Short-term outcomes of robotic left ventricular patch ventriculoplasty for significant mitral annular calcification

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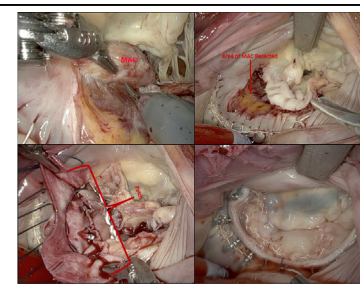
ABSTRACT

Objective: Surgical management of mitral annular calcification remains challenging. Our institution pursued a strategy of total mitral annular calcification resection with pericardial patch reconstruction of the left ventricle when primary atrioventricular groove closure was not possible. We present the short-term outcomes derived after implementing this strategy.

Methods: A single-institution retrospective analysis included patients with significant mitral annular calcification undergoing totally endoscopic robotic mitral valve surgery between October 2009 and August 2023. Mitral valve repair was performed in patients with sufficient posterior leaflet length. Patients requiring pericardial patch ventriculoplasty were compared with those in whom primary atrioventricular groove closure was possible (non–pericardial patch ventriculoplasty).

Results: Of 1441 patients who underwent totally endoscopic mitral valve surgery, 217 (15.1%) presented with significant mitral annular calcification. Pericardial patch ventriculoplasty was performed in 69 patients (31.8%). Patients undergoing non–pericardial patch ventriculoplasty were significantly younger than patients undergoing pericardial patch ventriculoplasty (63.4 vs 67.8 years, $P = .01$). Mitral valve repair was conducted in 145 patients (98.0%) in the non–pericardial patch ventriculoplasty group versus 56 patients (81.2%) in the pericardial patch ventriculoplasty group ($P < .01$). The median postoperative length of stay was significantly shorter in the non–pericardial patch ventriculoplasty group (3 vs 5 days, $P < .01$). There was no significant difference in postoperative stroke (0.7% vs 2.9%, $P = .50$) or 30-day mortality (1.4% vs 1.4%, $P = 1.00$). Three-year survival was comparable between the groups (97.4% vs 93.7%, $P = .52$).

Conclusions: Totally endoscopic robotic mitral valve repair is a safe and feasible technique for the management of mitral annular calcification with promising results at 3 years. Patients who required atrioventricular groove pericardial patch reconstruction had similar outcomes to those in whom primary closure was possible. (JTCVS Techniques 2024;27:81-90)



Intraoperative images of mitral repair in the setting of 3-segment MAC.

CENTRAL MESSAGE

Totally endoscopic robotic MV repair in patients with significant MAC offers favorable outcomes.

PERSPECTIVE

Totally endoscopic robotic MV repair is a safe and feasible technique for patients with significant MAC. Patients who required AVG reconstruction with PPV had similar outcomes to those in whom primary closure was possible.

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▶ Video clip is available online.

Mitral annular calcification (MAC) is a chronic degenerative process characterized by initial calcification of the mitral valve (MV) annulus.[1] The process of calcification can extend into leaflet tissues, papillary muscles (PMs), or the wall of the left atrium (LA) and left ventricle (LV). MAC is associated with presence of atherosclerosis risk factors, older age, and female gender according to autopsy and general population studies.[1,2] Although not all cases of MAC lead to MV

Abbreviations and Acronyms

AVG	= atrioventricular groove
LA	= left atrium
LV	= left ventricle
MAC	= mitral annular calcification
MV	= mitral valve
OR	= operating room
PM	= papillary muscle
PPV	= pericardial patch ventriculoplasty
STS	= Society of Thoracic Surgeons
TMVR	= transcatheter mitral valve replacement
TTE	= transthoracic echocardiography

dysfunction requiring intervention, the presence of MAC is associated with a higher risk of MV dysfunction compared with those without MAC.[3,4] Surgical intervention for MV disease in patients with significant MAC presents unique challenges, increased complexity, and heightened risks[5] due to the potential reconstruction of the atrioventricular groove (AVG) defect. It is imperative for cardiac surgeons to be well versed in the techniques and strategies for addressing MAC, because they will encounter more MAC cases in our rapidly aging population.

Our philosophical approach for MAC is total resection, allowing for a reparative rather than palliative procedure.[6] We previously reported our hospital outcomes using this doctrine after performing totally endoscopic robotic MV surgery in a limited number of patients with significant MAC.[7] Our current study aims to analyze the short-term outcomes of endoscopic robotic MV surgery approach for resected AVG MAC in patients with and without pericardial patch ventriculoplasty (PPV).

MATERIALS AND METHODS

Patient Population

Between October 2009 and August 2023, 1441 patients underwent totally endoscopic robotic MV surgery by a dedicated team. Among these patients, 217 (15.1%) were identified as having resection of MAC involving the AVG and are the subjects of this report (Figure 1). Patients with concomitant aortic disease were excluded. Patients were offered surgery in accordance with the current guidelines of the American College of Cardiology/American Heart Association.[8] Data collection for this study was performed prospectively with preoperative demographics, surgical techniques, and intraoperative and postoperative outcomes recorded via the electronic medical record. Long-term survival was captured by a commercial death index (Optum) that is incorporated into our electronic medical record. Approval for this retrospective study was obtained on January 27, 2023, from the NYU Langone Health Institutional Review Board with a waiver for patient consent (Study Number i23-00028). The median follow-up period was 3.9 years (interquartile range, 1.3-6.5).

