Double-layer horizontal cross sutures for intra-atrial mitral valve implantation: An effective surgical method for severe mitral annular calcification

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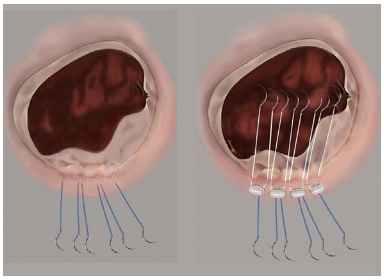
ABSTRACT

Objective: Severe mitral annular calcification (MAC) can make prosthetic implantation extremely difficult. Although intra-atrial mitral valve prosthesis implantation without annular decalcification offers a simpler approach, it poses a potential rupture risk due to high left ventricular pressure. We developed a double-layer (DL) horizontal cross-suture technique, which ensures close proximity of the valve prosthesis to the calcified annulus and segregates the left atrial wall from the left ventricle. The aim of this study was to compare the outcomes of DL suture with conventional single-layer (SL) suture in patients with severe MAC.

Methods: This retrospective cohort study consecutively enrolled patients with severe MAC undergoing mitral valve replacement at Beijing Anzhen Hospital from May 2018 to December 2022. A detailed description of the DL suture method is described. Follow-up medical evaluations, including transthoracic echocardiography measurements, were obtained through outpatient chart reviews.

Results: The study included 10 patients in the DL suture group and 20 in the SL suture group. All patients in the DL group and all but 3 in the SL group achieved technical success. Compared with the SL group, the DL suture technique was associated with lower rates of perivalvular leakage, stroke, new-onset atrial fibrillation, reoperation, and 30-day mortality. Follow-up was complete, with 1 late mortality in the DL group due to stroke and 4 cardiovascular deaths in the SL group.

Conclusions: The DL horizontal cross-suture technique offers a more effective and safer approach for intra-atrial mitral valve implantation in severe MAC cases than the conventional SL suture method. (JTCVS Techniques 2023;22:28-38)



Mitral valve replacement in severe mitral annular calcification.

CENTRAL MESSAGE

We developed a double-layer horizontal cross-suture technique for severe MAC during MVR. Double-layer provides a greater rate of successful repair and a lower rate of PVL compared with single-layer.

PERSPECTIVE

The double-layer horizontal cross-suture technique is an effective and safe solution for intra-atrial mitral valve implantation in severe MAC cases, offering a promising alternative to traditional methods. This innovative suture technique may also be applied in cases with left ventricular outflow tract stenosis, potentially revolutionizing the treatment of severe MAC and improving patient outcomes.

Video clip is available online.

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Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
DL	= double-layer
LVOT	= left ventricular outflow tract
MAC	= mitral annular calcification
MVR	= mitral valve replacement
MVS	= mitral valve surgery
PVL	= perivalvular leakage
SL	= single-layer
TMVR	= transcatheter mitral valve replacement
TEE	= transesophageal echocardiography
TTE	= transthoracic echocardiography
ViMAC	= transcatheter valve in mitral annular calcification

Severe mitral annular calcification (MAC) presents significant challenges during mitral valve surgery (MVS), leading to increased mortality and adverse cardiovascular events.[1,2] Over the past 40 years, various surgical procedures have been developed to address MAC.[3] These methods largely fall into 2 categories: "resect" or "respect" strategies, which are determined by the handling of the calcified annulus.[4,5] The "resect" strategy involves annular decalcification followed by annular reconstruction, whereas the "respect" strategy avoids extensive annular dissections.

In 1994, Nataf and colleagues[6] introduced a technique for inserting a mitral prosthesis into the left atrium without decalcifying the mitral annulus. Due to its simplicity and potential for reduced crossclamp and cardiopulmonary bypass (CPB) time, this method gained widespread endorsement. Nonetheless, despite advancements and modifications in intra-atrial insertion techniques over the last 2 decades, persistent challenges remain. These include the potential for left atrial aneurysm development, uncontrolled pinhole bleeding from the left atrial wall, and difficulties suturing a weak left atrial wall.[7]

In patients at high surgical risk, surgical transcatheter valve in mitral annular calcification (ViMAC) and transcatheter mitral valve replacement (TMVR) offer a less-invasive alternative.[8,9] The SAPIEN 3 (Edwards Lifesciences) is the only transcatheter heart valve commercially available for compassionate ViMAC in patients with previous mitral surgical rings and MAC.[10] Despite this, the outcomes reported have been inconsistent, often poor[10]; thus, surgical intervention continues to be the primary recommendation for the majority of patients with MAC.

Over the past 5 years, Beijing Anzhen Hospital has treated 32 patients with severe MAC by implanting a mitral valve prosthesis in the left atrium. To reduce the associated risks, we have developed a double-layer (DL), horizontal cross-suture method. This technique enables the implantation of the prosthesis into the left atrium, circumventing the necessity for mitral annulus decalcification. The objective of this study is to evaluate and compare the safety and efficacy of this innovative approach with the conventional single-layer (SL) suture technique in the management of patients with severe MAC.

METHODS

Study Design and Patients

This retrospective cohort study consecutively enrolled patients undergoing mitral valve replacement (MVR) in Beijing Anzhen Hospital from May 2018 to December 2022. Patients were included in the study if they had severe mitral regurgitation, mitral stenosis, or mixed mitral valve disease with severe MAC. Patients with severe left ventricular dysfunction (ejection fraction <30%) and severe uremia were excluded. A flow chart of the patients who were included and excluded is presented in Figure 1.

All patients underwent transthoracic echocardiography (TTE) and contrast-enhanced cardiac computed tomography to determine the severity of mitral valve disease before surgery. Postoperative TTE was performed to document prosthetic valve function, ascertain mean mitral valve pressure gradients, and evaluate the morphology of the prosthetic valve. Severe mitral regurgitation and mitral stenosis was defined using current guidelines of echocardiography criteria.[11] Severe MAC was defined as the calcification process involved at least one-third of the posterior annulus measured on cardiac computed tomography imaging (Figure 2). The informed consent to undergo MVR surgery was obtained from all patients. This study complies with the Declaration of Helsinki. The study was approved by the Ethics Committee of Beijing Anzhen Hospital, Capital Medical University, and the requirement for informed consent was waived due to the retrospective study design and use of deidentified patient data.

