining the strictly cardiac causes with the unknown causes of mortality, more than two-thirds of all mortalities remain noncardiac. Regrettably, we do not have the measurements for the LV end-systolic volume index to provide a more accurate comparison. Much to our disappointment, the old record of echocardiographic images has made retrospective extraction of other relevant radiological parameters such as coaptation length, coaptation height, stroke volume, and many others not possible because the images obtained by the technician or cardiologist at the time were simply not aimed at the calculation of any of these parameters.

CONCLUSIONS

IMR will likely continue to frustrate surgeons with its suboptimal long-term survival, perhaps even more so knowing that mortality occurs despite durable valve repair. At present, it seems that MV repair by means of posterior leaflet augmentation offers satisfactory long-term functional outcomes with minimal residual regurgitation in surviving patients.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/long-term-follow-up-of-posterior-mitral-leaflet-extension-for-type-iiib-ischemic-mitral-regurgitation.

Conflict of Interest Statement

Dr de Varennes is a consultant for Edwards Lifesciences Inc, Canada. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling 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: ischemic mitral regurgitation, mitral repair, posterior leaflet augmentation

TABLE E1. Normality tests

Variable	Median	Interquartile range	*P* value*
Age at time of surgery (y)	70.00	14.00	.0158
Parsonnet score	38.00	18.00	.7025
Left ventricular end-diastolic diameter	53.00	14.00	.0005

*Shapiro-Wilk test.