Preoperative Evaluation

All patients underwent the following preoperative tests: (1) transthoracic echocardiography (TTE) to assess valvular diseases; (2) cardiac catheterization or computed tomography angiography to evaluate coronary artery disease and MAC; (3) intraoperative transesophageal echocardiography to evaluate valvular pathology, the extent of MAC, and the outcomes of valve repair/replacement; and (4) computed tomography angiography of the chest, abdomen, and pelvis to evaluate for peripheral cannulation, retrograde perfusion, and endoaortic clamping. More recently, MAC 3-dimensional reconstruction was obtained from computed tomography angiography. The choice of surgical technique was made at the time of the surgical inspection. However, these preoperative imaging studies aided in preoperative planning.

Definitions Used for Analysis of Lesions

The etiologies, functional classification, and analysis of lesions were obtained by a combination of preoperative imaging and visual inspection at the time of surgery. Carpentier[9]'s functional classification was used to describe the mechanism of MV disease. MAC distribution on the mitral annulus was defined by the frequency with which each segment hinge was involved with MAC. MAC extension beyond the annular zone was categorized in 3 groups: (1) extension to the LV wall; (2) extension to the leaflet tissue; and (3) extension to the PMs.

Operative Procedure

Our robotic MV surgery techniques have been described previously.[7] All robotic MV operations were performed by a dedicated team including 2 experienced MV surgeons using the da Vinci Surgical System (Intuitive Surgical Inc) through 5 right chest ports. The posterior leaflet was detached from MAC and the calcium bar was excised in its entirety en bloc using electrocautery in all patients. MAC dissection was initiated in the often present fibrous capsule between the calcium bar and the LA wall, with subsequent progression onto the LV wall, while maintaining the dissection plane as close to the calcium as possible. Low-power robotic electrocautery shears allowed for expeditious separation of this capsule as well as cutting (Video 1). In cases where limited AVG dissociation was present (no visible yellow epicardial tissue between the LA and LV edge) or (LA and LV edge separated by epicardial tissue over a distance of ≤1 cm), primary closure of AVG was carried out using mattress sutures on pledgets (2-0 Ethibond, Ethicon Inc) (Video 2). For more extensive AVG dissociation (LA and LV edge separated by epicardial tissue over a distance > 1 cm) and in cases when MAC resection extended down into the LV wall, AVG reconstruction was performed with a bovine pericardial patch as previously described. The patch was trimmed to an oval shape with major and minor axes 1 cm larger than MAC dimensions. The lower edge of the patch was affixed to the LV wall with individual horizontal mattress sutures on pledgets (2-0 Ethibond) (Video 3). Subsequently, the long axis of the oval patch was attached to the LA wall using horizontal mattress sutures (2-0 Ethibond) that would be used later for securing the annuloplasty band or a MV prosthesis. If MV repair was performed, the upper half of the patch would be reserved to reattach the base of posterior leaflet with a 4-0 Gore-Tex interlocking suture.

Statistical Analysis

Early outcome was defined as an outcome during the same admission or within 30 days of the index surgery, and late outcome was defined as an outcome after discharge from the hospital and more than 30 days after the index surgery. The primary end point was defined as all-cause death, and the secondary end point was defined as MV reintervention. Descriptive statistics for categorical variables are reported as frequency and percentages and compared using the Fisher exact test or chi-square test. Continuous variables were reported as mean and SD. Parametrically distributed variables were compared with the Student *t* test and nonparametrically distributed variables were compared using the Mann–Whitney *U* test. Survival analysis was performed by the Kaplan–Meier method. Log-rank test was carried out to compare survival between the groups. Kaplan–Meier curves were generated with death as a competing risk. Gray's test was performed to compare cumulative incidence of mitral reintervention between