Surgical Technique

Under general anesthesia, a transesophageal echocardiography (TEE) probe was inserted orally. CPB was established via direct cannulation of the vena cava and ascending aorta following a median sternotomy. After pericardial opening, the mitral valve was exposed through a transseptal or interatrial groove approach. The extent of calcification in the mitral annulus, valves, and subvalvular structures, including chordae tendineae, papillary muscles, left ventricular wall, and aortomitral curtain, was assessed. While preserving the posterior leaflet and its attached chordae as much as possible, the anterior mitral leaflet was detached from the anterior annulus. In cases with leaflet calcification, the calcified leaflets were carefully debrided and trimmed to minimize the impact on prosthetic valve implantation.

Depending on calcification extension, the mitral valve prosthesis was partially or completely implanted in the left atrium. To secure the prosthesis, we introduced our newly developed DL horizontal cross suture technique (Video 1). This innovative method stands as an improvement on the conventional SL approach typically employed by other surgical teams.

Our DL horizontal cross suture is performed on the calcified portion of the mitral annulus, involving 2 steps. We first place horizontal mattress sutures without pledgets 2 mm laterally from the calcified annulus in the left atrial wall. Each suture width is 8 to 10 mm, with 1 to 2 mm of spacing between adjacent sutures. Second, pledgeted mattress sutures are positioned on both sides of the first suture layer's midline to overlap the interval between them. The needle is inserted 2 mm above the first suture layer, moves vertically downward to the calcified annulus, and exits through the atrial wall near the calcium bar. At the calcified segment endpoint, one end of a double-armed pledgeted suture is placed similarly, whereas the other end passes through the annulus from the atrial to ventricular aspect. In the normal annulus segment, conventional interrupted sutures are performed. After suturing through the sewing band, the prosthetic valve is

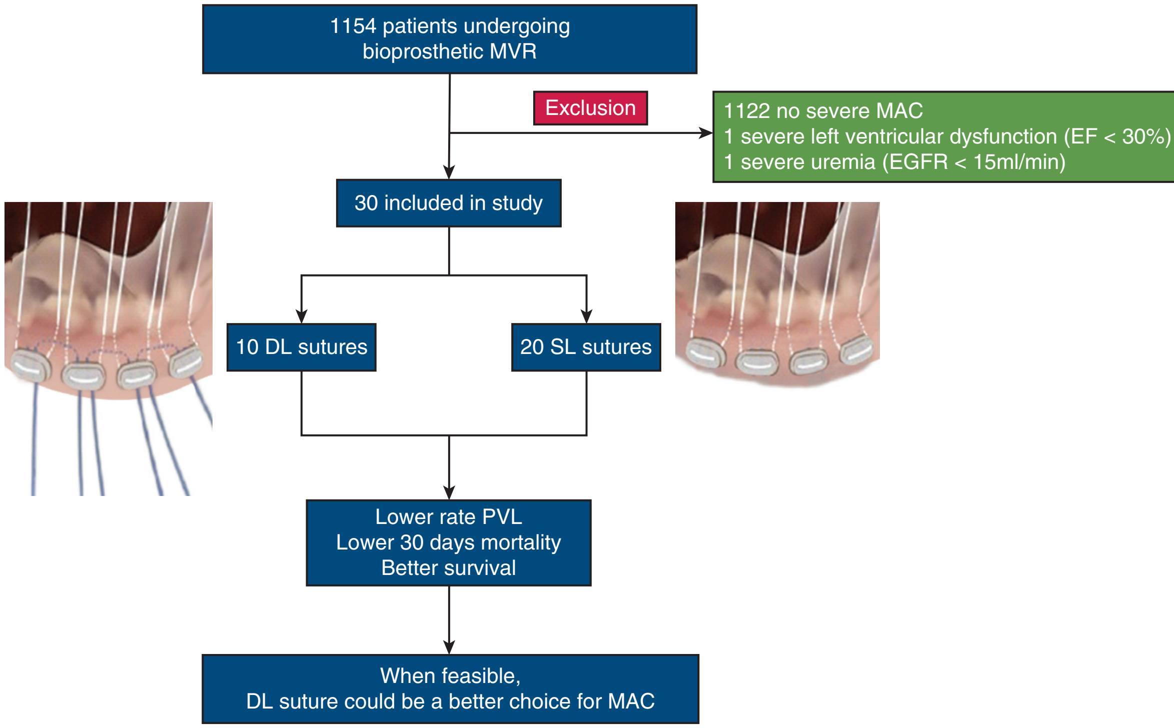


FIGURE 1. Study design: summary of inclusion and exclusion criteria. *MVR*, Mitral valve replacement; *MAC*, mitral annular calcification; *EF*, ejection fraction; *EGFR*, estimated glomerular filtration rate; *DL*, double layer; *SL*, single layer; *PVL*, perivalvular leakage.