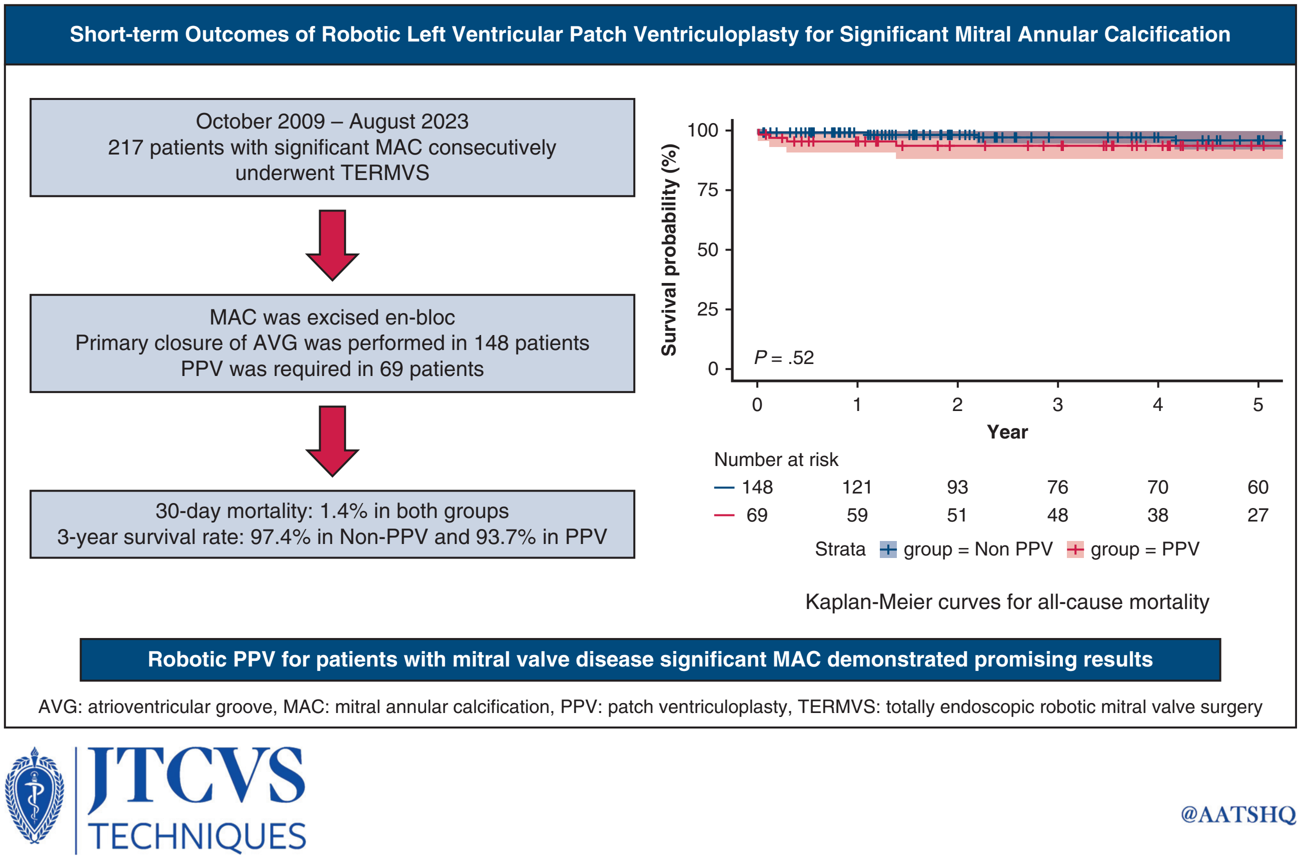


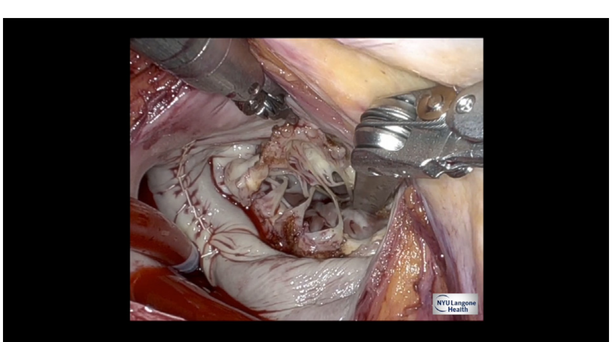
FIGURE 1. Graphical Abstract.

the groups. All statistical analyses were conducted using the SPSS (IBM) and R software (version 4.3.0, R Project; R Foundation for Statistical Computing) with the "survival," “survminer,” and “cmprsk” package.

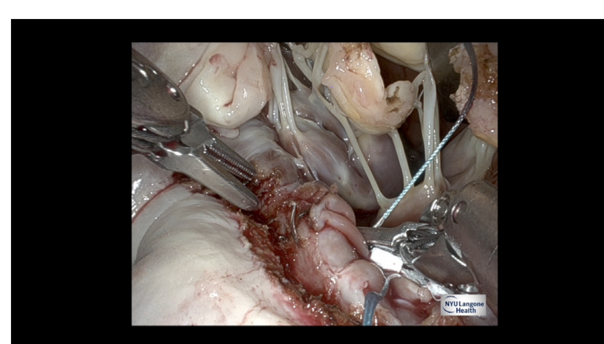
RESULTS

Preoperative Characteristics

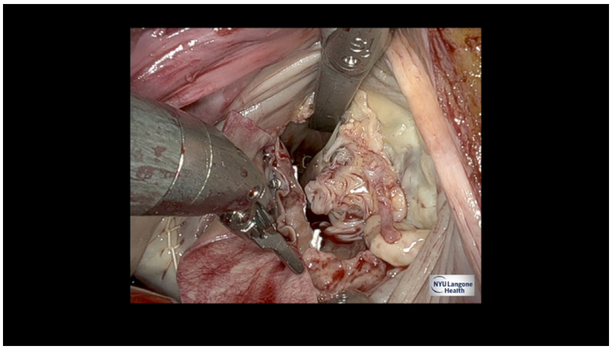
The preoperative characteristics of the 217 patients are presented in Table 1. The mean age was 64.8 ± 12.5 years, and 108 (49.8%) were male. Among the entire cohort, 23 (10.6%) patients were categorized as New York Heart Association Class III or higher. The mean left ventricular ejection fraction was 61.9% ± 6.7%. The non-PPV group accounted for 148 patients, and the PPV group accounted for 69 patients. Patients in the PPV group were significantly older, and patients in the non-PPV group were more often in recent congestive heart failure. However, there was no significant difference in the prevalence of preoperative comorbidities between the groups.



VIDEO 1. Robotic resection of MAC. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00265-7/fulltext.



VIDEO 2. Primary closure of aortic valve groover after MAC resection. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00265-7/fulltext.



VIDEO 3. Attachment of pericardial patch to residual LV myocardium after MAC resection. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00265-7/fulltext.

Physiopathology and Functional Classification

Table 2 demonstrates the pathophysiology and functional classifications of the groups. The majority of the cohort had primary mitral regurgitation, whereas only 4 patients had mixed MV disease. Type II MV dysfunction was more prevalent in the non-PPV group (95.3% vs 87.0%, $P = .047$). Conversely, patients in the PPV group demonstrated a higher prevalence of type I dysfunction (10.1% vs 2.7%, $P = .04$). Within the non-PPV group, 1 patient exhibited type IIIb dysfunction in the setting of nonischemic cardiomyopathy. Barlow's disease was more frequently observed in the non-PPV group (87.8% vs 76.8%, $P = .05$).

Mitral Annular Calcification Annular Distribution, Mitral Annular Calcification Annular and Extra-annular Extension

MAC annular distribution is illustrated in Figure 2. Among all patients, MAC involvement was most prevalent in the P2 segment, followed by P1 and P3. Table 2 provides the details of MAC annular and extra-annular extension. Patients in the non-PPV group exhibited a significantly lower average number of segments involved compared with the PPV group (1.5 ± 0.8 vs 2.5 ± 0.9 segments, $P < .01$). Regarding extra-annular extension, there was no significant difference in PM extension, but leaflet extension was more frequently observed in the PPV group (6.8% vs 17.4%, $P = .03$).

Intraoperative Outcomes

Comparison of intraoperative data between the groups is shown in Table 3. In each group, 3 patients were cannulated via the right axillary artery due to vasculature not amenable for retrograde perfusion. Intraoperative aortic dissection was seen in 1 patient in the non-PPV group, necessitating conversion to sternotomy. Conversion to sternotomy was required in 3 patients in the PPV group: 1 secondary to a pacing wire bleed, 1 secondary to persistent MR after a prolonged pump run, and 1 early in our experience (before 2016) due to the size of MAC and poor functioning of our instruments.

Both cardiopulmonary bypass times and aortic crossclamp times were significantly shorter in the non-PPV group compared with the PPV group. Extubation in the operating room (OR) occurred more frequently in the non-PPV group (68.9% vs 27.5%, $P < .01$). It is our preference to maintain adequate sedation overnight in patients receiving PPV, ensuring stable blood pressure control (systolic blood pressure <100 to 110 mm Hg) to limit excessive forces on the LV in the early postoperative period. If the hemodynamics remained stable and chest tube output was acceptable for more than 6 hours, the patients were weaned from mechanical ventilation with avoidance of high blood pressures. There were no intraoperative deaths.

Mitral Valve Repair Outcomes

Table 3 demonstrates outcomes of MV repair. MV repair was more frequently accomplished in the non-PPV group than in the PPV group (98.0% vs 81.2%, $P < .01$). More than 95% of the patients exhibited mild residual mitral regurgitation or less on postoperative TTE. However, in 1 patient receiving PPV, there was misjudgment of sufficient posterior leaflet resulting in postoperative severe MR necessitating early MV replacement. Mean transmitral pressure gradients were favorable in both groups (3.1 ± 1.2 mm Hg vs 3.2 ± 1.4 mm Hg, $P = .42$). Postoperative TTE before discharge demonstrated systolic anterior motion in 3 patients in the non-PPV group; however, systolic anterior motion was not hemodynamically significant and did not require reintervention. Two patients in the non-PPV group and 1 patient in the PPV group underwent early MV reinterventions ($P = 1.00$), 2 of which were catheter-based by way of the MitraClip. There were no incidences of postoperative ventricular rupture in either group.

Early Postoperative Outcomes

The early postoperative outcomes are detailed in Table 3. No patient required a return to the OR for bleeding from AVG. Although the length of stay in the intensive care unit did not differ, the length of hospital stay was significantly shorter in the non-PPV group (3 vs 5 days, $P = .01$). Postoperative atrial fibrillation was more often observed in the PPV group (5.4% vs 17.4%, $P = .01$); however, postoperative stroke rate and 30-day mortality rate did not differ significantly between the 2 groups. Of the 3 strokes that occurred, 2 of them were minor with no residual neurological deficits. The final patient experienced a stroke on postoperative day 1, although the patient died on postoperative day 3 after pulseless electrical activity arrest. Two other patients died within 30 days after the index surgery.