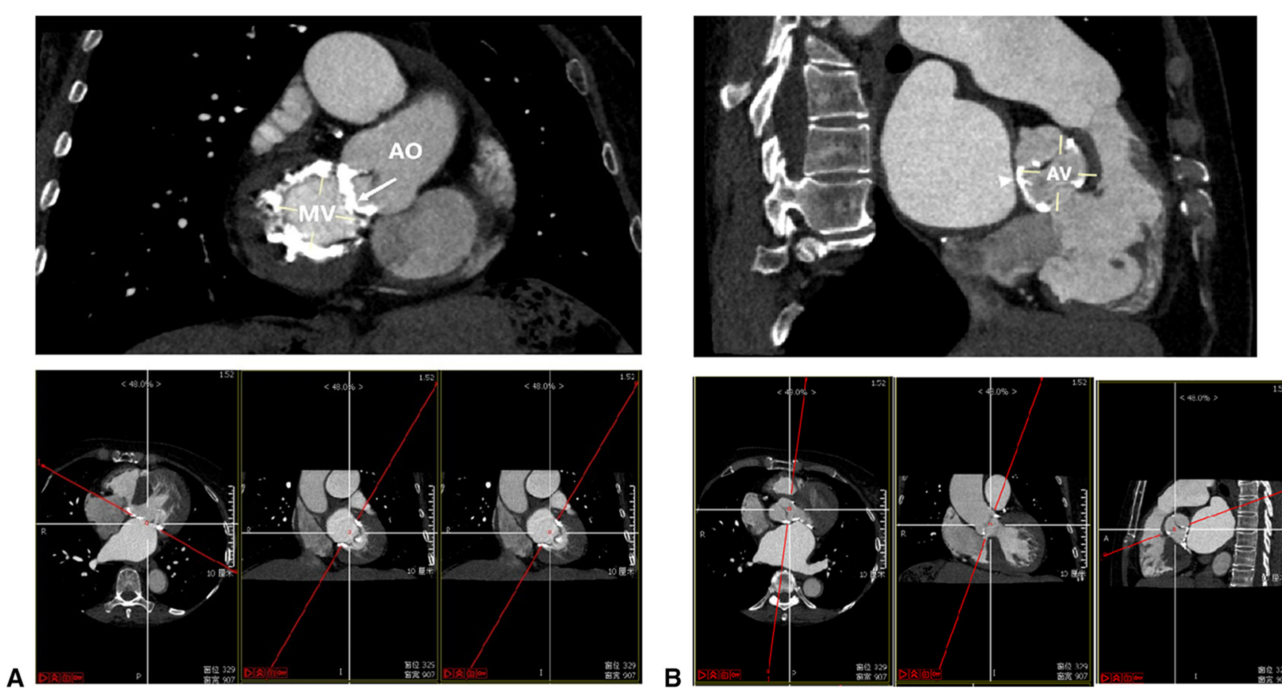


FIGURE 2. Representative patterns of severe MAC in patients with symptomatic MR. Images from gated, contrast-enhanced cardiac computed tomography are shown. A, Severe mitral annular calcification. B, Severe aortic annular calcification. Mitral annulus complete calcification often coexists with aortic annular calcification. *AO*, Aorta; *MV*, mitral valve; *AV*, aortic valve.

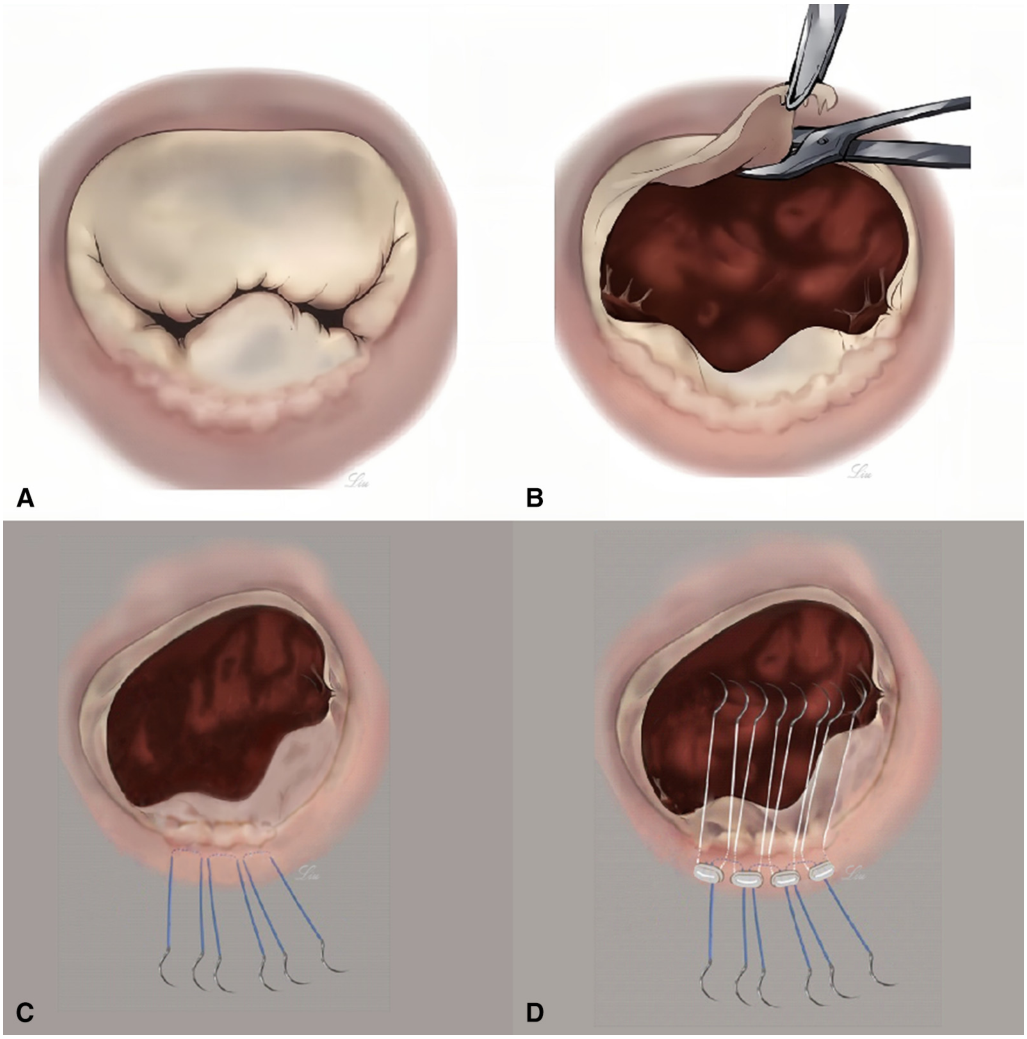


FIGURE 3. Surgical procedures for partial mitral annular calcification. A, Mitral valve with severe partial annular calcification. B, The anterior leaflet is resected, and the posterior leaflet and its attached chordae are preserved. C, Double-layer horizontal cross suture is performed in the calcified part of the mitral annulus, which can be divided into 2 steps. First, horizontal mattress sutures are placed in the left atrial wall approximately 2 mm lateral to the calcified annulus. D, Next, pledgeted mattress sutures are placed on each side of the midline of the first layer of suture to overlap the interval between them.

lowered into position (Figure 3). For posterior MAC cases, a similar technique is demonstrated in Figure E1.