TABLE 1. Baseline characteristics

Characteristics	Overall (N = 217)	Non-PPV (N = 148)	PPV (N = 69)	*P* value
Age, y, mean ± SD	64.8 ± 12.5	63.4 ± 13.2	67.8 ± 10.1	*.01*
Male sex, n (%)	108 (49.8)	76 (51.4)	32 (46.4)	.59
NYHA class ≥ III, n (%)	23 (10.6)	15 (10.1)	8 (11.6)	.93
LVEF, %, mean ± SD	61.9 ± 6.7	61.8 ± 5.9	62.1 ± 8.3	.78
Atrial fibrillation, n (%)	64 (29.5)	44 (29.7)	20 (29.0)	1.00
Recent congestive heart failure, n (%)	23 (10.6)	21 (14.2)	2 (2.9)	*.02*
Hypertension, n (%)	72 (33.2)	47 (31.8)	25 (36.2)	.62
Obesity, n (%)	8 (3.7)	5 (3.4)	3 (4.3)	1.00
Diabetes mellitus, n (%)	10 (4.6)	6 (4.1)	4 (5.8)	.82
COPD, n (%)	9 (4.1)	6 (4.1)	3 (4.3)	1.00
Asthma, n (%)	19 (8.8)	13 (8.8)	6 (8.7)	1.00
Chronic kidney disease, n (%)	4 (1.8)	4 (2.7)	0 (0.0)	.40
Coronary artery disease, n (%)	34 (15.7)	20 (13.5)	14 (20.3)	.28
Peripheral arterial disease, n (%)	13 (6.0)	8 (5.4)	5 (7.2)	.82
Prior cardiac surgery, n (%)	2 (0.9)	2 (1.4)	0 (0.0)	.84
STS risk score, %, mean ± SD	1.1 ± 1.1	1.0 ± 1.2	1.2 ± 1.0	.35

The italic *P* values indicate the values are statistically significant. *PPV*, Pericardial patch ventriculoplasty; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *COPD*, chronic obstructive pulmonary disease; *STS*, Society of Thoracic Surgeons.

Late Postoperative Outcomes

Figure 3 shows Kaplan–Meier curves for the overall survival of both groups. There was no significant difference in the 3-year survival (97.4% vs 93.7%, $P = .52$). Figure 4 depicts cumulative incidence of mitral reintervention with death as a competing risk. Cumulative incidence rates were 2.7% in the non-PPV group and 7.7% in the PPV group at 3 years. Gray's test indicated no significant difference in occurrence of mitral reintervention between the groups ($P = .20$).

TABLE 2. Physiopathology and functional classifications

Characteristics	Overall (N = 217)	Non-PPV (N = 148)	PPV (N = 69)	*P* value
MV dysfunction, n (%)				.10
Primary mitral regurgitation	213 (98.2)	147 (99.3)	66 (95.7)	
Mixed MV disease	4 (1.8)	1 (0.7)	3 (4.3)	
Functional classification, n (%)				
I	11 (5.1)	4 (2.7)	7 (10.1)	*.04*
II	201 (92.6)	141 (95.3)	60 (87.0)	*.05*
IIIa	4 (1.8)	2 (1.4)	2 (2.9)	.59
IIIb	1 (0.5)	1 (0.7)	0 (0.0)	1.00
Barlow's disease, n (%)	183 (84.3)	130 (87.8)	53 (76.8)	*.05*
No. annular segments with MAC, n (%)				
1	96 (44.2)	87 (58.8)	9 (13.0)	*<.01*
2	73 (33.6)	46 (31.1)	27 (39.1)	.28
3	41 (18.9)	14 (9.5)	27 (39.1)	*<.01*
≥4	7 (3.2)	1 (0.7)	6 (8.7)	*<.01*
Number of segments involved, mean ± SD	1.8 ± 0.9	1.5 ± 0.8	2.5 ± 0.9	*<.01*
Ventricular extension, n (%)	69 (31.7)	0 (0)	69 (100)	*<.01*
PPM extension, n (%)	56 (25.8)	42 (28.4)	14 (20.3)	.27
Leaflet extension, n (%)	22 (10.1)	10 (6.8)	12 (17.4)	*.03*

The italic *P* values indicate the values are statistically significant. *PPV*, Pericardial patch ventriculoplasty; *MV*, mitral valve; *MAC*, mitral annular calcification; *PPM*, papillary muscle.

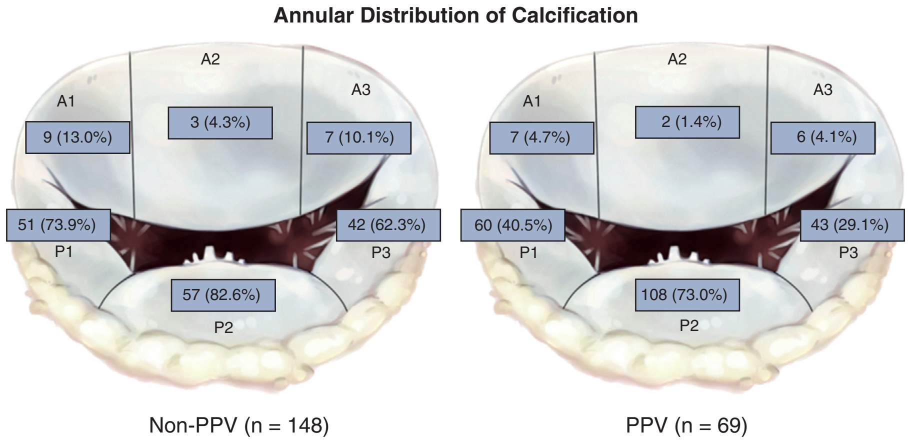


FIGURE 2. Annular distribution of calcification. *Left*: non-PPV (n = 148). *Right*: PPV (n = 69). P2 segment had the highest rate of calcification involvement in both groups. *PPV*, Pericardial patch ventriculoplasty.

DISCUSSION

This retrospective cohort study aimed to compare postoperative outcomes after robotic MV surgery in patients with significant MAC. Our results demonstrate that robotic MV surgery can be safely performed on patients with MAC extending to the AVG by reconstruction with or without a bovine PPV. Short-term mortality rate was only 1.4% in both groups, and no patient required a return to the OR for bleeding from the AVG. Although it is suggested that MAC is associated with increased postoperative mortality regardless of severity,[10] our study's short-term mortality rates were remarkably low. It is noteworthy that the Society of Thoracic Surgeons (STS) predicted risk of mortality does not explicitly account for the presence of MAC. The observed-to-expected ratio of short-term mortality was 1.4 in the non-PPV group and 1.2 in the PPV group.

In our study, approximately 15% of patients who underwent robotic MV surgery presented with MAC, which varied in its extension to the leaflet tissues, subvalvular apparatus, or the walls of the LA and the LV.[6] Although MAC extended into the LV in all of the PPV group (69 patients), it additionally extended to the PMs in 28.4% and 20.3%, and to the leaflet tissues in 6.8% and 17.4% in the non-PPV group and the PPV group, respectively. Overall, 98.2% of the patients had mitral regurgitation, with only 1.8% presenting with mixed valvular disease as the presenting pathophysiology. Although approximately 92.6% of the patients had type II dysfunction, MAC itself can cause valve dysfunction as well. MAC that does not extend to the leaflets can cause type I dysfunction without interfering with leaflet motion.

The presence of MAC makes MV surgery more challenging and can be associated with increased operative mortality and adverse events.[5,10] This is due to the inherent risk factors associated with MAC, necessity of MAC debridement, and reconstruction of the AVG. There is no consensus on a surgical approach for the MV dysfunction with MAC due to a lack of randomized trials. Therefore, individual risk factors and conditions should be considered when determining the indication and the surgical strategy. Surgical strategies for MAC lesions comprise 2 approaches. The first approach is to remove MAC completely (resect),[6,7,11] and the second is to preserve MAC in place (workaround/ignore).[12-14] Large studies comparing the 2 approaches do not exist. However, leaving a large bar of calcium can provide inconsistent results.[10] Placing sutures around MAC increases the risk of injury of the circumflex artery and disruption of AVG. Additionally, tying the suture around the calcium can cause fracture of the calcium bar resulting in embolism or drainage of a liquefied core. Finally, MAC that is left behind could only allow for undersized prosthetic implants. Our approach in this series demonstrated excellent postsurgical transvalvular gradients with large prosthesis sizes (Table 3). Last, rigidity and irregularity of the annulus caused by MAC elevate the risk of paravalvular leak or prosthetic dehiscence.

There is a growing interest of transcatheter mitral valve replacement (TMVR) for high-risk patients with MAC. However, short-term outcomes of TMVR are not favorable.[5,15,16] Guerrero and colleagues[15] reported 1-year outcomes of TMVR for MAC in patients with high STS scores of 15%. The study combined transseptal (40.5%), direct open transatrial (19.8%), and transapical (39.7%) approaches. Thirty-day mortality was notably high at 25%. Technical success was achieved in 76.7% of patients, and intraoperative complications included LV outflow tract obstruction (11.2%), valve embolization (4.3%), second valve requirement (14.7%) for valve migration or MR, and conversion to open surgery (3.4%). Transcatheter edge-to-edge mitral repair is another endovascular option; however, there is a paucity of data regarding outcomes for patients with MAC. One study indicated that open edge-to-edge MV repair without annuloplasty was associated with high reoperation rate in patients with MAC.[14]