For the SL suture technique, the first step is omitted, and the technique begins with the second suture. Place pledgeted mattress sutures on both sides of the suture layer's midline to overlap the interval between them and then follow the procedure as outlined for the DL method.

In 1 case, a patient with entire mitral annulus calcification combined with aortic annular calcification and significantly calcified aortomitral curtain presented with an exceedingly small mitral and aortic annulus. Initially, the aortic annulus and aortomitral curtain calcification were removed first using a previously reported fibrosa layer stripping technique (Figure E2).[12] Following this, a transverse incision in the aorta, extending into the anterior mitral leaflet, was made according to the method of Manouguian.[13] This procedure was succeeded by aortomitral curtain extension using a Dacron patch, widening the mitral and aortic annulus to prevent patient–prosthesis mismatch.

Follow-up

In-hospital and postdischarge adverse events were prospectively recorded. Follow-up medical evaluations, including TTE measurements, were obtained through outpatient chart reviews. No patients were lost to follow-up, ensuring 100% complete records.

Statistical Analysis

Normally distributed continuous variables were expressed as mean ± standard deviation and compared using the t test. Non-normally distributed continuous data were summarized as median [interquartile range] and compared using the Wilcox rank-sum test. Categorical variables were expressed as number (n) and percentage (%) and were compared using the Fisher exact test. The Kaplan–Meier method was used for survival analysis. All statistical analyses were performed using R 4.2.2 (R Project for Statistical Computing) and Stata/MP 17.0 (StataCorp).

TABLE 1. Baseline characteristics

Variable	Double-layer suture	Single-layer suture	*P* value
No.	10	20	
Preoperative characteristics			
Age, y	68.50 ± 7.32	67.05 ± 5.85	.561
Male sex, n (%)	4 (40)	7 (35)	1.000
Hypertension, n (%)	5 (50)	9 (45)	1.000
Diabetes mellitus, n (%)	2 (20)	5 (25)	1.000
Hyperlipidemia, n (%)	0	4 (20)	.342
Severe renal insufficiency, n (%)	0	2 (10)	.796
Smoker, n (%)	1 (10)	5 (25)	.628
Comorbidities			
TR, n (%)	6 (60)	12 (60)	1.000
AF, n (%)	6 (60)	12 (60)	1.000
AR, n (%)	6 (60)	4 (20)	.075
NYHA III or IV, n (%)	9 (90)	15 (75)	.623
CAD, n (%)	2 (20.00)	9 (45.00)	.348
EuroSCOREII, n (%)	5.1 ± 2.9	4.1 ± 2.3	.293
Previous stroke, n (%)	2 (20)	3 (15)	1.000
Previous PCI, n (%)	1 (10)	0	.719
Previous cardiac surgery, n (%)	1 (10)	1 (5)	1.000
Echocardiogram			
Left atrial diameter, mm	64.4 ± 7.2	64.3 ± 11.3	.970
LVEDD, mm	32.1 ± 6.7	30.1 ± 4.4	.321
LVEF, %	54.4 ± 7.7	60.0 ± 7.3	.065
Preoperative MAC grade, n (%)			.392
More than one-third of the posterior annulus	5 (50)	15 (75)	
Entire posterior annulus	4 (40)	4 (20)	
Entire mitral annulus	1 (10)	1 (5)	

TR, Tricuspid regurgitation; *AF*, atrial fibrillation; *AR*, aortic regurgitation; *NYHA*, New York Heart Association; *CAD*, coronary artery disease; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation; *PCI*, percutaneous coronary intervention; *LVEDD*, left ventricular end-diastolic dimension; *LVEF*, left ventricular ejection fraction; *MAC*, mitral annular calcification.

RESULTS

Study Patients

Of 1154 patients who underwent bioprosthetic MVR surgery at our institution, 30 met the inclusion criteria for this study (Figure 1). The DL suture and SL suture groups consisted of 10 and 20 patients, respectively. There were no significant differences in demographics and comorbidities between the DL and SL groups. All patients were treated electively. Patients in the DL group exhibited more severe symptoms (New York Heart Association class III or greater: 9 [90%] vs 15 [75%], $P = .623$) and common morbidities (European System for Cardiac Operative Risk Evaluation II: 5.1 ± 2.9 vs 4.1 ± 2.3, $P = .293$) than patients in the SL group. The severity of MAC in the DL group was greater than in the SL group: calcification involved at least one-third of the posterior annulus in 5 (50%) versus 15 patients (75%), the entire posterior annulus in 4 (40%) versus 4 patients (20%), and the entire mitral annulus in 1 (10%) versus 1 patient (5%). Baseline cardiovascular risk factors and echocardiographic data are presented in Table 1.