TABLE 3. Operative characteristics and outcomes

Operative characteristics/outcomes	Overall (N = 217)	Non-PPV (N = 148)	PPV (N = 69)	*P* value
MV procedure, n (%)				*<.01*
Repair	201 (92.6)	145 (98.0)	56 (81.2)	
Replacement	16 (7.4)	3 (2.0)	13 (18.8)	
Annuloplasty size, mm, mean ± SD	34.8 (2.5)	34.7 (2.4)	35.1 (2.6)	.34
Cannulation, n (%)				.39
Axillary	6 (2.8)	3 (2.0)	3 (4.3)	
Femoral	211 (97.2)	145 (98.0)	66 (95.7)	
Tricuspid valve repair, n (%)	7 (3.2)	6 (4.1)	1 (1.4)	.55
Maze procedure, n (%)	32 (14.7)	23 (15.5)	9 (13.0)	.78
Left atrial appendage occlusion, n (%)	210 (96.8)	141 (95.3)	69 (100.0)	.15
Hybrid PCI, n (%)	6 (2.8)	3 (2.0)	3 (4.3)	.39
Sternotomy conversion, n (%)	4 (1.8)	1 (0.7)	3 (4.3)	.06
Cardiopulmonary bypass time, min, mean ± SD	199.8 ± 56.6	179.6 ± 44.8	242.9 ± 55.2	*<.01*
Aortic crossclamp time, min, mean ± SD	145.5 ± 47.9	128.6 ± 40.9	181.7 ± 41.3	*<.01*
OR extubation, n (%)	121 (55.8)	102 (68.9)	19 (27.5)	*<.01*
Length of ICU stay, h, median (IQR)	18 (14-32)	17 (13-22)	23 (17-53)	.48
Postoperative length of stay, d, median (IQR)	4 (1-38)	3 (1-38)	5 (2-27)	*.01*
Residual mitral regurgitation, n (%)				
None	113 (52.1)	79 (53.4)	34 (49.3)	.67
Trace	80 (36.9)	52 (35.1)	28 (40.6)	.45
Mild	14 (6.5)	9 (6.1)	5 (7.2)	.77
Mild to moderate	6 (2.8)	5 (3.4)	1 (1.4)	.67
Moderate	3 (1.4)	3 (2.0)	0 (0.0)	.55
Severe	1 (0.5)	0 (0.0)	1 (1.4)	.32
Postoperative pressure gradient, mm Hg, mean ± SD	3.1 ± 1.2	3.1 ± 1.2	3.2 ± 1.4	.42
Postoperative SAM, n (%)	3 (1.4)	3 (2.0)	0 (0.0)	.57
Left circumflex artery kink/occlusion, n (%)	2 (0.9)	2 (1.4)	0 (0.0)	.84
Postoperative atrial fibrillation, n (%)	20 (9.2)	8 (5.4)	12 (17.4)	*.01*
Postoperative stroke, n (%)	3 (1.4)	1 (0.7)	2 (2.9)	.50
Return to OR for AVG bleeding, n (%)	0 (0)	0 (0)	0 (0)	1.00
Early MV reintervention, n (%)	4 (1.8)	3 (2.0)	1 (1.4)	1.00
30-d mortality, n (%)	3 (1.4)	2 (1.4)	1 (1.4)	1.00

The italic *P* values indicate the values are statistically significant. *PPV*, Pericardial patch ventriculoplasty; *MV*, mitral valve; *PCI*, percutaneous coronary intervention; *OR*, operating room; *ICU*, intensive care unit; *IQR*, interquartile range; *SAM*, systolic anterior motion; *AVG*, atrioventricular groove.

Although there have been improvements in procedural techniques, current transcatheter approach should be reserved for the patients at high or prohibitive risk, and careful patient selection is of utmost importance. When comparing TMVR for patients with MAC and without MAC, TMVR for patients with MAC was associated with higher mortality, lower procedural success, higher rate of LV outflow obstruction, and higher rate of conversion to surgery.[5,17] Given these considerations, our preference is "resect rather than ignore," in which the calcium bar is completely removed as a single bar and the AVG is reconstructed. In many cases, calcium formation can be easily removed as a single bar if the sheath of MAC is well preserved.[6,18] En bloc removal of MAC can be done safely by experienced surgeons at high-volume centers.[7,10] Upon the completion of MAC removal, any aortic valve dissociation needs to be reconstructed. Various ways of reconstruction have been published, including pericardial patch reconstruction and reconstruction by approximating the LA wall and LV wall.[6,11,18]

Despite comparative postoperative outcomes between the groups, there were a few differences in intraoperative outcomes. First, MV repair was more frequently achieved in the non-PPV group. The PPV group had a larger extent of MAC with a higher average number of annular segments involved by MAC and more frequent extension of MAC to

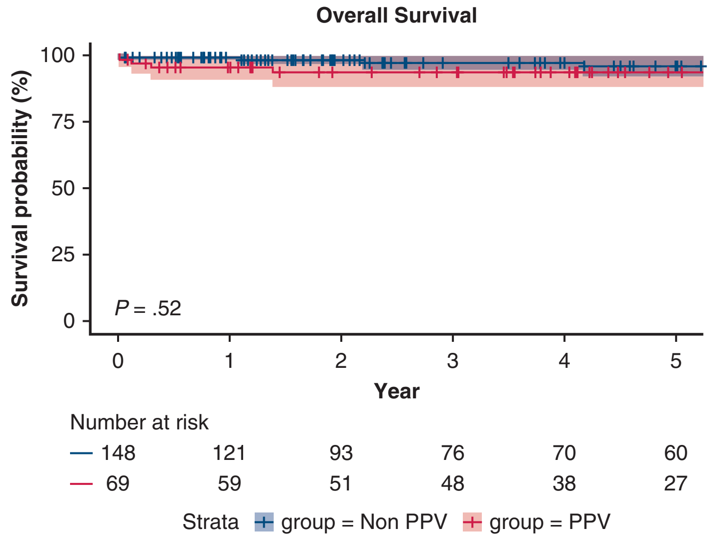


FIGURE 3. Kaplan–Meier curves for overall survival with 95% CIs. There was no significant difference in the 3-year survival between the groups (log-rank test, $P = .52$). *PPV*, Pericardial patch ventriculoplasty.

the leaflet tissues. Additionally, the non-PPV group was more frequently classified with type II functional class and had a higher prevalence of Barlow's disease compared with the PPV group. Barlow's disease is characterized by the presence of excess myxomatous or thickened tissues. Considering these factors, the feasibility of repair might be determined by extension of MAC and the amount of leaflet tissue available for valve reconstruction. Second, perioperative outcomes were more favorable in the non-PPV group with regard to cardiopulmonary bypass time, aortic crossclamp time, the rate of extubation in the OR, and the length of hospital stay, whereas length of intensive care unit stay tended to shorter in the non-PPV group without reaching the statistical significance. This may be due to the more time-consuming and complex procedures associated with AVG reconstruction with a bovine

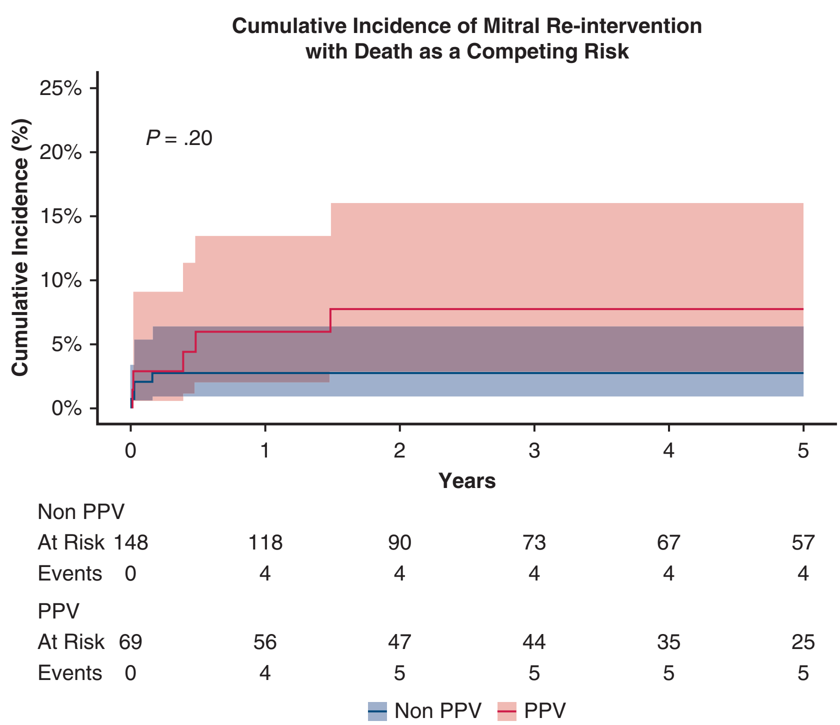


FIGURE 4. Cumulative incidence curves with 95% CIs of MV reintervention with death as a competing risk. There was no significant difference between the groups (Gray's test, $P = .20$). *PPV*, Pericardial patch ventriculoplasty.

pericardial patch. Longer cardiopulmonary bypass time and mechanical ventilation time might be associated with higher incidence of postoperative atrial fibrillation in the PPV group.[19,20] In contrast, by using minimally invasive robotic approach, optimal myocardial protection, and meticulous postoperative management by dedicated teams with experience, favorable postoperative outcomes were achieved even with 60 minutes longer aortic crossclamp time in the PPV group than in the non-PPV group.

This study also shed light on the late outcomes of robotic MV surgery in patients with MAC. The late outcomes of the surgery were favorable, with a survival of 97.4% and 93.7%, and a cumulative incidence rate of mitral reintervention in 2.7% and 7.7% of patients at 3 years in the non-PPV and PPV groups, respectively. These outcomes are comparable with other reports of MV surgery with MAC decalcification.[13,18,21-23] These data indicate the durability of MV surgery in this population and support the effectiveness of the surgical techniques used. These findings suggest that complete MAC resection with AVG reconstruction using robotics can be performed safely with favorable outcomes by experienced surgeons and high-volume centers. In contrast, a study using the STS Adult Cardiac Surgery Database showed that low MV procedure case volumes were associated with worse outcomes after MV replacement in MAC patients.[10]

Study Limitations

This is a single-center and retrospective observational study. Considering this is a study without randomization or matching, there is a risk of bias and confounding. All surgeries were conducted by the same surgical team, which may contribute to the favorable results due to their expertise. Although complete excision of MAC and MV procedures can be safely done with robotic approach, these procedures should be undertaken by a highly experienced surgical team in a high-volume center. The relatively short follow-up period, with approximately 65% of patients undergoing surgery within 5 years, highlights the necessity for further studies with long-term follow-up, because potential late complications, such as recurrent mitral regurgitation or thromboembolic events, could still occur.

CONCLUSIONS

Our robotic approach for MV surgery in patients with significant MAC demonstrated favorable results. The strategy of MAC resection and liberal patching yields excellent perioperative results with low mortality, high repair rates, low transprosthetic gradients, and excellent midterm survival. This study provides strong guidance for clinical practice in the management of patients with significant MAC undergoing MV surgery.

Conflict of Interest Statement

E.A.G. and D.F.L. are former proctors for Intuitive Surgical. 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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