Procedure and 30-Day Outcomes

Technical success was achieved in all patients in the DL group but not in 3 patients in the SL group. Bioprosthetic valves were used for all patients. Two 30-day mortalities occurred in the SL group (1 cardiac arrest, 1 major stroke). Three perivalvular leakages (PVLs) occurred in the SL group (2 significant, resulting in 30-day mortalities). A mean mitral valve pressure gradient ≥10 mm Hg was observed in 3 patients from the SL group but none in the DL group. The DL suture technique resulted in a lower rate of PVL (0 vs 3, $P = .519$), stroke (0 vs 3, $P = .519$), new-onset atrial fibrillation (0 vs 3, $P = .519$), reoperation (0 vs 1, $P = 1.000$), and 30-day mortality (0 vs 2, $P = .519$) compared with the SL group. Patients in the DL group had significantly shorter postoperative hospital stays (6.30 ± 1.57 vs 9.95 ± 4.77, $P = .027$). Surgical procedures and 30-day outcomes are shown in Table 2.

Follow-up

No patients were lost to follow-up. The mean follow-up was 40.00 ± 17.81 months in the DL group and

TABLE 2. Procedure and 30-day outcomes

Variable	DL, n = 10	SL, n = 20	*P* value
Surgery time, h	5.0 ± 1.1	5.3 ± 1.6	.661
Concomitant surgery			
AVR, n (%)	6 (60)	3 (15)	
CABG, n (%)	1 (10)	4 (20)	.862
TVP, n (%)	6 (60)	14 (70)	.891
Maze IV, n (%)	3 (30)	12 (60)	.245
Size of mitral prosthesis	27 [27,27]	27 [25,27]	.3020
Aortic crossclamp time, min	131.7 ± 38.0	107.0 ± 38.1	.104
Cardiopulmonary bypass time, min	169.7 ± 44.5	156.0 ± 66.0	.560
Mechanical ventilation time, h	20.8 [15.5, 22.0]	21.5 [17.5, 22.25]	.612
MVPG	3 (2, 4)	5 (3, 7.5)	.108
Reoperation, %	0	1 (5.00)	1.000
ICU stay, h	21.5 [16, 23]	22 [18.5, 23.5]	.580
Hospital stay, d	6.3 ± 1.6	9.95 ± 4.77	.027
30 days-mortality, n (%)	0	2 (10.00)	.796
Stroke, n (%)	0	3 (15.00)	.519
Pulmonary infection, n (%)	2 (20.00)	4 (20.00)	1.000
Acute kidney failure, n (%)	0	1 (5.00)	1.000
PVL, n (%)	0	3 (15.00)	.519
New-onset AF, n (%)	0	3 (15.00)	.519

DL, Double layer; *SL*, single layer; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *TVP*, tricuspid valvuloplasty; *MVPG*, mitral valve pressure gradient; *ICU*, intensive care unit; *PVL*, perivalvular leakage; *AF*, atrial fibrillation.

26.07 ± 15.82 months in the SL group. One late mortality occurred in the DL group, due to stroke without evidence of mitral valve prosthesis abnormality after 46 months. Four mortalities occurred in the SL group, all of which were cardiovascular deaths. Mortalities are shown in Figure E3. Technical success was stable in all (100%) patients in the DL and 14 (70%) patients in the SL group, *P* = .146. Subjective assessment of the mitral valve prosthesis revealed no signs of abnormalities in the DL group. All cases in the DL group were free from left atrial aneurysm and left ventricular outflow tract (LVOT) obstruction. Table 3 presents postoperative events during follow-up.

DISCUSSION

In this single-center retrospective study, we compared the clinical outcomes of patients with severe MAC who underwent MVR surgeries using either a DL horizontal cross-suture technique or a SL technique. The DL method preserves the calcified annulus and fixes the mitral bioprosthesis to the left atrial wall adjacent to the calcified annulus. To our knowledge, this is the first report that describes this new DL technique and evaluates its safety and effectiveness in comparison to the SL technique for patients with severe MAC during MVR.

TABLE 3. Clinical events in follow-up

Variable	DL, n = 10	SL, n = 20	*P* value
Any mortality, n (%)	1 (10)	4 (20)	.862
Cardiovascular mortality, n (%)	0	4 (20)	.342
Myocardial infarction, n (%)	0	1 (5)	.324
Stroke or TIA, n (%)	1 (10)	3 (15)	1.000
Rehospitalization, n (%)	2 (20)	3 (15)	1.000
AF, n (%)	6 (60)	7 (35)	.362
PVL, n (%)	0	6 (30)	.146
BARC 2, 3, or 5 bleeding, n (%)	0	1 (5)	1.000

DL, Double layer; *SL*, single layer; *TIA*, transient ischemic attack; *AF*, atrial fibrillation; *PVL*, perivalvular leakage; *BARC*, Bleeding Academic Research Consortium.

MAC, first described by Bonninger and colleagues in 1908, is an age-related degenerative process that occurs in up to 40% of septuagenarians, with a greater incidence in female patients.[1] Histologically, the posterior mitral annulus is more susceptible to damage in the systolic phase, leading to calcium and phosphorus deposition.[14,15] Echocardiogram data showed that most patients with MAC have dotted or focal calcification, typically not affecting mitral function. However, MVS remains a challenge in the presence of severe MAC.

Carpentier and colleagues[16] and David and colleagues[17] developed a surgical procedure that involved removing the calcified annulus and reconstructing the atrioventricular connection before mitral valve repair or replacement. However, this approach is intricate and necessitates considerable technical expertise. As patients with MAC often have other cardiac abnormalities, concomitant multiple cardiac surgical procedures are common, highlighting the need for simplified surgical management of MAC.

Nataf and colleagues[6] proposed an alternative strategy in which the circumference of the sewing ring of the prosthetic valve was expanded by a Dacron collar to enable implantation in the left atrium. This method significantly simplified the surgery, precipitating a series of modified intra-atrial insertion technologies. Despite the advantages of these "respect" strategies, life-threatening events such as left atrial aneurysm formation or uncontrolled pinhole bleeding are not uncommon.

In recent years, there has been an increasing interest in surgical ViMAC and TMVR for high-risk patients, particularly with the use of devices like the SAPIEN 3.[8,9] For those facing significant or prohibitive surgical risk, yet with suitable anatomy, TMVR presents as a promising option.[18] For surgical candidates diagnosed with severe MAC, the transatrial method marries the flexibility of standard surgical MVR with the simplicity of percutaneous TMVR, potentially presenting a more effective solution than each strategy independently.[18] However, both surgical and transcatheter ViMAC procedures are confronted with notable 30-day mortality rates, despite their inherent advantages.[19] To address these limitations, we developed a new intra-atrial insertion technology based on a better understanding of the pathologic and anatomical characteristics underlying MAC over the past 5 years.

Initially, we used SL interrupted sutures with cotton mattress stitches to fix the prosthetic valve to the left atrial wall near the calcified mitral annulus. This approach allowed the soft left atrial tissue to fill the gap between the prosthetic sewing ring and the calcified annulus, tightening the prosthesis to the calcified annulus and preventing the impact of high left ventricular pressure on the left atrial wall below the sewing ring. This also helped avoid the formation of a left atrial aneurysm. However, we observed a relatively high rate of paravalvular leakage (30% in SL group), likely due to the nonplanar shape and rigidity of the calcified mitral annulus, which made a close adherence of the prosthetic ring challenging.

To address this issue, we improved the technique by designing a DL suture method. The first layer of sutures consists of interrupted nonpledget mattress sutures, placed horizontally above the calcified annulus and parallel to it, fixing the prosthetic valve in place. The second layer is made up of interrupted pledget mattress sutures, placed vertically on each side of the midline of the first layer to overlap the interval between them. This layer prevents bleeding from pinhole injury caused by the first suture layer and allows the prosthetic ring to adhere snugly to the calcified annulus. In our study, we observed no complications such as paravalvular leakage, annulus dehiscence, left atrial wall pinhole hemorrhage, left atrial wall tear, or left atrial aneurysm formation, demonstrating the superior safety and effectiveness of this new method. Moreover, the DL horizontal cross-suture technique significantly reduces crossclamp and CPB time compared with the "resect" strategy, which is crucial for minimizing perioperative mortality and morbidity.[20-22]

As previously mentioned, MAC frequently coexists with aortic valve calcification, sharing similar risk factors.[23] Extension and convergence of calcifications on the aortic valve and posterior mitral annuli towards the aortomitral curtain may cause whole MAC and a small aortic annulus. Restricted motion of the anterior mitral valve leaflets and loss of annulus contraction are the primary mechanisms of mitral stenosis.[23,24] Thus, aortic and mitral double annulus enlargement with fibrous skeleton reconstruction is recommended for these patients to avoid severe PPM.[25-27] However, this procedure is extremely complicated and challenging in MAC patients. The DL horizontal cross-suture approach can significantly simplify such complex surgical procedures and improve the safety and efficacy of the treatment, as demonstrated by the optimal outcome of 1 patient with entire MAC in our study. We completely removed the calcified tissue on the aortic annulus and the aortomitral fibrous curtain, then widened the aortomitral fibrous curtain with a Dacron patch according to the Manouguian technique. We followed this by using the DL horizontal cross-suture method to sew the mitral bioprosthesis on the patch and the left atrial wall. In this case, the aortic crossclamp time was 190 minutes, the CPB time was 231 minutes, and intraoperative TEE detected no PPM or PVL.

To prevent the retained calcified mitral valve annulus and subvalvular tissue from restricting the motion of mechanical valve leaflets, we used bioprosthetic valves for all patients. A notable complication of mitral bioprosthesis implantation is secondary obstruction of the LVOT,

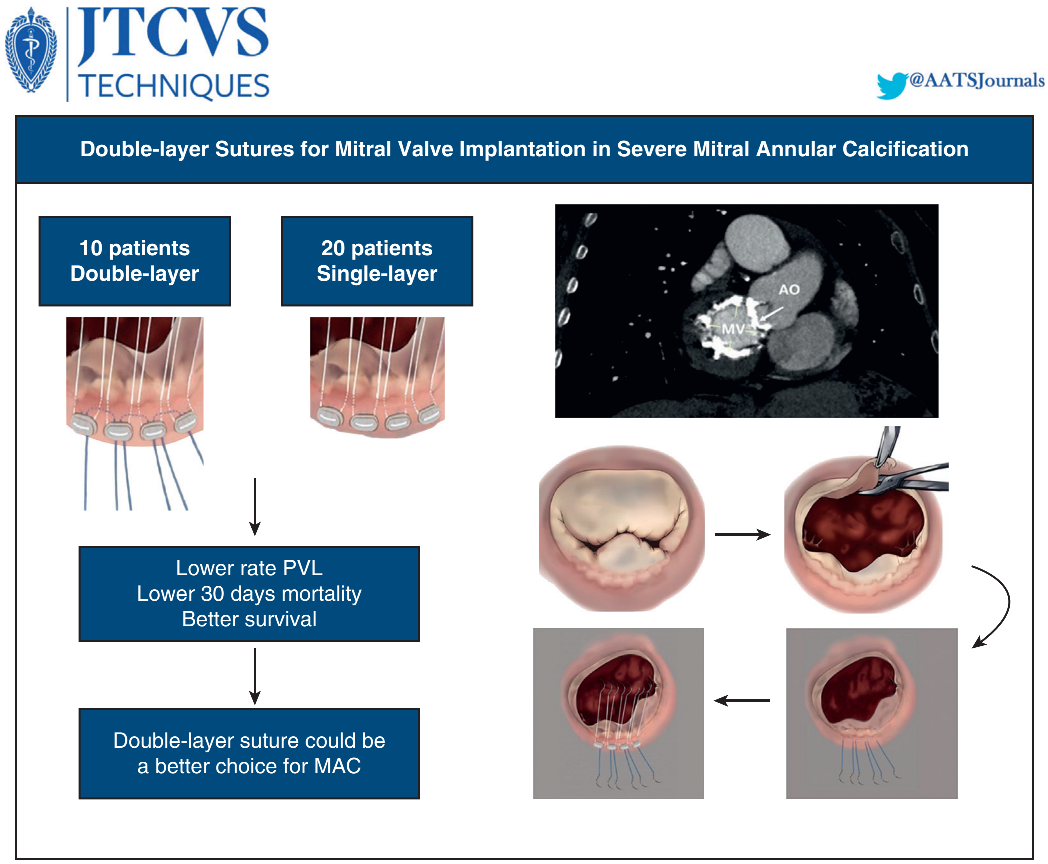
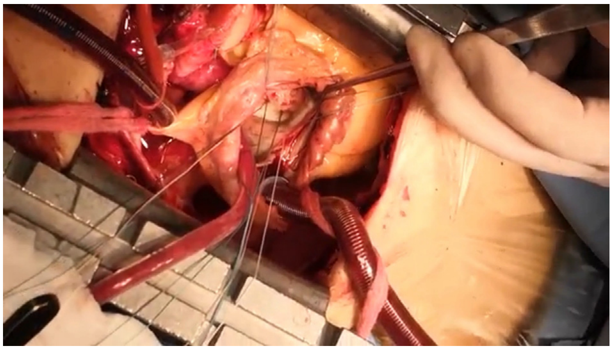


FIGURE 4. Graphic abstract: double-layer horizontal cross-suture technique for mitral valve implantation in patients with severe mitral annular calcification. *AO*, Aorta; *MV*, mitral valve; *PVL*, perivalvular leakage; *MAC*, mitral annular calcification.

particularly in patients with small left ventricular cavities or hypertrophic cardiomyopathy.[28] However, in our study, we did not identify any cases of LVOT obstruction following surgery. In one patient with combined obstructive hypertrophic cardiomyopathy and a left ventricular end-diastolic volume of only 44 mL, we first performed an extended septal myectomy, and then used the DL horizontal cross-suture approach to secure a mitral bioprosthesis in the left atrium. Intraoperative TEE showed that the LVOT gradient decreased after surgery (from 79 to 13 mm Hg). The absence of increased LVOT obstruction risk with mitral bioprosthesis implantation in the left atrium could be attributed to 2 factors: (1) the intra-atrial insertion strategy reduces the entry height of the bioprosthetic valve strut into the LVOT; and (2) the choice of an appropriately oversized prosthesis, unrestricted by the calcified mitral annulus' diameter, enhances the aortic-mitral angle and directs the strut away from the LVOT.[29]

The present study has several limitations. First, due to the relative rarity of patients with severe MAC requiring MVS, our sample size is small. According to Carpentier's classification of mitral valve calcification, a calcification process involving less than one-third of the posterior annulus is categorized as localized MAC.[16] At our institution, more than 90% of patients with MAC requiring MVS exhibit only localized MAC, which can be easily managed with either the "resect" or "respect" strategy. Consequently, this study did not include patients with localized MAC. Second, this study is limited by its single-center design. Finally, the feasibility of using this method for mechanical valve replacement has not yet been investigated. Therefore, future multicenter studies with larger sample sizes are warranted to further validate and generalize our findings.



VIDEO 1. Surgical video of our double-layer suture technique. Video available at: https://www.jtcvs.org/article/S2666-2507(23)00309-7/fulltext.

CONCLUSIONS

The DL horizontal cross-suture technique offers a more effective and safer approach for intra-atrial mitral valve implantation in severe MAC cases than the conventional SL suture method (Figure 4). Future research should focus on comparing the long-term outcomes of this technique with other approaches to better understand its overall benefits and limitations in treating patients with severe MAC.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: mitral valve replacement, mitral annular calcification, mitral regurgitation, retrospective cohort study

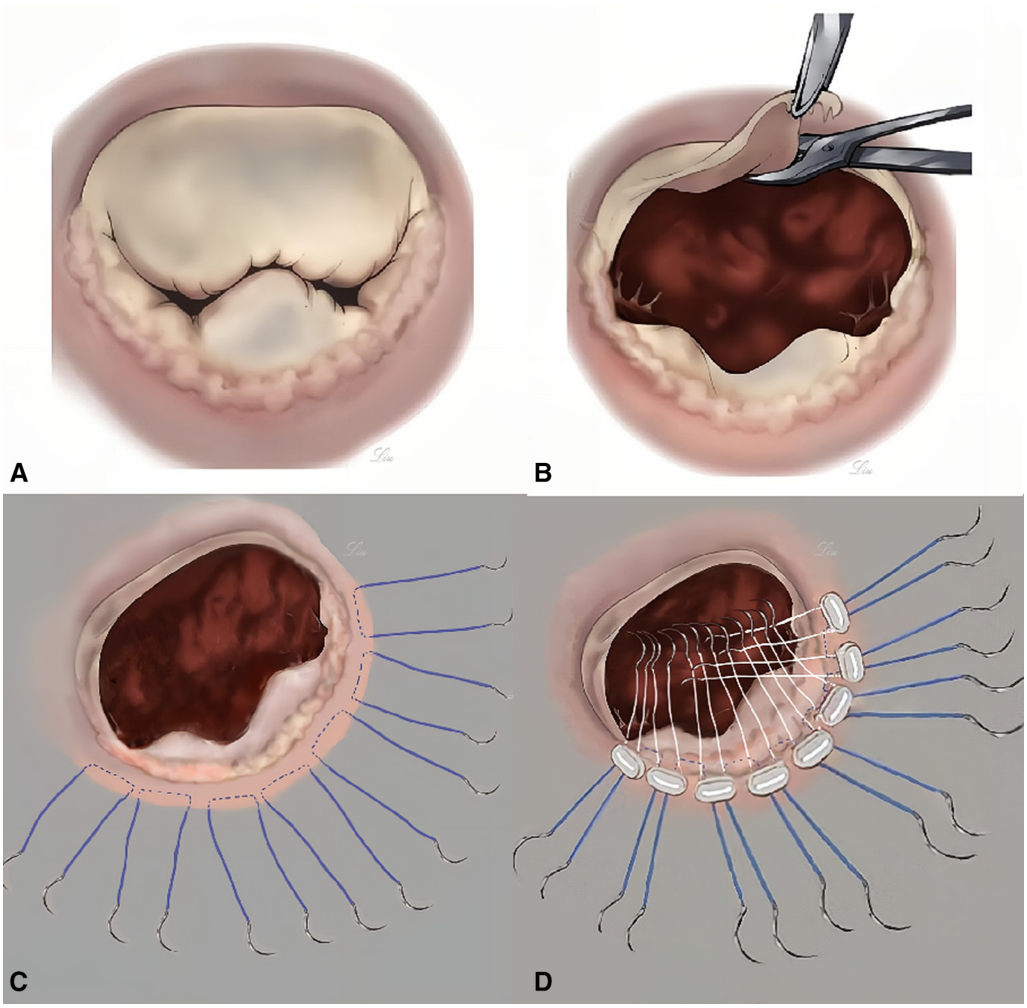

FIGURE E1. Surgical procedures for posterior mitral annular calcification. A, Mitral valve with severe posterior annular calcification. B, The anterior leaflet is resected, and the posterior leaflet and its attached chordae are preserved. C, Double-layer horizontal cross suture is performed in the calcified part of the mitral annulus, which can be divided into 2 steps. First, horizontal mattress sutures are placed in the left atrial wall approximately 2 mm lateral to the calcified annulus. D, Next, pledgeted mattress sutures are placed on each side of the midline of the first layer of suture to overlap the interval between them.

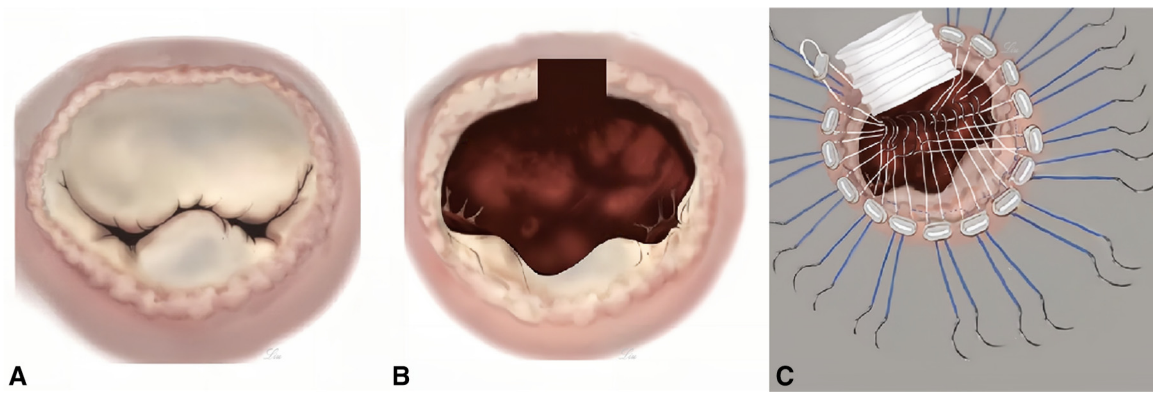

FIGURE E2. Surgical procedures for entire mitral annular calcification. A, Mitral valve with severe entire annular calcification. B, The aortic annulus and aortomitral curtain calcification were removed first using a previously reported fibrosa layer stripping technique. C, Fix the Dacron patch to it as the starting segment for suturing.

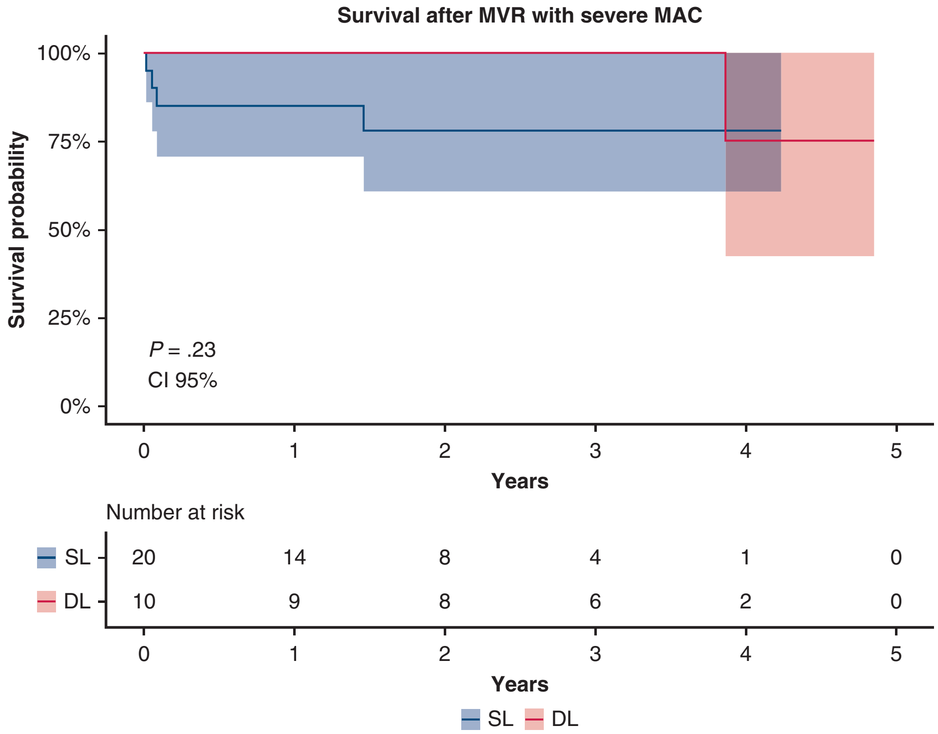

FIGURE E3. Survival curve for DL and SL suture group. *MVR*, Mitral valve replacement; *MAC*, mitral annular calcification; *SL*, single layer; *DL*, double layer; *CI*, confidence interval.